

THE BIOLOGY AND EFFECTS OF PARASITES ON THE DIAMOND-BACK MOTH,

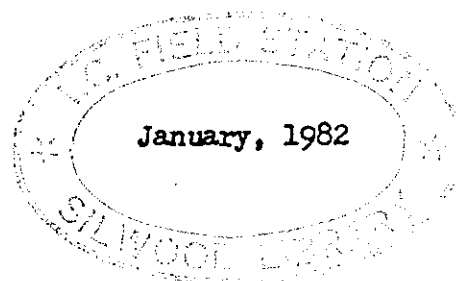
PLUTELLA XYLOSTELLA (L.)

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## A B S T R A C T

The pest status of Diamond-Back Moth (DBM) is reviewed with particular emphasis on numerous problems associated with its chemical control, thereby leading to the need and rationale for examining its biological control.

An indigenous primary endo-larval parasite (Apanteles plutellae Kurdj.) was discovered in West Malaysia and its effect on DBM was assessed experimentally in the laboratory and field.

After establishing the importance of the parasite detailed investigations were made on its basic biology and ecology in relation to the host; these aimed to provide insights on how the parasite might be made more effective. Conserving the parasite, particularly as a critical component for integrated pest control (IPC), was given emphasis. In this context, the use of microbial agents and the encouragement of adult food sources were specially considered. The spatial distribution and population development of both the host and parasite with respect to the plant and crop were also examined, particularly as a basis for more effective and judicious employment of insecticides. These were considered along with investigations into the effects of a wide range of insecticides on DBM as well as their hazards to the parasite, in order to identify the usefulness and limitations of the various toxicants.

An appraisal was also made of the current status of the imported parasites [Diadegma eucero-phaga Horstm. and Thyraeella collaris (Grav.)] that were recently established in West Malaysia, particularly the competitive/complementary role of D.eucero-phaga relative to that of A.plutellae.

Finally, the practical management of DBM in West Malaysia and elsewhere is discussed. In particular, emphasis is laid on exploiting the effects and potentials of the parasites and their employment in an IPC context.

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## 1. INTRODUCTION

The Diamond-Back Moth (DBM) has been recorded as far back as 1746. Like many other insects, it had a rather confusing taxonomic history as evident from the accounts of Muggeridge (1930) and Harcourt (1963a). Apparently, it was first illustrated by Roesel (1746) who also provided a short account of its habits. Subsequently, confusing it with the species (Harpiteryx xylostella L.) feeding on honeysuckle, Linnaeus (1758, 1761, 1767) described it under the name Phalaena Tinea xylostella.

Since 1837, the moth was also commonly referred to under the name of Cerostoma xylostella (Curtis, 1883) in spite of the fact that the genus Plutella was erected by Schrank in 1802 and a proper separation of the species with the proposed name maculipennis made by Curtis in 1832. Besides, Zeller (1843), overlooking the species separation by Curtis proposed for the cruciferous-feeding species the name cruciferarum, leading to the use of Plutella cruciferarum Zell. for many years. Later, Meyrick (1885) pointed out that Curtis had previously described it under the name maculipennis. This was subsequently confirmed by Whitehead (1894) and Walsingham & Durrant (1897), and Plutella maculipennis Curt. was then widely adopted for more than 70 years until Bradley (1966) proposed that the specific name xylostella should replace that of maculipennis since the former is valid and has priority, with maculipennis falling as a junior synonym. Since then, it has been generally accepted as Plutella xylostella (L.) [Lep: Yponomeutidae (or Hyponomeutidae)]<sup>7</sup>.

### 1.1 THE GLOBAL DISTRIBUTION AND IMPORTANCE OF DBM

Throughout the literature on economic entomology, there are many accounts of the importance of DBM. In some countries, such as Argentina, Australia, New Zealand and South Africa, its depredations were the cause of serious economic losses to cruciferous crops well before 1930 (Muggeridge, 1930). Since then and until 1939, Robertson (1939) noted that although little detailed work appeared to have been done, the moth was recorded as a pest of crucifers in many other parts of the world: Tanganyika, Morocco, Chile, Bahamas, British Columbia, Jamaica, Montana, Vancouver, Cyprus, Kona, Northern Caucasus, Lower Volga, Pulawy and Lubin, Latvia, Poland, Finland, Denmark and Britain. Many more localities were subsequently added in later years, viz: Brazil (Becker, M., 1981, pers. comm.), Bulgaria (Khristova, 1957), Egypt (Hassanein, 1958), Hong Kong (Lee, 1968), India (Abraham & Padamanaban,

1968), Indonesia (Ankersmit, 1953; Vos, 1953), Malaysia (Henderson, 1957; Ho, 1965), the Philippines (Capco, 1959), Singapore (Chuo, 1973) and Taiwan (Hsu & Wang, 1971; Chin, 1974). Altogether, up to 1972 (CIE, 1967; Salinas, 1972) at least 128 countries have been listed by the Commonwealth Institute of Entomology (Fig. 1.1).

In general, attacks by DBM vary considerably according to the locality. For example, it is particularly serious in most of the countries in South and Southeast Asia while only moderately so in several other Asian regions. On the other hand, in many parts of Canada, Europe and the United States (Muggeridge, 1930; Hardy, 1938; Sutherland, 1966; Oatman & Flatner, 1969) it is generally of minor concern. In England, only very occasionally were large economic losses involved, resulting from mass immigration (Ormerod, 1892; Hardy, 1938; French & White, 1960; French, 1965). In Germany, France and Italy, this insect is not present in sufficient numbers to be a serious pest, and in the last-named country it is comparatively rare (Muggeridge, 1930). Nevertheless, it is very widely distributed, and the true distribution is undoubtedly greater than indicated in Fig.1.1. Hardy (1938) believed that it can survive wherever Brassica crops are cultivated.

Although climate alone often controls the spread of a species by limiting it to certain areas outside which life is unsupportable, in the case of DBM, climatic factors are believed to be chiefly temperature and perhaps rain on some occasions (Hardy, 1938). Tolerance of the moth is such that it not only can survive in most parts of the world but also would multiply rapidly where the temperature is always within the moth's developmental threshold ( $10-40^{\circ}\text{C}$ ). According to Hardy (1938), the most favourable conditions ( $30-35^{\circ}\text{C}$ ) correspond largely to the sub-tropics and warmer temperate zones. In the equatorial regions the higher altitude is considered more favourable as the maximum lethal temperature is never reached altogether.

In spite of the wide adaptability of DBM, the moth is held in check in some regions as mentioned earlier. Marsh (1917), in outlining the situation in the United States, states that "DBM is a striking example of a potentially serious pest normally held in repression by parasites .....Although it develops with remarkable rapidity and is capable of causing extensive damage if unchecked, the DBM is so effectively held in repression by parasites that it rarely becomes more than a minor pest." The occurrence of such natural control of DBM is, however, also recorded in many other places where the moth has remained relatively scarce (Muggeridge, 1930; Hardy, 1938; Robertson, 1939; Uilyett, 1947; Kopvillem, 1960). Such records thus suggest that

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DISTRIBUTION MAPS OF PESTS

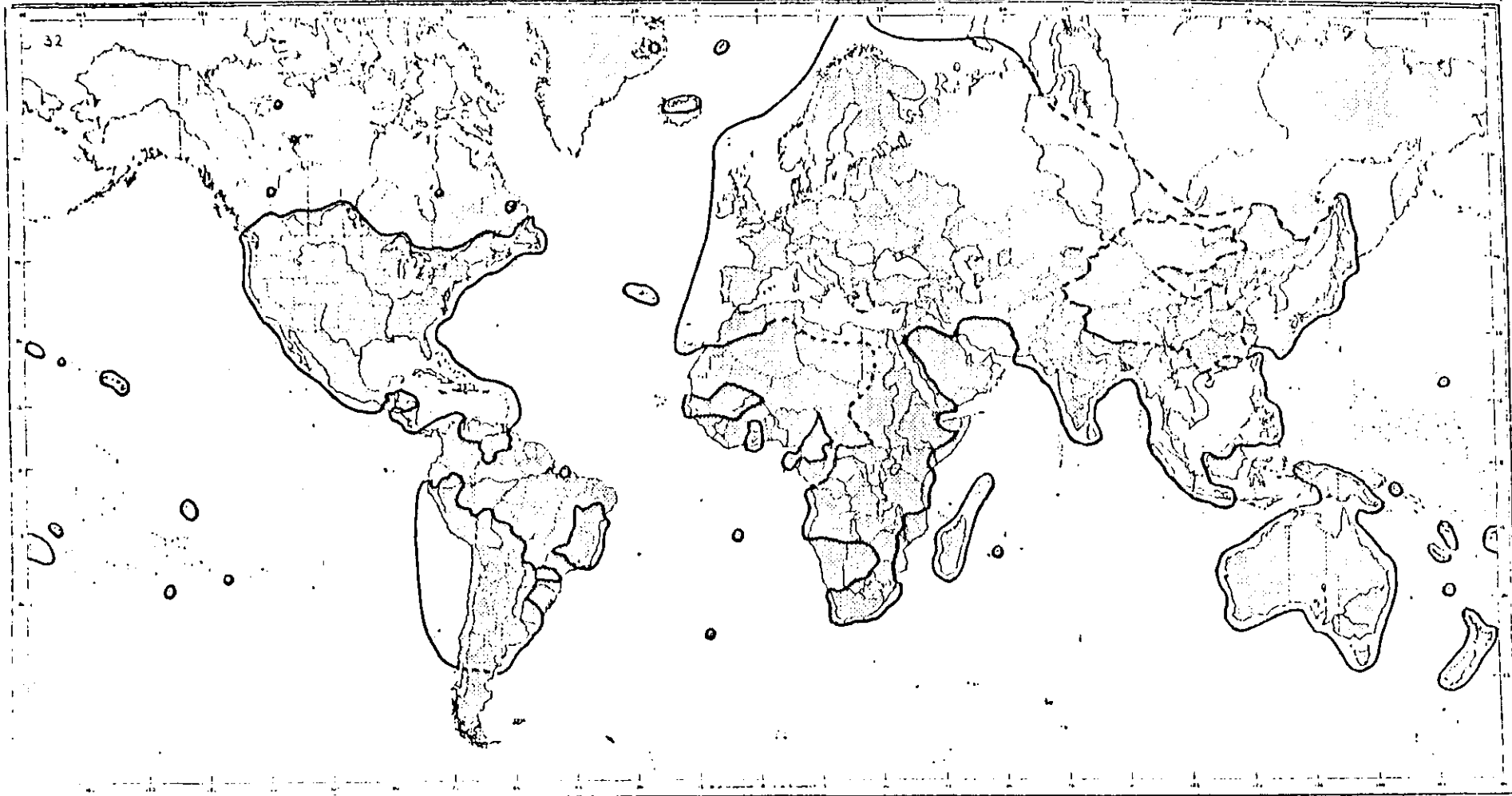
Series A (Agricultural), Map No. 32 (revised). December 1967.

Published at:—56 Queen's Gate, London, S.W.7.

Pest: *Plutella xylostella* (L.) (*maculipennis* Curt.)

(Lep., Plutellidae) (Diamond-back Moth)

Host Plants: Cultivated and wild Cruciferae, notably *Brassica* spp.



© Commonwealth Agricultural Bureaux, 1967 **FIGURE 1.1** World distribution of *Plutella xylostella* (L.). (The known limits of distribution are the inner edges of the black lines on the map. A broken line is where the limit is not exactly known. C.I.E. has also advised (Salinas, 1972) that Chad, in Central Africa, should be included).

DBM has only become a serious pest in those countries in which natural enemies are absent or ineffective. In spite of the apparent importance of the natural enemies, there has been little work on these agents. This was clearly revealed in an analysis by Salinas (1972), wherein most of the published work on DBM between 1947-71 were related to chemical control while studies on its general biology (life-history, population dynamics, distribution and host-plant records) ranked second. In contrast, papers mentioning natural enemies comprised barely 23%, with those containing detailed biology and ecology even fewer. As such, it was felt that there was need for more comprehensive investigations on them.

Encompassed in the broad objectives of the present studies is an attempt to identify some of the major natural enemy agents along with their relative contributions, and to determine how these may be best exploited for rational management of DBM. It is also hoped that the findings will not only have general interest to similar pest programmes elsewhere but may also benefit others by developing basic understanding of the utilization of natural enemies. More specifically, however, other objectives are to understand more comprehensively the biological and ecological implications of the action of such agents locally, and how these may relate to overcoming or minimising the problems presently experienced with chemical insecticides.

It is evident that in many of the countries where DBM has posed a serious problem, chemicals have invariably constituted a major control component. For some, the exclusive dependence on these toxicants has, apparently, also become unavoidable. Arising inevitably out of this are several other associated problems which, under the present circumstances, are perhaps best illustrated by situations in the Cameron Highlands in West Malaysia (see 1.2) where the pattern of development of problems has been most thoroughly examined. Although the conditions in other heavily-infested areas are not exactly similar to that of the present case-study, the overall trends in pesticide usage and development as well as the problems encountered are similar. Differences are, perhaps in the different severity of the problems. In any case, all these have generally proved serious enough to demand attention and concern; and to fully appreciate the extent and nature of these, the position in the Cameron Highlands is dealt with in detail in the immediate following sub-section.

## 1.2 STATUS AND ASSOCIATED PROBLEMS OF DBM IN THE CAMERON HIGHLANDS

Although most cruciferous crops have their origins in the temperate region, many are now extensively cultivated in tropical areas,

largely at the higher altitudes. In Malaysia, these are mainly concentrated in the Cameron Highlands at elevations of about 900-1530 m. Presently, commercial planting in the lowlands is confined to only a few small areas, mainly Malacca and Johore, although some expansion is expected there largely due to the recent development of heat-tolerant cultivars.

In the Cameron Highlands, although vegetable cultivation ranks second to tea in terms of area it is the most important agricultural activity, essentially because of its rapid and high economic returns (Lim, 1972). Covering an area of about 1,214 ha in 1974, it had an annual output exceeding 60,000 tonnes of which at least 60% were crucifers. The crop values for the years 1964-74 averaged \*Ringgits  $17.5 \times 10^6$  per annum.

Due to fluctuations in market demand which has enormous influence on the kinds of vegetables cultivated at any one period, the breakdown on the extent of each vegetable type that is planted can never be precise. Nevertheless, cabbages [both Head cabbage (Brassica oleracea var. capitata L.) and Chinese cabbage (Brassica campestris ssp pekinensis)] predominate, constituting nearly 60% in coverage. Of these, the Head cabbage is almost double in extent. A more important feature, however, is that these crops generally constitute the primary commodity and occupy the central activity of the farmers, with the control of insect pests their major problem.

To date, insects feeding on cabbages in Malaysia total not less than 31 species (Yunus & Ho, 1970a) with 17 reported from the Cameron Highlands (Ooi, 1979a). Most of these have never attained pest status while a few are regarded only as incidental pests that are readily managed. However, DBM has attained prominence as the most serious pest of cruciferous crops, frequently causing extensive damage to both Head and Chinese cabbages. Since the affected crops constitute a primary produce and a major source of income in the Highlands, such infestations by DBM have special significance. Under these conditions, it is thus not unexpected that great efforts and attention have been devoted to crop protection. In general, production inputs are unusually high, with insecticides alone absorbing about 30% of the cost (Lim, 1972).

In the Cameron Highlands, control of DBM by conventional chemical insecticides has so far been the only practice. This unilateral approach and over-reliance on chemicals have, however, led to several problems, viz:

---

\* In 1974, 1 U.S. dollar was equivalent to 2.9 Malaysian ringgits.



a) Increasing incidence of pesticide poisoning of the farmers: This is due mainly to the rampant and unscrupulous use of insecticides (Singh, 1971; Lim, 1972; Ooi & Sudderuddin, 1978). From 1968-70, an increase of accidental poisoning from 5 in 1968 to 10 in 1970 was reported (Singh, 1971).

b) Development of insecticide resistance: Field experience dating as far back as the mid-1950s first indicated that insecticide resistance may have developed in the DBM. Since then, it has also been repeatedly suggested from a number of other observations. However, the problem became really apparent when in 1974 an overall analysis of the findings and experiences of various relevant sectors associated with DBM control (e.g. farmers, pesticide industries and government officials) was first attempted (Lim, 1974), and wherein the pesticide history clearly illustrated the seriousness and magnitude of the insecticide resistance problem. Expanded once by Ooi & Sudderuddin in 1978 this compilation and analysis is now further amplified and updated in Fig. 1.2 to provide the complete history/status of pesticide usage against the moth in the Cameron Highlands until early 1980. As can be seen, the diversity of pesticides employed to date has been enormous. Furthermore, there has been constant need to increase dosages or to change frequently to more potent insecticides. Such a situation is also evident from official recommendations. For instance, nicotine was first recommended prior to the war (Milsum & Grist, 1941). But after the war, DDT and BHC were introduced and regularly used. By 1957, however, field resistance was evident, leading to diazinon and malathion being recommended (Henderson, 1957). Between 1956-65, other chemicals proved effective and were introduced, *viz*, endosulfan, endrin, Telodrin<sup>R</sup> and trichlorfon (Ho, 1965). However, within a few years, DBM was reported to have become resistant again, resulting in Bacillus thuringiensis Berliner (B.t.) and 3 moderately effective chemicals (DDVP, Metacil<sup>R</sup> and phenthoate) out of 13 recently introduced materials to be recommended (Ho & Ng, 1970). Except for B.t. which continues to be used on a limited extent, the others have now been replaced by newer insecticides. Among the latter, no less than 15 insecticides of various groups have since followed a similar sequence of usage (increasing dosages and frequency) and ultimate replacement.

The rapid development of insecticide resistance of DBM in the Cameron Highlands has been evident for a long time, but field resistance was confirmed experimentally and quantified only recently. Assay studies

---

R = Registered trade product.

FIGURE 1.2 Insecticidal usage against insect pests, mainly Plutella xylostella(L.) in the Cameron Highlands, Malaysia<sup>1/</sup>.  
(Shaded area and break indicate the period and change in usage, respectively).

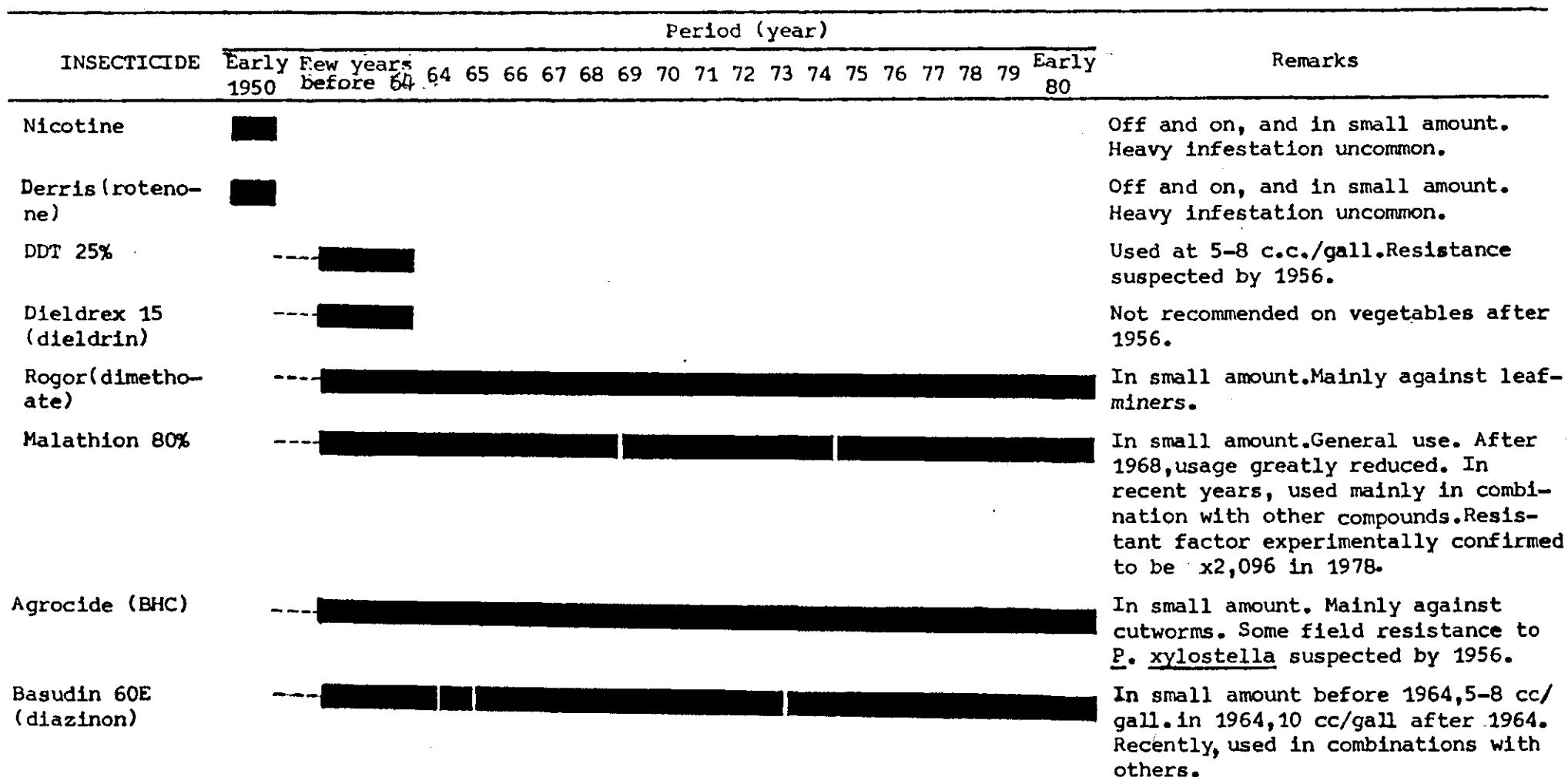


FIGURE 1.2 (Continued 1).

| INSECTICIDE                      | Period (year)                     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             |   |                                                                                                                                                                                                               | Remarks |
|----------------------------------|-----------------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-------------|---|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
|                                  | Early Few years<br>1950 before 64 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | Early<br>80 |   |                                                                                                                                                                                                               |         |
| Dipterex 80 SP<br>(trichlorphon) |                                   | ■  | ■  | ■  | ■  |    |    |    |    |    |    |    |    |    |    |    |    |             |   | 1964: Commonly used, 5-8cc/gall., good <u>Plutella</u> control; 1965-1966: Used at 20cc/gall., poor control at end of 1966; After 1966: usage greatly reduced.                                                |         |
| Telodrin 15<br>(isobenzan)       |                                   | ■  | ■  | ■  | ■  |    |    |    |    |    |    |    |    |    |    |    |    |             |   | Used at 5cc/gall. Very good control. Many wild birds died after feeding on contaminated worms. In ponds, fish killed from washing after spraying. At end of 1966, 10cc/gall. used. No control. Usage stopped. |         |
| Perfekthion<br>(dimethoate)      |                                   | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■           | ■ | Used at 5-8 cc/gall. Mainly for leaf-miners. After 1967, usage greatly reduced.                                                                                                                               |         |
| Wailong <sup>2/</sup>            |                                   |    |    |    |    | ■  |    |    |    |    |    |    |    |    |    |    |    |             |   | Good <u>Plutella</u> control only for a few months.                                                                                                                                                           |         |
| Suising <sup>2/</sup>            |                                   |    |    |    |    | ■  |    |    |    |    |    |    |    |    |    |    |    |             |   | As above                                                                                                                                                                                                      |         |
| Vapona (dichlorvos)              |                                   |    |    |    |    |    | ■  | ■  | ■  |    |    |    |    |    |    |    |    |             |   | In small amount. Mainly against flies.                                                                                                                                                                        |         |
| Lannate<br>(methomyl)            |                                   |    |    |    |    |    |    | ■  | ■  | ■  | ■  |    |    |    |    |    |    |             |   | Used at less than ¼ oz/gall. Mainly against tomato fruit borer, cutworm and <u>Plutella</u> . Usage greatly reduced after mid-1970.                                                                           |         |
| Malamac<br>(DDT+malathion)       |                                   |    |    |    |    |    |    | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■  | ■           | ■ | General use, at 8cc/gall. Usage greatly reduced after 1969.                                                                                                                                                   |         |

FIGURE 1.2 (Continued 2).

| INSECTICIDE                            | Period (year) |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             |                                                                                                                                                                                                                                                                       | Remarks |
|----------------------------------------|---------------|------------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
|                                        | Early<br>1950 | Few years<br>before 64 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | Early<br>80 |                                                                                                                                                                                                                                                                       |         |
| Tedion                                 |               |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             | Used at 4-5 cc/gall. Mainly against citrus mites.                                                                                                                                                                                                                     |         |
| Stock Brand <sup>2/</sup>              |               |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             | Good <u>Plutella</u> control. Many cases of fainting,vomiting, nose and leg swelling.                                                                                                                                                                                 |         |
| "77" Brand <sup>2/</sup>               |               |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             | As above                                                                                                                                                                                                                                                              |         |
| Chlorox <sup>2/</sup> insecticide      |               |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             | As above                                                                                                                                                                                                                                                              |         |
| Metacil<br>(aminocarb)                 |               |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             | Initially, used at ¼ oz./gall. with good control. No control in 1970.                                                                                                                                                                                                 |         |
| Barusil(qui-<br>nalphos)               |               |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             | Used at 5-8 cc/gall. Good control initially. No control in 1970.                                                                                                                                                                                                      |         |
| Phosvel (lep-<br>tophos)               |               |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             | Used at 5-8 cc/gall. Good control initially. No control in 1971.                                                                                                                                                                                                      |         |
| Assorted<br>insecticides <sup>3/</sup> |               |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             | Usage lasted only for few months.                                                                                                                                                                                                                                     |         |
| Tamaron 50%<br>(methamidop-<br>hos)    |               |                        |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |             | Used at 5 cc/gall.initially, good control. Increased to 10-18 cc/gall.in 1971. After 1971, used at 40-50cc/gall.Poor control reported in several cases. Recently, used in combination with others. Resis-<br>tant factor experimentally confirmed to be x6.2 in 1978. |         |

FIGURE 1.2 (Continued 3).

| INSECTICIDE                         | Period (year) |                     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |          |                                                                                                                                                                                                                                                                     | Remarks |
|-------------------------------------|---------------|---------------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|
|                                     | Early 1950    | Few years before 64 | 64 | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | 73 | 74 | 75 | 76 | 77 | 78 | 79 | Early 80 |                                                                                                                                                                                                                                                                     |         |
| Monitor 50%<br>(methamidop-<br>hos) |               |                     |    |    |    |    |    |    |    |    | ■  | ■  | ■  | ■  | ■  |    |    |    |          | Used at 5-8cc/gall. initially. After 1972, increased to 20cc/gall. No more in use in recent years.                                                                                                                                                                  |         |
| Padan 50%<br>(cartap)               |               |                     |    |    |    |    |    |    |    |    |    | ■  | ■  | ■  | ■  |    |    |    |          | Used at 4-5 gm/litre. Field resistance suspected by 1974. Very poor control in 1975 and usage greatly reduced.                                                                                                                                                      |         |
| Sayuran (bio-<br>resmethrin)        |               |                     |    |    |    |    |    |    |    |    |    |    |    |    |    | ■  |    |    |          | Good control reported only initially.                                                                                                                                                                                                                               |         |
| Sumicidin<br>30EC(fenvalerate)      |               |                     |    |    |    |    |    |    |    |    |    |    |    |    |    | ■  | ■  | ■  | ■        | Used at 5-10 cc/9 litres initially. In 1978, increased to 15-30 cc/9 litres. After 1978, some applied at 35-50 cc/9 litres. Field resistance suspected by 1978/79. Usage greatly reduced by mid-1979. Resistant factor experimentally confirmed to be x4.5 in 1978. |         |
| Tokuthion 50%<br>(prothiophos)      |               |                     |    |    |    |    |    |    |    |    |    |    |    |    |    |    | ■  | ■  | ■        | Pattern of usage quite similar to that of Sumicidin. After 1979, number of farmers using 35-50 cc/9 litres have increased rapidly.                                                                                                                                  |         |
| Ambush 80%<br>(permethrin)          |               |                     |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    | ■  | ■        | Used at 3-8 cc/9 litres.                                                                                                                                                                                                                                            |         |

1/ Information compiled from Milsum & Grist (1941), Henderson (1957), Ho (1965), Ho & Ng (1970), Lim (1974), Ooi & Sudderuddin (1978), Sudderuddin & Kok (1978), Ooi (1979a) and field surveys.

2/ Locally repacked insecticides.

3/ These include the following chemicals, applied separately or mixed together: Dede vap 50%, Vapdrin, A.I. Insecticide, Briothion, Stella Maris, Dizin, Derriphytan, Fusect, Cyclotan, Kadol Insecticide, Lion Brand Insecticide, Cockhead Brand, Lion Brand X99, Cado Insecticide, Corona Insecticide, Lion Brand BHC, and Bacillus thuringiensis.

by Sudderuddin & Kok (1978) revealed that it was resistant to chemicals in all major groups of insecticides, viz, BHC, carbaryl, chlorpyrifosmethyl, DDT, dichlorvos, fenvalerate, malathion, methamidophos, methomyl and resmethrin. For malathion, the resistant factor was 2,096 while that for methamidophos and fenvalerate 6.2 and 4.5, respectively. Ooi (1979a) suggested that the rapid development of resistance is due to the occurrence of multiple resistance in the pest emerging mainly as a result of long and sequential use of pesticides.

- c) Presence of insecticidal residues on marketed brassicas: This was indicated in several instances when fresh leafy brassicas purchased from the grocers were noted to produce a high mortality of DBM larvae when served as food (Balasubramaniam, 1974). To a large extent, this is mainly due to the failure of farmers to observe a delay before harvesting.
- d) Hazards to other organisms in the ecosystem: Although complete evidence is as yet not available on the deleterious effects to other organisms by the insecticides used against DBM, this is suggested by the relatively much reduced fauna of treated crops. Not unexpectedly, any beneficial species (parasites and predators) that may have existed are also likely to be decimated. This could be critical as the pest infestation and its stability could well be much dependent on the abundance of these species.

Among the vertebrates, birds have been found to be common victims between 1964-66. During this period when Telodrin 15<sup>R</sup> was used extensively against DBM, numerous wild birds were noted to die after feeding on contaminated worms (Lim, 1974).

- e) Spiralling cost in crop production: To a large extent, this is closely related to the development of insecticide resistance which ultimately leads to increased dosages and more frequent applications of an insecticide in use.

From the above, it is evident that brassica production in the Cameron Highlands is continually facing serious setbacks due to DBM. The pesticides that have been employed against this pest have been enormous in both quantity and variety. In particular, the need to increase the application dosage and frequency, or to change frequently to more powerful pesticides have become a serious problem. These were necessitated essentially by resistance development, although pesticide adulteration was also believed to play a role.

The rapid build-up of resistance by DBM appears inevitable in the Cameron Highlands. Firstly, the life cycle of the moth there is relatively short, averaging only about 27 days (Ho, 1965). This yields approximately 13 moth generations per year, and together with the continuous presence of cruciferous crops and the extremely high

insecticidal pressure, creates excellent opportunity for resistance build-up. Such a situation seems the more likely since the moth has been found (Sun *et al.*, 1978) to be inherently capable of rapidly becoming resistant (only 14 generations to diazinon). Furthermore, this resistance build-up will be more rapid if the pest has already become resistant to other chemicals of similar or closely-allied groupings, a situation apparent in the Cameron Highlands where almost every insecticide introduced into the country has been tried. Secondly, the Cameron Highlands has been described as an 'ecological island' (Corbett & Pagden, 1941) being surrounded by dense tropical jungle and isolated from other agricultural areas in the lowlands. It is further made up of a number of valleys, each of which is itself an isolated agroecosystem in miniature (Plate 1.1). Under such a situation, localised immigration of the pest from untreated populations outside the area is likely to be small; this is especially so since DBM is not indigenous and has no other known hosts in the country besides crucifers which are themselves imported. Comins (1977) has suggested that without such immigrations, problems with resistance will tend to be more severe.

Presently, although spraying of insecticides is justified because vegetable production is still profitable, many of the problems are becoming more aggravated. To date, DBM control has largely depended upon reacting quickly to emergency situations as well as on calendar spraying. The farmers are resigned to using chemicals and determined to look for newer insecticides to replace less effective ones. Many have even resorted to using high concentrations of 'insecticidal cocktails' (Ooi, 1979a). Besides, the changes of insecticides have become more frequent while the amounts employed are rising rapidly. Undoubtedly, this is a very strong 'pesticide syndrome' (Doutt & Smith, 1971), with development of field resistance to insecticides becoming more apparent and widespread. A recent survey revealed that notwithstanding the regular use of insecticides DBM is still present in fair abundance (Ooi & Sudderuddin, 1978). It seems clear that the problems encountered in relation to its control are critical and approaching the 'crisis phase' of a pest problem (Smith, 1969). In general, the trend of development closely parallels that of the Cañete Valley in Peru (Barducci, 1969) prior to the 'disaster phase'. Should the trend of wide and indiscriminate use of pesticides persist, it is feared that eventually extensive areas of brassicas (especially cabbages) in the Cameron Highlands may go out of production. Such an occurrence, in this particular situation, could have far-reaching effects mainly because cabbage cultivation has almost



PLATE 1.1

Cabbage cultivation in the Mensum Valley, Cameron Highlands. Such terracing and hillside cultivation is quite typical in the Cameron Highlands which has been described as an "ecological island", being surrounded by dense tropical jungle and isolated from other agricultural areas in the lowlands. It is further made up of a number of valleys, each of which is itself an isolated agroecosystem in miniature.



complete dominance in this region (Chye & Loh, 1972). With production failure, dire consequences, both economic and social may follow, such as those experienced in a parallel situation on cotton in the Lower Rio Grande region of Texas and Mexico (Huffaker & Smith, 1973), wherein the discharge of farm workers and declined cash flows have also impoverished other associated activities.

It appears imperative that as a state of crisis in the control of DBM in the Cameron Highlands is approached, there is the urgent need to drop the dogma of continually searching for more potent chemicals and of total dependence on them. Although insecticides will continue to remain a powerful and essential tool there, it is highly necessary that their use be minimised if a 'disaster phase' is to be avoided. This clearly demands an improved pest management system that does not rely solely on the indiscriminate employment of chemical insecticides. Such an approach, which needs to incorporate economic, social and ecological considerations, not only would help over a long term period in reducing many of the problems associated with the over-use of chemical insecticides but also better ensure a more productive and stable crop output in an environment that is both cleaner and less hazardous. A prime strategy is to build a broader ecological base that would make possible the integration of various pest management techniques. In such an attempt that aims towards developing an integrated pest control (IPC) programme, the need for some core information which could at least initially serve to form the basic guiding framework, can hardly be over-emphasised.

Presently, except for a few investigations largely confined to insecticide and antifeedant evaluation (Henderson, 1957; Ho, 1965; Ho & Ng, 1970; Tan & Sudderuddin, 1978) or their undesirable effects (Lim, 1972; Singh, 1971; Balasubramaniam, 1974; Lim, 1974; Ooi & Sudderuddin, 1978; Sudderuddin & Kok, 1978), as well as two other recent studies that also examined some aspects of its natural enemies (Lim & Ko, 1975; Ooi, 1979a), much of the fundamental understanding that is critically needed to help produce appropriate changes is lacking. Generating such basic data has been the major task of the present studies. It is hoped that these investigations, even though still somewhat limited with respect to the field of coverage, will help stimulate the development of a more rational approach in the management of DBM, both in the Cameron Highlands and elsewhere.

## 2. GENERAL EXPERIMENTAL CONDITIONS, MATERIALS AND METHODS

Wherever possible, certain standardised experimental conditions were adopted. The basic and common features, according to the nature of the studies, were as follows:

- a) Field trials: In the Cameron Highlands, these were laid down in the Research Station of the Malaysian Agricultural Research & Development Institute (MARDI) under ambient conditions which have the following monthly means; temperature =  $18.2^{\circ}\text{C}$  (range =  $15.2 - 19.5^{\circ}\text{C}$ ), RH = 88.2% (range = 68.2 - 99.9%), rainfall = 191.9 mm (range = 30.0 - 538.7 mm) and daily sunshine period of 4.5 hrs. As regards planting, the cabbage variety Constanta F.1 Danish was used while the cultural practices closely followed that of the farmers (Appendix 1). In the lowlands, where field surveys were also carried out, the general conditions were, however, quite different. These were: temperature =  $27.3^{\circ}\text{C}$  (range  $19.6 - 34.8^{\circ}\text{C}$ ) and RH = 80.5% (range 47.8 - 98.3%).
- b) Laboratory investigations: These were conducted in MARDI Headquarters at Serdang under either normal laboratory conditions or in Conviron<sup>R</sup> growth chambers. In the former, the following conditions were maintained; temperature  $25 \pm 3^{\circ}\text{C}$ , RH 70 - 80% and natural illumination of about 12/24 hrs. Within the Conviron<sup>R</sup>, the temperature was  $20 \pm 0.5^{\circ}\text{C}$ , RH  $75 \pm 5\%$  and light of 8 hrs per 24-hr cycle.
- c) Test insects: For the field trials, natural infestations were normally used. However, for most of the laboratory experiments, insects from cultures maintained under laboratory conditions were used. DBM and A. plutellae cultures were initiated from collections made in mid-1973 from Mensum Valley, while Diadegma eucerothaga Horstm. (Hym: Ichneumonidae) came from Tanah Rata in early 1980. Detailed procedures for maintenance of the stock cultures are in Appendix 2.
- d) Experimental enclosures (glass jars, cages, etc.): During the investigations, different types of enclosures were used depending on the studies. In most instances, cylindrical glass jars 24 cm x 10 cm diameter and with the open top covered with muslin were used (Plate 2.1). Depending on the purpose, such jars have been variously referred to in the different experimental studies as 'oviposition jars', 'breeding jars', 'host pupation jars' and 'parasite cocoon emergence jars'. They differed only in their contents. In both the 'oviposition jars' and 'breeding jars', fresh leaves of Brassica rapa L. served either for adult oviposition or as food for DBM larvae. Throughout each study, leaves were replenished every 3-4 days. They were generally held upright by a cotton plug in glass vials containing water. Within each jar, water and 17%

honey through cotton wicks were also provided for the adults. 'Host pupation jars' and 'parasite cocoon emergence jars', were essentially the same except that no leaves were provided.

Where large population of feeding larvae was expected or a large space considered necessary, then the larger 'larval developmental cages' were normally used. These were 46.5 cm x 61.5 cm x 61 cm and meshed all over with copper gauze (~~#~~ 40) except the wooden floor, glass top and part of the door which was rubber (Plate 2.2). In these cages, leaves of B.rapa were replenished in excess every 2 days to ensure an adequate supply of fresh leaves for developing larvae. Where any adults were also expected to emerge within the cage, water and 17% honey were also provided.

Another enclosure commonly employed was the 'larval emergence dish'. This consisted essentially of a plastic petri dish with a mesh-covered window (5.1 cm diameter) on the cover for ventilation (Plate 2.3). Where maintenance of the emerging larvae was expected, fresh B.rapa leaves were also provided every 3-4 days.

It should be noted that the above constituted only the general experimental conditions, materials and methods adopted in the present studies. More details are given in the presentation of the respective studies. Where certain specific requirements necessitated some further adjustments to the above general methodology, these modifications have also been clearly specified in the descriptions of the experiment concerned.



PLATE 2.1

A breeding jar (24 cm x 10 cm diameter) used as "oviposition jar", "host pupation jar" and "parasite cocoon emergence jar" having the top open end covered with muslin cloth and the bottom fitting into a gauze metal base.



PLATE 2.2

A "larval developmental cage" (46.5 cm x 61.5 cm x 61 cm) meshed all over with copper gauze (#40) except the wooden floor, glass top and part of the door which is rubber.

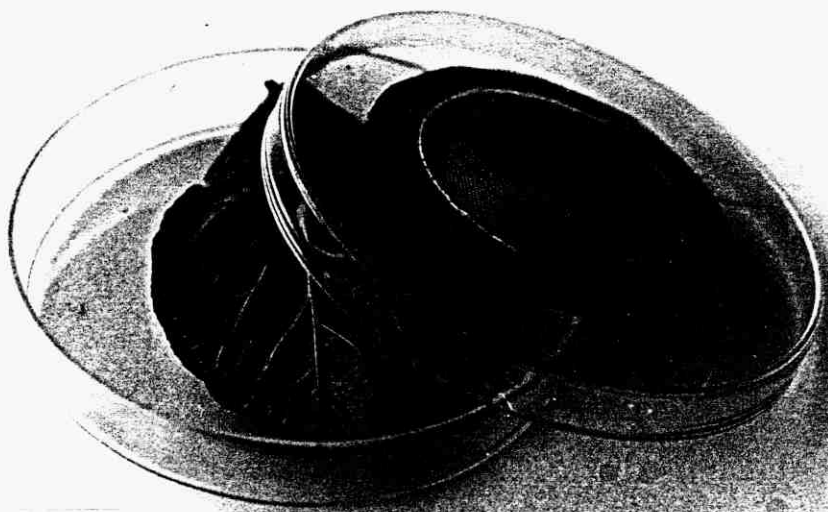


PLATE 2.3

A plastic petri dish having a mesh-covered window (5.1 cm diameter) on the cover. This also served as a "larval emergence dish".

### 3. INITIAL SEARCH AND SURVEY FOR PARASITES OF DBM IN WEST MALAYSIA

#### 3.1 INTRODUCTION, AND RATIONALE FOR PARASITE SEARCH

In attempts to widen the ecological base for pest control various components may be considered, viz plant resistance, cultural techniques, biological control agents, and some other more recent and novel techniques. With respect to plant resistance considerable scope generally exists for adding restraints on the pests' food supply (Painter, 1951; van Emden, 1966), being largely governed by the wide range of influences that host plants can have on the population dynamics of insects (van Emden & Way, 1973). For some, a small change in the plant's condition may be sufficient to exert economic control (van Emden & Wearing, 1965). In the case of DBM some specific components for resistance/susceptibility have been identified: allyl isothiocyanate, glucocheirolin, glucoerucin, gluconapin, gluconasturtiin, gluconringiin, glucotropaeolin, progoitrin, sinalbin and sinigrin (Thorsteinson, 1960; Nayar & Thorsteinson, 1963; van Emden, 1966; Hillyer & Thorsteinson, 1969). Although differences in varietal resistance of cabbages to the moth are now known (Rudder & Brett, 1967; Weires & Chiang, 1973; AVRDC, 1976), under existing conditions in the Cameron Highlands there is little possibility of selecting and developing plant resistant materials since cabbage flowering cannot be readily induced there. Other approaches based largely on newer techniques such as hormonal control (Sato, 1968; Chow et al., 1974; Tamaki et al., 1977; Koshihara et al., 1978; Ando et al., 1979; Fujiyoshi et al., 1979; Morallo-Rejesus & Tetangco-Fabellar, 1980; Tan, 1981), sterile mating (Bonnemaison, 1966; Cook & Hooper, 1974) and the use of antifeedants (Findlay, 1970; Ruscoe, 1972; Tan & Sudderuddin, 1978) have only been of exploratory nature, largely in the laboratory. As such, their scopes for practical employment are presently still very limited. In the case of cultural management, although Raros (1973) and Buranday & Raros (1975) have demonstrated that intercropping of cabbages with tomatoes reduced infestations of DBM on cabbages, this relationship could not be reproduced consistently, as experienced by Phillips (1977), and Kuntha (1981, pers. comm.) in England, Megallona (1977, 1978) in the Philippines, and the Asian Vegetable Research & Development Center (Megallona, 1977) in Taiwan. Moreover, this practice could not be readily implemented as the choice of crops for cultivation during a particular period is normally governed by festive seasons and market demands (FAMA, 1974). For tomatoes and cabbages, their plantings generally do not coincide. Similarly, others such as modified crop

rotation would demand drastic changes in some other long-standing traditional practices, a situation that is usually difficult to accept.

For most situations, due consideration given to natural enemies in pest control has often been regarded as a sound approach, largely because biological control is a natural ecological phenomenon. Potentially, biological control when applied successfully to a pest problem can provide a relatively permanent, harmonious and economical solution (DeBach, 1964; Huffaker, 1971a; van den Bosch & Messenger, 1973; Simmonds & Bennett, 1976). For the DBM in particular, effective host suppression have already been reported; in some instances the control achieved was impressive (Hardy, 1938; Muggeridge, 1930, 1939; Ulllyett, 1947; Vos, 1953; Goodwin, 1979). With such encouragement, and considering the present limitations of other control components as well as the acute problems arising from the excessive use of insecticides in the Cameron Highlands, it thus seemed appropriate that natural enemy agents need to be given priority. Such investigations could lead to a more rational integrated approach wherein natural control would constitute the core.

Until recently, no serious attempt has been made to explore the potential of natural enemies against DBM in the Cameron Highlands. This is due mainly to the persistent and firm adherence to the unsubstantiated belief that 'no biological control or parasites could exist there because of the intensive and indiscriminate use of insecticides'. Such belief was so widespread and pervasive that all efforts were devoted to the unilateral chemical approach, solely guided by the belief that 'no cabbage can be produced in the Cameron Highlands without frequent and heavy insecticide application'. Clearly, if any meaningful change towards a more rational and ecological outlook is to develop, disproving the above beliefs would appear critical and highly desirable. Initially, at least a thorough and careful parasite search seemed necessary, especially since parasites had never been reported there. Existence of indigenous species could justify studies on import and introduction of other parasites if necessary.

### 3.2 MATERIALS AND METHODS

Having recognised the urgent need to check for parasites of DBM in the Cameron Highlands, a thorough parasite search was immediately initiated in March, 1973. Initially, the survey was conducted in the experimental farm of MARDI at Tanah Rata. This was chosen as most of the experimental cabbage fields received very much less insecticidal inputs than those of the farmers.

In the initial search, eggs, larvae and pupae of DBM were collected from transplanted crops ( $1\frac{1}{2}$  -  $2\frac{1}{2}$  months old) in  $1/32$  -  $1/8$  ha plots distributed over an area of about 4 ha. The daily collections, made over

a period of 5 days (August 3 - 7), were kept separately according to the different stages. Eggs were confined in petri dishes (9 cm diameter) until hatching or parasite emergence. The larvae were reared on cabbage leaves in 'breeding jars' (Plate 2.1) until host pupation or parasite emergence. Throughout the studies, adequate food was maintained fresh through replenishment every 4 days. Pupae were kept in petri dishes (9 cm diameter) until emergence of either parasites or DBM adults.

In the initial parasite search at Tanah Rata, a parasite was found on DBM (see 3.3.1). However, it was not known if the parasite was also present elsewhere in the highlands or lowlands where brassicas are cultivated under conditions of high insecticidal inputs. An extensive survey was therefore made. Such an investigation, it was envisaged, would provide some understanding of the field performance of the parasite. Determination on its distribution would also indicate how widespread the parasite is under farmers' conditions. Such information could indicate the potential of the parasite. Furthermore, since the survey would be conducted over an extensive area, it might also reveal other possible parasite species.

Seven major cabbage areas at different altitudes and in different geographical regions of the Cameron Highlands were selected, viz: Kampong Raja (976-1,159 m), Kuala Terla (976-1,159 m), Tringkap (1,007-1,159 m), Mensum Valley (1,434-1,525 m), Brinchang (1,433-1,489 m), Kampong Taman Sedia (1,393-1,458 m) and Bertam Valley (976-1,159 m) (Fig. 3.1). In the lowlands, 3 major cabbage-growing areas in Selangor State were selected. These were Sungai Kelambu and Kuala Langat/Tanjong Sepat in the Banting District, and Sungai Yu in the Tanjong Karang District. For each assessment, 25 plants in the highlands and 30 plants in the lowlands were taken at random for thorough examination of eggs, larvae and pupae of DBM, and cocoons of the parasite. As in the earlier parasite search in Tanah Rata, the different stages of DBM were kept separately and reared for determination and assessment of parasitism. Parasite cocoons were confined in petri dishes (9 cm diameter) for observation of parasite adult or hyper-parasite emergence.

### 3.3 RESULTS

#### 3.3.1 Discovery of *Apanteles plutellae* Kurdj.

The results obtained (Table 3.1) in the initial parasite search at Tanah Rata clearly revealed for the first time that parasites were present on DBM in the Cameron Highlands. From the collections of 140 eggs, 740 larvae and 86 pupae, a total of 265 parasites were obtained. All

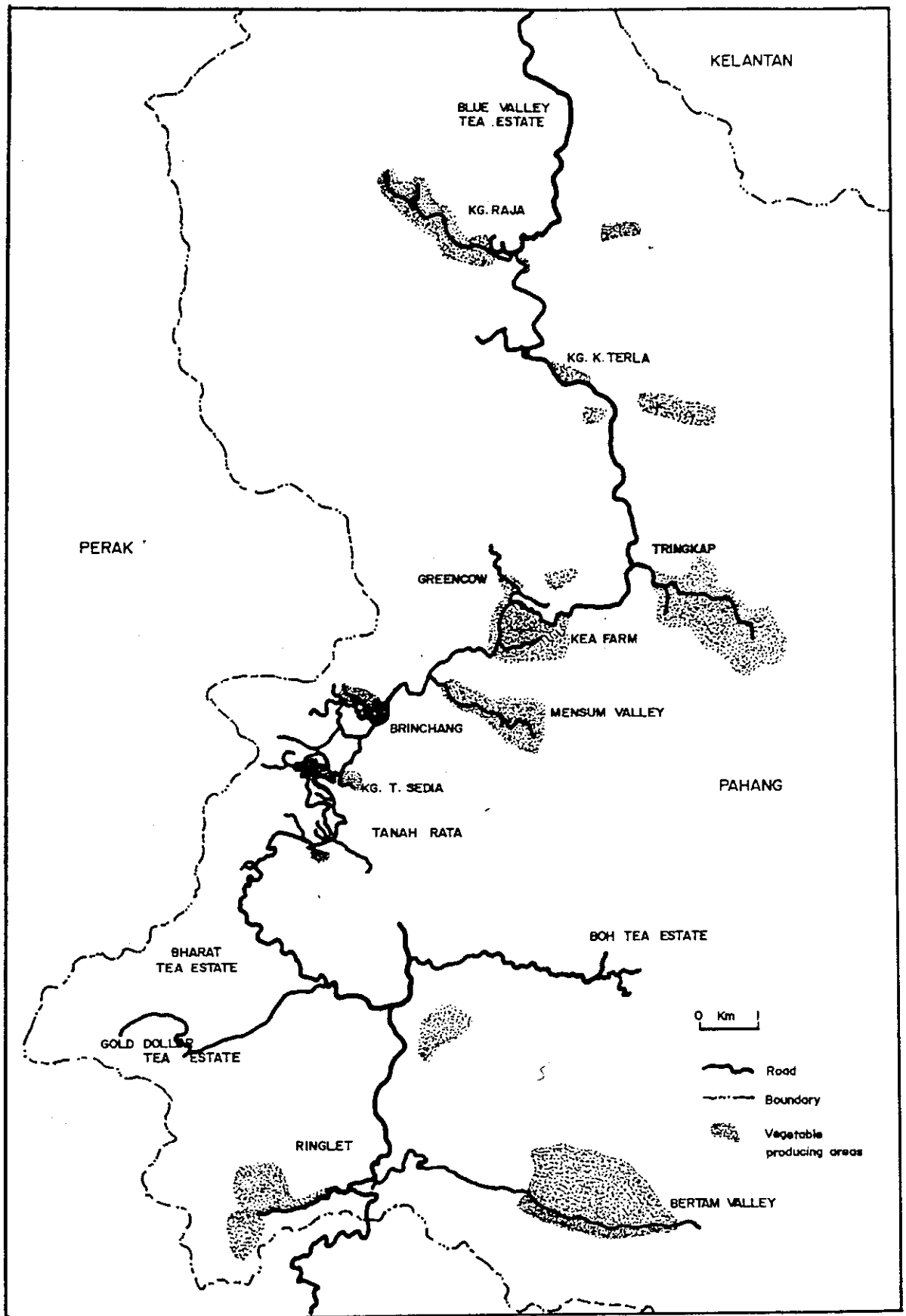


FIGURE 3-1 Major vegetable production areas in the Cameron Highlands, Malaysia.



Table 3.1 Survey for parasites in the different stages of Plutella xylostella (L.) collected from cabbages in the MARDI Research Station (Tanah Rata, Cameron Highlands).

| Date   | Immature stages of <u>P.xylostella</u> |       |             |           |       |              |           |       |             |
|--------|----------------------------------------|-------|-------------|-----------|-------|--------------|-----------|-------|-------------|
|        | Egg                                    |       |             | Larva     |       |              | Pupa      |       |             |
|        | Collected                              |       | Parasitised | Collected |       | Parasitised* | Collected |       | Parasitised |
|        | (No.)                                  | (No.) | (%)         | (No.)     | (No.) | (%)          | (No.)     | (No.) | (%)         |
| 3.3.73 | 12                                     | 0     | 0.0         | 292       | 86    | 29.5         | 8         | 0     | 0.0         |
| 4.3    | 25                                     | 0     | 0.0         | 114       | 32    | 28.1         | 11        | 0     | 0.0         |
| 5.3    | 63                                     | 0     | 0.0         | 113       | 69    | 61.1         | 22        | 0     | 0.0         |
| 6.3    | 10                                     | 0     | 0.0         | 184       | 41    | 22.3         | 14        | 0     | 0.0         |
| 7.3    | 30                                     | 0     | 0.0         | 37        | 37    | 100.0        | 31        | 0     | 0.0         |
| Total  | 140                                    | 0     | 0.0         | 740       | 265   | 35.8         | 86        | 0     | 0.0         |

\* Only one species, Apanteles plutellae Kurdj., was obtained.

emerged from the larvae.

The parasitism rates, in general, were observed to vary widely in the different batches and ranged from 22.3% to 100% (Table 3.1). The average was 35.8%.

On discovery of the parasites, attempts were then made to ascertain the species involved. Specimens sent to the Director, Commonwealth Institute of Entomology, London were confirmed as Apanteles plutellae Kurdj. (Hym: Braconidae) while those despatched via Dr. K.I. Sudderuddin (University of Malaya) to Dr. M. Fitton (British Museum) were identified (det. T. Huddleston) as Apanteles ruficrus Haliday (Hym: Braconidae). This difference in identification created uncertainty for some time since it was possible that: (i) both the parasite species were present, (ii) only one species was present, the other being misidentified, and (iii) the two names were synonyms. Similar confusion was also encountered by Ooi (1979a) in subsequent investigations with the same parasite. Specimens provided by him to G.E.J. Nixon (British Museum) and W.R.M. Mason (Biosystematic Research Institute) were identified as A.plutellae while P.M. Marsh (USDA, Beltsville) had them determined as A.ruficrus. Part of the reason leading to the identification as A.ruficrus was apparently due to the use of Wilkinson's (1928) key and another publication (Wilkinson, 1929) which synonymized antipoda with ruficrus. However, the uncertainty was subsequently clarified through Wilkinson's (1939) revision which separates plutellae from ruficrus. He noted that in the former species the 4 anterior coxae are almost invariably entirely black and the 3rd tergite invariably with much minute punctation. The cocoons are pale

cream and solitary. In the case of ruficrus the 4 anterior coxae are entirely red testaceous and the 3rd tergite has a single transverse row of, and occasionally a few other, minute punctures. The cocoons are white and more usually gregariously placed. With this clarification and following Parrot's (1964) description, all the parasite specimens collected from Tanah Rata were closely re-examined, and finally confirmed and reported (Lim & Ko, 1975) to belong to only one species, i.e. A. plutellae.

### 3.3.2 Occurrence and local distribution of DBM

From the survey results (Tables 3.2 & 3.3), it was evident that there were no parasites on the eggs and pupae of DBM, both in the Cameron Highlands and in the surveyed areas of the lowlands. As in Tanah Rata, only one species of parasite was obtained from the larvae, viz A. plutellae (Tables 3.4 & 3.5).

The survey also showed that A. plutellae occurred commonly and widely in all the major sub-regions of the Cameron Highlands. In the lowlands, although only few sites were surveyed, the parasite was found in all of them. cursory observations recently revealed A. plutellae in two other areas of the lowlands, Jalan Kebun and Serdang. So, present information (Lim & Ko, 1975; Ooi & Sudderuddin, 1978; Tables 3.1, 3.4 & 3.5) strongly suggests that the parasite is common and widespread in West Malaysia.

### 3.3.3 Abundance of A. plutellae

A. plutellae occurred in significant abundance in most areas surveyed, except in the lowlands where parasitism averaged only 12.1%. Over the whole of the Cameron Highlands, wide variation was observed in parasitism rates, ranging from 0-100%. Within each sub-region the variation was less. On average, the highest parasitism occurred in Kuala Terla (48.6%) while Kampong Taman Sedia had the least (12.7%). For the remaining sub-regions, 36.5%, 34.0%, 30.1% and 18.1% were obtained in Kampong Raja, Tringkap, Bertam Valley and Mensum Valley, respectively. Much higher levels (31.9% to 57.9%) were however recorded for the Brinchang region during 1979, while for the lowlands, only low levels were obtained, ranging from 8.8% to 14.0% (Table 3.5).

The abundance of A. plutellae noted in the survey is very encouraging in that the parasite can effect a generally high level of parasitism even under heavy insecticidal treatment. It strongly suggests the possible development of field tolerance to the chemicals by the parasite. Whether this is so, however, requires confirmation.

Table 3.2 Survival of the eggs and immature stages of Plutella xylostella(L.), and Apanteles plutellae Kurdj. cocoons, collected from different localities in the Cameron Highlands (1973-74).

| Locality | Date     | No. <u>Plutella</u> egg |                  |              | No. <u>Plutella</u> pupa |                  |                         | No. <u>Apanteles</u> cocoon |                         |                                     |                                 | Status of insecticide usage**                                                                                                                                               |
|----------|----------|-------------------------|------------------|--------------|--------------------------|------------------|-------------------------|-----------------------------|-------------------------|-------------------------------------|---------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|          |          | Collec-<br>ted*         | Parasi-<br>tised | Hatch-<br>ed | Collec-<br>ted*          | Parasi-<br>tised | With adult<br>emergence | Collec-<br>ted*             | With adult<br>emergence | With hyper<br>parasites<br>emerging | With noth-<br>ing emer-<br>ging |                                                                                                                                                                             |
| Bertam   | 22.8.73  | 40                      | 0                | 40           | 15                       | 0                | 11                      | 23                          | 10                      | 7                                   | 6                               | Spraying irre-<br>gular(depen-<br>ding on infes-<br>tations) but<br>generally once<br>a week.Tamaron<br>used.                                                               |
| Valley   | 27.9.73  | 12                      | 0                | 12           | -                        | -                | -                       | 53                          | 51                      | 0                                   | 2                               |                                                                                                                                                                             |
|          | 15.11.73 | 15                      | 0                | 14           | -                        | -                | -                       | 90                          | 46                      | 20                                  | 24                              |                                                                                                                                                                             |
|          | 21.12.73 | 63                      | 0                | 60           | 22                       | 0                | 15                      | 23                          | 23                      | 0                                   | 0                               |                                                                                                                                                                             |
|          | 30.1.74  | 23                      | 0                | 23           | 28                       | 0                | 26                      | 8                           | 6                       | 1                                   | 1                               |                                                                                                                                                                             |
|          | 6.3.74   | 32                      | 0                | 31           | 5                        | 0                | 4                       | 14                          | 3                       | 5                                   | 6                               |                                                                                                                                                                             |
| Kampong  | 20.9.73  | 7                       | 0                | 7            | 59                       | 0                | 47                      | 19                          | 10                      | 3                                   | 6                               | Sprays mainly<br>directed at<br>cabbage head<br>only.Spraying<br>depending on<br>infestations,<br>but generally<br>twice a week.<br>Both Tamaron<br>and Padan were<br>used. |
| Raja     | 7.11.73  | 25                      | 0                | 23           | -                        | -                | -                       | 28                          | 14                      | 8                                   | 6                               |                                                                                                                                                                             |
|          | 13.12.73 | 16                      | 0                | 16           | 3                        | 0                | 3                       | 33                          | 16                      | 9                                   | 8                               |                                                                                                                                                                             |
|          | 30.1.74  | 31                      | 0                | 31           | 59                       | 0                | 53                      | 0                           | 0                       | 0                                   | 0                               |                                                                                                                                                                             |
|          | 28.2.74  | 6                       | 0                | 6            | 57                       | 0                | 45                      | 89                          | 59                      | 10                                  | 20                              |                                                                                                                                                                             |
|          | 10.4.74  | 26                      | 0                | 24           | 27                       | 0                | 19                      | 46                          | 34                      | 5                                   | 7                               |                                                                                                                                                                             |
| Kuala    | 20.9.73  | 12                      | 0                | 12           | 47                       | 0                | 45                      | 40                          | 37                      | 0                                   | 3                               | Crops sprayed<br>very frequently.<br>Insecticide<br>mixtures used,<br>components<br>unknown.                                                                                |
| Terla    | 7.11.73  | 22                      | 0                | 21           | 30                       | 0                | 20                      | 98                          | 35                      | 20                                  | 43                              |                                                                                                                                                                             |
|          | 13.12.73 | -                       | -                | -            | 15                       | 0                | 10                      | 26                          | 11                      | 8                                   | 7                               |                                                                                                                                                                             |
|          | 28.2.74  | 63                      | 0                | 63           | 59                       | 0                | 50                      | 91                          | 57                      | 14                                  | 20                              |                                                                                                                                                                             |
|          | 10.4.74  | 81                      | 0                | 78           | 35                       | 0                | 30                      | 61                          | 48                      | 8                                   | 5                               |                                                                                                                                                                             |

Table 3.2 (Continued).

| Locality                  | Date     | No. <u>Plutella</u> egg |                  |              | No. <u>Plutella</u> pupa |                  |                         | No. <u>Apanteles</u> cocoon |                         |                                     |                                 | Status of insecticide usage**                                                                                   |
|---------------------------|----------|-------------------------|------------------|--------------|--------------------------|------------------|-------------------------|-----------------------------|-------------------------|-------------------------------------|---------------------------------|-----------------------------------------------------------------------------------------------------------------|
|                           |          | Collec-<br>ted*         | Parasi-<br>tised | Hatch-<br>ed | Collec-<br>ted*          | Parasi-<br>tised | With adult<br>emergence | Collec-<br>ted*             | With adult<br>emergence | With hyper<br>parasites<br>emerging | With noth-<br>ing emer-<br>ging |                                                                                                                 |
| Mensum<br>Valley          | 29.8.73  | 45                      | 0                | 40           | 64                       | 0                | 45                      | 40                          | 16                      | 20                                  | 4                               | Crops sprayed<br>twice a week<br>with Monitor.<br>Mixture of<br>Tamaron and<br>Badan also used<br>occasionally. |
|                           | 10.10.73 | -                       | -                | -            | 17                       | 0                | 14                      | 41                          | 17                      | 21                                  | 3                               |                                                                                                                 |
|                           | 21.11.73 | 51                      | 0                | 47           | 55                       | 0                | 36                      | 8                           | 6                       | 1                                   | 1                               |                                                                                                                 |
|                           | 9.1.74   | 13                      | 0                | 13           | 40                       | 0                | 34                      | 31                          | 9                       | 20                                  | 2                               |                                                                                                                 |
|                           | 19.2.74  | 9                       | 0                | 8            | 159                      | 0                | 150                     | 24                          | 3                       | 16                                  | 5                               |                                                                                                                 |
|                           | 13.3.74  | 72                      | 0                | 71           | 38                       | 0                | 22                      | 22                          | 3                       | 18                                  | 1                               |                                                                                                                 |
| Tring-<br>kab             | 6.9.73   | 18                      | 0                | 18           | 11                       | 0                | 8                       | 70                          | 50                      | 8                                   | 12                              | Crops sprayed<br>with Tamaron<br>or/and Padan<br>every 4 days.                                                  |
|                           | 17.10.73 | 47                      | 0                | 46           | 20                       | 0                | 13                      | 12                          | 8                       | 1                                   | 3                               |                                                                                                                 |
|                           | 5.12.73  | 109                     | 0                | 106          | -                        | -                | -                       | -                           | -                       | -                                   | -                               |                                                                                                                 |
|                           | 16.1.74  | 67                      | 0                | 60           | 79                       | 0                | 65                      | 99                          | 73                      | 9                                   | 17                              |                                                                                                                 |
|                           | 13.2.74  | -                       | -                | -            | 159                      | 0                | 136                     | 23                          | 17                      | 3                                   | 3                               |                                                                                                                 |
|                           | 21.3.74  | 33                      | 0                | 33           | 106                      | 0                | 88                      | 116                         | 56                      | 24                                  | 36                              |                                                                                                                 |
| Kampong<br>Taman<br>Sedia | 17.8.73  | -                       | -                | -            | 42                       | 0                | 20                      | 15                          | 8                       | 4                                   | 3                               | Crops sprayed<br>weekly with<br>Padan or insec-<br>ticide mixtures.                                             |
|                           | 29.8.73  | 83                      | 0                | 81           | 31                       | 0                | 25                      | 7                           | 5                       | 0                                   | 2                               |                                                                                                                 |
|                           | 17.10.73 | 65                      | 0                | 65           | 25                       | 0                | 18                      | 5                           | 2                       | 2                                   | 1                               |                                                                                                                 |
|                           | 5.12.73  | 71                      | 0                | 70           | 8                        | 0                | 8                       | 24                          | 1                       | 11                                  | 12                              |                                                                                                                 |

\*On 25 sampled plants.

\*\*methamidophos = (Tamaron, Monitor); cartap = (Padan).

Table 3.3 Survival of the immature stages of Plutella xylostella (L.) and Apanteles plutellae Kurdj. cocoons, collected from different localities in the lowland and the Cameron Highlands (1979-80).

| Locality                      | Date    | No. <u>Plutella</u> pupa |             |                      | A. <u>Plutellae</u> cocoons |                      |                               |                       | Status of insecticide usage                                                                                                              |
|-------------------------------|---------|--------------------------|-------------|----------------------|-----------------------------|----------------------|-------------------------------|-----------------------|------------------------------------------------------------------------------------------------------------------------------------------|
|                               |         | Collected*               | Parasitised | With adult emergence | Collected*                  | With adult emergence | With hyper-parasites emerging | With nothing emerging |                                                                                                                                          |
| <u>LOWLAND</u>                |         |                          |             |                      |                             |                      |                               |                       |                                                                                                                                          |
| Sg. Yu (Tanjung Karang)       | 25.6.79 | 61                       | 0           | 56                   | 43                          | 17                   | 1                             | 25                    | Spraying irregular (depending on infestations). Dipel, Tamaron and Hostathion used.                                                      |
| Sg. Kelambu (Banting)         | 22.1.80 | 116                      | 0           | 108                  | 68                          | 33                   | 0                             | 35                    | Crops sprayed mainly against <u>Hellula</u> sp. Insecticide mixtures (Decis, Padan, Sumicidin) used. Staggered planting clearly evident. |
| K. Langat/Tg. Sepat (Banting) | 29.1.80 | 0                        | 0           | 0                    | 24                          | 12                   | 0                             | 12                    | As above                                                                                                                                 |
| <u>CAMERON HIGHLANDS</u>      |         |                          |             |                      |                             |                      |                               |                       |                                                                                                                                          |
| Brinchang (Town)              | 26.9.79 | 0                        | -           | -                    | 100                         | 96                   | 4                             | 0                     | Frequent spraying with Ambush.                                                                                                           |
| Brinchang (7 miles)           | 26.9.79 | 13                       | 0           | 12                   | 54                          | 38                   | 12                            | 4                     | Frequent spraying with Ambush.                                                                                                           |
| Brinchang (45 miles)          | 26.9.79 | 9                        | 0           | 6                    | 37                          | 18                   | 17                            | 2                     | Spraying irregular (depending on infestations). Dipel and Ambush used.                                                                   |
| Kuala Terla (49-50 miles)     | 4.12.79 | 15                       | 0           | 15                   | 22                          | 19                   | 3                             | 0                     | Frequent spraying with mixtures. BHC and Dynafot commonly used.                                                                          |
| Kg. Raja (52 miles)           | 5.12.79 | 47                       | 0           | 38                   | 22                          | 17                   | 5                             | 0                     | Frequent spraying with mixtures of Dynafot, Dipel and Surecide.                                                                          |

\*On 30 sampled plants.

Table 3.4. The fate of *Plutella xylostella*(L.) larvae collected from different localities in the Cameron Highlands. (1973-74).

| Locality         | Date     | Total no. of <i>Plutella</i> larvae* |                |                    |                                      | (e)<br>No. adult<br><i>Plutella</i><br>obtained<br>from (b) | (f)<br>No. adult<br>parasite<br>obtained<br>from (c) | % larval mortality<br>due to:-       |                                       | % pupal mortality<br>of<br><i>Plutella</i> Parasite |      | % larvae<br>reaching<br>adult<br>stage |
|------------------|----------|--------------------------------------|----------------|--------------------|--------------------------------------|-------------------------------------------------------------|------------------------------------------------------|--------------------------------------|---------------------------------------|-----------------------------------------------------|------|----------------------------------------|
|                  |          | (a)<br>Collected                     | (b)<br>Pupated | (c)<br>Parasitised | (d)<br>Died of<br>other<br>factors** | Parasite<br>( $\frac{c}{a} \times 100$ )                    | Other factors<br>( $\frac{d}{a} \times 100$ )        | **<br>( $\frac{b-e}{b} \times 100$ ) | ***<br>( $\frac{c-f}{c} \times 100$ ) | ( $\frac{e}{a} \times 100$ )                        |      |                                        |
| Bertam<br>Valley | 22.8.73  | 132                                  | 21             | 58                 | 53                                   | 7                                                           | 39                                                   | 43.9                                 | 40.2                                  | 66.7                                                | 32.8 | 5.3                                    |
|                  | 27.9.73  | 273                                  | 232            | 41                 | 0                                    | 113                                                         | 41                                                   | 15.0                                 | 0.0                                   | 51.3                                                | 0.0  | 41.4                                   |
|                  | 15.11.73 | 210                                  | 173            | 32                 | 5                                    | 162                                                         | 30                                                   | 15.2                                 | 2.4                                   | 6.4                                                 | 6.3  | 77.1                                   |
|                  | 21.12.73 | 120                                  | 38             | 55                 | 27                                   | 10                                                          | 42                                                   | 45.8                                 | 22.5                                  | 73.7                                                | 23.6 | 8.3                                    |
|                  | 30.1.74  | 186                                  | 117            | 64                 | 5                                    | 72                                                          | 49                                                   | 34.4                                 | 2.7                                   | 38.5                                                | 23.4 | 38.7                                   |
|                  | 6.3.74   | 108                                  | 45             | 60                 | 3                                    | 31                                                          | 54                                                   | 55.6                                 | 2.8                                   | 31.1                                                | 10.0 | 28.7                                   |
| Kampong<br>Raja  | 20.9.73  | 252                                  | 223            | 29                 | 0                                    | 76                                                          | 12                                                   | 11.5                                 | 0.0                                   | 65.9                                                | 58.6 | 30.2                                   |
|                  | 7.11.73  | 100                                  | 16             | 60                 | 24                                   | 15                                                          | 58                                                   | 60.0                                 | 24.0                                  | 6.3                                                 | 3.3  | 15.0                                   |
|                  | 13.12.73 | 20                                   | 9              | 9                  | 2                                    | 6                                                           | 5                                                    | 45.0                                 | 10.0                                  | 33.3                                                | 44.4 | 30.0                                   |
|                  | 30.1.74  | 47                                   | 24             | 19                 | 4                                    | 23                                                          | 15                                                   | 40.4                                 | 8.5                                   | 4.2                                                 | 21.1 | 48.9                                   |
|                  | 28.2.74  | 161                                  | 37             | 110                | 14                                   | 12                                                          | 84                                                   | 68.3                                 | 8.7                                   | 67.6                                                | 23.6 | 7.5                                    |
|                  | 10.4.74  | 110                                  | 53             | 25                 | 32                                   | 30                                                          | 20                                                   | 22.7                                 | 29.1                                  | 43.4                                                | 20.0 | 27.3                                   |
| Kuala<br>Terla   | 20.9.73  | 265                                  | 115            | 150                | 0                                    | 34                                                          | 42                                                   | 56.6                                 | 0.0                                   | 70.4                                                | 72.0 | 12.8                                   |
|                  | 7.11.73  | 100                                  | 17             | 9                  | 74                                   | 6                                                           | 7                                                    | 9.0                                  | 74.0                                  | 64.7                                                | 22.2 | 6.0                                    |
|                  | 13.12.73 | 8                                    | 0              | 8                  | 0                                    | 0                                                           | 5                                                    | 100.0                                | 0.0                                   | 0.0                                                 | 37.5 | 0.0                                    |
|                  | 28.2.74  | 131                                  | 20             | 98                 | 13                                   | 16                                                          | 85                                                   | 74.8                                 | 9.9                                   | 20.0                                                | 13.3 | 12.2                                   |
|                  | 10.4.74  | 120                                  | 73             | 38                 | 9                                    | 43                                                          | 35                                                   | 31.7                                 | 7.5                                   | 41.1                                                | 7.9  | 35.8                                   |
| Nensum<br>Valley | 29.8.73  | 253                                  | 253            | 0                  | 0                                    | 63                                                          | 0                                                    | 0.0                                  | 0.0                                   | 75.1                                                | 0.0  | 24.9                                   |
|                  | 10.10.73 | 359                                  | 177            | 81                 | 101                                  | 98                                                          | 78                                                   | 22.6                                 | 28.1                                  | 44.6                                                | 3.7  | 27.3                                   |
|                  | 21.11.73 | 230                                  | 131            | 99                 | 0                                    | 66                                                          | 99                                                   | 43.0                                 | 0.0                                   | 49.6                                                | 0.0  | 28.7                                   |
|                  | 9.1.74   | 427                                  | 316            | 62                 | 49                                   | 281                                                         | 51                                                   | 14.5                                 | 11.5                                  | 11.1                                                | 17.7 | 65.8                                   |
|                  | 19.2.74  | 141                                  | 123            | 15                 | 3                                    | 108                                                         | 11                                                   | 10.6                                 | 2.1                                   | 12.2                                                | 26.7 | 76.6                                   |
|                  | 13.3.74  | 155                                  | 129            | 26                 | 0                                    | 97                                                          | 25                                                   | 16.8                                 | 0.0                                   | 24.8                                                | 3.9  | 62.6                                   |

Table 3.4 (Continued).

| Locality | Date     | Total no. of <u>Plutella</u> larvae * |                |                         |                                      | (e)                              | (f)                              | % larval mortality due to:-              |                                                      | % pupal mortality of                              |                                            | % larvae reaching adult stage<br>( $\frac{e}{a} \times 100$ ) |
|----------|----------|---------------------------------------|----------------|-------------------------|--------------------------------------|----------------------------------|----------------------------------|------------------------------------------|------------------------------------------------------|---------------------------------------------------|--------------------------------------------|---------------------------------------------------------------|
|          |          | (a)<br>Collected                      | (b)<br>Pupated | (c)<br>Para-<br>sitised | (d)<br>Died of<br>other<br>factors** | Plutella<br>obtained<br>from (b) | parasite<br>obtained<br>from (c) | Parasite<br>( $\frac{c}{a} \times 100$ ) | Other fac-<br>tors**<br>( $\frac{d}{a} \times 100$ ) | Plutella<br>***<br>( $\frac{b-e}{b} \times 100$ ) | Parasite<br>( $\frac{b-e}{c} \times 100$ ) |                                                               |
| Tringkap | 6.9.73   | 30                                    | 13             | 17                      | 0                                    | 4                                | 17                               | 56.7                                     | 0.0                                                  | 69.2                                              | 0.0                                        | 13.3                                                          |
|          | 17.10.73 | 120                                   | 22             | 45                      | 53                                   | 22                               | 21                               | 37.5                                     | 44.2                                                 | 0.0                                               | 53.3                                       | 18.3                                                          |
|          | 5.12.73  | 110                                   | 30             | 36                      | 44                                   | 10                               | 33                               | 32.7                                     | 40.0                                                 | 66.7                                              | 8.3                                        | 9.1                                                           |
|          | 16.1.74  | 110                                   | 26             | 30                      | 54                                   | 26                               | 24                               | 27.3                                     | 49.1                                                 | 0.0                                               | 20.0                                       | 23.6                                                          |
|          | 13.2.74  | 132                                   | 75             | 20                      | 37                                   | 60                               | 8                                | 15.2                                     | 28.0                                                 | 20.0                                              | 60.0                                       | 45.5                                                          |
|          | 21.3.74  | 60                                    | 16             | 43                      | 1                                    | 12                               | 40                               | 71.7                                     | 1.7                                                  | 25.0                                              | 7.0                                        | 20.0                                                          |
|          | 17.8.73  | -                                     | -              | -                       | -                                    | -                                | -                                | -                                        | -                                                    | -                                                 | -                                          | -                                                             |
| Kg.      | 29.8.73  | 120                                   | 115            | 5                       | 0                                    | 34                               | 5                                | 4.2                                      | 0.0                                                  | 70.4                                              | 0.0                                        | 28.3                                                          |
| Taman    | 17.10.73 | 61                                    | 31             | 5                       | 25                                   | 17                               | 4                                | 8.2                                      | 41.0                                                 | 45.2                                              | 20.0                                       | 27.9                                                          |
| Sedia    | 5.12.73  | 56                                    | 20             | 25                      | 11                                   | 14                               | 22                               | 44.6                                     | 19.6                                                 | 30.0                                              | 12.0                                       | 25.0                                                          |

\*On 25 sampled plants.

\*\*Numerous larvae turned blackish.

\*\*\*Numerous pupae covered with whitish fungal mycelia.

- No collection made.

Table 3.5. The fate of *Plutella xylostella* (L.) larvae collected from different localities in the lowland and the Cameron Highlands (1979-80).

| Locality                           | Date    | Total no of <i>Plutella</i> larvae* |       |         |           | (e)             | (f)       | % larval mortality           |                              | % pupal mortality of:          |                                | % larvae                     |
|------------------------------------|---------|-------------------------------------|-------|---------|-----------|-----------------|-----------|------------------------------|------------------------------|--------------------------------|--------------------------------|------------------------------|
|                                    |         | (a)                                 | (b)   | (c)     | (d)       | No. adult       | No. adult | due to:                      |                              |                                |                                | reaching                     |
|                                    |         | Collec-                             | Pupa- | Parasi- | Died of   | <i>Plutella</i> | parasite  | Parasite                     | Other factors**              | <i>Plutella</i> ***            | Parasite                       | adult                        |
|                                    |         | ted                                 | ted   | tised   | other     | obtained        | obtained  | ( $\frac{c}{a} \times 100$ ) | ( $\frac{d}{a} \times 100$ ) | ( $\frac{b-e}{b} \times 100$ ) | ( $\frac{c-f}{c} \times 100$ ) | stage                        |
|                                    |         |                                     |       |         | factors** | from (b)        | from (c)  |                              |                              |                                |                                | ( $\frac{e}{a} \times 100$ ) |
| LOWLAND                            |         |                                     |       |         |           |                 |           |                              |                              |                                |                                |                              |
| Sg. Yu<br>(Tg.Karang)              | 25.6.79 | 92                                  | 38    | 11      | 43        | 36              | 6         | 12.0                         | 46.7                         | 5.3                            | 45.5                           | 39.1                         |
| Sg.Kelambu<br>(Banting)            | 22.1.80 | 57                                  | 31    | 5       | 21        | 29              | 3         | 8.8                          | 36.8                         | 6.5                            | 40.0                           | 50.9                         |
| K.Langat/<br>Tg.Sepat<br>(Banting) | 29.1.80 | 100                                 | 32    | 14      | 54        | 32              | 8         | 14.0                         | 54.0                         | 0.0                            | 42.9                           | 32.0                         |
| CAMERON HIGHLANDS                  |         |                                     |       |         |           |                 |           |                              |                              |                                |                                |                              |
| Brinchang<br>(Town)                | 26.9.79 | 38                                  | 4     | 22      | 12        | 4               | 20        | 57.9                         | 31.6                         | 0.0                            | 9.1                            | 10.5                         |
| Brinchang<br>(7 miles)             | 26.9.79 | 85                                  | 11    | 36      | 38        | 9               | 30        | 42.4                         | 44.7                         | 18.2                           | 16.7                           | 10.6                         |
| Brinchang<br>(45 miles)            | 26.9.79 | 113                                 | 36    | 36      | 41        | 27              | 28        | 31.9                         | 36.3                         | 25.0                           | 22.2                           | 23.9                         |
| Kuala Terla                        | 4.12.79 | 483                                 | 349   | 101     | 33        | 341             | 80        | 20.9                         | 6.8                          | 2.3                            | 20.8                           | 70.6                         |
| Kg.Raja                            | 5.12.79 | 831                                 | 587   | 158     | 86        | 563             | 119       | 19.0                         | 10.4                         | 4.1                            | 24.7                           | 67.8                         |

\* On 30 sampled plants.

\*\* Numerous larvae turned blackish.

\*\*\* Numerous pupae covered with whitish fungal mycelia.



### 3.3.4 Effect of hyperparasites and other mortality factors on A.plutellae

Survival of A.plutellae was observed to vary greatly among the different sub-regions in the Cameron Highlands. As high as 79.6% adult parasite emergence from cocoons was obtained in Brinchang while only 31.4% occurred in Kampong Taman Sedia (Table 3.2). Throughout the surveyed areas, an average mortality of 39.7% was recorded, with 21.0% contributed by hyperparasites and the remainder by unknown factors. Among the parasites from hosts collected at the larval stage, the total mean mortality was 22.8% (Table 3.4).

For the survey in the lowlands and Brinchang in 1979-80, parasite survival differed notably, averaging 79.6% in Brinchang and 45.9% in the lowlands (Table 3.3). Whilst mortality due to hyperparasites constituted about 17.3% in Brinchang, it was unimportant (0.7%) in the lowlands (Table 3.3). Evidently, in the lowlands some other factor(s) must be responsible for the observed parasite mortality. In the highlands the impact of hyperparasites on the performance of the existing parasites seems evident from Fig.3.2, wherein a lower percentage parasitism by A.plutellae was associated with a higher level of hyperparasitism.

In the Cameron Highlands, 3 species of hymenopterous hyperparasites were reared from the field-collected cocoons of A.plutellae although in subsequent studies 5 additional species were recorded by Ooi (1979a). The 3 species were Hemiteles sp. (Hym: Ichneumonidae), Tetrastichus sp. (Hym: Eulophidae) and Mesochorus sp. (Hym: Ichneumonidae). Hemiteles sp. predominated constituting 77.1% of a total of 192 hyperparasites that emerged. The next commonest hyperparasite was Tetrastichus sp. (19.3%) while Mesochorus sp. occurred only occasionally. In the lowlands, only 1 specimen of Hemiteles sp. was recorded, and was obtained from Sungai Yu.

In general Hemiteles sp. obtained resembles A.plutellae superficially in size and colour. However, there are differences in the wing venation and antennal length. The body of A.plutellae is also more robust. Only one adult in all the 3 hyperparasite species emerged from each A.plutellae cocoon. The hole made by the emerging hyperparasite is usually irregular and differs from that made by A.plutellae which normally pushes open a circular lid at the end of a cocoon.

### 3.3.5 Relationship of DBM incidence to parasitism and other mortality factors

The survey showed that the incidence of DBM ranged from 3.2 to 10.4 larvae/plant in most parts of the highlands for the years 1973-74 (Table 3.4). Among the different sub-regions, Mensum Valley had the

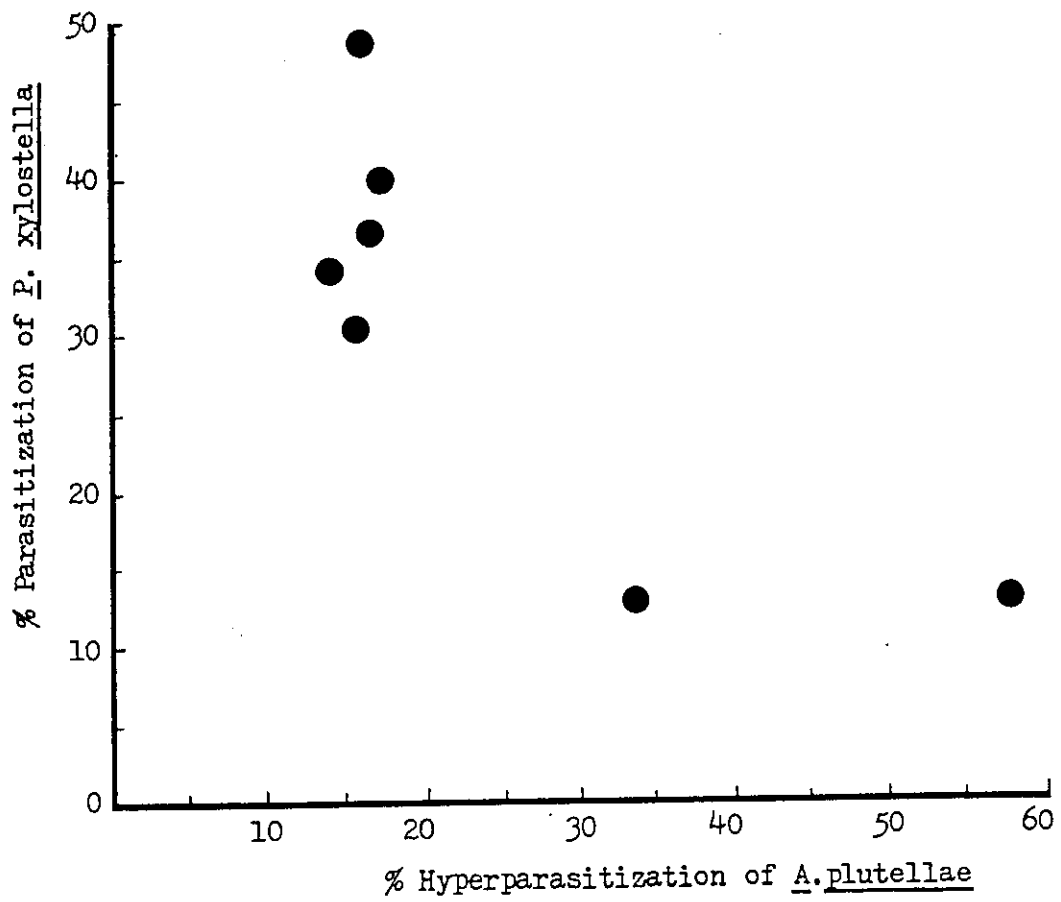


FIGURE 3.2 Relationship between the parasitization of Plutella xylostella (L.) by Apanteles plutellae Kurdj. and hyperparasitization of the latter by hyperparasites.

highest infestation while Kampong Taman Sedia had the least. In the lowlands, the mean incidence recorded during 1979-80 did not exceed 3.3 larvae/plant (Table 3.5) suggesting that DBM was relatively much less important there.

As to the fate of DBM larvae collected in the Cameron Highlands it was noted that for many of the localities surveyed relatively few became adult: 45.6% in Mensum Valley, 38.4% in Bertam Valley, 27.4% in Kampong Taman Sedia, 23.8% in Tringkap, 23.5% in Kampong Raja, 15.9% in Kuala Terla (Table 3.4) and 17.0% in Brinchang (Table 3.5). The differences were due in part to the effects of the various mortality factors (including pesticides) in the various sub-regions. Excepting Tringkap (33.6%) and Brinchang (38.6%), most of the larvae apparently succumbed to the parasite since mortality due to other factors was slight (9.0% - 15.4%) in general. A substantial further loss occurred at the pupal stage, ranging from 26.4% to 60.8% and averaging 41.7% (Table 3.4). In the lowlands, the reverse was observed; the pupal mortality being low (0-6.5%) while the proportion (32.0% to 50.9%) of larvae reaching the adult stage was relatively much higher (Table 3.5).

Egg hatch was more than 94% for all the localities surveyed (Table 3.2). The lowest was in Mensum Valley (94.2%) while Kampong Taman Sedia had the highest (98.6%).

Emergence from pupae collected directly from the fields was also high. With the exception of Kampong Taman Sedia which had only 67.0% emergence, that for the remaining sub-regions ranged from 80.0% to 83.3% (Tables 3.2 & 3.3). In general, during 1973-74 this field mortality (19.4%) was much lower than that of pupae bred in the laboratory from field collected larvae (41.7%). Perhaps, this was due mainly to the inevitable bias towards collecting healthier pupae that had survived through the initial developmental phase, including the prepupal stage.

### 3.4 DISCUSSION

The discovery of A. plutellae in the current studies would appear to be the first record of a DBM parasite occurring there. This finding is of particular significance in that it shattered the unfounded belief of 'no possibility of parasite occurrence' that had been firmly and persistently adhered to. Since then, many pest control personnel have become more readily attuned to considering possible biological control inputs. So, conceptually, the unilateral chemical approach has to some extent given way to one that is relatively more ecological in outlook.

It is not known exactly when A. plutellae first gained access

to the Cameron Highlands. Ho (1965) specifically mentioned that there was no parasite on DBM at that time. It is unlikely that the parasite could have escaped detection then since it is now generally obvious. Ho & Ng (1970) who then conducted extensive field investigations on the moth, again did not report the presence of a parasite. It thus appears that A.plutellae must have first spread to the Cameron Highlands during the period 1970-73. If this was so, and judging from the widespread establishment and high incidence that the parasite has so rapidly attained, it would appear that A.plutellae is a highly adaptable and robust species.

Throughout the investigations it was evident that only A.plutellae occurred as a parasite of DBM in the Cameron Highlands. Later studies (Ooi & Kelderman, 1977; Ooi, 1979b), however, revealed two other parasites; an incidental pupal parasite Tetrastichus ayyari Rohw. (Hym: Eulophidae) and an unidentified chalcid ectoparasite of the family Eupelmidae. Both were noted to be of little importance and occurred only in negligible numbers; only a single individual of the ectoparasite was obtained. Apparently, among the naturally-occurring parasites recorded there so far, only A.plutellae seems to be of significance. The preponderance of this species is perhaps due in part to the lack of other more efficient and competitive parasites.

Over the Cameron Highlands, the level of parasitism by A.plutellae averaged 29.6%. Wide variation was recorded for the different sub-regions, and in general, the population of DBM tended to be lower in areas with a higher level of parasitism. For example, in the 1973-74 survey, regions such as Kampong Raja, Kuala Terla, Tringkap, Bertam Valley and Kampong Taman Sedia had a DBM population which did not exceed 6.9 larvae/plant; while, except for Kampong Taman Sedia, the level of parasitism ranged from 30.1% to 48.6% (Table 3.6). On the other hand, in Mensum Valley, it had 10.4 larvae/plant and the parasitism rate was only 18.1%. Such a relationship was again evident in the 1979 survey where Brinchang had a very low level of DBM infestation accompanied by high parasitism, and this contrasted strongly with reverse situations in Kampong Raja and Kuala Terla (Table 3.6). In 1978, Ooi (1979a) also showed a somewhat similar relationship. However, when data from the lowlands were considered, such a trend was not apparent. Compared to the highlands, all the surveyed areas had insignificant numbers of DBM per plant (1.9-3.3) with very low parasitism rates that only reached up to 14.0% and averaged 12.1% (Table 3.5). Except for this discrepancy which perhaps resulted from other factors since the conditions in the lowlands are usually very different, the relationship observed in the Cameron Highlands

Table 3.6 Changing trends of insecticidal usage, *Plutella xylostella* (L.) infestations, and the parasitism rates of *Apanteles plutellae* Kurdj. in the various sub-regions of the Cameron Highlands during 1973-79.

| Locality              | No. <i>P.xylostella</i> /plant |                    |      | % parasitism |                    |      | Manner of insecticidal usage |                      |           |                 |                      |      |      |               |         |                      |      |      |
|-----------------------|--------------------------------|--------------------|------|--------------|--------------------|------|------------------------------|----------------------|-----------|-----------------|----------------------|------|------|---------------|---------|----------------------|------|------|
|                       |                                |                    |      |              |                    |      | "Cocktails"                  |                      | Frequency |                 |                      |      |      | Amount        |         |                      |      |      |
|                       | 1973-74                        | 1978 <sup>1/</sup> | 1979 | 1973-74      | 1978 <sup>1/</sup> | 1979 |                              |                      |           |                 |                      |      |      |               |         |                      |      |      |
|                       |                                |                    |      |              |                    |      | 1973-74                      | 1978 <sup>1,2/</sup> | 1979      | 1973-74         | 1978 <sup>1,3/</sup> |      |      | 1979          | 1973-74 | 1978 <sup>1,4/</sup> |      | 1979 |
|                       |                                |                    |      |              |                    |      |                              |                      |           |                 | 3t/w                 | 2t/w | 1t/w |               |         | Low                  | High |      |
| Kampong Raja          | 4.6                            | 27.2               | 27.7 | 36.5         | 23.1               | 19.0 | No                           | 14                   | Yes       | Very frequent   | 4                    | 10   | 3    | Very frequent | High    | 7                    | 11   | High |
| Kuala Terla           | 5.0                            | 10.2               | 16.1 | 48.6         | 44.5               | 20.9 | Yes                          | 12                   | Yes       | "               | 3                    | 5    | 10   | "             | Low     | 10                   | 7    | High |
| Tringkap              | 3.8                            | 4.8                | -    | 34.0         | 29.2               | -    | Yes                          | 16                   | -         | "               | 1                    | 14   | 7    | -             | High    | 11                   | 10   | -    |
| Kea Farm/Greencow     | -                              | 1.6                | -    | -            | 42.4               | -    | -                            | 14                   | -         | -               | 2                    | 0    | 17   | -             | -       | 12                   | 5    | -    |
| Mensum Valley         | 10.4                           | 8.6                | -    | 18.1         | 52.9               | -    | Yes                          | 12                   | -         | Very frequent   | 1                    | 12   | 11   | -             | Low     | 15                   | 4    | -    |
| Bertam Valley/Ringlet | 6.9                            | 6.4                | -    | 30.1         | 36.0               | -    | No                           | 6                    | -         | Fre-<br>quently | 2                    | 2    | 6    | -             | Low     | 7                    | 4    | -    |
| Kampong Taman Sedia   | 3.2                            | -                  | -    | 12.7         | -                  | -    | Yes                          | -                    | -         | Fre-<br>quently | -                    | -    | -    | -             | High    | -                    | -    | -    |
| Brinchang:            |                                |                    |      |              |                    |      |                              |                      |           |                 |                      |      |      |               |         |                      |      |      |
| Town                  | -                              | -                  | 1.3  | -            | -                  | 39.5 | -                            | -                    | No        | -               | -                    | -    | -    | Frequently    | -       | -                    | -    | Low  |
| 7 miles               | -                              | -                  | 2.8  | -            | -                  | 42.4 | -                            | -                    | No        | -               | -                    | -    | -    | Frequently    | -       | -                    | -    | Low  |
| 45 miles              | -                              | -                  | 3.8  | -            | -                  | 31.9 | -                            | -                    | No        | -               | -                    | -    | -    | Frequently    | -       | -                    | -    | Low  |

1/ After Ooi & Sudderuddin, 1978.

2/ Number using insecticidal "cocktails" out of 114 farmers surveyed.

3/ t/w = No. of times (insecticidal application) per week.

4/ Low = Amount of insecticides used ranging from 10-39 ml/9 litres; High = Amount ranging from 40-60ml/9 litres.

strongly suggests that A.plutellae has been exerting some control over DBM. Where the level of parasitism increases, the host larval population would tend to decline and be suppressed. However, as with many other parasite species (Morrison & Strong, 1980), a negative regression (Fig.3.3) was observed for all the sub-regions. This, however, contrasted with the positive regression obtained under laboratory conditions (see 4.2.1). A tendency towards positive regressions (Table 3.7) was, however, also observed when crops were untreated\*, although lack of correlation was more common as have been frequently reported for other species (Morrison & Strong, 1980). That applied chemicals in the field may have an influencing effect is suggested by the contrasting situations in these treated and insecticide-free conditions. However, other factors are also involved as tendency towards negative regressions was evident even in untreated crops when host densities exceeded beyond 6 larvae/plant (Fig.3.4). Such a situation where the proportion killed declines with increasing host population clearly revealed the parasite's limitation.

The suppressive effects of A.plutellae is further indicated from the changing trend of the DBM population in the Cameron Highlands. For example, in both Kampong Raja and Kuala Terla the host larval population increased drastically from 1973 to 1979 (Table 3.6). In parallel, there was a sharp drop in parasitism. Likewise, such a relationship was noted for Tringkap although the change over the years was much less. Unlike these sub-regions, the converse was observed in Mensum Valley and Bertam Valley (i.e. increased parasitism correlated with decreased DBM population), confirming further the beneficial role of A.plutellae.

In the Cameron Highlands, the differing changes of both the host and parasite appear likely to be associated with the extensive insecticidal application in practice there. Parasite decline, for instance, was most drastic in areas with greater insecticidal inputs such as Kampong Raja and Kuala Terla. Here, the amount used, application frequency, as well as the employment of 'insecticidal cocktails' tended to be much higher (Ooi, 1979a; Table 3.6). In spite of these, DBM still survived in high numbers suggesting insecticide resistance. However, in other sub-regions such as Mensum Valley and Bertam Valley, insecticidal usage was much less (Table 3.6), thereby not only enabling the continual existence of the parasite but also allowing it to increase. This, in turn, appeared to have led to the lowering of the pest population from 10.4 to 8.6 larvae/

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\*For details of this investigation see 4.1

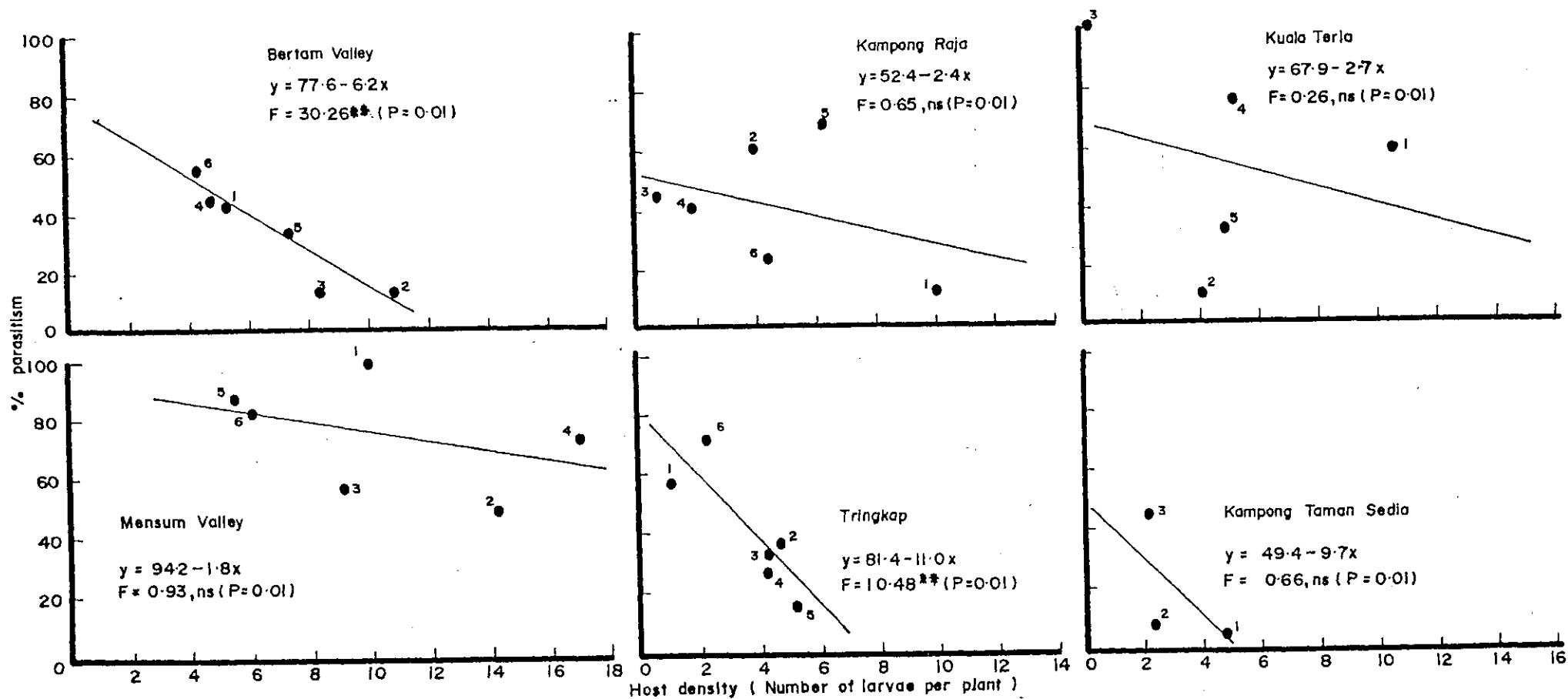


Figure 3/3 Relationship between the density of *Plutella xylostella* (L.) and the parasite *Apanteles plutellae* Kurdj. at different localities in the Cameron Highlands. (Numbers against the points indicate the sequence of sampling).

Table 3.7 Regressions between the densities of Plutella xylostella (L.) and the levels of parasitism (%) caused by Apanteles plutellae Kurdj. over 22 cabbage crops cultivated free of insecticides in the Cameron Highlands.

| Host density<br>(Mean No./plant) | Crop No. | Regression equations<br>(% parasitism vs host<br>density) | Statistical analyses <sup>1/</sup> |
|----------------------------------|----------|-----------------------------------------------------------|------------------------------------|
| Less than 6                      | 1        | $y = 26.27x - 12.57$                                      | $t = 5.562, df = 6(**)$            |
|                                  | 2        | $y = -14.10x + 50.27$                                     | $t = 2.074, df = 10(ns)$           |
|                                  | 3        | $y = 3.03x + 0.37$                                        | $t = 3.285, df = 16(**)$           |
|                                  | 4        | $y = -8.66x + 33.77$                                      | $t = 1.880, df = 15(ns)$           |
|                                  | 5        | $y = 0.52x + 4.96$                                        | $t = 0.350, df = 14(ns)$           |
|                                  | 6        | $y = 1.93x + 14.82$                                       | $t = 1.662, df = 7(ns)$            |
|                                  | 7        | $y = 3.63x + 33.80$                                       | $t = 0.799, df = 16(ns)$           |
|                                  | 8        | $y = 9.99x - 4.57$                                        | $t = 5.005, df = 15(**)$           |
|                                  | 9        | $y = 1.15x + 37.44$                                       | $t = 0.524, df = 16(ns)$           |
|                                  | 10       | $y = 0.28x + 48.64$                                       | $t = 0.056, df = 15(ns)$           |
|                                  | 11       | $y = 0.57x + 33.02$                                       | $t = 0.158, df = 8(ns)$            |
|                                  | 12       | $y = -0.49x + 23.48$                                      | $t = 0.193, df = 11(ns)$           |
|                                  | 13       | $y = 3.63x + 8.29$                                        | $t = 0.802, df = 4(ns)$            |
|                                  | 14       | $y = 2.43x + 39.32$                                       | $t = 0.190, df = 4(ns)$            |
|                                  | 15       | $y = 9.09x + 1.96$                                        | $t = 4.228, df = 6(**)$            |
|                                  | 16       | $y = -9.26x + 63.99$                                      | $t = 2.232, df = 3(ns)$            |
|                                  | 17       | $y = -3.35x + 44.28$                                      | $t = 0.626, df = 4(ns)$            |
|                                  | 18       | $y = 3.03x + 38.30$                                       | $t = 1.114, df = 7(ns)$            |
|                                  | 20       | $y = -0.35x + 33.85$                                      | $t = 0.077, df = 8(ns)$            |
|                                  | 21       | $y = 8.45x + 6.48$                                        | $t = 1.930, df = 6(ns)$            |
|                                  | 22       | $y = 1.72x + 35.74$                                       | $t = 0.480, df = 5(ns)$            |
| More than 6                      | 13       | $y = -2.57x + 34.80$                                      | $t = 5.397, df = 1(ns)$            |
|                                  | 14       | $y = 0.61x + 21.48$                                       | $t = 0.115, df = 3(ns)$            |
|                                  | 15       | $y = -5.0x + 84.0$                                        | -                                  |
|                                  | 16       | $y = 2.25x + 20.28$                                       | $t = 1.669, df = 1(ns)$            |
|                                  | 19       | $y = -11.32x + 224.92$                                    | $t = 3.743, df = 2(ns)$            |

<sup>1/</sup> \*\* = Highly significant, ns = Not significant.

plant in Mensum Valley. In Bertam Valley, the situation was mainly preservation of existing infestations at relatively lower levels as the decline was insignificant, from 6.9 to 6.4 larvae/plant (Table 3.6).

From these findings, it is evident that the extensive and indiscriminate employment of insecticides are sometimes not only unable to contain a pest situation but also may aggravate the problem. The former situation, under the conditions in the Cameron Highlands, is perhaps largely due to the widespread development of insecticide resistance in the pest. Furthermore, the eggs and pupae of DBM may also be intrinsically resistant and thus have remained little affected by the chemicals as suggested from the high egg hatch (96.6%) and high adult emergence (80.6%) from field-collected pupae (Table 3.2). The future introduction of possible natural enemies of the eggs and pupae should therefore prove a useful supplement for the control of DBM.

In the Cameron Highlands, A. plutellae was surprisingly abundant (Table 3.4) in spite of excessive insecticidal usage. Whether this was



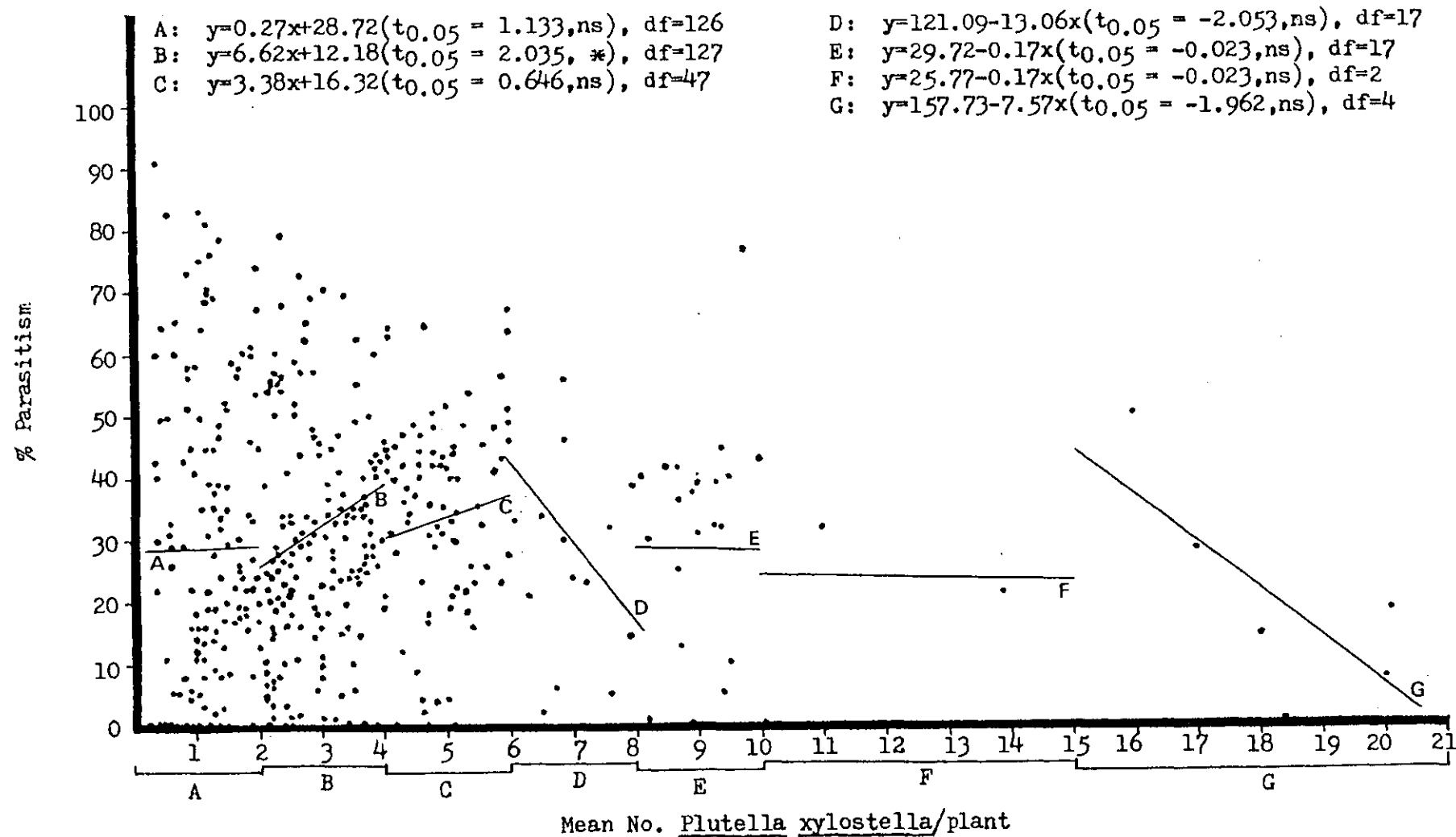


FIGURE 3.4 Regressions between % parasitism by Apanteles plutellae Kurdj. and the abundance of its host [Plutella xylostella (L.)] at different density range.

partly through the development of a resistant parasite strain or from parasites coming in from reservoirs outside the treated crop is not known. In any case, a clear understanding into this aspect should prove useful in broadening any control strategy that exploits the usefulness of the parasite. In relation to the high parasite incidence, for some areas, some chemicals employed are perhaps less harmful intrinsically. For example, in Brinchang where B.t. (Dipel BT<sup>R</sup>) and Ambush<sup>R</sup> were used predominantly (Table 3.3), the parasite incidence was observed to be much higher in spite of frequent applications. Further probes into possible selectivity in insecticides could prove highly rewarding and should be fully examined.

Besides being governed by the nature and effects of insecticides, parasite abundance is also affected by hyperparasites. This is clearly reflected by contrasting situations in the various sub-regions of the Cameron Highlands where the average hyperparasitism was about 21.0% (Table 3.2). In some of the sub-regions (e.g. Kuala Terla, Tringkap and Brinchang), there were fewer hyperparasites (Table 3.3), in conformity with higher levels of parasitism and lower infestations by DBM. However, in Mensum Valley it was as high as 57.8%, in which instance, the parasitism rate of A.plutellae was as low as 18.1%. To some extent, the higher level of hyperparasitism in the Cameron Highlands may be responsible for the increasing use of insecticides there. Evidently, the effects of hyperparasites must be considered when biological control inputs are involved.

In general, the survey suggests that A.plutellae has contributed significantly towards the suppression of DBM. The importance of this is all the more significant when it is noted that mortality of the host eggs and pupae are negligible. Had A.plutellae been absent, the survival of the host would undoubtedly increase tremendously, everything else being equal. Presently, perhaps the full potential of the parasite has still not been sufficiently exploited, largely because of the hyperparasite activity and extensive insecticidal upsets. In any case, the discovery of A.plutellae has provided further avenues for the management of DBM in the Cameron Highlands. Such possibilities appear hopeful since the parasite can effect fairly high parasitism (Lim & Ko, 1975; Tables 3.4 & 3.5). Furthermore, the same parasite species has been well utilized as part of a control programme against DBM in Taiwan (Chiu et al, 1974), clearly demonstrating both its potential and feasibility. These features thus deserve to be further examined in the light of local conditions.

#### 4. ASSESSING THE EFFECT OF A. PLUTELLAE IN THE CONTROL OF DBM

The field survey for parasites of DBM (see 3.3) has indicated that A. plutellae can have a suppressing effect on the population of the moth. How important the parasite really is and to what extent it is beneficial is not exactly known. There is clearly a need to evaluate these so that priorities may be assessed in attempts to exploit its beneficial role. This seems all the more important since the other parasite species were rare (Ooi & Kelderman, 1977; Ooi, 1979b).

In the assessment, the importance and effect of the parasite were evaluated by several means in laboratory and field. Basically, these were comparisons of host population development and survival in the presence and absence of the parasite.

##### 4.1 MATERIALS AND METHODS

In the laboratory studies, the survival of a pair of freshly-emerged DBM adult and that of its subsequent 2-3 generations were closely followed in breeding cages in the presence and absence of A. plutellae. For the former, freshly-emerged adult parasites were introduced in a ratio of 1 parasite pair to 20 host larvae 7 days after host introduction. This was replicated 4 times and followed to the 3rd generation. The treatment without the parasite was replicated 3 times and studied up to the 2nd generation because beyond this developmental stage the population had already become too high and unwieldy for accurate handling. The study was conducted under laboratory conditions (see 2b).

Initially, the pair of freshly-emerged adult moth was confined in 'oviposition jars' (Plate 2.1). All the eggs were counted daily and transferred with a portion of the leaf to the 'larval emergence dish' (Plate 2.3) which was examined daily. Following egg hatching all emerging and living larvae were immediately transferred to a wooden 'larval developmental cage' (Plate 2.2). In the parasite treatment, the appropriate number of A. plutellae adults were also introduced and maintained with water and honey (17%). Daily checks were made and whatever host pupae and parasite cocoons formed were counted and removed to the 'host pupation jar' and 'parasite cocoon emergence jar' respectively (see 2d; Plate 2.1). All adult emergences were recorded daily, and following emergence, the host adults transferred again to the 'oviposition jar' to repeat the whole process until completion of the studies. However, for the parasites, the adults were transferred to the 'larval developmental cage' instead (Plate 2.2).

Among the field assessments, an approach adopted involved measuring the changing level of DBM infestations and its rate of parasitism

by A. plutellae over a number of overlapping cabbage crops where no insecticide was applied. Along with these were also determined the resulting cabbage yields. By complete withdrawal of insecticidal applications, it is hoped that the upsetting effects of chemicals suggested earlier in the survey (see 3.3) could be removed to allow the parasite to manifest freely its impact and potential.

The studies were conducted over a period of 32 overlapping crops of size 28m x 56m during 1973-80 at Tanah Rata in the MARDI Research Station. Cabbage crops of the variety Constanta F.1. Danish were located side by side and continuously cultivated by staggered planting; each subsequent crop following approximately 2 months the immediate preceding crop. This made certain that the crop following would be available for sampling when the preceding one was ready for harvest, thus also ensuring the presence of cabbages at all times. Planting and cultural practices closely followed those of the farmers (Appendix 1).

In the assessment of injury by the pest, the following damage index (Seaman et al, 1963; Williams, 1966) was employed:

$$\text{Damage index (\%)} = \frac{(N_0 \times 5) + (N_1 \times 20) + (N_2 \times 60) + (N_3 \times 100)}{N_0 + 1 + 2 + 3} \quad (1)$$

where,  $N_0$  = number of plants with score '0' (i.e. 5% damage and less),  $N_1$  = number of plants with score '1' (i.e. 20% damage and less, but more than 5%),  $N_2$  = number of plants with score '2' (i.e. 60% damage and less, but more than 20%),  $N_3$  = number of plants with score '3' (i.e. 100% damage and less, but more than 60%), and  $N_0+1+2+3$  = total number of plants (Plate 4.1). Following such scoring under normal field conditions, a 10% damage index would correspond approximately to yield losses (ca 20%) that are beginning to become unacceptable, while a 20% damage index may result in about 50% yield reduction. During the study, a total of 27 plants were taken at random for each assessment. These were subsequently removed for detailed examination and population counts of all the larvae and pupae of DBM and cocoons of A. plutellae. Whatever hosts and parasites collected were then separately confined and reared in breeding jars for survival determination.

Another approach adopted in the field assessment was through a chemical exclusion method. Although possessing some limitations it has been used fairly effectively for several parasite species (DeBach & Bartlett, 1964; DeBach & Huffaker, 1971; van den Bosch & Messenger, 1973). This method, unlike insecticidal withdrawal which measured the changes that subsequently occurred, compared directly and simultaneously the pest-parasite position in a natural situation with one where most of the parasite



PLATE 4.1

Damage scores of feeding injuries by *Plutella xylostella* (L.) on cabbages.

A = Score "0", 5% damage or less; B = Score "1", 20% damage or less, but more than 5%; C = Score "2", 60% damage or less, but more than 20%; D = Score "3", 100% damage or less, but more than 60%.

has been selectively eliminated by chemicals. Growth of the host population in comparison with that in an untreated check plot provides evidence of natural enemy effectiveness (DeBach & Bartlett, 1964).

For this study, 4 treatments were compared, viz Dipel<sup>R</sup>, Padan<sup>R</sup>, Sevithion<sup>R</sup> and the untreated control. Dipel<sup>R</sup>, essentially a biological insecticide of B.t. was selectively toxic to DBM but not against the parasite A.plutellae (see 8.2). In the case of Sevithion<sup>R</sup> (carbaryl + malathion) the reverse situation was true while for Padan<sup>R</sup> (cartap) it was highly toxic to both the host and parasite. Except for Dipel<sup>R</sup> which was applied at 2.5 gm/4.5 litre, both Padan<sup>R</sup> and Sevithion<sup>R</sup> were sprayed at 0.1% a.i.\*. A total of 8 sprays were made for each chemical, beginning 2 weeks after transplanting and at weekly intervals. The layout was of randomised complete block with 3 replications. For each treatment, the plot size was 14.3 m x 12.2 m and it contained 23 beds which included 2 outer guard rows. The beds were spaced 0.6 m apart with each bed having 27 plants including 2 guard row plants at the end. A 0.5 m planting distance was used resulting in a total of 525 plants/plot and 1575 plants/treatment. The cabbage variety Constanta F.1 Danish was planted while fertilizer practices closely followed that of the farmers (Appendix 1).

In the evaluation of damage, weekly assessment based on 10 random plants/replicate (i.e. a total of 30 plants/treatment) were adopted for the computation of the damage index (%). Also taken were the populations of the larvae and pupae of DBM and cocoons of A.plutellae. These were obtained weekly from 10 plants/replicate.

For the assessment of host larval survival, 20 larvae/collection/replicate were randomly obtained over a total of 9 samplings spread throughout the cropping period. The larvae collected were maintained in 'breeding jars' (Plate 2.1) until adult host or parasite emergence. In the studies, survival of the parasite cocoons were also similarly examined. This was based on 15 cocoons/collection/replicate which was repeated over 9 samplings.

From the chemical exclusion method a rapid build-up of the host species was noted in the Sevithion<sup>R</sup> treatment (see 4.2.3). However, this could be due to the insecticide stimulating directly the reproduction and population growth of the host, or indirectly through a physiological effect on the host (van den Bosch & Messenger, 1973). To date, such possibilities of insecticide stimulations have been clearly demonstrated in several pest species (Luckey, 1968; Dittrich et al, 1974) and these prompted further experiments to verify such effects in Sevithion<sup>R</sup> in order to elucidate if the field resurgence could be due to this factor. The effects may be exhibited in the form of increased fecundity, longevity

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\*a.i. = active ingredient.

and other population-determining characteristics. In elucidating whether these did occur, 1-month old potted cabbage plants of the variety K-K Hybrid Cross were used; one group sprayed with 0.1% a.i. Sevithion<sup>R</sup> for 4 consecutive weeks while another acting as 'controls' were treated only with water. Following treatment, each plant was then enclosed over in a netted cage of dimension 51 cm x 51 cm x 51 cm. For the determination of oviposition rate, 3 newly-emerged and mated females of DBM were released into the cage 10 days after the last spray treatment. Every 24 hrs, for the next 5 days, the plant was replaced by another which was similarly treated. All eggs deposited on each plant were counted. Throughout the study, water and 30% honey was provided as food to the adult insects. The experiment was replicated 5 times for both the 'controls' and the treated.

In the determination of developmental period, 100 freshly-laid eggs (deposited within the first 24 hours) were isolated; 20 eggs from each replicate. These were transferred to 'breeding jars' and on hatching were individually reared to the adult stage. For each developmental stage the period was also recorded, while the sex of the emerging adults determined. Studies on fecundity and longevity of the F<sub>1</sub> generation adults were made from isolation of 10 individuals from each of the freshly-emerged females obtained from the treatment group as well as the 'controls'. These were provided daily with 30% honey water solution fed through a wick, as well as, a fresh B.rapa leaf of standard size for oviposition. All eggs deposited daily were recorded until the female died.

Unlike the above study which attempted to explore possible effect of Sevithion<sup>R</sup> indirectly through the host plants, a parallel and separate experiment was also conducted to determine the direct effect via the infesting insect. Under the latter situation the overall procedure was in general similar to that of the previous study except that instead of the plants the 2nd-instar larvae of DBM used were exposed to the insecticide. Only those surviving the treatment and completing the life cycle were considered. For the 'controls' the larvae were sprayed with water only.

## 4.2 RESULTS

### 4.2.1 Laboratory studies on the survival of DBM in the absence and presence of A.plutellae

From the partial population curves for generation 1 (Fig. 4.1) little difference was observed in the development of eggs and larvae. There was, however, evidence that in the presence of A.plutellae the pupal and adult populations were lower. Such a situation was also obvious from the total population curves of generation 1 (Fig. 4.2).

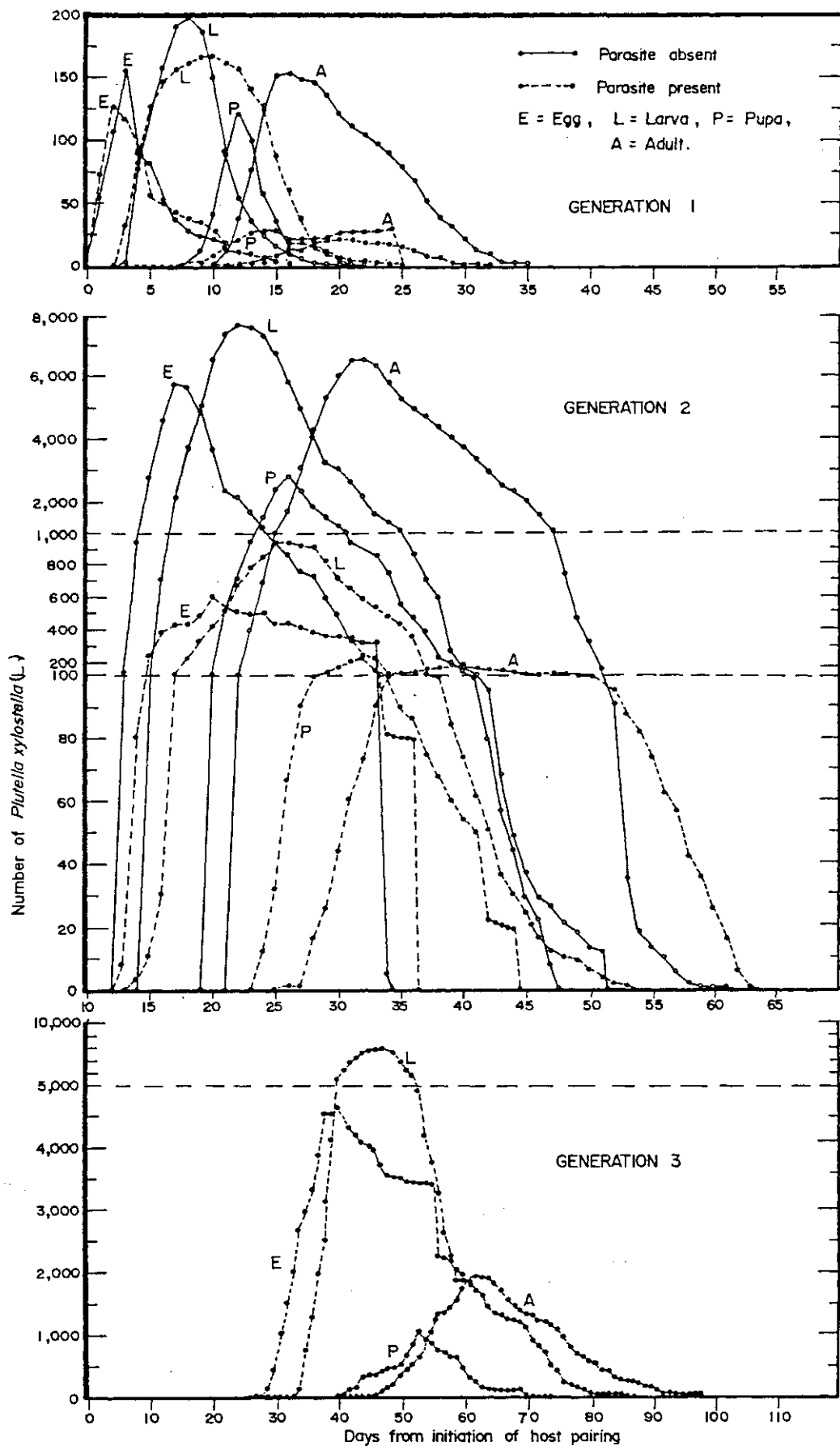


FIGURE 4-1 The partial population curves for the egg, the larva, the pupa and the adult of *Plutella xylostella* (L) in the presence and absence of the parasite, *Apanteles plutellae* Kurdj.



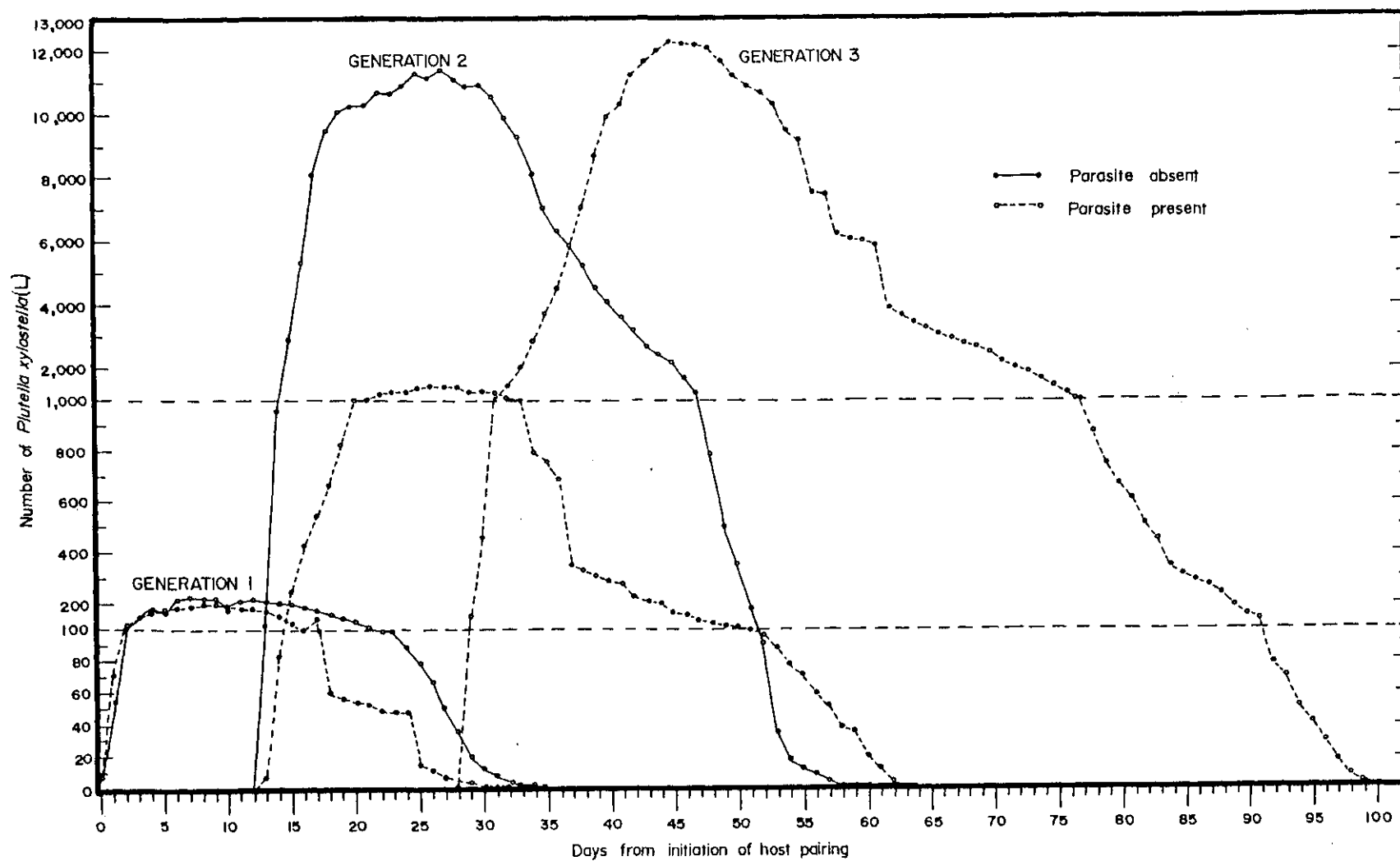


FIGURE 4-2 The total population curves of *Plutella xylostella*(L.) in the presence and absence of the parasite, *Apanteles plutellae* Kurdj.

In the 2nd generation, the difference was much greater (Fig. 4.1). Because of the unequal number of adults attained from the 1st generation, a big difference was observed even for the egg stage. This was carried through into the subsequent stages resulting in about 43-fold difference for the adult stage. Such a distinct difference was clearly reflected in the total population curves (Fig. 4.2).

For generation 3 the study was discontinued in the absence of the parasite for reason already given (see 4.1). In the presence of the parasite, a peak of 7904 was observed (Fig. 4.1). This approximated that for the 2nd generation where the parasite was absent (Figs. 4.1 & 4.2). It is of interest that the parasite delayed host build-up by a generation.

Although the difference in host population build-ups in the presence and absence of the parasite was clearly manifested by the partial (Fig. 4.1) and total (Fig. 4.2) population curves of the separate host generations, this was even more apparent when both generations 1 and 2 were considered together (Fig. 4.3). With subsequent generations the gap can be expected to widen tremendously since the population development in the absence of any significant mortality would likely to be exponential.

Throughout the studies development of the parasite population followed the same pattern as that of the host (Figs. 4.3 & 4.4). It increased and declined similarly with changes of the host population and lagging slightly, suggesting some delayed density-dependence.

With regard to stage recruitment, the generation histogram (Fig. 4.5) reveals little difference within the 1st generation. By generation 2, in the absence of parasite it increased sharply while it still remained low when exposed to the parasite. In the latter situation, egg recruitment was, however, noted to rise by the 3rd generation. While the larval recruitment also remained high, there was a sharp drop in the pupal and adult recruitments that followed, clearly suggesting that A. plutellae was fully responsible as it was the only major mortality factor of the larvae present then. Over the 3 generations, the increase in adult recruitment approximated about 10 fold, while in the absence of the parasite the increase was 46 fold from the 1st to the 2nd generation. Such a substantial effect by A. plutellae demonstrates unquestionably the potential importance of this parasite in the suppression of DBM.

Using life table analysis the suppressive role of A. plutellae was particularly evident. In the absence of the parasite, the K-values respectively were only 0.08 and 0.17 for the 1st and 2nd generation, with larval mortality in both instances negligible (Table 4.1). On the other hand, the corresponding K-values were 0.92 and 0.89, respectively, when the parasite was present (Table 4.2). For these, about 50% of the mortality

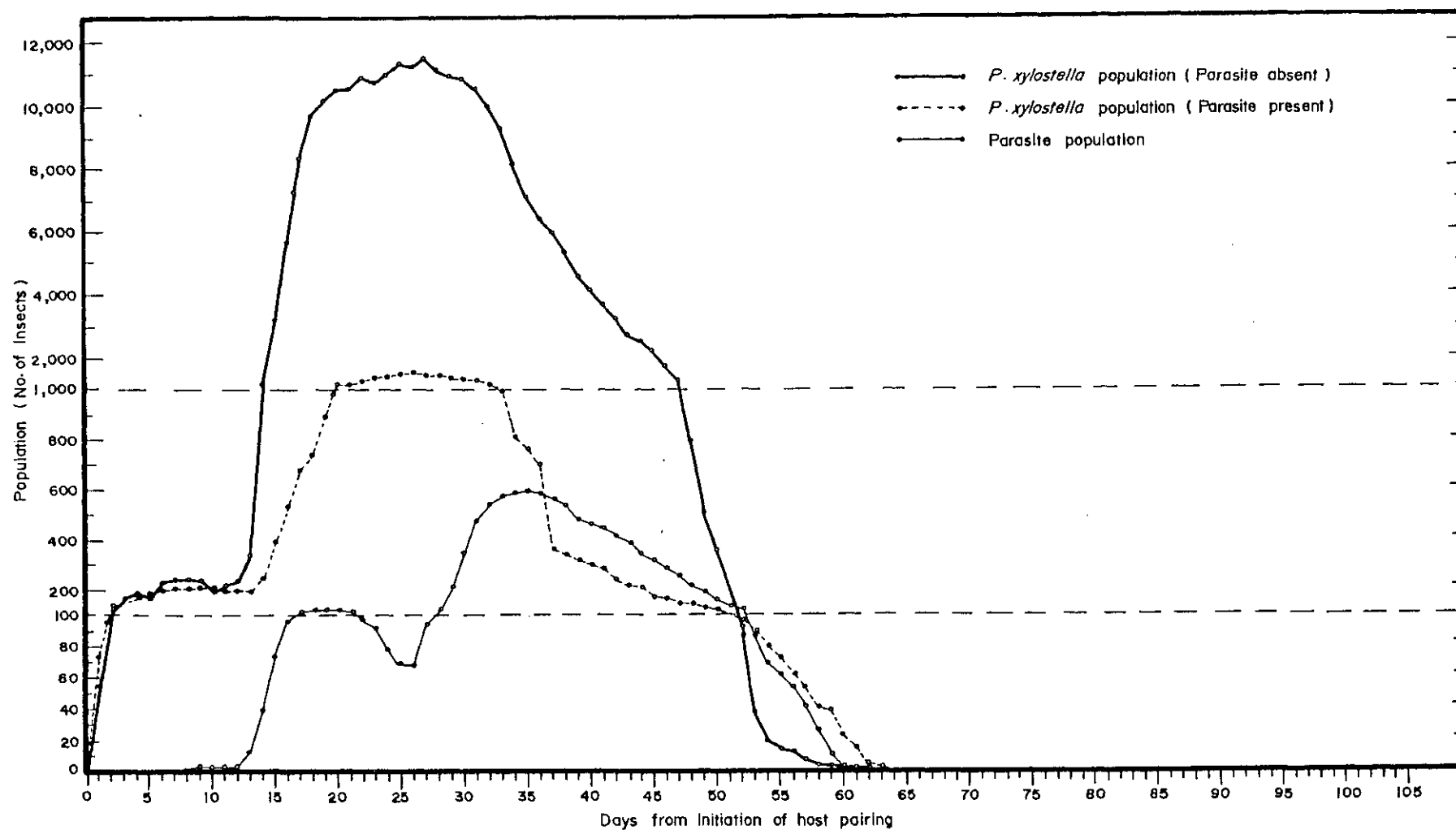


FIGURE 4.3 Total population curves ( generations 1 + 2 ) of *Plutella xylostella*(L) and its parasite *Apanteles plutellae* Kurdj . Where parasites were present, 1 : 20 parasite pair / host larvae were initially introduced at 7 days from initial host ( 1 pair ) introduction .

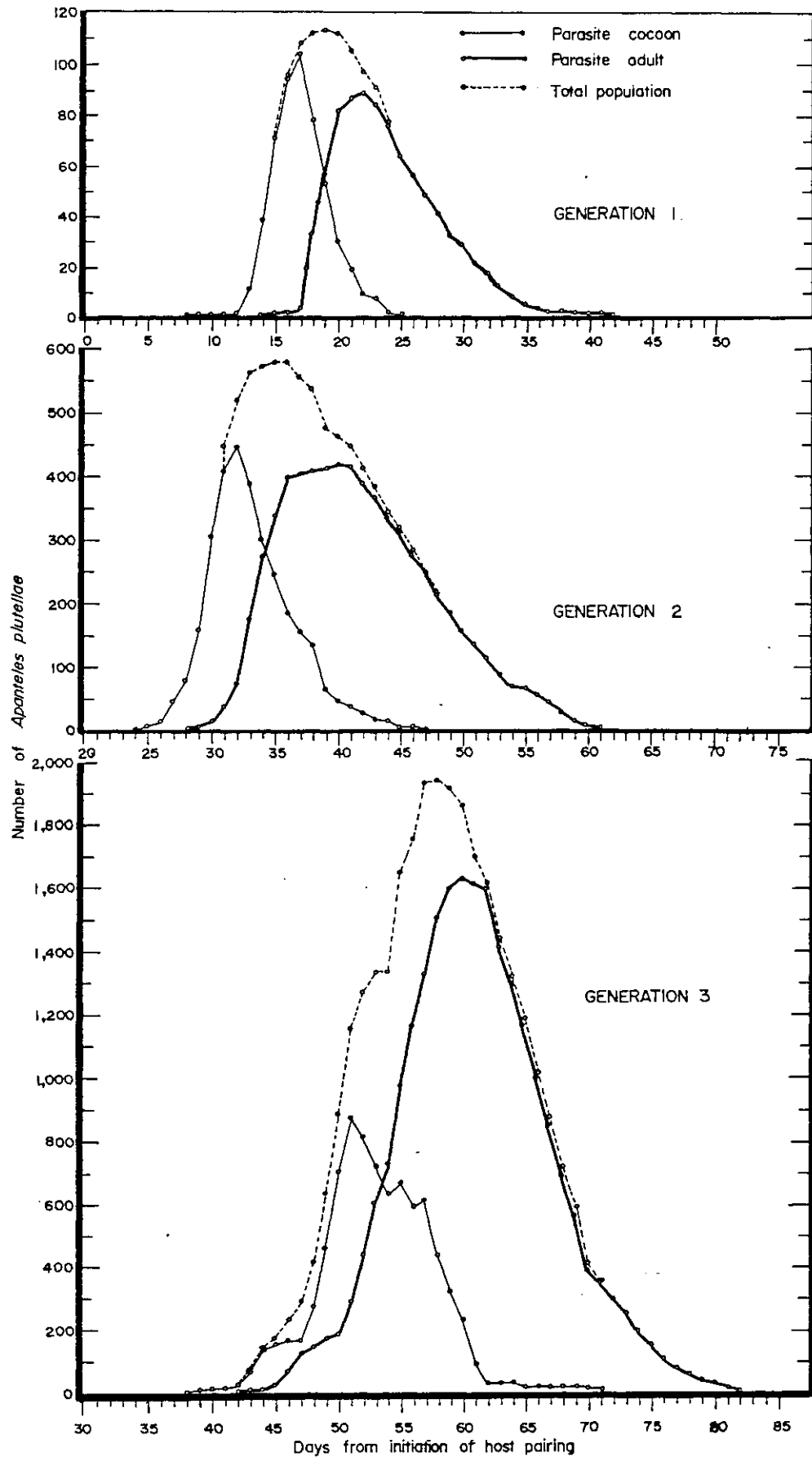


FIGURE 4.4 Population curves of the parasite *Apanteles plutellae* Kurdj. resulting from 1 pair of freshly-emerged adult *Plutella xylostella*(L) with introduction of 1:20 parasite pair/host larvae at 7 days from initiation of host pairing.

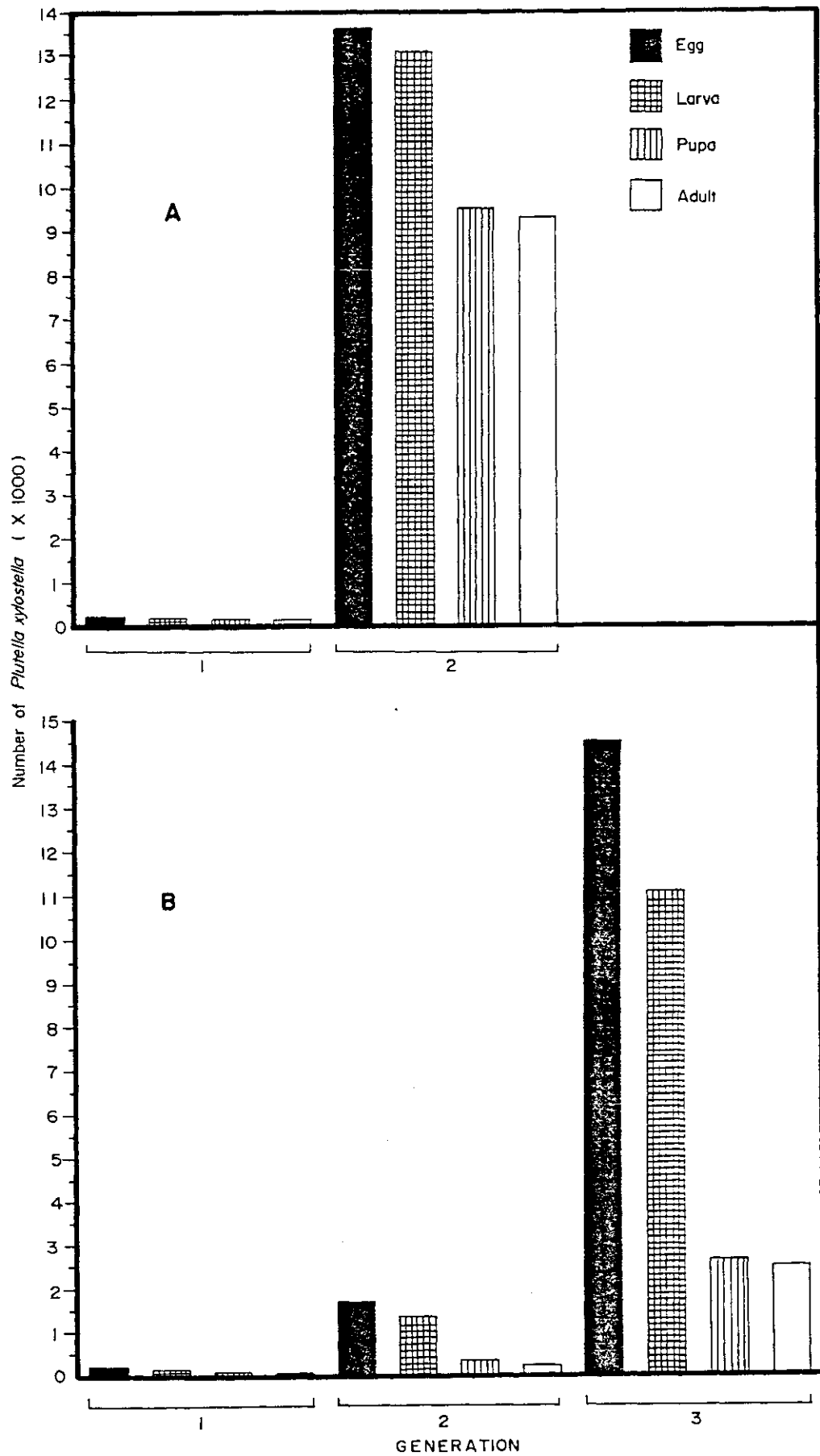


FIGURE 4-5 Generation histogram of *Plutella xylostella*(L) in the absence(A) and presence (B) of the parasite *Apanteles plutellae* Kurdj.

Table 4.1 Population change and age-specific mortality of Plutella xylostella in the absence of the parasite, Apanteles plutellae. (From 1 pair of freshly emerged adult P. xylostella initially).

| Genera-<br>tion | Line                            | Eggs            | Larvae          | Pupae           | Adults          |                                 |
|-----------------|---------------------------------|-----------------|-----------------|-----------------|-----------------|---------------------------------|
|                 |                                 | N <sub>E1</sub> | N <sub>L1</sub> | N <sub>P1</sub> | N <sub>A1</sub> |                                 |
| I               | 1. Population                   | 244             | 225             | 210             | 205             |                                 |
|                 | 2. No. dying<br>in interval     | 19              | +               | 15              | +               | 5 Sum: 39                       |
|                 | 3. % apparent<br>mortality      | 7.8             |                 | 6.7             |                 | 2.4                             |
|                 | 4. % successive<br>survival     | 92.2            |                 | 93.3            |                 | 97.6                            |
|                 | 5. Fraction<br>surviving        | 0.92 x          |                 | 0.93 x          |                 | 0.98 Product = 0.84<br>Survival |
|                 | 6. % real morta-<br>lity        | 7.8             | +               | 6.2             | +               | 2.1 Sum: 16.1%<br>mortality     |
|                 | 7. % indispensable<br>mortality | 7.0             |                 | 6.0             |                 | 2.0                             |
|                 | 8. Mortality/<br>survivor ratio | 0.08            |                 | 0.07            |                 | 0.02                            |
|                 | 9. Log population               | 2.39            |                 | 2.35            |                 | 2.32 2.31                       |
|                 | 10. k-value                     | 0.04            | +               | 0.03            | +               | 0.01 Sum: K = 0.08              |
| II              | 1. Population                   | 13,596          | 13,112          | 9,514           | 9,345           |                                 |
|                 | 2. No. dying<br>in interval     | 484             | +               | 3598            | +               | 169 Sum: 4251                   |
|                 | 3. % apparent<br>mortality      | 3.6             |                 | 27.4            |                 | 1.8                             |
|                 | 4. % successive<br>survival     | 96.4            |                 | 72.6            |                 | 98.2                            |
|                 | 5. Fraction<br>Surviving        | 0.96 x          |                 | 0.73 x          |                 | 0.98 Product = 0.69<br>survival |
|                 | 6. % real morta-<br>lity        | 3.6             | +               | 26.5            | +               | 1.2 Sum: 31.3%<br>mortality     |
|                 | 7. % indispensable<br>mortality | 2.6             |                 | 26.0            |                 | 1.2                             |
|                 | 8. Mortality/<br>survivor ratio | 0.04            |                 | 0.38            |                 | 0.02                            |
|                 | 9. Log population               | 4.13            |                 | 4.12            |                 | 3.98 3.97                       |
|                 | 10. k-value                     | 0.02            | +               | 0.14            | +               | 0.01 Sum: K = 0.17              |

Table 4.2 Population change and age-specific mortality of Flutella xylostella in the presence of the parasite, Apanteles plutellae. (From 1 pair of freshly-emerged adult P. xylostella initially, with introduction of 1:20 parasite pair: host larvae at 7 days from initiation).

| Genera-<br>tion | Line                            | Eggs     | Larvae   | Pupae    | Adults   |                               |
|-----------------|---------------------------------|----------|----------|----------|----------|-------------------------------|
|                 |                                 | $N_{E1}$ | $N_{L1}$ | $N_{P1}$ | $N_{A1}$ |                               |
| I               | 1. Population                   | 212      | 190      | 64       | 26       |                               |
|                 | 2. No. dying<br>in interval     | 22       | +        | 126      | +        | 38 Sum: 186                   |
|                 | 3. % apparent<br>mortality      | 10.4     |          | 66.3     |          | 59.4                          |
|                 | 4. % successive<br>survival     | 89.6     |          | 33.7     |          | 40.6                          |
|                 | 5. Fraction<br>surviving        | 0.90 x   |          | 0.34 x   |          | 0.41 Product=0.13<br>survival |
|                 | 6. % real<br>mortality          | 10.4     | +        | 59.4     | +        | 17.9 Sum: 87.7%<br>mortality  |
|                 | 7. % indispensable<br>mortality | 1.4      |          | 24.1     |          | 17.9                          |
|                 | 8. Mortality/<br>survivor ratio | 0.10     |          | 0.66     |          | 0.59                          |
|                 | 9. Log population               | 2.33     |          | 2.28     |          | 1.81 1.41                     |
|                 | 10. k-value                     | 0.05     |          | 0.47     |          | 0.40 Sum: K=0.92              |
| II              | 1. Population                   | 1694     | 1355     | 366      | 219      |                               |
|                 | 2. No. dying<br>in interval     | 339      | +        | 989      | +        | 147 Sum: 1475                 |
|                 | 3. % apparent<br>mortality      | 20.0     |          | 73.0     |          | 40.2                          |
|                 | 4. % successive<br>survival     | 80.0     |          | 27.0     |          | 59.8                          |
|                 | 5. Fraction<br>surviving        | 0.80 x   |          | 0.27 x   |          | 0.60 Product=0.13<br>survival |
|                 | 6. % real morta-<br>lity        | 20.0     | +        | 58.4     | +        | 8.7 Sum: 87.1%<br>mortality   |
|                 | 7. % indispensable<br>mortality | 3.2      |          | 34.9     |          | 8.7                           |
|                 | 8. Mortality/<br>survivor ratio | 0.20     |          | 0.73     |          | 0.40                          |
|                 | 9. Log population               | 3.23     |          | 3.13     |          | 2.56 2.34                     |
|                 | 10. k-value                     | 0.10     |          | 0.57     |          | 0.22 Sum: K=0.89              |

Table 4.2 (Continued).

| Generation | Line                         | Eggs            | Larvae          | Pupae           | Adults                |
|------------|------------------------------|-----------------|-----------------|-----------------|-----------------------|
|            |                              | N <sub>E1</sub> | N <sub>L1</sub> | N <sub>P1</sub> | N <sub>A1</sub>       |
|            | 1. Population                | 14490           | 11077           | 2527            | 2490                  |
|            | 2. No. dying in interval     | 3413 +          | 8450 +          | 137             | Sum:12000             |
|            | 3. % apparent mortality      | 23.6            | 76.3            | 5.2             |                       |
|            | 4. % successive survival     | 76.4            | 23.7            | 94.8            |                       |
| III        | 5. Fraction surviving        | 0.76 x          | 0.24 x          | 0.95            | Product=0.17 survival |
|            | 6. % real mortality          | 23.6 +          | 58.3 +          | 1.0             | Sum:82.9% mortality   |
|            | 7. % indispensable mortality | 5.3             | 55.3            | 0.1             |                       |
|            | 8. Mortality/survivor ratio  | 0.24            | 0.76            | 0.05            |                       |
|            | 9. Log population            | 4.16            | 4.04            | 3.42            | 3.40                  |
|            | 10. k-value                  | 0.12            | 0.62            | 0.02            | Sum:K =0.76           |

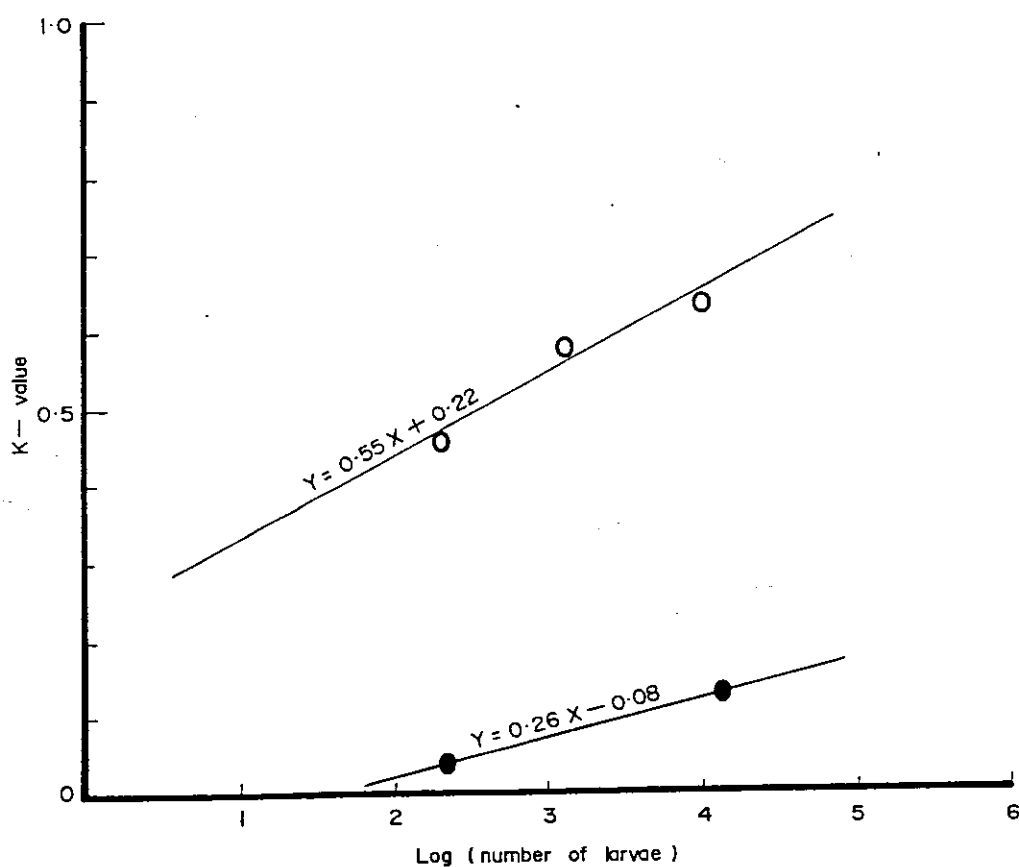


FIGURE 4-6 The mortality relationships of *Plutella xylostella*(L) in the presence (O) and absence (●) of the parasite *Apanteles plutellae* Kurdj.



were due to larval parasitism  $\sqrt{k}$ (1st generation) = 0.47, and  $k$  (2nd generation) = 0.57]. By the 3rd generation this mortality factor has further increased ( $k = 0.62$ ). The increasing  $k$ -value in relation to rising host population showed the relationship to be of direct density-dependence. However, even though it is undercompensating ( $0 < b < 1$ ), the steeper slope ( $b = 0.55$ ) obtained over that without the parasite ( $b = 0.26$ ) indicated it to be able to strengthen the density-dependent relationship thereby tending towards greater stabilization (Fig. 4.6).

#### 4.2.2 Insecticidal withdrawal and its consequential effects in relation to natural infestations of DBM and its parasites

From Fig. 4.7 there appears to be a drastic change in the infestations of DBM over the years in the Cameron Highlands. Up to 1969, untreated plots in insecticidal screening experiments had infestations ranging from 14.8 - 21.1 larvae/plant and averaging 18.3 larvae/plant (Henderson, 1957; Ho, 1965; Ho & Ng, 1970). Whilst the treatment plots had negligible infestations (mean = 3.8 larvae/plant) most cabbage crops of the farmers in later years (even up to recent times) continued to show heavy infestations despite frequent insecticidal applications (Table 3.6). For the locality Kampong Raja, as many as 27.2 larvae/plant were obtained. In contrast, by 1973 following insecticidal withdrawal in the experimental fields, a sharp decline in DBM infestations was observed (Fig. 4.7). With the exception of the 19th crop the total population on all the crops remained relatively low. This fluctuated about a mean of only 3.1 larvae/plant throughout.

With regard to the parasite, apparently none was present prior to 1970 (see 3.4). By 1973, however, for the initial 5 crops the mean parasitism rates of A. plutellae ranged from 1.8 - 12.7% with an average of 8.1%. Following this, the level of parasitism rose sharply to fluctuate at a much higher level of equilibrium (32.8%). This 4-fold increase was maintained up to the 32nd crop, apparently being unaffected by the newly introduced parasite species D. eucerothra (Ooi, 1979a). However, the total parasitism rates were observed to continue increasing, reaching as high as 70.3% (Fig. 4.7).

Mortality from other other factors was less stable. In general, except for the last few croppings following the introduction of additional parasites, the variation was observed to be extremely wide (Fig. 4.7). Also, by the 23rd cropping, the total mortality which included fungal infection by Entomophthora sphaerosperma (Fres.) (Syphomycetes: Entomophthoraceae), bacterial diseases and other unknown factors, had declined slightly. Together, all these factors contributed only about 17.9% of the larval mortality.

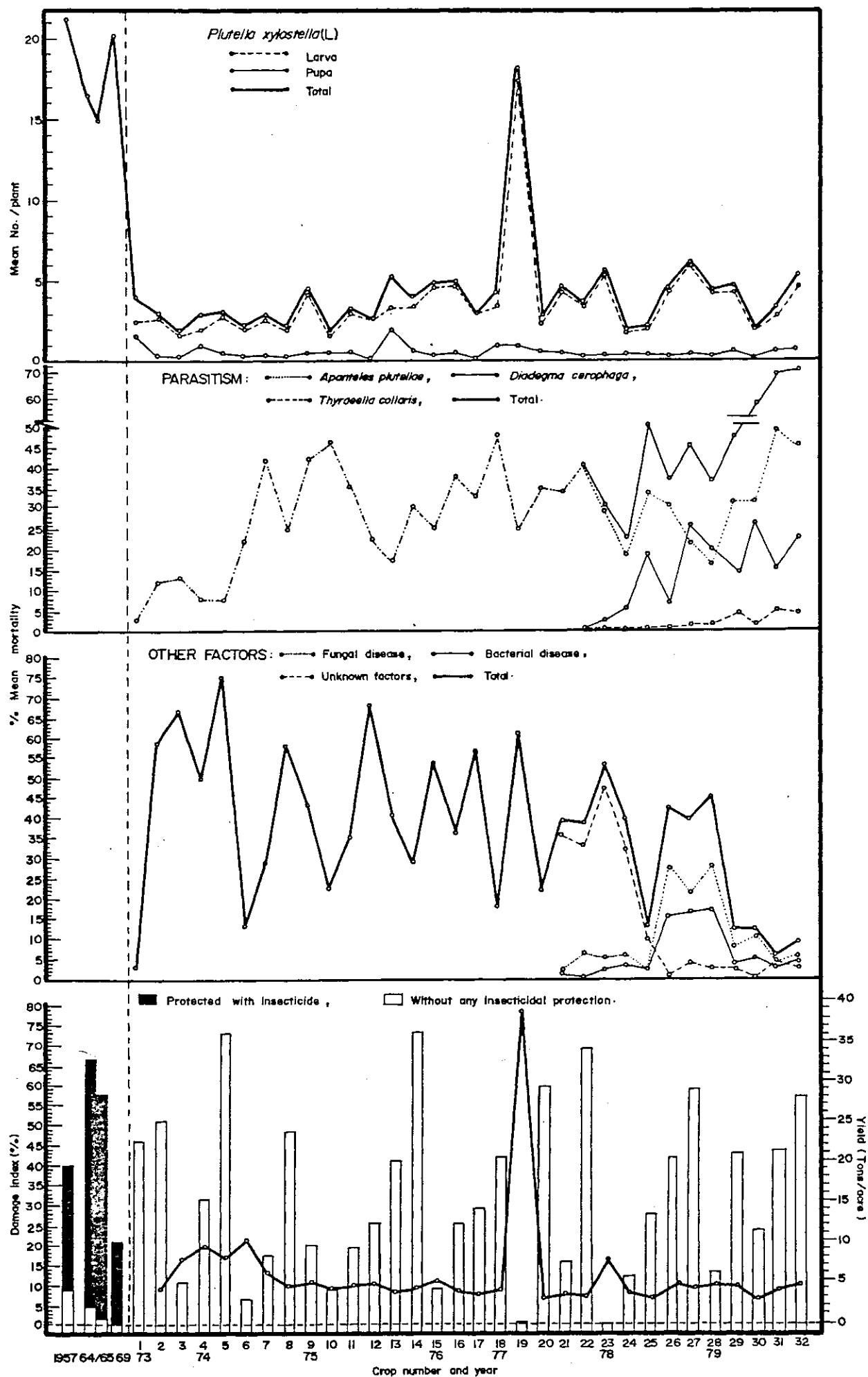


FIGURE 4-7 Infestations of *Plutella xylostella* (L) in relation to various mortality factors, crop damage and yield following insecticidal withdrawal over 32 continuous and overlapping cabbage crops.

In terms of cabbage production, the yields obtained were observed to be inconsistent. Although there were several crops of rather poor yields ( $< 15$  tons/acre), many were comparable to those obtained with full insecticidal protection (Fig. 4.7). For at least 5 crops, the harvests well exceeded 55 tons/acre. Evidently, satisfactory cabbage yields are obtainable even when no chemical insecticides are used at all. With regard to the damage index, no distinct relationship with the production yields was clearly apparent (Fig. 4.7). Such a situation strongly suggests that besides the DBM other adverse factors not recorded in the studies were also important and had contributed to final crop yield.

#### 4.2.3 Chemical exclusion method

The yield data obtained (Table 4.3) clearly showed that the Padan<sup>R</sup> and Dipel<sup>R</sup> treatments had significantly ( $P < 0.05$ ) higher yields than both Sevithion<sup>R</sup> treatment and the untreated control. Between Padan<sup>R</sup> and Dipel<sup>R</sup>, although the former had slightly higher yield, the difference was not significant ( $P > 0.05$ ). As for Sevithion<sup>R</sup> the yield was observed to be even less ( $P < 0.05$ ) than that of the control, suggesting that insecticidal applications need not necessarily always increase the yields of crops. Not only was it unable to provide the needed protection of the crop from DBM, but it also incurred additional costs in inputs.

The yield differences observed for the various treatments were apparently largely related to successful head formation as well as individual plant weight. For the latter, although no significant difference existed among the different treatments the ranking in magnitude of the mean plant weight closely paralleled that of the overall crop yields, i.e. Padan<sup>R</sup> having the highest followed by Dipel<sup>R</sup>, the control and Sevithion<sup>R</sup> (Table 4.3). In terms of head formation, the treatment Dipel<sup>R</sup> had the highest number of heads formed per unit area. Although the weight/plant was less than that for Padan<sup>R</sup> the higher number of head formation apparently compensated to some extent in raising the overall yield in the Dipel<sup>R</sup> treatment (Table 4.3). With treatment Sevithion<sup>R</sup> and the control, significantly less heads were formed thus depressing further the overall yields for these treatments.

Assessment of damage by DBM clearly showed that the damage inflicted was higher on non-marketable heads, suggesting that reduced crop yields are both closely associated and dependent on the extent in infestations by the moth. Within both categories of marketable and non-marketable heads, a much lower damage occurred in treatments Padan<sup>R</sup> and Dipel<sup>R</sup> (Table 4.3). This trend was observed for the assessments throughout the cropping period (Fig. 4.8) as well as at harvest (Table 4.3). Also, in

Table 4.3 Cabbage yield production and crop damage inflicted by Plutella xylostella(L.) as affected by various insecticidal treatments in the Cameron Highlands.

| Treatment  | Head formation |      | Mean damage index (%) |                      |       | Mean weight per marketable head (kg) | Plot yield (Kg)** |
|------------|----------------|------|-----------------------|----------------------|-------|--------------------------------------|-------------------|
|            | Mean no.       | %*   | Marketable heads      | Non-marketable heads | Total |                                      |                   |
| Dipel      | 439            | 83.6 | 9.43                  | 20.77                | 14.65 | 1.49                                 | 415.6 a           |
| Fadan      | 429            | 81.7 | 6.80                  | 13.33                | 9.75  | 1.59                                 | 431.6 a           |
| Sevithion  | 330            | 62.9 | 13.90                 | 24.43                | 19.90 | 1.32                                 | 290.6 c           |
| Control    | 368            | 70.1 | 11.27                 | 25.73                | 16.72 | 1.39                                 | 356.2 b           |
| LSD (0.05) |                |      |                       |                      |       | ns                                   | 48.2              |

\*Cut of a potential total of 1575 plants per treatment.

\*\*Values followed immediately by the same letter are not significantly different at the 5% level.

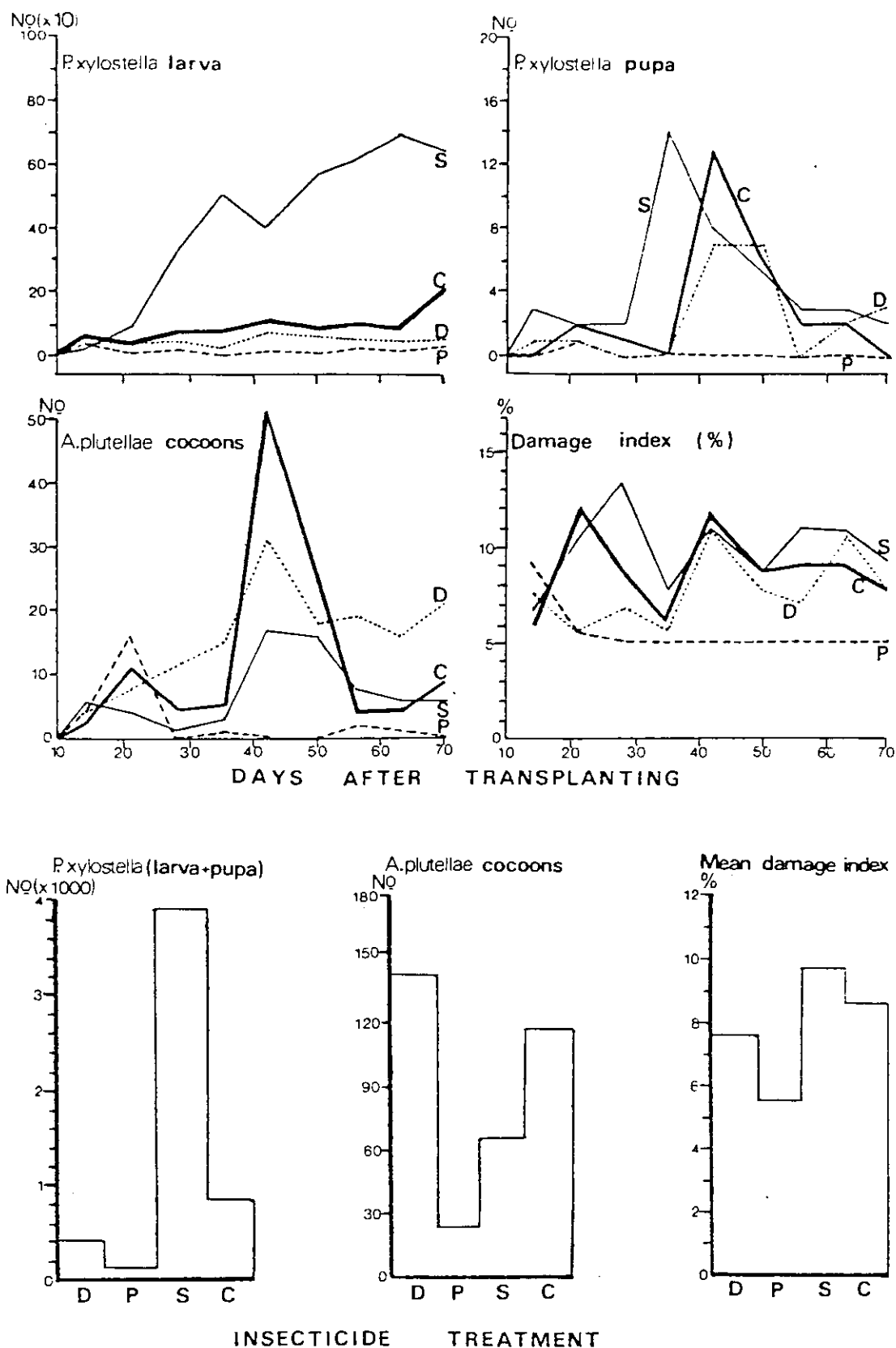


FIGURE 4.8 Field development of *Plutella xylostella* (L.), its parasite *Apanteles plutellae* Kurdj., and the crop damage inflicted as affected by different insecticidal treatments. ( D = Dipel<sup>R</sup>, P = Padan<sup>R</sup>, S = Sevithion<sup>R</sup>, C = Untreated control).

both Padan<sup>R</sup> and Dipel<sup>R</sup> treatments, the number of plants showing high damage scores was distinctly less.

With regard to infestations of DBM, again the Padan<sup>R</sup> and Dipel<sup>R</sup> treatments had much lower levels while that for treatment Sevithion<sup>R</sup> and the control were extremely high (Table 4.4). Of the larvae that escaped being parasitized by A. plutellae, the percentage numbers entering the pupal stage was highest in the control, followed by the treatments Sevithion<sup>R</sup>, Padan<sup>R</sup> and Dipel<sup>R</sup>. This trend was also noted for the percentage adult emergence from the surviving pupae. From these results and the relative abundance of the larvae in the field (Table 4.4), it is evident that very much higher numbers of larvae reached the adult stage in the Sevithion<sup>R</sup> treatment and the control. These were respectively 47.9 and 8.0 times that of Padan<sup>R</sup>. For Dipel<sup>R</sup>, the number was nearly double that of Padan<sup>R</sup>, although very much less than the others (Table 4.4).

In general, the pupal population in the field showed a similar trend to that of the larvae. This was clearly evident from the population development observed in the periodic samplings as well as the overall total (Fig. 4.8).

In terms of parasitism by A. plutellae, it was observed that both the control and Dipel<sup>R</sup> treatment had significantly higher levels of parasite attack. The parasitic rate was least in the treatment Padan<sup>R</sup> while Sevithion<sup>R</sup> had moderate level of parasitism (Table 4.5). For parasite cocoons collected over the crop, very much higher numbers were obtained from the untreated control and the cabbages sprayed with Dipel<sup>R</sup>; that from the latter was approximately 6 times more as compared to those collected in the Padan<sup>R</sup> treatment (Fig. 4.8). Such differential survival and abundance of the parasite among the different treatments not only strongly indicate the adverse effects of both Padan<sup>R</sup> and Sevithion<sup>R</sup> but also the selectivity of Dipel<sup>R</sup> for the parasite. These differential effects were also clearly reflected in the percentage parasite emergence from field-collected cocoons in which 69.4%, 67.2%, 55.6% and 45.6% were recorded for the control, Dipel<sup>R</sup>, Sevithion<sup>R</sup> and Padan<sup>R</sup> treatment, respectively. This order of parasite emergence was also observed in the case where the cocoons resulted from field-collected host larvae (Table 4.5). Basing on these and the relative abundance of parasite cocoons in the field, it was evident that very much higher numbers of adult parasites occurred and survived in the fields sprayed with Dipel<sup>R</sup> and in the untreated control. These were, respectively, 7.8 and 6.7 times more than that of Padan<sup>R</sup>-treated fields (Table 4.5). For the Sevithion<sup>R</sup> treatment, it had only about 3.2 times as many.

**Table 4.4** Survival and relative abundance of the diamond-back moth, Plutella xylostella (L.) as affected by various insecticidal treatments on cabbages in the Cameron Highlands.

| Treatment | No. of <u>F. xylostella</u> larvae |                      |       | Surviving larvae becoming pupae |       | Surviving pupae becoming adults |       | % larvae initially collected becoming adults | Field larval population |                                 |               | Adult ratio (over Padan treatment) |
|-----------|------------------------------------|----------------------|-------|---------------------------------|-------|---------------------------------|-------|----------------------------------------------|-------------------------|---------------------------------|---------------|------------------------------------|
|           | Initially Collected*               | Surviving parasitism |       | No.                             | %     | No.                             | %     |                                              | No. per 270 plants      | Adult equivalent per 270 plants | per hectare** |                                    |
|           |                                    | No.                  | %     |                                 |       |                                 |       |                                              |                         |                                 |               |                                    |
|           |                                    |                      |       |                                 |       |                                 |       |                                              |                         |                                 |               |                                    |
| Dipel     | 540                                | 255                  | 47.22 | 71                              | 27.84 | 55                              | 77.46 | 10.19                                        | 400                     | 41                              | 5,448         | 1.9                                |
| Padan     | 289                                | 188                  | 65.05 | 66                              | 35.11 | 59                              | 89.39 | 20.42                                        | 109                     | 22                              | 2,924         | 1.0                                |
| Sevithion | 540                                | 320                  | 59.26 | 156                             | 48.75 | 147                             | 94.23 | 27.22                                        | 3869                    | 1053                            | 139,932       | 47.9                               |
| Control   | 540                                | 268                  | 49.63 | 132                             | 49.25 | 119                             | 90.15 | 22.04                                        | 797                     | 176                             | 23,388        | 8.0                                |

\*From 9 samplings of 20 larvae/sampling/replicate between February 19-April 16, 1975. In the Padan treatment, the data were based only on 289 larvae as there were hardly any larvae after March 12, 1975.

\*\*Potentially, 1 hectare would contain 35,880 cabbage plants.

**Table 4.5** Survival and relative abundance of the diamond-back moth parasite, Apanteles plutellae Kurdj., as affected by various insecticidal treatments on cabbages in the Cameron Highlands.

| Treatment | No. of <u>P. xylostella</u> larvae |                 |       | No.(%) of parasite adults emerging | <u>Parasite population in the field</u> |                                 |               | Adult ratio (over Padan treatment) | Parasite: host ratio |
|-----------|------------------------------------|-----------------|-------|------------------------------------|-----------------------------------------|---------------------------------|---------------|------------------------------------|----------------------|
|           | Initially Collected*               | Parasitised No. | %     |                                    | Cocoon no. per 270 plants               | adult equivalent per 270 plants | per hectare** |                                    |                      |
| Dipel     | 540                                | 285             | 52.78 | 262 (91.93)                        | 143                                     | 132                             | 17,541        | 7.8                                | 3.22                 |
| Padan     | 289                                | 101             | 34.95 | 73 (72.28)                         | 24                                      | 17                              | 2,259         | 1.0                                | 0.77                 |
| Sevithion | 540                                | 220             | 40.74 | 180 (81.82)                        | 66                                      | 54                              | 7,176         | 3.2                                | 0.05                 |
| Control   | 540                                | 272             | 50.37 | 261 (95.96)                        | 118                                     | 113                             | 15,016        | 6.7                                | 0.64                 |

\*From 9 samplings of 20 larvae/sampling/replicate between February 19-April 16, 1975. In the Padan treatment, the data were based only on 289 larvae as there were hardly any larvae after March 12, 1975.

\*\*Potentially, 1 hectare would contain 35,880 cabbage plants.

The findings also revealed that in a host-parasite system the ratio of their respective numbers may be altered in various ways by the use of different insecticides. In the case of the Padan<sup>R</sup> treatment there was hardly any significant change in the parasite: host ratio of 0.77 from the untreated control (0.64). This, to a large extent, was probably due to Padan<sup>R</sup> being equally effective in its destruction of DBM and *A. plutellae* (Table 4.5). With Sevithion<sup>R</sup>, however, because of its selective kill against the parasite a shift to an extremely small ratio (0.05) had resulted, while it was greatly increased (3.22) in favour of the parasite when Dipel<sup>R</sup>, which had insecticidal property reversed to that of Sevithion<sup>R</sup>, was applied (Table 4.5). Such findings also suggest that the correct choice in the chemical to be used could be crucial for any effective pest management of DBM.

#### 4.2.3.1 Development and reproductive biology of DBM as affected by Sevithion<sup>R</sup> exposed indirectly through the host plant

The insecticide Sevithion<sup>R</sup> was observed to have no significant ( $P > 0.01$ ) effect on the number of eggs deposited by DBM (Table 4.6). Nevertheless, variations occurred as numerically the number of eggs laid by the moths reared on treated plants was higher in several cases compared to the control.

Several other parameters considered were found to be unaffected; these included the developmental period, the sex ratio, as well as the longevity and fecundity of the F<sub>1</sub> females (Table 4.6). The mean fecundities of the control and Sevithion<sup>R</sup>-exposed females were  $304 \pm 17.6$  eggs and  $254 \pm 21.3$  eggs respectively, and their mean longevities  $13.8 \pm 1.0$  days and  $14.0 \pm 1.4$  days. Both differences were found to be non-significant at  $P = 0.05$ .

#### 4.2.3.2 Development of DBM as affected by direct exposure of the larvae to Sevithion<sup>R</sup>

Measures of the mean fecundity for female DBM of both generations F<sub>1</sub> and F<sub>2</sub> showed that there were no statistical differences between the Sevithion<sup>R</sup>-exposed treatment and the unexposed control. For the F<sub>1</sub> generation females, the mean fecundities were  $96.8 \pm 11.6$  eggs and  $97.7 \pm 17.3$  eggs for the treated and control respectively, while that for the F<sub>2</sub> generation females  $48.0 \pm 17.3$  eggs and  $54.7 \pm 7.8$  eggs respectively (Table 4.7). Although the mean fecundity obtained was much lower in the 1st generation, comparisons made for the F<sub>1</sub> and F<sub>2</sub> generations in treated adults gave a non-significant difference. For the controls, the difference was, however, significant at the 5% level.

Studies on the mean longevity also revealed little difference



**Table 4.6** Reproductive characteristics of *Plutella xylostella* (L.) when indirectly exposed (+) to 0.1% a.i. Sevithion<sup>®</sup> applied onto the host plants. In the unexposed (-) control the plants received only water spray.

| Parameter                                                     | n   | Status of <i>P. xylostella</i> |           | Significance<br>(P = 0.01) |
|---------------------------------------------------------------|-----|--------------------------------|-----------|----------------------------|
|                                                               |     | +                              | -         |                            |
| Mean no. eggs deposited/<br>3 females for the first<br>5 days | 5   | 305.6                          | 207.0     | ns                         |
| Mean developmental period<br>(days)                           |     |                                |           |                            |
| Egg                                                           | 100 | 3.2                            | 3.2       | ns                         |
| Larva                                                         | 100 | 7.5                            | 7.9       | ns                         |
| Pupa                                                          | 100 | 3.3                            | 3.3       | ns                         |
| Total                                                         |     | 14.1                           | 14.9      | ns                         |
| Total no. adults obtained                                     |     |                                |           |                            |
| Male                                                          |     | 273                            | 215       |                            |
| Female                                                        |     | 276                            | 217       |                            |
| Total                                                         |     | 549                            | 432       |                            |
| Sex ratio                                                     |     | 1 : 1                          | 1 : 1     |                            |
| F <sub>1</sub> generation females                             |     | Mean±S.E.                      | Mean±S.E. |                            |
| Fecundity                                                     | 10  | 254±21.3                       | 304±17.6  | ns                         |
| Longevity (days)                                              | 10  | 14.0±1.4                       | 13.8± 1.0 | ns                         |

**Table 4.7** Reproductive characteristics of *Plutella xylostella* (L.) when directly exposed(+) to 0.1% a.i. Sevithion<sup>®</sup>. In the unexposed (-) control, the 2nd-instar larvae received direct spray of water only.

| Parameter                  | n  | Status of <i>P. xylostella</i> |          | Significance<br>(1% level) |
|----------------------------|----|--------------------------------|----------|----------------------------|
|                            |    | +                              | -        |                            |
| F <sub>1</sub> generation: |    |                                |          |                            |
| Fecundity                  | 10 | 97±11.6                        | 98±17.3  | ns                         |
| Longevity - Male           | 10 | 30.4±1.3                       | 34.2±1.6 | ns                         |
| - Female                   | 10 | 21.0±1.2                       | 14.1±1.3 | ns                         |
| No. adults obtained        |    |                                |          |                            |
| Male                       |    | 125                            | 106      |                            |
| Female                     |    | 89                             | 116      |                            |
| Total                      |    | 214                            | 222      |                            |
| Sex ratio                  |    | 1 : 07                         | 1 : 1.1  |                            |
| F <sub>2</sub> generation: |    |                                |          |                            |
| Fecundity                  | 10 | 40±17.3                        | 55±7.0   | ns                         |
| Longevity - Male           | 10 | 22.1±1.0                       | 22.4±0.9 | ns                         |
| - Female                   | 10 | 14.3±1.1                       | 15.0±1.2 | ns                         |

between the treated females and those of the control. In the  $F_1$  generation females, the mean longevity were observed to be  $21.0 \pm 1.2$  days for the treated and  $14.1 \pm 1.3$  days for the control (Table 4.7). For females of  $F_2$  generation, the difference was, however, again non-significant, being  $14.3 \pm 1.1$  days in the treated and  $15.0 \pm 1.2$  days in the control. Similarly, in the case of the males, the mean longevity for both  $F_1$  and  $F_2$  generations was found to differ little (Table 4.7).

In terms of the sex ratio, that for the treated set was found to possess more males. This, however, was not significantly different at  $P = 0.05$  (Table 4.7).

#### 4.3 DISCUSSION

In the laboratory studies on survival of DBM in the presence and absence of A. plutellae, the influencing role of its parasite was especially evident, in particular the following two features: (i) the immense effect it had in reducing numerically the host population, and (ii) the delay of an equivalent host population build-up. In the absence of the parasite the host population increase was 46 fold from the 1st to the 2nd generation while it was only about 8.4 times when the parasite was present. This approximated to a parasite reduction factor (numerical increase of host per generation in the absence of the parasite  $\div$  numerical increase of host per generation in the presence of the parasite) of 47.4 for A. plutellae when introduced at a ratio of 1 parasite pair to 20 host larvae.

In spite of the relatively small parasite: host ratio (1:20) adopted in the present studies the resulting effect on the two above-mentioned features was noted to be remarkably substantial. Both these features of host population reduction and delay of an equivalent host build-up could be expected to be even much greater should the parasite: host ratio be increased beyond the present value, a condition that has been frequently observed under normal field situations. Moreover, these would further multiply many folds when the resulting effects at the end of each successive generation are accumulated and repeatedly built up into subsequent generations. When the influencing role of both host population suppression and delay of an equivalent host build-up further interact and exert in combination, the overall effects would inadvertently increase still further. Such a situation appears inevitable as both these features are interrelated and inter-dependent. Theoretically, with all these multiplicities of host-suppressing factors continuously building up upon one another it could be expected that the ultimate manifestation of the differences in host numbers would be enormous between a situation where the parasite occurs freely and one in which the parasite is totally absent.

This would especially be so for situations that are considered over a substantial period encompassing many host-parasite generations.

Unlike the above which merely compares directly the population development and differences, the life table analysis was also employed in the laboratory studies to determine the killing power 'k' of A. plutellae. When the parasite was present, the 'k' values for the larval stage in the 1st and 2nd generation were, respectively, 15.7 and 4.1 times greater than that without, confirming further the suppressive role of the parasite. More important, however, is the clear indication that the parasite-caused mortality is density-dependent, suggesting it may have some regulatory effect on the host population.

Although the above experimental means of evaluation and analysis have helped to verify and confirm on the usefulness of A. plutellae, the methods are not free of weaknesses. DeBach & Huffaker (1971) believed that periodic census and life-table data do provide much valuable information, but considered that such quantitative methods are inadequate in rating the regulating or controlling power of natural enemies. They and Legner (1969) emphasised that neither precise laboratory studies nor quantitative field studies of parasitization furnish adequate means of evaluating the effectiveness of a parasite in host population regulation and control. Along the same line, Hassell & Varley (1969) stated: "Laboratory studies can go some way to predict which species (among several introduced) may be successful, but an introduction provides the only real test".

Legner, in 1969, pointed out that: "The ultimate and probably only reliable method for judging a parasite's effectiveness is the reduction in host equilibrium position following liberation". Such an evaluation of the effectiveness by using before and after density comparisons under field situation was also attempted in the present studies to help supplement the laboratory investigations. As was clearly evident (Fig. 4.7), the host equilibrium position was impressively reduced when A. plutellae was present. Correspondingly, the percentage parasitism rose sharply to maintain at fairly high equilibrium level, indicating with considerable confidence the effectiveness of the control exerted. Although the beneficial role exhibited is quite impressive, the impact is not consistent as suggested by the poor crop yields obtained on a number of occasions. Nonetheless, even though the control was only partial in these instances, the equally high number of cases in which the yields realized were comparable to that obtained under full insecticidal protection is of tremendous significance in that it has shattered the second belief that 'no cabbage can be produced in the Cameron Highlands without frequent and heavy insecticide applications'. With this, as with disproving the belief that 'no biological control or

parasite could exist because of the intensive and indiscriminate use of insecticides', perhaps the firm adherence to the dogma of continually searching for more potent chemicals or total dependence on them could be increasingly relaxed, paving for easier and more rapid acceptance of an ecological outlook as well as a rational development towards the control of DBM, particularly in the Cameron Highlands.

In the consideration of the yields that may be attained, that for most of the croppings were closely related to both the extent of DBM infestations and its parasite's activity. Prior to 1969 the unprotected crops generally had high populations of DBM and hence very low yields. Subsequently, in the presence of the parasite since 1973 the infestations remained relatively low in spite of no insecticidal protection, clearly indicating the significant contributions of the parasite. However, it is also evident that since the parasitic control exerted was only partial further supplementary measures would be necessary. This, perhaps, also explains why under farm situations insecticides are currently still commonly and widely applied.

In general, somewhat similar conclusions to the above were also obtained and confirmed by findings from the chemical exclusion studies, wherein a much poorer crop yield resulted through higher infestations of DBM due to the selective destruction of its parasite by Sevithion<sup>R</sup>. However, the accelerated host increase may well be also due to an altered plant physiology such as improved nutrition in the case of phytophagous mites (Chaboussou, 1965) or hormoligosis (from the Greek: hormo = excite and oligo = small quantities) (Locher, 1958; Luckey, 1968; Dittrich *et al.*, 1974) wherein Luckey (1968) conceptualized that "subharmful quantities of any stressing agent will be stimulatory to an (the) organism by providing it (with) increased sensitivity to respond to changes in its environment and increased efficiency to develop new or better systems to fit a suboptimum environment". In the present studies, no significant differences were obtained for all the parameters considered (developmental period, fecundity, adult longevity and sex ratio) (Table 4.6), showing conclusively that hormoligosis (stimulation by small quantities of a stressor) nor an improved nutritional basis via an altered physiology of the host plant were responsible for the observed effects. With these factors ruled out, it thus follows that the resurgence of DBM following Sevithion<sup>R</sup> treatment could only be logically attributed to the selective removal of A. plutellae; the vast increase obtained furnishing proof of the parasite's controlling power and potential. However, that the control exerted was only partial is again suggested; largely by the fairly high infestation in the untreated control where the parasite's activity was

undisturbed, as well as, in the Dipel<sup>R</sup> and Padan<sup>R</sup> treatments where these chemicals assisted as supplementary measures to provide effective control.

From investigations on the adverse effects of Sevithion<sup>R</sup> on A. plutellae (see 8.2) it was noted that the effects, although substantial, could not exterminate completely the parasite population. As such, the total extent of host increase was not fully expressed in the chemical exclusion studies because the parasite was not completely eliminated, and so may continue to produce some effect in limiting the DBM. Such a situation is probably more akin to the case of partial interference, wherein was demonstrated in this instant that A. plutellae was responsible for the observed lower host level, but the maximum level the host would attain in its complete absence remains unknown.

The effectiveness of A. plutellae was clearly discernable even though the insecticidal-check treatment was carried through only one crop season. Although quite evident, the resurgence effect was not as spectacular as in other parallel studies, such as, the biological control exerted by the parasite Aphytis maculicornis (Masi) on the infestation of olive scale Parlatoria oleae Colvee. In the latter situation, the infestation occurring under undisturbed parasite activity when compared with the exploded infestation characteristic of DDT-caused depression of natural enemy activity had ratio of initial to final densities of 100-fold and 1000-fold (DeBach & Huffaker, 1971). Similar studies involving the purple scale Lepidosaphes beckii (Newm.) that is parasitized by Aphytis lepidosaphes Compere, and the selective check-insecticide endrin, gave an increase in host population over a 3-year period from an initial scale density of 174 to 20,615 (DeBach & Huffaker, 1971). Such impressive difference is probably also obtainable with Sevithion<sup>R</sup> should the period of exposure be greatly extended; this being so is strongly supported by the experience of DeBach & Huffaker (1971) who noted "that the biological control potential from established enemies cannot be accurately evaluated in study plots which have not gone without major chemical pesticide treatments for significant periods".

It is recognized that certain of the methods employed in the present studies may have individual shortcomings. As such, the simultaneous utilization of the diverse techniques should provide the necessary confirmation, each of them serving to confirm others as valid means of evaluating the effectiveness of A. plutellae. That the parasite can and has contributed significantly to the control of DBM is now firmly established by the different evaluating approaches utilized in the current studies. With this, answer on the effectiveness of the parasite has now become available to clarify for the critics and sceptics who still have doubts in accepting the beneficial role of the parasite. Moreover, the

application of the various test techniques outlined herein would also make it easier for those who are sceptical to answer many of their own questions with hard evidence.

Although A. plutellae has a definite role in the management of DBM, it is important to recognize that the full impact is often affected by several factors, both physical and biological. Among the latter are included the parasite's behaviour (foraging, emigration tendency and immigration), its hyperparasites (see 3.3.4), and the diseases of the host as well as other competitive parasites. Both the latter two aspects will be treated in greater details subsequently in Section 7 and Section 9, respectively. Presently, however, it suffice merely to note that all these factors merit serious and full considerations in determining the contributory potential of A. plutellae and for its successful exploitation in the control of DBM.

## 5. SOME ASPECTS ON THE BASIC BIOLOGY OF A. PLUTELLAE

From the preceding investigations, A. plutellae was noted to be both common and widespread, being the only major parasite of DBM on cabbages in the Cameron Highlands (see 3.4). It has also been shown (see 4.2) to be an important natural parasite there and potentially could probably contribute more under a proper programme of environmental management. However, for its full exploitation as a controlling agent of the host, some information on the basic biology are generally desirable, particularly the biology of the mature female which has been regarded (Doutt, 1964) as the major determinant of efficiency of the species. Presently, although some data are available (Delucchi et al, 1954; Chiu & Chien, 1972) these are still limited. In view of this, and because the parasite was only recently recorded (Lim & Ko, 1975) here, some relevant studies on its basic biology were considered necessary. Factors regarded to be important and examined included (i) the life cycle, (ii) host stages preferred, (iii) initial parasitism on different host instars, and parasite survival, (iv) oviposition and fecundity, (v) sex ratios produced, (vi) food requirements, (vii) alternative hosts, and (viii) the influence of temperature and humidity on the parasite's biology and development. It was also hoped that these studies would provide greater insights into the biological characteristics of the parasite, and hence, the possible biological control of its hosts.

### 5.1 LIFE STAGES, DESCRIPTIONS AND DEVELOPMENT PERIOD OF THE PARASITE

Earlier studies on the basic biology of A. plutellae were largely confined to brief treatments of its life cycle/stages (Delucchi et al, 1954; Fan & Ho, 1971; Chiu & Chien, 1972; Ho & Chio, 1972), with notable emphasis on identification and taxonomic description of the adult (Wilkinson, 1928, 1929, 1939; Parrots, 1964; Chiu & Chien, 1972). In this study, a greater effort was therefore devoted to examining details of its life cycle, and particularly the immature stages. In doing so, freshly-emerged adult A. plutellae obtained from laboratory stocks initiated from collections made in the Cameron Highlands in 1973 were first held for 24 hrs with 30% honey and water in 'breeding jars' for mating (Plate 2.1). Each female was then removed and individually confined in a glass vial (7.5 cm x 1.5 cm diameter) wherein was introduced singly 1st-instar host larva. As soon as oviposition had occurred the parasitized larva was transferred and maintained on B. rapa leaves in groups of 15 larvae/jar (Plate 2.1). For determination of the stage development of the parasite, the host larvae were dissected at various intervals (5 hrs, 1,2,3,4,5,6,

7 and 8 days) following parasite oviposition. The immature stages were closely examined both under fresh conditions as well as stained with lignin pink following clearing with 15% KOH and temporary mounting in glycerol (A.R. Grade) after subjecting through serial transfers of increasing alcohol concentrations (15%, 30%, 75%, 95%, absolute). Daily, measurements were made for each stage obtained with the aid of a slide micrometer.

In determining the developmental period of the different life stages, batches of 30 (from an initial stock of 750) parasitized host larvae at successive days after parasite oviposition were dissected for thorough examination of parasite larval cast skins and the stages present. Prepupa and pupa were studied from dissected parasite cocoons. Some of the parasite cocoons obtained were also kept until exit of the adults which were then reared for observation on adult behavioural activities. Throughout, the studies were conducted under laboratory conditions (see 2b).

#### 5.1.1 Egg

The hymenopteriform egg of A. plutellae is transparent and cylindrical with rounded ends (Plate 5.1.1,A); the narrower caudal end having a straight short peduncle typical of the stalked-type eggs of many braconids (Hagen, 1964). At the broad end it measures  $0.064 \pm 0.005$  mm at 5 hrs after oviposition and its length and peduncle, respectively,  $0.251 \pm 0.016$  mm and  $0.050 \pm 0.007$  mm (Table 5.1.1). The chorion is transparent, thin, and without sculpturing. Twenty-four hours after oviposition, the egg increases in size to  $0.438 \pm 0.022$  mm by  $0.117 \pm 0.006$  mm and the peduncle  $0.016 \pm 0.003$  mm long (Table 5.1.1).

The egg is normally found free in the haemocoel of the host larva, and the embryo developing within the egg (Plate 5.1.1, A & B) is usually visible through the transparent chorion. More than 1 egg may be found in a single host under long exposure of the latter to oviposition, or when the host was exposed to several female parasites; however, normally only 1 egg can be found per host. During hatching, the 1st-instar larva usually emerges at the side towards the anterior end of the egg (Plate 5.1.1, C & D).

#### 5.1.2 Larva

It was not certain how many moults the parasite larva underwent because, during the life stages study, exuviae and moulting between the 2nd and 3rd larval instars were sometimes not clearly evident. In general, based largely on the developmental forms, it seems that there are 3 larval stadia.

The 1st-instar larva has a transparent body and is of the



Table 5.1.1 Some physical measurements (mean  $\pm$  S.E.) of the various life stages of *Apanteles plutellae* Kurdj.

| Period after oviposition | Parasite stage      | n  | Length (mm)       | Width (mm)        | Head width (mm)   | Mandible length (mm) |                   | Peduncle (mm)     | Caudal horn (mm)  | Anal vesicle (mm) |
|--------------------------|---------------------|----|-------------------|-------------------|-------------------|----------------------|-------------------|-------------------|-------------------|-------------------|
|                          |                     |    |                   |                   |                   | Left                 | Right             |                   |                   |                   |
| 5 hours                  | Egg                 | 10 | 0.251 $\pm$ 0.016 | 0.064 $\pm$ 0.005 | -                 | -                    | -                 | 0.050 $\pm$ 0.007 | -                 | -                 |
| 1 day                    | Egg                 | 10 | 0.438 $\pm$ 0.022 | 0.117 $\pm$ 0.006 | -                 | -                    | -                 | 0.016 $\pm$ 0.003 | -                 | -                 |
| 2 days                   | 1st-instar larva    | 10 | 0.451 $\pm$ 0.031 | 0.100 $\pm$ 0.008 | 0.170 $\pm$ 0.007 | 0.076 $\pm$ 0.007    | 0.077 $\pm$ 0.006 | -                 | 0.091 $\pm$ 0.014 | -                 |
| 3 days                   | 1st-instar larva    | 10 | 0.697 $\pm$ 0.207 | 0.200 $\pm$ 0.075 | 0.173 $\pm$ 0.010 | 0.076 $\pm$ 0.005    | 0.076 $\pm$ 0.004 | -                 | 0.115 $\pm$ 0.034 | -                 |
| 4 days                   | 2nd-instar larva    | 10 | 1.069 $\pm$ 0.104 | 0.287 $\pm$ 0.067 | 0.172 $\pm$ 0.010 | 0.073 $\pm$ 0.005    | 0.074 $\pm$ 0.007 | -                 | 0.066 $\pm$ 0.012 | 0.229 $\pm$ 0.014 |
| 5 days                   | 2nd-instar larva    | 10 | 1.098 $\pm$ 0.087 | 0.300 $\pm$ 0.019 | 0.164 $\pm$ 0.015 | 0.074 $\pm$ 0.004    | 0.075 $\pm$ 0.004 | -                 | negligible        | 0.233 $\pm$ 0.028 |
| 6 days                   | 2nd-instar larva    | 10 | 1.535 $\pm$ 0.273 | 0.393 $\pm$ 0.052 | 0.166 $\pm$ 0.015 | 0.070 $\pm$ 0.004    | 0.070 $\pm$ 0.006 | -                 | absent            | 0.329 $\pm$ 0.045 |
| 7 days                   | 2nd-instar larva    | 10 | 2.350 $\pm$ 0.439 | 0.730 $\pm$ 0.134 | No distinct head  | 0.076 $\pm$ 0.004    | 0.078 $\pm$ 0.003 | -                 | absent            | 0.446 $\pm$ 0.053 |
| 8 days                   | 2nd-instar larva    | 10 | 3.230 $\pm$ 0.464 | 1.024 $\pm$ 0.116 | No distinct head  | 0.073 $\pm$ 0.006    | 0.073 $\pm$ 0.006 | -                 | absent            | 0.515 $\pm$ 0.056 |
| 8-9 days                 | 3rd-instar larva    | 10 | 3.536 $\pm$ 0.275 | 1.072 $\pm$ 0.049 | 0.355 $\pm$ 0.020 | 0.188 $\pm$ 0.013    | 0.184 $\pm$ 0.012 | -                 | -                 | -                 |
| 8-15 days                | Cocoon: M**         | 29 | 3.33 $\pm$ 0.27   | 1.29 $\pm$ 0.10   | -                 | -                    | -                 | -                 | -                 | -                 |
|                          | F                   | 33 | 3.37 $\pm$ 0.17   | 1.30 $\pm$ 0.09   | -                 | -                    | -                 | -                 | -                 | -                 |
| 8-9 days                 | Prepupa             | 15 | 2.83 $\pm$ 0.16   | 0.91 $\pm$ 0.08   | *                 | *                    | *                 | -                 | -                 | -                 |
| 9-16 days                | Pupa                | 15 | 2.65 $\pm$ 0.10   | 0.69 $\pm$ 0.06   | *                 | *                    | *                 | -                 | -                 | -                 |
| 10-16 days               | Emergence as adult: |    |                   |                   |                   |                      |                   |                   |                   |                   |
|                          | M**                 | 10 | 2.56 $\pm$ 0.131  | 0.77 $\pm$ 0.049  | 0.62 $\pm$ 0.038  | *                    | *                 | -                 | -                 | -                 |
|                          | F                   | 10 | 2.62 $\pm$ 0.161  | 0.73 $\pm$ 0.054  | 0.63 $\pm$ 0.024  | *                    | *                 | -                 | -                 | -                 |

\*Measurements not made.

\*\*M = Male, F = Female.

caudate-mandibulate form (Plate 5.1.2, A & B). It was usually found in the posterior part of the host's haemocoel, and had not been observed attached to the host tissue. It has a large sclerotized head with distinct mandibles and labrum (Plate 5.1.2, A & B). The caudal horn (or caudal appendage) is prominent and distinctive (Plate 5.1.2, A & B) which, according to Clausen (1940), is a modification of the last abdominal segment into a fleshy organ. Ten body segments are clearly evident, with short spines present in the last few. Overall, the larva measures  $0.451 \pm 0.031$  mm (excluding the caudal horn) by  $0.100 \pm 0.008$  mm within 1 day after egg hatch, and  $0.697 \pm 0.207$  mm by  $0.200 \pm 0.075$  mm at 2 days (Table 5.1.1). For the length of the caudal horn and head width, these are correspondingly  $0.091 \pm 0.014$  mm and  $0.170 \pm 0.007$  mm within 1 day, and  $0.115 \pm 0.034$  mm and  $0.173 \pm 0.010$  mm at 2 days, while the left mandible length  $0.076 \pm 0.007$  mm and  $0.076 \pm 0.005$  mm, respectively (Table 5.1.1).

Occasionally, many 1st-instar larvae have been observed to occur within a host, but 1-2 was the usual number. Allen (1958) reported some species of Apanteles as being cannibalistic in the 1st-instar; no cannibalism was, however, noted here for A. plutellae as with Apanteles marginiventris (Cresson) (Boling & Pitre, 1970). A living larva may be seen among other dead ones fully intact but shrivelled up.

The 2nd-instar larva is whitish, semi-transparent and vesiculate (Plate 5.1.2, C - G), and differs greatly from the 1st instar. There is no visible sclerotised head and the mouthparts 3-lobed (labium and a pair of maxillae) (Plate 5.1.2, F). It has a well-segmented and more robust body that also gradually becomes opaque; the opacity increasing with growth and longevity. To a large extent the opacity is due mainly to the deposition of whitish fatty tissues as well as the increasing ramification and greater development of the trachea system. From 7-8 days, some larvae may also have a greenish tinge; this perhaps resulted through the accumulation of some chlorophyll material that were transferred over from the host's ingested food.

Although the caudal horn was still present in the larvae at 4-5 days after oviposition this was inconspicuous (Table 5.1.1); largely being masked by the anal vesicle which was very prominent and which also increased in size with growth and longevity (Table 5.1.1; Plate 5.1.2, C - G). This somewhat spherical vesicle was observed to result from the evaginated proctodeum.

On average, from 4-8 days of oviposition, the 2nd-instar larva grew extensively, and had trebled from its initial size. This was especially

evident from the daily measurements obtained (Table 5.1.1).

The 3rd-instar larva was hymenopteriform, and the moult to become this instar occurred just prior to its emergence from the host. It tapers anteriorly and is creamy white to yellowish green in colour (Plate 5.1.3). Segmentation is distinct and the body slightly curved with pleura of 1st to 7th abdominal segments distinctly convex and the anal vesicle absent. During this stage, the spiracles were also distinctly visible. The larva measures  $3.536 \pm 0.275$  mm in length and  $1.072 \pm 0.049$  mm in width (Table 5.1.1).

Usually, the parasite emerges from the side of the host larva, generally at approximately the 3rd-4th abdominal segments (Plate 5.1.3, B - D). It takes about  $\frac{1}{2}$ -1 hr for the larva to emerge fully (Plate 5.1.3, C), using the same peristaltic-like motion observed by Cushman (1918) with Apanteles congregatus (Say). Many of these parasites emerged completely from the host before beginning to spin the cocoon; if so, the larva did not crawl about the plant, but usually began spinning immediately. Others began spinning the cocoon as soon as the head and thorax were out of the host.

Following emergence, the exit hole of the larva on the host took on a scablike appearance (Plate 5.1.3, C & G). In all cases the larva was never observed to feed on the host.

### 5.1.3 Cocoon

The parasite cocoon is spun from white silky thread released orally by the matured larva ca 8-9 days after oviposition. It is spindle-shaped with smoothly rounded ends (Plate 5.1.3, H). Normally, the parasite larva was observed to construct a loose lacy and 1-sided crescent-shaped cocoon, then moved its posterior end into it first (Plate 5.1.3, D - F). As with A. marginiventris (Boling & Pitre, 1970), the cocoon was shaped by rippling motions of the body, with the parasite often reversing its position within the cocoon. After the body was firmly seated in the cocoon, the larva began closing the open side of the case. Generally, spinning movements were up and down at first, followed by cross spinning to enforce the sides. After about 3 hrs (range: 2.4 - 3.3 hrs) the parasite was barely visible through the pupal case (Plate 5.1.3, G); however, construction of the cocoon was still in progress.

The newly-spun cocoon of A. plutellae is white, and may be covered with loose silken network which began its construction. Although generally spun on the undersurface of cabbage leaves in the field, it may also be formed on a variety of surfaces under laboratory conditions, such as, perspex, mylar polyester film, wooden cages, glass vials, nylon and muslin

covers, copper gauze and filter papers. Over all surfaces, the cocoon was firmly attached by silken threads and was not easily dislodged except with considerable force. As such, its removal from leaf surface by rain and wind in nature appears highly unlikely.

Unlike some other braconid cocoons which may change colour and darken to yellow or various shades of brown prior to adult emergence as in the case of Meteorus pulchricornis (Wesmael) (Askari et al, 1977), that of A. plutellae usually remains white throughout. The adult parasite emerges from the cocoon through 1 end where a uniformly round cap ca 1 mm in diameter would be cut with the mandibles (Plate 5.1.4). Because of the loose outer network of silk on the cocoon, the cap frequently remained hinged to the cocoon after emergence.

On average, the cocoons of A. plutellae measure  $3.33 \pm 0.27$  mm by  $1.29 \pm 0.10$  mm for the males, and  $3.37 \pm 0.17$  mm and  $1.30 \pm 0.09$  mm for the females (Table 5.1.1).

#### 5.1.4 Prepupa

The prepupa which lasts ca 20-30 hrs, has discernable head, thorax and abdomen, and segmentation in the latter is much more distinct than in the 3rd-instar larva (Plate 5.1.4). Anteriorly, the mouthparts are quite apparent while the antennae absent. On the head 2 reddish brown and oval-shaped eye spots are present dorso-laterally, while between the eye spots and situated dorsally near the posterior margin of the head are 3 kidney-shaped ocelli (reddish brown). In general, the cephalic structures are more heavily sclerotized and the general body colour light yellowish with the ventral whitish. During this stage the appendages and wing pads are still absent. The mean length of the prepupa ( $n = 15$ ) is  $2.83 \pm 0.16$  mm, and the width  $0.91 \pm 0.08$  mm (Table 5.1.1).

#### 5.1.5 Pupa

The pupa, at the stage of 2nd day after cocooning has a distinct head, thorax and abdomen. It is bright yellow with 7 visible abdominal segments. The eyes have turned deep brown and the head slightly orange while the ocelli reddish brown. A pair of yellow 18-segmented antennae is present; these being folded ventrally towards the posterior. Legs and wing pads which are transparent and yellowish are also clearly evident; the latter folded on the sides and pointing posteriorly, but not extending beyond the first  $\frac{1}{3}$  of the abdomen.

On the 3rd day after cocooning, the head, thorax, dorsal and ventral surfaces of the abdomen, femur, eyes and ocelli had changed to black, while the antennae still remaining yellow although slightly darkish. The wing pads were now larger but never extending beyond the mid-abdomen,

while on the 5th and 6th abdominal segments, a pair of oval-shaped spiracles were clearly discernable. In the females a fully-developed ovipositor was also visible.

By the 4th day after cocooning, the antennae had turned to black while the legs, except for some yellow portions, were generally brownish black. The wings were fully formed and free, with all other adult features also clearly visible (Plate 5.1.4). Attached to its abdominal apex may be seen the exuviae of the 3rd-instar larva. At this stage, the pupa ( $n = 15$ ) measures  $2.65 \pm 0.10$  mm by  $0.69 \pm 0.06$  mm (Table 5.1.1).

#### 5.1.6 Adult

The adult usually emerges by tearing the silky cocoon with its well-developed mandibles (Plate 5.1.4). Usually, the males tend to emerge earlier than the females (Fig. 5.1.1). This appears advantageous as the females normally are ready to oviposit shortly after emergence, with or without copulation.

As noted earlier, the adult parasite has been fully described elsewhere (Wilkinson, 1928, 1929, 1939; Parrots, 1964) and it thus suffice to provide here only the following brief characteristics. The adult is black in colour and has a pair of light brown mandibles, yellow palpi, black or dark brown antennae (18-segmented) and hyaline wings with blackish pterostigma and fuscous veins. The light brown legs have black coxae except the hind-coxa which is also partially brownish. Both the front and middle tarsi; tibia and hind femur are partially black, while the hind tarsi almost entirely black. In general, all the legs of the males are usually darker than those of the females. On the face, fine punctures are clearly evident while the body densely punctated. Although absent in the posterior half of the mesopleurum, the propodeum is coarsely and densely punctated with a few distinct wrinkles which are more prominent in the females. Likewise, the first 2 abdominal tergites are densely and coarsely punctated, while that on the others rather fine and scarce, or almost lacking. In the female, a distinct ovipositor is also distinguishable posteriorly (Plate 5.1.5).

On average, the males measure  $2.56 \pm 0.131$  mm by  $0.77 \pm 0.049$  mm, and the females  $2.62 \pm 0.161$  mm by  $0.73 \pm 0.054$  mm (Table 5.1.1).

#### 5.1.7 Developmental period and life cycle

Under the conditions of the present studies, the average durations of the individual stages are: egg, more than 1 day, generally just slightly less than 2 days; 1st stadium, 1-2 days with most about 1 day; 2nd stadium, 4-5 days, averaging 3.8 days; 3rd stadium, 1-3 days, averaging 1.8 days; prepupa, ca 1 day; and pupa, 3-6 days, averaging 4.5 days (Table

5.1.2). For the cocoons, however, great variation was observed; ranging from 2-7 days, and averaging 5 days (Fig. 5.1.1). In general, the cocoon period for the males is shorter, averaging only 4.7 days while that of the females 5.2 days. Some cocoons have developmental period of only 2 days; these, however, were entirely males (Fig. 5.1.1).

The total time required for the completion of a life cycle or one generation (from egg to adult emergence) averaged 13 days (Tables 5.1.1 & 5.1.2). Although the shortest period was 10 days and the longest 16 days, most individuals, however, emerged together showing a high degree of uniformity in the duration of the developmental stages.

## 5.2 PREFERENCE OF HOST STAGES BY A. PLUTELLAE

Initial cursory observations indicated that A. plutellae, like many other parasites, exhibits distinct preference not only for certain host species but also specific stages of a particular host. A clear understanding into this could lend much towards a more efficient manipulation of the parasite, such as, in developing mass rearing technique as well as in improving the proper timing for parasite releases should these be needed. Besides, it would also enrich understanding of other related aspects of the parasite's biology, e.g. successes in parasitism and total individuals obtainable when a particular host stage is exposed.

### 5.2.1 Preference over the host's eggs, larvae and pupae

In the field survey in Section 3, the parasite was obtained only from field-collected host larvae. To further confirm this and to determine the actual host stage(s) that the parasite would attack (oviposit) or prefer, all the main stages (eggs, larvae and pupae) of DBM were simultaneously exposed for 24 hrs to the parasite in either 'larval developmental cages' (Plate 2.2) or 'breeding jars' (Plate 2.1). Freshly-emerged and mated female parasites were used, and following exposure the different host stages were separately maintained and reared for determination of successful parasitism. This study was repeated 14 times under laboratory conditions (see 2b).

The results obtained (Table 5.2.1) showed without doubt that A. plutellae is strictly an endo-larval parasite. Out of a total of 9521 eggs and 607 pupae of the host exposed, not one was parasitized, while 62.1% of the host larvae (2nd + 3rd instars) resulted in full parasite development and emergence to the cocooning stage.

### 5.2.2 Preference for the different host larval instars

Previous studies (3.3.1 & 5.2.1) have revealed that the host larvae constituted the only stage selected by A. plutellae for oviposition

Table 5.1.2. Developmental stages and period of Apanteles plutellae Kurdj. reared on Plutella xylostella (L.) at 25±3°C and RH 70-80%.

| Developmental stage               | No. of the immature stages observed at following days from oviposition |    |                  |                                   |                  |                  |                                    |                                         |                                    |     |     |        |         |        |     |      | Developmental period (day) |  |
|-----------------------------------|------------------------------------------------------------------------|----|------------------|-----------------------------------|------------------|------------------|------------------------------------|-----------------------------------------|------------------------------------|-----|-----|--------|---------|--------|-----|------|----------------------------|--|
|                                   | Same day                                                               | 1  | 2                | 3                                 | 4                | 5                | 6                                  | 7                                       | 8                                  | 9   | 10  | 11     | 12      | 13     | 14  | Mean | Range                      |  |
| EGG                               | 30                                                                     | 30 | -                | -                                 | -                | -                | -                                  | -                                       | -                                  | -   | -   | -      | -       | -      | -   | >1   | 1 < 2                      |  |
| LARVA:1st instar(L <sub>1</sub> ) | -                                                                      | -  | 30L <sub>1</sub> | -                                 | -                | -                | -                                  | -                                       | -                                  | -   | -   | -      | -       | -      | -   | 1    | 1 - 2                      |  |
| 2nd instar(L <sub>2</sub> )       | -                                                                      | -  | -                | 1L <sub>1</sub> +29L <sub>2</sub> | -                | -                | -                                  | -                                       | -                                  | -   | -   | -      | -       | -      | -   | 3.8  | 4 - 5                      |  |
|                                   | -                                                                      | -  | -                | -                                 | 30L <sub>2</sub> | -                | -                                  | -                                       | -                                  | -   | -   | -      | -       | -      | -   |      |                            |  |
|                                   | -                                                                      | -  | -                | -                                 | -                | 30L <sub>2</sub> | -                                  | -                                       | -                                  | -   | -   | -      | -       | -      | -   |      |                            |  |
| 3rd instar(L <sub>3</sub> )       | -                                                                      | -  | -                | -                                 | -                | -                | 18L <sub>2</sub> +12L <sub>3</sub> | -                                       | -                                  | -   | -   | -      | -       | -      | -   | 1.8  | 1 - 3                      |  |
| PREFUPA (pp)                      | -                                                                      | -  | -                | -                                 | -                | -                | -                                  | 4L <sub>2</sub> +14L <sub>3</sub> +12pp | -                                  | -   | -   | -      | -       | -      | -   | 1    | 1                          |  |
| UPA (P)                           | -                                                                      | -  | -                | -                                 | -                | -                | -                                  | -                                       | 2L <sub>3</sub> +16pp+12P          | -   | -   | -      | -       | -      | -   | 4.5  | 3 - 6                      |  |
|                                   | -                                                                      | -  | -                | -                                 | -                | -                | -                                  | -                                       | -                                  | 30P | -   | -      | -       | -      | -   |      |                            |  |
|                                   | -                                                                      | -  | -                | -                                 | -                | -                | -                                  | -                                       | -                                  | -   | 30P | -      | -       | -      | -   |      |                            |  |
| ADULT                             | -                                                                      | -  | -                | -                                 | -                | -                | -                                  | -                                       | -                                  | -   | -   | 22P+8A | -       | -      | -   |      |                            |  |
|                                   | -                                                                      | -  | -                | -                                 | -                | -                | -                                  | -                                       | -                                  | -   | -   | -      | 11F+19A | -      | -   |      |                            |  |
|                                   | -                                                                      | -  | -                | -                                 | -                | -                | -                                  | -                                       | -                                  | -   | -   | -      | -       | 7P+23A | -   |      |                            |  |
|                                   | -                                                                      | -  | -                | -                                 | -                | -                | -                                  | -                                       | -                                  | -   | -   | -      | -       | -      | 30A |      |                            |  |
| Exuviae (No.)                     | 0                                                                      | 0  | 0                | 29L <sub>1</sub>                  | 30L <sub>1</sub> | 30L <sub>1</sub> | 30L <sub>1</sub> +12L <sub>2</sub> | 29L <sub>1</sub> +24L <sub>2</sub>      | 30L <sub>1</sub> +12L <sub>2</sub> | E   | E   | E      | E       | E      | E   |      |                            |  |

? = Exuviae could not be found.

E = By this time all have emerged out of the host.

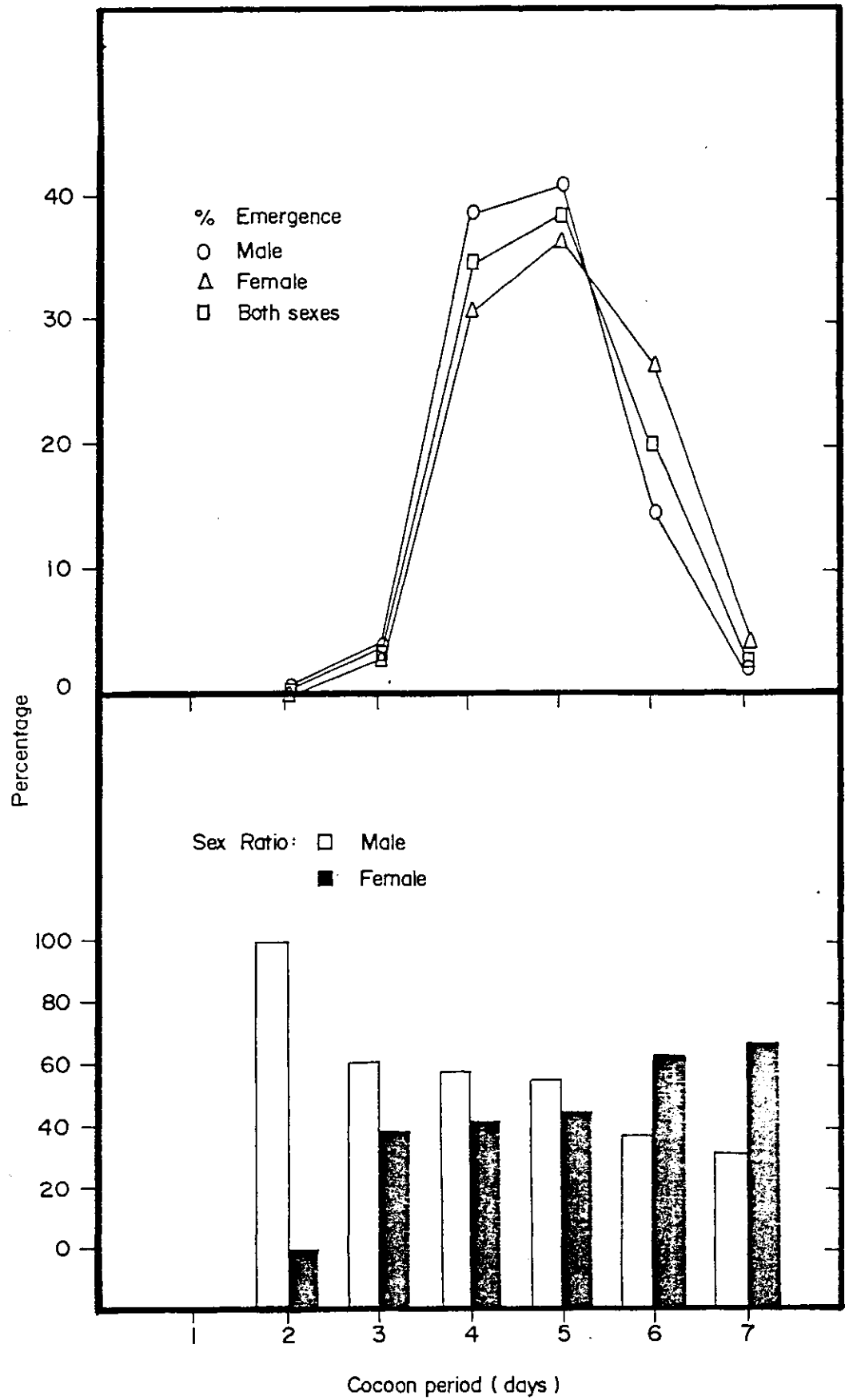


Figure 5.1.1 Emergence and sex ratio of *Apanteles plutellae* Kurdj in relation to varying developmental cocoon periods.



Table 5.2.1 Susceptibility of the different stages of Plutella xylostella (L.) to parasitization by Apanteles plutellae Kurdj. The different host stages were exposed simultaneously.

| Test* | Mated female parasites used | No. and stage of host exposed |          |       | No. (%) parasitized*** |            |       |
|-------|-----------------------------|-------------------------------|----------|-------|------------------------|------------|-------|
|       |                             | Eggs                          | Larvae** | Pupae | Eggs                   | Larvae     | Pupae |
| 1     | 3                           | 20                            | 90       | 9     | 0(0)                   | 25(27.8)   | 0(0)  |
| 2     | 3                           | 23                            | 88       | 14    | 0(0)                   | 71(80.7)   | 0(0)  |
| 3     | 24                          | 687                           | 161      | 18    | 0(0)                   | 107(66.5)  | 0(0)  |
| 4     | 7                           | 458                           | 148      | 15    | 0(0)                   | 110(74.3)  | 0(0)  |
| 5     | 24                          | 862                           | 106      | 22    | 0(0)                   | 52(49.1)   | 0(0)  |
| 6     | 13                          | 137                           | 81       | 34    | 0(0)                   | 26(32.1)   | 0(0)  |
| 7     | 24                          | 188                           | 61       | 34    | 0(0)                   | 13(21.3)   | 0(0)  |
| 8     | 15                          | 272                           | 44       | 22    | 0(0)                   | 20(45.5)   | 0(0)  |
| 9     | 5                           | 80                            | 28       | 20    | 0(0)                   | 20(71.4)   | 0(0)  |
| 10    | 7                           | 165                           | 47       | 9     | 0(0)                   | 36(76.6)   | 0(0)  |
| 11    | 1                           | 132                           | 16       | 3     | 0(0)                   | 3(18.8)    | 0(0)  |
| 12    | 4                           | 178                           | 97       | 3     | 0(0)                   | 72(74.2)   | 0(0)  |
| 13    | 60                          | 4031                          | 613      | 200   | 0(0)                   | 434(70.8)  | 0(0)  |
| 14    | 89                          | 2288                          | 558      | 204   | 0(0)                   | 339(60.8)  | 0(0)  |
| Total | 279                         | 9521                          | 2138     | 607   | 0(0)                   | 1328(62.1) | 0(0)  |

\*Except for tests 13 and 14 which were made in 46.5 cm x 6.15 cm x 61 cm cages, all were tested in 24 cm x 10 cm diameter glass cylinders.

\*\*Largely 2nd and 3rd-instar larvae.

\*\*\*Based on successful parasite cocoon formation.

(Table 5.2.1). Although both 2nd and 3rd instar larvae were 'attacked' by the parasite it is uncertain if there was any preference exerted. To investigate the ovipositional preference by A. plutellae for the different larval stadia of DBM, 3 approaches were employed. All involved exposing a leaf of B. rapa containing the host larvae to freshly-emerged and mated female parasites in the 'oviposition jar' (Plate 2.1). Immediately following exposure the larvae were dissected for egg determination. In the first method, various host stadia were exposed separately for 15 mins each, and at a host:parasite ratio of 6:3. With the 2nd method, equal numbers of each host stadium were mixed together and simultaneously exposed for 24 hrs. The 3rd method involved exposing for 24 hrs two larval stadia at a time. Different combinations of larval ratio (0La:20Lb, 2La:18Lb, 4La:16Lb, 6La:14Lb, 8La:12Lb, 10La:10Lb, 12La:8Lb, 14La:6Lb, 18La:2Lb, 20La:0Lb; La = ath larval stadium and Lb = bth larval stadium), with the total larvae of the stadia concerned adding up to 20 were evaluated. In the investigations, this test was replicated 4-5 times.

As with the previous study, the experiments were conducted under

the laboratory conditions (see 2b).

From the findings, it was evident (Tables 5.2.2 & 5.2.3) that A. plutellae would parasitize on all larval stadia of DBM, and is unlike some other parasites which would totally discriminate against some stages, as with A. marginiventris where the 3rd to 5th larval stages of Plathypena scabra (F.) (Lep:Noctuidae) were never parasitized (Kunnalaca & Mueller, 1979). Although this was so, there was also a clear display of preference. In particular, a distinctly higher number of parasitized individuals as well as the number of parasite's eggs deposited per female, or per host, was noticeable on the 2nd larval instar (Tables 5.2.2 & 5.2.3). This stage also had a higher frequency of 'ovipositional stings' (Table 5.2.2) and greater number of individuals containing more than 15 parasite's eggs (Table 5.2.3). Based on these parameters, it was evident that the preference was of the following order: 2nd host instar > 3rd host instar > 1st host instar > 4th host instar.

Table 5.2.2 Susceptibility of various host stages to Apanteles plutellae Kurdj. ovipositional attack, and rate of successful egg deposition. (Host: parasite = 6:3; exposure time = 15 mins).

| Host stage* | Replication | Oviposition frequency | Host parasitized** |        | No. of eggs deposited |            |       |
|-------------|-------------|-----------------------|--------------------|--------|-----------------------|------------|-------|
|             |             |                       | No.                | %      | Total                 | Per female | Range |
| First       | 1           | 8                     | 4                  |        | 6                     |            | 0-13  |
|             | 2           | 10                    | 4                  |        | 5                     |            | 0-2   |
|             | 3           | 6                     | 1                  |        | 2                     |            | 0-2   |
|             | 4           | 13                    | 4                  |        | 9                     |            | 0-3   |
|             | Total       | 37                    | 13                 | 54.17  | 22                    | 1.8        | 0-3   |
| Second      | 1           | 49                    | 6                  |        | 43                    |            | 2-14  |
|             | 2           | 28                    | 6                  |        | 28                    |            | 3-6   |
|             | 3           | 32                    | 6                  |        | 26                    |            | 3-7   |
|             | 4           | 32                    | 6                  |        | 44                    |            | 5-10  |
|             | Total       | 141                   | 24                 | 100.00 | 141                   | 11.8       | 2-14  |
| Third       | 1           | 20                    | 4                  |        | 9                     |            | 0-4   |
|             | 2           | 15                    | 5                  |        | 14                    |            | 0-4   |
|             | 3           | 14                    | 2                  |        | 3                     |            | 0-2   |
|             | 4           | 16                    | 6                  |        | 23                    |            | 1-9   |
|             | Total       | 65                    | 17                 | 70.83  | 49                    | 4.1        | 0-9   |
| Fourth      | 1           | 23                    | 2                  |        | 3                     |            | 0-2   |
|             | 2           | 3                     | 0                  |        | 0                     |            | 0     |
|             | 3           | 7                     | 1                  |        | 1                     |            | 0-1   |
|             | 4           | 7                     | 5                  |        | 5                     |            | 0-1   |
|             | Total       | 40                    | 8                  | 33.33  | 9                     | 0.8        | 0-2   |

\*The different larval stages were exposed separately.

\*\*Based on parasite cocoons formed.

Table 5.2.3. Cvipositional pattern and number of eggs deposited by apanteles plutei Kurdj. when different larval stages of Plutella xylostella (L.) are exposed together.

| Host         |             | Trial No. | No. of host containing the following number of parasite eggs* |   |   |   |   |   |   |   |   |   |    |    |    |    |    | Total Parasite eggs(No.) | Parasi-<br>tised host<br>(No.)           | Mean egg<br>No./host<br>% |      |      |     |
|--------------|-------------|-----------|---------------------------------------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|--------------------------|------------------------------------------|---------------------------|------|------|-----|
| Instar stage | No. Exposed |           | 0                                                             | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |                          |                                          |                           |      | 15   |     |
| First        | 10          | I         | 6                                                             | 2 | 2 |   |   |   |   |   |   |   |    |    |    |    |    |                          | 6                                        | 4                         |      |      |     |
|              | 10          | II        | 2                                                             | 0 | 4 | 0 | 3 | 1 |   |   |   |   |    |    |    |    |    |                          | 25                                       | 8                         |      |      |     |
|              | 20          | III       | 3                                                             | 1 | 0 | 6 | 2 | 2 | 1 | 0 | 1 | 1 | 1  | 1  | 0  | 0  | 0  | 0                        | 1(16)                                    | 97                        | 17   |      |     |
| Total        | 40          |           | 11                                                            | 3 | 6 | 6 | 5 | 3 | 1 | 0 | 1 | 1 | 1  | 1  | 0  | 0  | 0  | 0                        | 1(16)                                    | 128                       | 29   | 72.5 | 4.4 |
| Second       | 10          | I         | 2                                                             | 0 | 3 | 2 | 2 | 0 | 1 |   |   |   |    |    |    |    |    |                          | 26                                       | 8                         |      |      |     |
|              | 10          | II        | 0                                                             | 1 | 0 | 1 | 3 | 0 | 2 | 1 | 0 | 0 | 0  | 0  | 0  | 0  | 0  | 0                        | 1(16), 1(19)                             | 70                        | 10   |      |     |
|              | 20          | III       | 1                                                             | 1 | 0 | 0 | 2 | 0 | 1 | 2 | 0 | 2 | 0  | 1  | 1  | 0  | 3  | 0                        | 1(17), 1(19), 2(21), 1(26), 1(40)        | 256                       | 19   |      |     |
| Total        | 40          |           | 3                                                             | 2 | 3 | 3 | 7 | 0 | 4 | 3 | 0 | 2 | 0  | 1  | 1  | 0  | 3  | 0                        | 1(16), 1(17), 2(19), 2(21), 1(26), 1(40) | 352                       | 37   | 92.5 | 9.5 |
| Third        | 10          | I         | 0                                                             | 3 | 2 | 1 | 1 | 1 | 1 | 0 | 1 |   |    |    |    |    |    |                          | 33                                       | 10                        |      |      |     |
|              | 10          | II        | 4                                                             | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0  | 0  | 0  | 1  | 0  | 0                        | 1(16)                                    | 48                        | 6    |      |     |
|              | 20          | III       | 3                                                             | 0 | 0 | 3 | 1 | 0 | 1 | 1 | 0 | 0 | 1  | 1  | 2  | 1  | 0  | 1                        | 2(17), 2(19), 1(20)                      | 191                       | 17   |      |     |
| Total        | 40          |           | 7                                                             | 4 | 2 | 4 | 3 | 2 | 2 | 1 | 1 | 1 | 1  | 1  | 2  | 2  | 0  | 1                        | 1(16), 2(17), 2(19), 1(20)               | 272                       | 33   | 82.5 | 8.2 |
| Fourth       | 10          | I         | 5                                                             | 2 | 2 | 1 |   |   |   |   |   |   |    |    |    |    |    |                          | 9                                        | 5                         |      |      |     |
|              | 10          | II        | 7                                                             | 2 | 0 | 1 |   |   |   |   |   |   |    |    |    |    |    |                          | 5                                        | 3                         |      |      |     |
|              | 20          | III       | 5                                                             | 0 | 1 | 1 | 2 | 2 | 2 | 3 | 0 | 2 | 1  | 0  | 1  |    |    |                          | 96                                       | 15                        |      |      |     |
| Total        | 40          |           | 17                                                            | 4 | 3 | 3 | 2 | 2 | 2 | 3 | 0 | 2 | 1  | 0  | 1  |    |    |                          | 110                                      | 23                        | 57.5 | 4.8  |     |

\*Where the number of parasite eggs is more than 15, this is indicated within parenthesis.

In the studies involving paired host larval stadia, the preference may be graphically displayed as suggested by Murdoch (1969) who formally defined the relationship in the form:

$$\frac{N_e}{N'_e} = C \frac{N}{N'} \quad (2)$$

where  $N_e$ ,  $N'_e$  = the numbers of prey types I and II eaten,  $N$ ,  $N'$  = the numbers of prey types I and II initially present, and  $C$  = the Index 4 as explained by Cock (1978). Although this method, among several others, was developed essentially with predator-prey interactions, it is also applicable to the host-parasite situation (Cock, 1978). In the preference evaluation involving Murdoch's  $C$ , the ratio of the prey types eaten (or 'attack'  $N_a$  in the case of DBM) was plotted against the ratio at which they were present [i.e. illustrating equation (2)]. By this method, the constant preference will take the form of straight line relationship where a slope of 1 indicates no preference, a slope  $> 1$  positive preference, and a slope  $< 1$  negative preference. Thus, preference can be readily detected as a deviation from the slope of unity (Murdoch, 1969; Cock, 1978) and wherein the straight line is fitted through the origin (Snedecor & Cochran, 1967).

Figure 5.2.1 clearly illustrates the preference of *A. plutellae* for the various host larval stages of DBM, and Table 5.2.4 the statistical analyses. In computing the latter, values for the combinations 0La:20Lb and 20La:0Lb were omitted as these, inadvertently, would either be 0 or  $\infty$ , and being so, would unnecessarily reduce the overall accuracy of the analysis.

From this study it is again evident that the parasite was able to 'attack' all the 4 larval stadia exposed, although there was a marked preference for the 2nd. Except for the 1st instar, the preference order was again confirmed to be similar to that of the other 2 methods, i.e. 2nd instar  $>$  3rd instar  $>$  4th instar. As for the 1st instar, no preference was exhibited when matched against both 2nd and 3rd instars, although it was again noted to be preferred over the 4th instar. This slight discrepancy observed with the 1st instar could be due to the many influencing factors on preference, much of which are still inadequately understood, such as (i) the parasite or host densities, which were unequal for the different methods, and (ii) the presence or absence of other host stages that also constitute a choice for 'attack'.

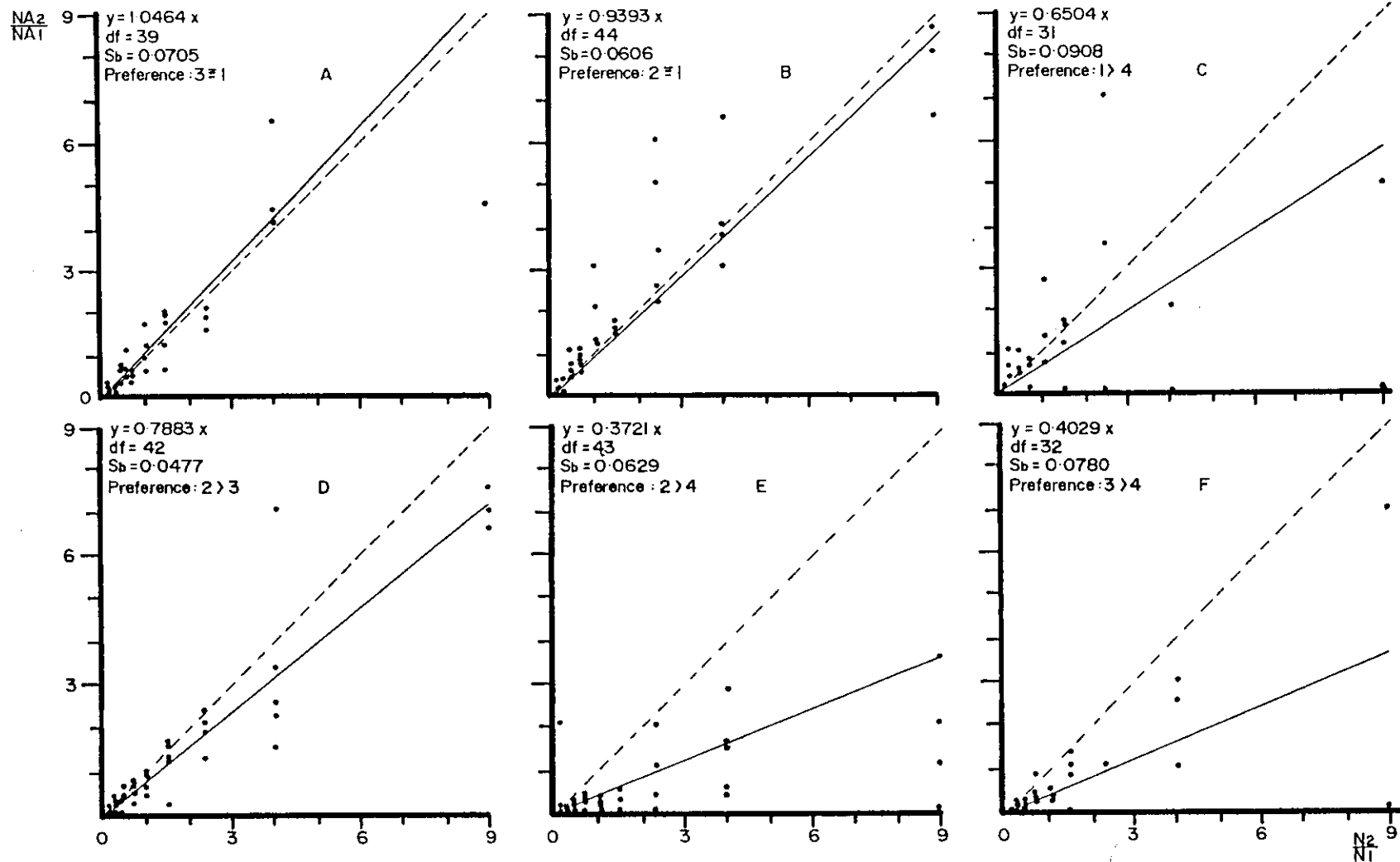


Figure 5-2: Parasitism of *Plutella xylostella* (L.) by *Apanteles plutellae* Kurdj. when two larval host instars were presented. A: 3rd instar (N2) and 1st instar (N1). B: 2nd instar (N2) and 1st instar (N1). C: 4th instar (N2) and 1st instar (N1). D: 3rd instar (N2) and 2nd instar (N1). E: 4th instar (N2) and 2nd instar (N1). F: 4th instar (N2) and 3rd instar (N1). NA2 and NA1 are the respective number of hosts parasitised or "attacked".

Table 5.2.4 Regression analyses to the preference of Apanteles plutellae Kurdj. over the different host larval instars of Plutella xylostella (L.).

| Instar Preference | df | $t_{0.05}$ | Regression equation | $S_b$  | $\pm$ SE |
|-------------------|----|------------|---------------------|--------|----------|
| 1st = 2nd         | 44 | 2.021      | $y = 0.9393x$       | 0.0606 | 0.1225   |
| 1st = 3rd         | 39 | 2.021      | $y = 1.0464x$       | 0.0705 | 0.1425   |
| 1st > 4th         | 31 | 2.042      | $y = 0.6504x$       | 0.0908 | 0.1854   |
| 2nd > 3rd         | 42 | 2.021      | $y = 0.7883x$       | 0.0477 | 0.0964   |
| 2nd > 4th         | 43 | 2.021      | $y = 0.3721x$       | 0.0629 | 0.1271   |
| 3rd > 4th         | 32 | 2.042      | $y = 0.4029x$       | 0.0780 | 0.1593   |

### 5.3 DEVELOPING BIOLOGY OF THE HOST AND THE PARASITE AS AFFECTED BY THE INITIAL HOST STAGE IN WHICH PARASITISM OCCURS

Presently, it is not known how different is the developing biology of A. plutellae and its DBM host when parasitism first occurs on the different larval stadia of the host. In studies to gather information on this aspect, newly-moulted and different larval instars of DBM were individually confined with a female parasite in glass vials (7.5 cm x 2.5 cm diameter) and closely observed to ensure single oviposition per larva. Immediately following egg deposition, each parasitized larva was separately reared on B. rapa in a 'breeding jar' (Plate 2.1) for detailed determination of the developmental time (instar period and life cycle) of the host and parasite. For each larval stage considered, 36-59 individuals were studied. In a separate series involving 70-110 larvae per stage, 40 parasitized larvae were dissected daily for determination of the parasite developmental stage attained. This study, it is hoped, would further enlighten on the influence of host stage over the parasite development.

Previous investigations have provided evidence that the presence of endoparasite larvae may change the development of their hosts. Clausen (1954) reported that the endoparasite may cause variations in the growing rate of hosts and these may appear in the different ages. For instance, although there was no significant difference in larval size, there was some delay in the development of the larvae of Spodoptera littoralis (Boisduval) (Lep: Noctuidae) when parasitized by Chelonus inanitus (L.) (Hym: Braconidae), particularly from the 2nd day until the 5th (Rechav & Orion, 1975). After the 6th day, the development was slow and practically stopped on the 9th day, while the weight of the unparasitized larvae increased tenfold. In the present investigations, such an effect on development was also observed in DBM when parasitized by

A. plutellae. However, the effect was largely evident only when parasitism initially occurred on the 3rd and 4th larval instar. For instance, for the developmental period from host hatching to parasite emergence (or cocooning), there was an increase from  $7.969 \pm 0.244$  days to  $13.133 \pm 0.165$  days as parasite oviposition was delayed from the 1st to the 4th host instar (Table 5.3.1). This increase became greater with progressive delay in the oviposition, as well as, with progressive advancement of the developmental stage. Among these, the main increase occurred in the developing stage between the 3rd moulting to parasite cocooning, suggesting that this probably acted as the main 'waiting' stage, since contributions by the others were relatively minor. It was also evident that host development was little affected when the parasite oviposition occurred in the 1st larval instar.

In terms of host mortality resulting from parasitism, differences were also evident; these depending on which host stages the parasite oviposition first occurred (Fig. 5.3.1). With the exception of the 2nd-instar stage which had least mortality (16.67%), that of the others showed a progressive increase of 33.33%, 43.86% and 54.29% for the larvae which were oviposited at the 1st, 3rd and 4th instar stage, respectively. The reverse was, however, recorded for success parasitism rates, wherein the 2nd-instar stage showed the highest of 83.33% (Fig. 5.3.1). This trend, with the exception of the 1st-instar, was similar to that observed in the preference studies wherein similar order of preference was again observed: 2nd instar > 3rd instar > 4th instar (see 5.2).

As for the various developmental periods of the parasite itself, these appeared to be little affected. For all the larval stages studied, except the 1st, the following were generally about equal irrespective of when the oviposition took place: egg-larval period, cocoon period, and egg-to-adult period (Table 5.3.1). Where oviposition occurred during the 1st instar stage the overall developmental period tended to be slightly longer. That the parasite's developmental period was in general unaffected was further evident from another study where parasitized host larvae were dissected daily for determination of the developmental stage attained by the parasite. From such a study, the developmental periods for the various immature stages were observed to differ little irrespective of whether parasitism occurred at the 1st, 2nd, 3rd or 4th instar stage (Table 5.3.2). The only difference noted relates essentially to the parasite survival, wherein a higher mortality occurred as the instar stage initially parasitized became progressively later. This, however, was also evident from the previous study (see 5.3, Fig. 5.3.1).

TABLE 5.3.1. Host-parasite developmental period in unparasitised *Plutella xylostella* (L.) and when the host was oviposited upon during the different larval stages by the parasite *Apanteles plutellae* Kurdj.

| Developmental Characteristics        | Host larval stage in which oviposition occurred |              |              |              | Unparasitised |
|--------------------------------------|-------------------------------------------------|--------------|--------------|--------------|---------------|
|                                      | 1st-instar                                      | 2nd-instar   | 3rd-instar   | 4th-instar   |               |
| HOST:                                |                                                 |              |              |              |               |
| a) Developmental period              |                                                 |              |              |              |               |
| 1st-instar                           | 1.596±0.095                                     | 1.444±0.084  | 1.818±0.100  | 2.000±0.064  | 2.31±0.0830   |
| 2nd-instar                           | 1.575±0.087                                     | 1.657±0.081  | 1.566±0.069  | 1.956±0.084  | 1.57±0.0884   |
| 3rd-instar                           | 1.919±0.085                                     | 1.500±0.100  | 2.078±0.100  | 1.932±0.082  | 1.65±0.0984   |
| From 3rd moult to cocooning          | 2.781±0.167                                     | 4.000±0.150  | 4.765±0.190  | 6.917±0.150  | 2.64±0.0988*  |
| From hatching to parasite cocooning  | 7.969±0.244                                     | 8.500±0.164  | 9.882±0.188  | 13.133±0.165 | 8.25±0.1344** |
| b) Mortality                         |                                                 |              |              |              |               |
| No. parasitised                      | 32                                              | 30           | 32           | 15           | -             |
| No. died prior to parasite cocooning | 16                                              | 6            | 25           | 27           | 9(20.0%)*     |
| Total                                | 48                                              | 36           | 57           | 42           | 45            |
| PARASITE:                            |                                                 |              |              |              |               |
| a) Developmental period              |                                                 |              |              |              |               |
| Egg-larval                           | 7.625±0.466                                     | 7.067±0.150  | 6.824±0.140  | 7.000±0.140  | -             |
| Cocoon                               | 3.906±0.094                                     | 3.667±0.100  | 3.938±0.110  | 3.933±0.120  | -             |
| Egg to adult                         | 11.844±0.238                                    | 10.833±0.190 | 10.774±0.150 | 10.929±0.200 | -             |
| b) No.Female:Male                    |                                                 |              |              |              |               |
|                                      | 19 : 13                                         | 16 : 14      | 11 : 21      | 6 : 9        | -             |

\* 4th instar period.

\*\* 1st-4th instar period.

\*\*\* Prior to reaching the pupal stage.



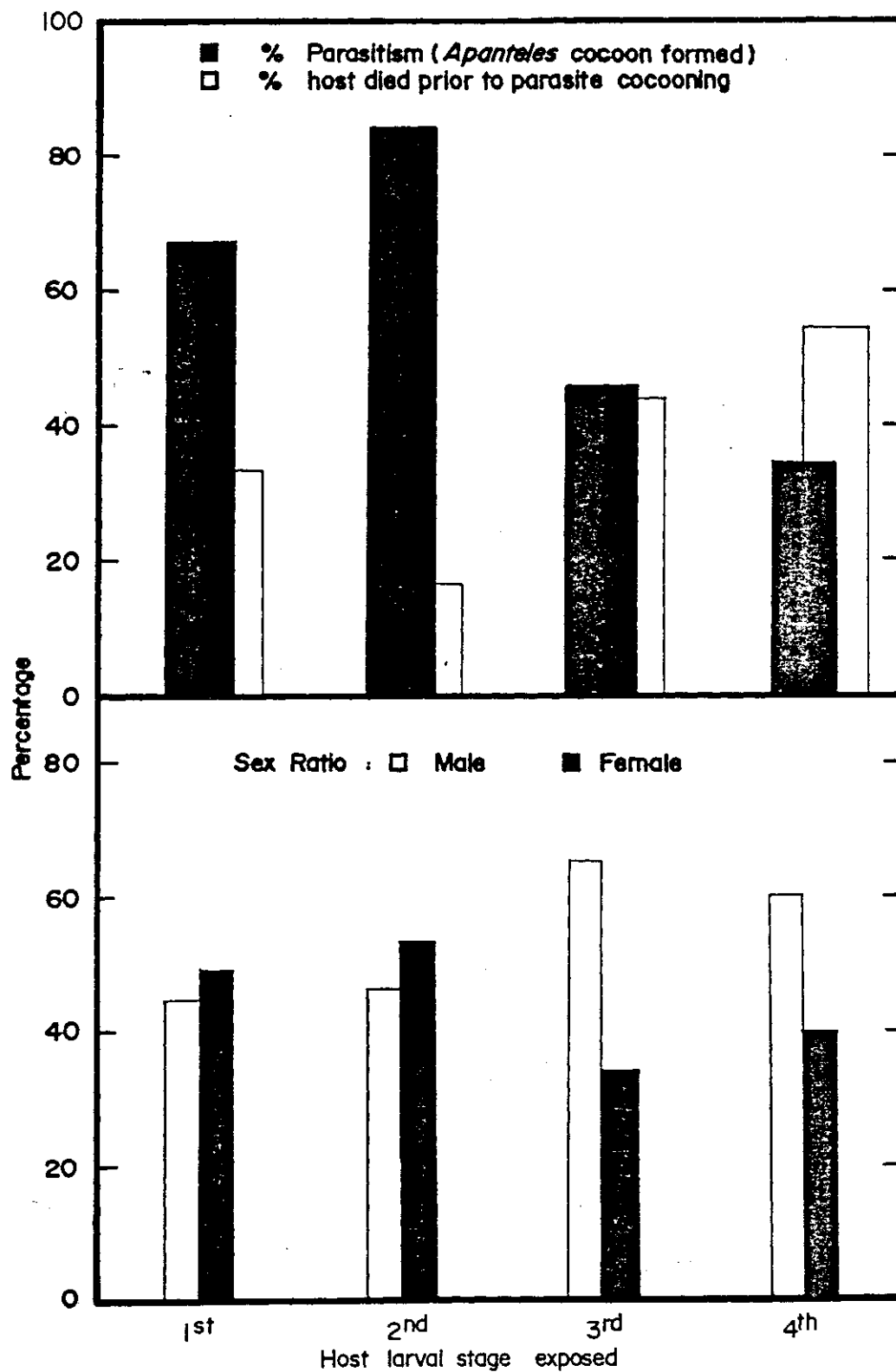


**Figure 5-3-1** Relationships of host mortality, parasitism rates and parasite sex ratios when the different larval instars of *Plutella xylostella* (L.) were oviposited upon by *Apanteles plutellae* Kurdj.

Table 5.3.2 Development of Apanteles plutellae Kurdj. in relation to the stage of host instar<sup>1/</sup> at which parasitization initially occurs.

| Host instar initially parasitized | No. dissected & examined | Days after parasitization <sup>2/</sup> |         |      |               |           |           |          |         |     |
|-----------------------------------|--------------------------|-----------------------------------------|---------|------|---------------|-----------|-----------|----------|---------|-----|
|                                   |                          | 1                                       | 2       | 3    | 4             | 5         | 6         | 7        | 8       | 9   |
| First                             | 10                       | 10EE                                    | 10EE/EL | 10EL | 10LL          | 10LL      | 10LL      | 10LL     | 2LL, 8C | 10C |
| Second                            | 10                       | 10EE                                    | 10EE/EL | 10EL | 3EL, 7LL      | 10LL      | 10LL      | 10LL     | 1LL, 9C | 10C |
| Third                             | 44                       | 44EE                                    | 44EE/EL | 44EL | 41LL, 3D      | 26LL, 18D | 13LL, 31D | 4LL, 40D |         |     |
| Fourth                            | 21                       | 21EE                                    | 21EE/EL | 21EL | 4EL, 10LL, 7D | 9LL, 12D  | 2LL, 19D  | 1LL, 20D | 1C      |     |

1/ Larval host of Plutella xylostella (L.).

2/ Stage of developing parasite: EE = Egg, EL = Early Larva, LL = Late Larva, C = Cocoon, D = Died

With respect to the emerging parasites, there was noted a preponderance of males when initial oviposition occurred on the 3rd and 4th instar. The respective female:male ratios were 0.52:1 and 0.67:1 (Table 5.3.1, Fig. 5.3.1). Where the 1st and 2nd instar were first oviposited upon, the ratios were respectively, 1.46:1 and 1.14:1; these evidently appeared more favourable.

#### 5.4 DEVELOPMENTAL BIOLOGY OF A. PLUTELLAE AS AFFECTED BY DIFFERENT LEVELS OF TEMPERATURE AND HUMIDITY

Some of the most important criteria that can be presumed to influence a parasite's ability to persist and increase in abundance in localities where its host exists are its moisture-tolerance and temperature-tolerance limits. To a large extent it is also governed by the rapidity with which it can develop within these limits. Generally, the wider these limits are, the more widespread can be its geographic range. Also, the more rapidly it can develop to maturity, the more rapidly can it be expected to increase in numbers in relation to its host and to its competitors, all other factors being equal. The importance of these parameters in relation to biological control and pest management programmes has been well-reviewed by Messenger (1959, 1970, 1971). For the present bioclimatic studies, the aims are thus directed at testing the entire range of temperature and humidity levels that exist in Malaysia, and also how these may support the survival of A. plutellae. In essence, the temperature threshold and the thermal constant for development were determined, as Messenger

(1959, 1970) has shown that these could be useful indicators of an insect's potential distribution and abundance.

#### 5.4.1 Materials and methods

Basically, 3 series of experiments were conducted; the 1st and 2nd to determine the effects of different constant temperatures, and the 3rd that of different constant level of humidity. For these investigations, all the DBM larvae were individually parasitized at the 1st-instar stage. Immediately following parasitism, each larva was transferred and separately maintained on an excised B.rapa leaf overlying a moist filter paper in a petri dish. On every 2nd or 3rd day, the leaf was replaced with fresh ones. The studies were conducted in programmed Conviron<sup>R</sup> growth chambers which had variations of temperature and humidity of not more than  $\pm 0.5^{\circ}\text{C}$  and  $\pm 5\%$ , respectively. A 12-hr light-dark cycle was provided, except for the  $10^{\circ}\text{C}$  treatment where there was no lighting. This was necessary in order to preserve the temperature and humidity required for this treatment. In any case, the complete absence of light has been found to have little or no effect on larval development of DBM (Way et al, 1951).

For the 1st experimental series, only the incubation period of the egg was examined. At each temperature considered ( $10^{\circ}\text{C}$ ,  $15^{\circ}\text{C}$ ,  $20^{\circ}\text{C}$ ,  $25^{\circ}\text{C}$ ,  $30^{\circ}\text{C}$  and  $35^{\circ}\text{C}$ ), groups of 5 larvae were dissected daily under the microscope for determination of egg-hatching. This was continued for 2 weeks, by which time, all the eggs had hatched.

In the 2nd series, a total of 30 larvae were studied for each constant temperature ( $10^{\circ}\text{C}$ ,  $15^{\circ}\text{C}$ ,  $20^{\circ}\text{C}$ ,  $25^{\circ}\text{C}$ ,  $30^{\circ}\text{C}$  and  $35^{\circ}\text{C}$ ), and the relative humidity kept within 70-80%. Examination of the larvae was made daily for records of mortality factors and other developmental aspects.

Procedures for the 3rd series were essentially the same as the above except that the variables considered were different ranges of relative humidities (40-50%, 60-70%, 70-80% and 90-100%) while the temperature kept constant at  $25 \pm 0.5^{\circ}\text{C}$ .

#### 5.4.2 Results

Within the provided temperature parameters ( $10$ - $35^{\circ}\text{C}$ ), duration of the egg, larval and pupal stages were observed to shorten progressively with each additional increment in temperature (Table 5.4.1). This was true for both the sexes, between which little difference was noted. When the developmental period is considered over the range of temperatures, there was observed considerable variation. The total developmental period at  $10^{\circ}\text{C}$  was about 12.4 times longer than at  $35^{\circ}\text{C}$ . In general, developmental rate increased rapidly with rising temperature until about  $25^{\circ}\text{C}$  where development remained relatively constant (Fig. 5.4.1). Except for

the egg stage, developmental rates for others began to decline at approximately 28-30°C and beyond, and progressively more thereafter. Upon extrapolation of the linear region at medium temperature range (Fig. 5.4.1, Table 5.4.2) this technique has provided for the establishment of the temperature threshold ( $t$ ) and thermal constant ( $K$ ); these values for A. plutellae obtained in the present studies are, respectively: egg ( $t_e = 11.2^\circ\text{C}$ ,  $K_e = 41.67 \text{ day}^{-\circ\text{C}}$ ), larva ( $t_l = 15.5^\circ\text{C}$ ,  $K_l = 58.82 \text{ day}^{-\circ\text{C}}$ ), pupa ( $t_p = 15.5^\circ\text{C}$ ,  $K_p = 63.16 \text{ day}^{-\circ\text{C}}$ ) and from oviposition to adult emergence ( $t_T = 13.8^\circ\text{C}$ ,  $K_T = 178.57 \text{ day}^{-\circ\text{C}}$ ).

Table 5.4.1 Mean ( $\pm$  S.D.) developmental periods (days) and the resultant sex ratios of Apanteles plutellae Kurdj. reared at various constant temperatures and 70-80% RH.

| Temperature<br>( $^\circ\text{C}$ ) | Mean ( $\pm$ S.D.) developmental period (days) |                  |                  |                                      | Adult sex<br>ratio (Female:<br>Male) |
|-------------------------------------|------------------------------------------------|------------------|------------------|--------------------------------------|--------------------------------------|
|                                     | Egg                                            | Larva            | Pupa             | Oviposition<br>to adult<br>emergence |                                      |
| 10                                  | 11.11 $\pm$ 0.23                               | 49.12 $\pm$ 0.24 | 43.23 $\pm$ 0.59 | 103.46 $\pm$ 0.53                    | 0.86                                 |
| 15                                  | 6.20 $\pm$ 0.22                                | 21.83 $\pm$ 0.26 | 22.17 $\pm$ 0.34 | 50.20 $\pm$ 0.10                     | 0.79                                 |
| 20                                  | 3.75 $\pm$ 0.16                                | 11.60 $\pm$ 0.14 | 11.15 $\pm$ 0.21 | 26.20 $\pm$ 0.26                     | 1.22                                 |
| 25                                  | 2.94 $\pm$ 0.06                                | 6.33 $\pm$ 0.12  | 5.89 $\pm$ 0.08  | 15.16 $\pm$ 0.09                     | 0.87                                 |
| 30                                  | 2.18 $\pm$ 0.04                                | 4.11 $\pm$ 1.10  | 4.32 $\pm$ 0.13  | 10.61 $\pm$ 0.07                     | 0.36                                 |
| 35                                  | 1.72 $\pm$ 0.01                                | 3.28 $\pm$ 0.36  | 3.38 $\pm$ 0.13  | 8.38 $\pm$ 0.13                      | 0.29                                 |

When the data are replotted on a temperature-time relationship (Fig. 5.4.1) the curves for all the stages were noted to be clearly that of the conventional type (Howe, 1967), and these fitted well the logistic equation (Davidson, 1944):

$$Y = \frac{1 + e^{(a-bX)}}{k} \quad (3)$$

where  $Y$  = developmental time,  $X$  = temperature, and  $a$ ,  $b$  and  $k$  are constants. No significant deviations from the fitted curves were obtained when they were subjected to the test of analysis of variance (Williams, 1959). From these curves, it is evident that the points of inflection for the egg, larval and pupal periods closely approximate about 25-27°C. Since mortality also sharply increased beyond this point (Fig. 5.4.1), it thus

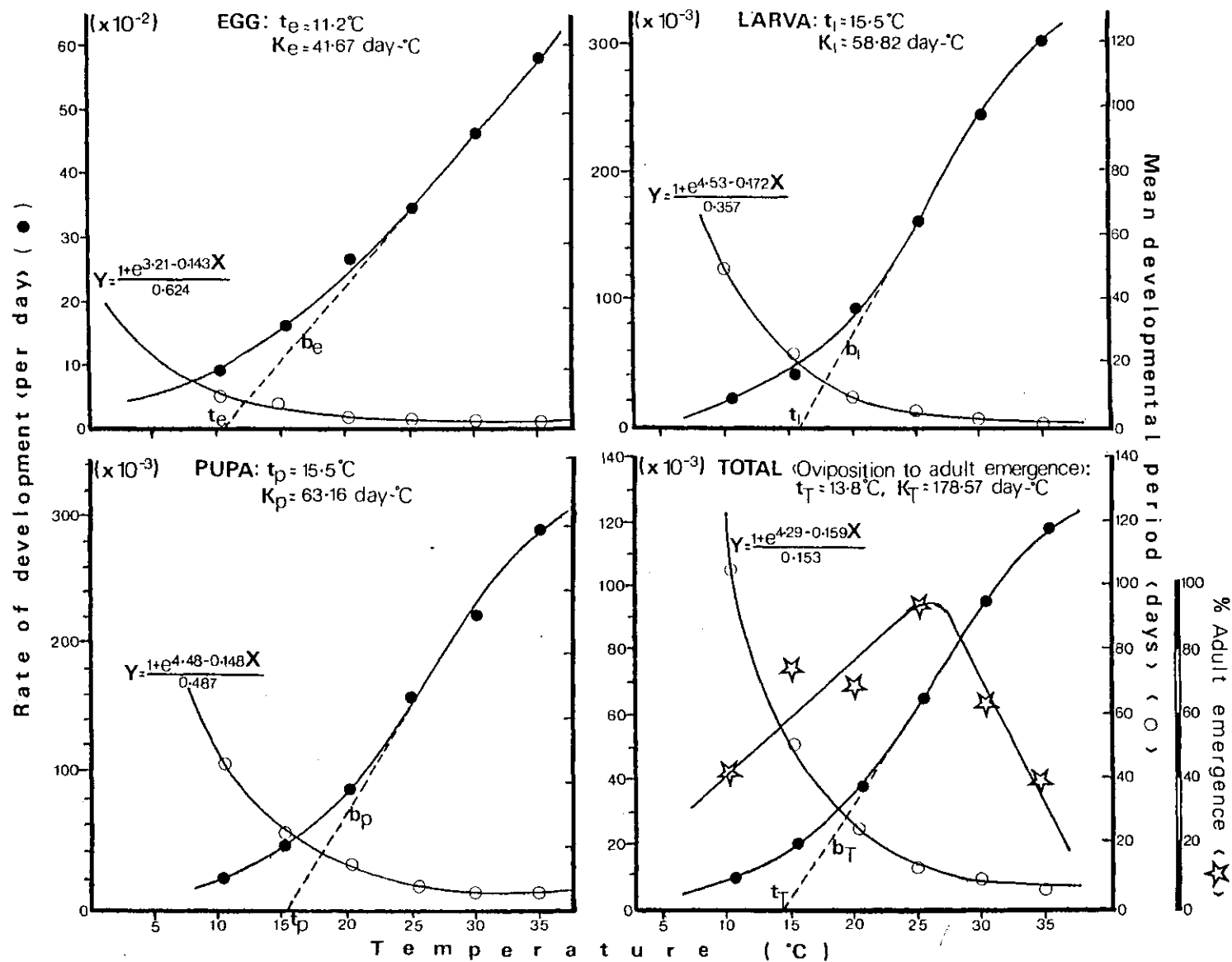


FIGURE 5.4.1 Relationships of temperature with the rate of development of the immature stages of *Apanteles plutellae* Kurdj. and the resultant parasite survival. ( $t$  = Temperature threshold of the respective parasite stages,  $K$  = Degree-days above  $t$  required for complete development to adult; this is equivalent to the reciprocal of the slope  $b$ ).

Table 5.4.2 Temperature thresholds and thermal constant (degree-days) for development of the immature stages of Apanteles plutellae Kurdj.

| Developmental stage | Linear equation*     | Temperature threshold (°C) | Thermal constant (day-°C) |
|---------------------|----------------------|----------------------------|---------------------------|
| Egg                 | $y = 0.024x - 0.270$ | $t_e = 11.2$               | $K_e = 41.67$             |
| Larva               | $y = 0.017x - 0.260$ | $t_l = 15.5$               | $K_l = 58.82$             |
| Pupa                | $y = 0.016x - 0.240$ | $t_p = 15.5$               | $K_p = 63.16$             |
| Total**             | $y = 0.006x - 0.078$ | $t_T = 13.8$               | $K_T = 178.57$            |

\*This refers to the linear portion.

\*\*From oviposition to adult emergence.

appears that this would constitute the critical temperature range of the parasite.

In general, maladies caused by disease pathogens accounted for most of the recorded mortality. These were responsible for about 80% of the total mortality. However, at the temperature extremes (10°C and 35°C), incomplete cocoon formation and failure by the emerging adult to dislodge from the cocoon were observed to be the main causes.

On the effect of different controlled humidities, a high mortality was noted only in the egg-larval stage at 90-100% RH and in the pupal stage from 40-70% (Table 5.4.3). The substantial pupal mortality at the lower humidity range was probably due to dessication, as suggested from dissections of unemerged cocoons, which often revealed the presence of dead and well-formed adults that were apparently free of diseases. Way et al (1951) have pointed out that low humidities are most likely to affect the insect when the temperature approaches the critical value (Wigglesworth, 1945) and the normally efficient water proofing mechanism of the insect cuticle begins to fail. This is especially so in the pupae since in contrast with feeding larvae they are not capable of replacing water lost by transpiration. On the other hand, majority in the egg-larval stage were diseased, suggesting that high humidity (90-100%) probably acts as predisposing factors for disease development. Disease susceptibility of the carrier host to such damp conditions has also been well-borne by field findings (Gunn, 1917; Smith, 1931; Kanervo, 1936). However, caution should be exercised in the present study when considering the differential survival of the parasite since development of the latter is also invariably

affected by the reaction of the host to humidities in which they were subjected. Even though, when considered in conjunction with the overall developmental periods, the relative humidity range of 70-80% seems most favourable; it resulted in maximum survival as well as ensuring sufficient developing time. The latter is generally essential for the development of females (see 5.3), hence the higher female: male ratio obtained in this humidity range (Table 5.4.3). The accelerated development in the other humidity range, particularly 40-50%, is perhaps largely due to stress generated by the adverse moisture condition.

Table 5.4.3 Developmental periods, mortality and sex ratio of Apanteles plutellae Kurdj. reared under different controlled humidities at 25°C constant temperature.

| Relative humidity<br>(%) | Mean ( <u>+ S.D.</u> ) developmental period (days) <sup>1/</sup> |                 |                                | Mortality    |       |       |       |       |       | Sex ratio<br>(Female: Male) |
|--------------------------|------------------------------------------------------------------|-----------------|--------------------------------|--------------|-------|-------|-------|-------|-------|-----------------------------|
|                          | Egg + larval                                                     | Pupal           | Oviposition to adult emergence | Egg + larval |       | Pupal |       | Total |       |                             |
|                          |                                                                  |                 |                                | No.          | %     | No.   | %     | No.   | %     |                             |
| 40-50                    | 7.11<br>± 0.12a                                                  | 4.75<br>± 0.18a | 11.83<br>± 0.21a               | 3            | 10.00 | 15    | 55.56 | 18    | 60.00 | 0.71                        |
| 60-70                    | 8.96<br>± 0.16b                                                  | 5.13<br>± 0.13b | 14.04<br>± 0.18b               | 3            | 10.00 | 7     | 25.93 | 10    | 33.33 | 0.67                        |
| 70-80                    | 9.27<br>± 0.08c                                                  | 5.89<br>± 0.08c | 15.16<br>± 0.09c               | 2            | 6.67  | 0     | 0.00  | 2     | 6.67  | 0.87                        |
| 90-100                   | 9.81<br>± 0.13d                                                  | 5.29<br>± 0.75b | 14.33<br>± 0.14b               | 9            | 30.00 | 0     | 0.00  | 9     | 30.00 | 0.40                        |

<sup>1/</sup>Means followed by the same letter in each column are not significantly different at the 5% level. Each mean pair was separately compared using the t-test for small samples (Bailey, 1959).

#### 5.4.3 Discussion

Although parameters such as temperature and humidity are by themselves generally insufficient for the accurate assessment of a parasite's potentials, they nonetheless are useful in providing relevant indications of its survival limits. With A. plutellae, they clearly show that the parasite is able to tolerate and survive in rather wide climatic conditions, and this to some extent helps to explain its rather cosmopolitan nature. In West Malaysia, the tolerance limits have well-exceeded all existing conditions, hence its possible wide occurrence locally in both the cooler highlands as well as the warmer lowlands.

However, its abundance is evident only in the Cameron Highlands where the daily mean temperature of  $18.2^{\circ}\text{C}$  (range =  $12.8-23.0^{\circ}\text{C}$ )\* and 88.2% RH (range = 68.2 - 99.9%)\* are found to better satisfy the parasite's optimum range of conditions (approximately  $18-28^{\circ}\text{C}$ ). Within the highland's climatic limits, not less than 75% survival could normally be expected (Fig. 5.4.1). On the other hand, extremes in temperature and atmospheric humidity rarely occur, and as such, any threat of massive suppression there is unlikely to result directly from these extremes. Whenever any decline occurs, the adverse management activities are more usually the cause, in particular, the widespread and indiscriminate use of pesticides.

Variation in the sex ratio of progeny is an important factor that could alter the level of parasite production, hence parasite efficacy. Such variation may result from climatic changes as for the case with the parasite Praon palitans Musebeck (Hym: Braconidae), in which extreme temperatures were found to alter its progeny in favour of more males (Messenger & Force, 1963). Particularly during the cooler period, this has resulted in the parasite becoming ineffective in preventing its aphid host, Therioathis maculata (Buckton) (Homoptera: Aphididae) from increasing to plant-damaging levels. In the present investigation, more males are likewise produced towards the temperature extremes wherein reduced activity of the parasite may result. Probably, this also contributes to its relative scarcity in most of the cooler temperate region and the hot tropical lowlands. In the latter locations, the sharp increase in mortality due to the higher day temperatures (mean =  $32.64^{\circ}\text{C}$ , range =  $31.2 - 34.8^{\circ}\text{C}$ ) which usually exceed the critical survival limit for most individuals (beyond  $28^{\circ}\text{C}$ ) seems a more important factor.

It is realized that laboratory bioclimatic investigations such as the present studies may not faithfully simulate the situations in nature. Usually, numerous interacting factors are responsible. For example, constant temperatures have constituted the basis for the experimental results in the present investigations, and as such, the developmental rates and other statistics calculated from these may not exactly coincide with those from the natural fluctuating temperatures of the same mean value. Relatively recent studies by others (Pradhan, 1945; Messenger, 1959, 1969; Messenger & Flitters, 1959) have shown that at low and high thermal levels the development is respectively accelerated and retarded by fluctuating temperatures, while at intermediate thermal levels it proceeds at about the same rates as would be expected relative to constant temperature

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\*Based on the data for the years 1974-80.



exposures. Furthermore, climatic parameters (temperature, humidity, illumination, etc.) are generally reacting upon one another and thus only to a limited extent can they be considered separately (Way et al, 1951; Messenger, 1959). Nevertheless, in spite of these limitations, such bioclimatic inputs have provided much in-depth understanding and insight that have enormous applied significance (Hardy, 1938; Way et al, 1951; Messenger, 1959, 1969, 1970, 1971; Messenger & Force, 1963; Force & Messenger, 1964a, b, 1965; Campbell et al, 1974; Ashley et al, 1976; Johnson et al, 1979). In some instances, they have even been used successfully to predict the time of occurrence of the different developmental stages in the field (Ito et al, 1968; Morris & Fulton, 1970). Furthermore, Johnson et al, (1979) were able to develop successfully an apple pest management programme for effective control of the spotted tentiform leaf-miner [Lithocolletis blancardella (Fab.) (Lep: Gracillariidae)] through preservation of its major endoparasite [Apanteles ornigis Weed (Hym: Braconidae)] based largely on optimizing insecticidal applications that are guided by prediction of adult emergence from degree-day relationships. In the light of these, further bioclimatic investigations on A. plutellae would seem warranted, and more comprehensive studies may well lead to possible improvements on its management as an aid towards the control of DBM. However, for the present and basing mainly on the climatic tolerance obtained, A. plutellae is seen to be unable to fulfil satisfactorily all the climatic niche of its DBM host. The latter is able to breed satisfactorily at temperatures from 10-40°C, with more than 75% survival being readily obtained within the range of 15-30°C (Hardy, 1938). For A. plutellae, although the full temperature range was not tested it appears to fall within about 9-39°C by extrapolation. While this is only marginally narrower than that of DBM, the temperature range enabling survival of 75% or more is substantially smaller, being only 18-28°C. At temperatures beyond this optimum range but within that of the DBM, the parasite would obviously be of great disadvantage when compared with the host. Evidently, in any location where such a situation exists, as with the temperate region and the lowlands of the tropics, it would be unlikely for A. plutellae to constitute an effective biological control agent of DBM. Thus, in the attempt to exploit whatever usefulness of the parasite, this consideration should not be overlooked.

### 5.5 OVIPOSITION STUDIES OF A. PLUTELLAE

Oviposition behaviour, pattern, and success rates often have great influence and govern the level of parasitism that may be achieved

by a parasite. Occasionally, these may have influence that is far-reaching, such as the parasitism of P.scabra by A.marginiventris, where multiple ovipositions resulted in death of host larva even though there was no parasite emerging (Kunnalaca & Mueller, 1979). In some instances, other aspects such as the regulatory potential of the parasite have also been made more apparent, as with the studies relating to functional response. Presently, much of these information are still lacking with respect to A.plutellae 'attacking' DBM. The following studies thus attempt to delve into some of these. During the investigations, normal laboratory conditions (see 2b) were maintained, and where possible the 2nd host instar stage was used as it has been noted to be most preferred (see 5.2).

#### 5.5.1 Mating, host searching and oviposition behaviour

Some female parasites have been observed to mate and oviposit within several minutes after emerging, but most were more aggressive when held for about 4 hrs prior to exposure to each other and the host. Mating occurred with the male approaching the female from the rear, tapping her with his antennae, and then moultng her for approximately half a second. Both sexes may mate many times freely with other individuals. Females have also been observed to often mate after initiating egg laying, and as in A.marginiventris (Boling & Pitre, 1970), no distinct pattern of ovipositing could be detected.

In general, a female parasite would almost immediately settle on the leaves of the enclosed brassica when introduced into an 'ovipositing jar' (Plate 2.1). It then roamed excitedly all over the leaf surface and touched the substrate vigourously with the antennae until encountering a host. Upon finding a host, the female would immediately attempt to insert an egg and move away from the larva. During oviposition the host was not paralysed and the parasite did not feed at the puncture site.

Frequently, when the parasite came into contact with a host larva, the latter would become momentarily agitated and react vigourously by dropping off the leaf to hang on a silk thread. In its continual pursuit of the host, the parasite would invariably be in contact with the thread. Almost immediately, it would descend along the thread causing the host larva to drop further down, whereupon reaching it the parasite would rapidly pounce over the host and oviposit. This 'attack' behaviour was also witnessed when the host was crawling or resting on the vertical surface of glass jars. As the parasite ran into it, the larva immediately became dislodge to a lower position aided by the silk thread which soon provided a lead for the parasite. The chances of oviposition occurring by such means of 'silk-tracking' was certainly greater than in the case where the

host larva remained still at the bottom of a container. Under the latter situation, the parasite may run into the host several times without any ovipositing unless the contact stimulated wriggling.

That some host movements were needed to attract follow-up action from the parasite towards successful ovipositions was strongly suggested in the above behavioural response. The importance of these movements was further indicated from observation on the direct attraction of several other female parasites towards a host larva when the latter was actively 'fighting back' during the process of being oviposited by a female in the immediate vicinity.

#### 5.5.2 Comparative egg deposition by A. plutellae on dead and living host larvae

In this study, a total of 131 oviposition attempts with recovery (through dissections) of 129 eggs was observed for 18 female parasites that were enclosed for 15 mins with 36 living and 36 dead larvae in 'oviposition jars' (Plate 2.1). All were, however, found associated with the living hosts (Table 5.5.1). That none was recorded for the dead larvae was perhaps further evidence to the need of host movements in stimulating parasite oviposition as suggested by the observational studies on oviposition behaviour (see 5.5.1).

Table 5.5.1 Frequency of ovipositional attack and egg deposition by Apanteles plutellae Kurdj. on dead and living 2nd-instar host larvae of Plutella xylostella (L.). (Host:parasite = 12\*: 3; exposure time = 15 minutes).

| Replication | Oviposition frequency |            | No. of eggs deposited on |            |
|-------------|-----------------------|------------|--------------------------|------------|
|             | Living hosts          | Dead hosts | Living hosts             | Dead hosts |
| 1           | 8                     | 0          | 9                        | 0          |
| 2           | 30                    | 0          | 26                       | 0          |
| 3           | 25                    | 0          | 30                       | 0          |
| 4           | 11                    | 0          | 13                       | 0          |
| 5           | 28                    | 0          | 28                       | 0          |
| 6           | 29                    | 0          | 23                       | 0          |
| Total       | 131                   | 0          | 129                      | 0          |

\*Equal number of living and dead larvae were provided together for each test.

### 5.5.3 Relation between ovipositor insertion and the number of eggs laid by *A. plutellae*

From previous observation (see 5.5.2) it was noted that 131 oviposition attempts yielded a total of 129 eggs suggesting that probably only 1 egg was deposited by one insertion of the parasite's ovipositor. An attempt to confirm this relationship was made with 10 female parasites to each of which 10 host larvae were separately provided. Each host was dissected after the required number of ovipositor insertions have been achieved. As shown in Table 5.5.2, it was evident that normally only 1 egg was deposited by 1 insertion of the ovipositor. In some instances egg deposition was noted to be unsuccessful, while on very few occasions 2 eggs may, however, also be laid.

Table 5.5.2 Relationship between the frequency of ovipositor insertion by *Apanteles plutellae* Kurdj. on the 2nd larval host instar of *Plutella xylostella* (L.) and the number of eggs deposited.

| <u>Insertion Frequency</u>   |                   | <u>Female Parasite</u> |      |      |      |      |      |      |      |      |       |
|------------------------------|-------------------|------------------------|------|------|------|------|------|------|------|------|-------|
| <u>Actual</u>                | <u>Cumulative</u> | 1                      | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10    |
| <u>No. of eggs deposited</u> |                   |                        |      |      |      |      |      |      |      |      |       |
| 1                            | 1                 | 1                      | 1    | 1    | 1    | 1    | 1    | 1    | 2    | 0    | 1     |
| 2                            | 3                 | 2                      | 3    | 1    | 1    | 1    | 1    | 2    | 2    | 2    | 1     |
| 3                            | 6                 | 3                      | 3    | 3    | 1    | 3    | 3    | 3    | 2    | 2    | 3     |
| 4                            | 10                | 3                      | 4    | 2    | 3    | 5    | 4    | 4    | 3    | 4    | 6     |
| 5                            | 15                | 2                      | 5    | 2    | 5    | 5    | 7    | 9    | 5    | 5    | 5     |
| 6                            | 21                | 4                      | 6    | 7    | 7    | 6    | 6    | 6    | 8    | 5    | 6     |
| 7                            | 28                | 5                      |      | 7    |      | 8    |      |      |      |      |       |
| 8                            | 36                | 11                     |      | 4    |      | 9    |      |      |      |      |       |
| 9                            | 45                | 12                     |      | 9    |      | 7    |      |      |      |      |       |
| 10                           | 55                | 10                     |      | 7    |      | 6    |      |      |      |      |       |
| Total                        |                   | 53                     | 22   | 53   | 18   | 51   | 22   | 25   | 22   | 18   | 22*   |
| Mean                         |                   | 0.98                   | 1.05 | 0.98 | 0.82 | 0.93 | 1.05 | 1.14 | 1.05 | 0.82 | 1.05* |

\*Total = 9, Mean = 1

### 5.5.4 Effect of multiple oviposition on parasite development and host mortality

As with many other parasites (Shin, 1970; Askari *et al.*, 1977; Kunnalaca & Mueller, 1979) multiple oviposition in *A. plutellae* was fairly common, especially when few hosts were offered to a parasite. In *A. marginiventris* (Kunnalaca & Mueller, 1979) the multiple stings

were observed to affect both the parasite development and host mortality. Whether such a situation also occurred with A. plutellae has not been reported. Studies were therefore made to investigate into this, wherein DBM larvae were subjected to different extent of multiple oviposition and reared on B. rapa leaves until parasite emergence or death of the hosts.

From the findings it was evident (Table 5.5.3) that excessive 'stings' or oviposition of an individual host could lead to the latter's death. This effect increased rapidly with higher number of ovipositions; a 100% host mortality being effected when the oviposition rate reached 10 and beyond. Conversely, the parasitism (%) declined proportionately (Table 5.5.3).

Table 5.5.3 Effect of multiple oviposition by Apanteles plutellae Kurdj. on host mortality and its own development.

| No. of oviposition per host | Larvae of <u>Plutella xylostella</u> (L.) |                         |        |                   |       |       |     | Died prior to parasite emergence |  |
|-----------------------------|-------------------------------------------|-------------------------|--------|-------------------|-------|-------|-----|----------------------------------|--|
|                             | Total (No.)                               | With parasite emergence |        |                   |       | Total |     |                                  |  |
|                             |                                           | Male                    | Female | Male:Female ratio | (No.) |       |     |                                  |  |
|                             |                                           |                         |        |                   |       |       |     |                                  |  |
|                             |                                           |                         |        |                   |       | (No.) | (%) |                                  |  |
| (No.)                       | (%)                                       |                         |        |                   |       |       |     |                                  |  |
| 1                           | 30                                        | 13                      | 15     | 0.87              | 28    | 93.3  | 2   | 6.7                              |  |
| 2                           | 15                                        | 2                       | 9      | 0.22              | 11    | 73.3  | 4   | 26.7                             |  |
| 3                           | 15                                        | 3                       | 4      | 0.75              | 7     | 46.7  | 8   | 53.3                             |  |
| 4                           | 15                                        | 4                       | 3      | 1.33              | 7     | 46.7  | 8   | 53.3                             |  |
| 5                           | 29                                        | 3                       | 3      | 1.00              | 6     | 20.7  | 23  | 79.3                             |  |
| 7                           | 15                                        | 2                       | 1      | 2.00              | 3     | 20.0  | 12  | 80.0                             |  |
| 10                          | 15                                        | 0                       | 0      | -                 | 0     | 0.0   | 15  | 100.0                            |  |
| 15                          | 15                                        | 0                       | 0      | -                 | 0     | 0.0   | 15  | 100.0                            |  |

Presently, it is not clear how the death of the host was brought about. Although it first appeared to be due to direct physical injury, other causes, particularly biochemical, could not be ruled out. Only more detailed investigations, however, could enlighten further on this aspect.

#### 5.6 FACTORS INFLUENCING THE SEX RATIO OF A. PLUTELLAE

A balanced ratio of the sexes in the progenies of a parasite is generally considered to be critical for any effective regulation of its

host population. Where a disproportionate increase of one sex occurs over the other, wide fluctuations and instability of the host may frequently result. Apparently, the sex ratio may be governed by several factors (Gifford & Mann, 1967; Bryan et al, 1969; Bryan et al, 1971), some of which were examined here in relation to A. plutellae.

Comparative studies of both mated and unmated female parasites showed that sex ratio of the progeny of A. plutellae is a function of successful mating. As with Microplitis croceipes (Cresson) (Hym: Braconidae) (Bryan et al, 1969) and M. demolitor Wilk. (Hym: Braconidae) (Hafez, 1951), it was found to be capable of arrhenotokous parthenogenetic reproduction when the female was not fertilized (Table 5.6.1). There was, however, no reduction in the overall individuals produced where mating was not permitted, as opposed to the situation observed for Apanteles flavipes (Cameron) (Hym: Braconidae) (Gifford & Mann, 1967).

Among mated females, the sex ratio was partly dependent on the stage of the host larvae initially parasitized (see 5.3). More females were obtained only when parasitism first occurred on the 1st and 2nd host instars (Table 5.3.1, Fig. 5.3.1). Such a situation was probably due to the longer available period of host suitability which was needed for the development of females. For the males, generally a shorter period was sufficient (Figs. 5.1.1 & 5.6.1), hence, the higher proportions of males when oviposition occurred on both the 3rd and 4th host instars.

Another factor that may influence the sex ratio in A. plutellae is the number of 'ovipositional attack' that a parasitized larva has received. Table 5.5.3 clearly shows that hosts which survived a higher number of 'attacks' would tend to produce more male parasites. Perhaps, this is due to the available parasite nutrition becoming reduced through initial competition, thus enabling any surviving male parasites to complete their development more readily as these are generally smaller and probably requiring less nutrients for maturation.

Extremes in climatic condition may also influence sex ratio in favour of more males as was observed in the study on bioclimatic effects (see 5.4).

Although wide variations in the sex ratios of A. plutellae were noted from laboratory investigations, in contrast, this was not normally observed in the field. This is evident from the long series of samplings of both parasitized host larvae (Table 5.6.2) and parasite cocoons (Table 5.6.3) made over 3-5 plantings during assessments on the impact of A. plutellae (see 4.2.2). A fairly balanced sex ratio was obtained; this approximating 1:1 with the females being marginally more. Such a case was also found for the sex ratios taken from series of solitary Apanteles (13

Table 5.6.1 Resulting progeny of mated and unmated female  
Apanteles plutellae Kurdj.

| Female No. | Mating status* | No. host larvae exposed** | Host parasitized |           | Emerging parasite adults |            |             |
|------------|----------------|---------------------------|------------------|-----------|--------------------------|------------|-------------|
|            |                |                           | No.              | %         | Male (M)                 | Female (F) | Ratio (M:F) |
| 1          | +              | 100                       | 38               | 38.0      | 26                       | 12         |             |
| 2          | +              | 100                       | 42               | 42.0      | 28                       | 14         |             |
| 3          | +              | 90                        | 58               | 64.4      | 38                       | 20         |             |
| 4          | +              | 135                       | 65               | 48.2      | 40                       | 25         |             |
| 5          | +              | 88                        | 31               | 35.2      | 20                       | 11         |             |
| 6          | +              | 100                       | 99               | 99.0      | 73                       | 26         |             |
| 7          | +              | 100                       | 86               | 86.0      | 44                       | 42         |             |
| 8          | +              | 100                       | 81               | 81.0      | 59                       | 22         |             |
| 9          | +              | 100                       | 74               | 74.0      | 36                       | 38         |             |
| 10         | +              | 100                       | 82               | 82.0      | 55                       | 27         |             |
| Total: 10  | +              | 1013                      | 656              | 64.8      | 419                      | 237        |             |
| Range:     |                |                           |                  | 35.2-99.0 |                          |            | 1.8: 1      |
| 1          | -              | 90                        | 44               | 48.9      | 44                       | 0          |             |
| 2          | -              | 90                        | 67               | 74.4      | 67                       | 0          |             |
| 3          | -              | 120                       | 90               | 75.0      | 90                       | 0          |             |
| 4          | -              | 60                        | 15               | 25.0      | 15                       | 0          |             |
| 5          | -              | 150                       | 45               | 30.0      | 45                       | 0          |             |
| 6          | -              | 90                        | 51               | 56.7      | 51                       | 0          |             |
| 7          | -              | 90                        | 34               | 37.8      | 34                       | 0          |             |
| 8          | -              | 90                        | 51               | 56.7      | 51                       | 0          |             |
| 9          | -              | 120                       | 36               | 30.0      | 36                       | 0          |             |
| 10         | -              | 150                       | 82               | 54.7      | 82                       | 0          |             |
| Total: 10  | -              | 1050                      | 515              | 49.1      | 515                      | 0          |             |
| Range:     |                |                           |                  | 25.0-74.4 |                          |            | All males   |

\* (+) = mated, (-) = unmated

\*\* Both 1st and 2nd host instars were used.

species) bred from wild collected larvae, wherein a total of 1176 males was recorded against 1172 females (Richards, 1940; Ford, 1943). From these, it thus appears that A. plutellae, like all other solitary Apanteles, somehow or other, is able to adjust its sex balance to a 1:1 ratio in the field.

#### 5.7 INFLUENCE OF FOODS ON THE SURVIVAL AND REPRODUCTION OF A. PLUTELLAE

Female parasites that are synovigenic require feeding for the continuous production of eggs throughout their effective adult life (Doutt, 1964). The needs may, in some species, be supplied by honeydew.

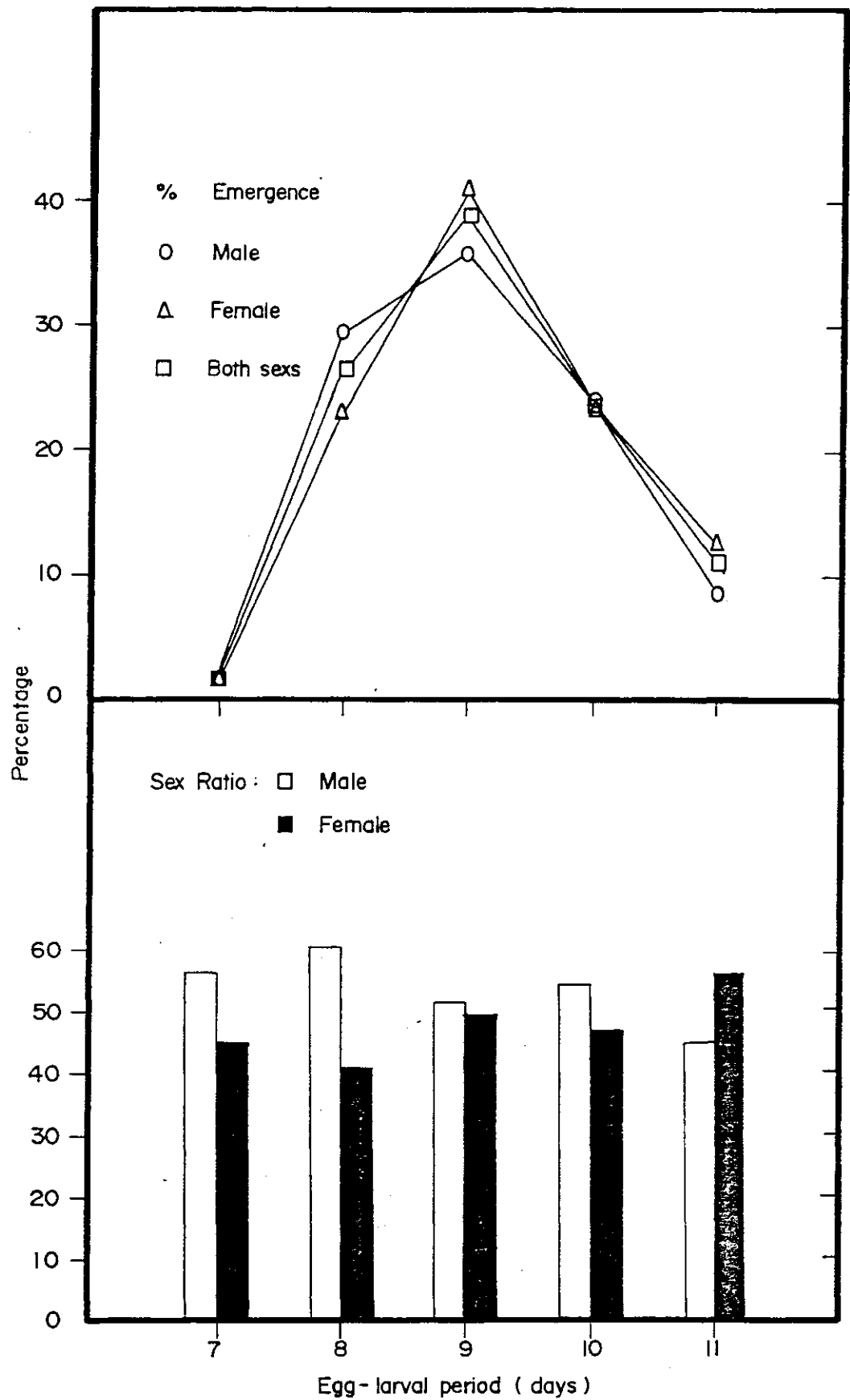


Figure 5-6-1 Emergence and sex ratio of *Apanteles plutellae* Kurdj in relation to varying egg-larval periods.



Table 5.6.2

Sex ratio of Apanteles plutellae Kurdj. emerging from host larvae (Plutella xylostella(L.)) collected from unsprayed cabbage crops in Tanah Rata, Cameron Highlands.

| Date                   | No. of <u>A. plutellae</u> |        |       | Sex ratio<br>(Male : Female) |
|------------------------|----------------------------|--------|-------|------------------------------|
|                        | Male                       | Female | Total |                              |
| 20.12.78 <sup>1/</sup> | 14                         | 19     | 33    |                              |
| 27.12                  | 10                         | 9      | 19    |                              |
| 3.1.79                 | 22                         | 26     | 48    |                              |
| 10.1                   | 34                         | 37     | 71    |                              |
| 24.1                   | 17                         | 21     | 38    |                              |
| 31.1                   | 13                         | 16     | 29    |                              |
| 14.2                   | 2                          | 4      | 6     |                              |
| 21.2                   | 6                          | 8      | 14    |                              |
| Sub-total              | 118                        | 140    | 258   | 1 : 1.2                      |
| 7.6.79 <sup>2/</sup>   | 9                          | 11     | 20    |                              |
| 13.6                   | 4                          | 5      | 9     |                              |
| 27.6                   | 22                         | 26     | 48    |                              |
| 4.7                    | 26                         | 21     | 47    |                              |
| 11.7                   | 21                         | 19     | 40    |                              |
| 25.7                   | 8                          | 13     | 21    |                              |
| 1.8                    | 21                         | 28     | 49    |                              |
| 8.8                    | 20                         | 23     | 43    |                              |
| Sub-total              | 131                        | 146    | 277   | 1 : 1.1                      |
| 9.8.79 <sup>3/</sup>   | 12                         | 13     | 25    |                              |
| 16.8                   | 6                          | 7      | 13    |                              |
| 22.8                   | 5                          | 6      | 11    |                              |
| 29.8                   | 3                          | 2      | 5     |                              |
| 12.9                   | 5                          | 7      | 12    |                              |
| 19.9                   | 4                          | 4      | 8     |                              |
| 3.10                   | 14                         | 16     | 30    |                              |
| 10.10                  | 11                         | 12     | 23    |                              |
| 17.10                  | 20                         | 26     | 46    |                              |
| Sub-total              | 80                         | 93     | 173   | 1 : 1.2                      |
| 2.11.79 <sup>4/</sup>  | 12                         | 18     | 30    |                              |
| 7.11                   | 17                         | 21     | 38    |                              |
| 22.11                  | 8                          | 12     | 20    |                              |
| 28.11                  | 9                          | 10     | 19    |                              |
| 5.12                   | 8                          | 9      | 17    |                              |
| 19.12                  | 13                         | 18     | 31    |                              |
| 16.12                  | 12                         | 15     | 27    |                              |
| Sub-total              | 79                         | 103    | 182   | 1 : 1.3                      |

Table 5.6.2 (continued)

| Date                 | No. of <u>A. plutellae</u> |        |       | Sex ratio<br>(Male : Female) |
|----------------------|----------------------------|--------|-------|------------------------------|
|                      | Male                       | Female | Total |                              |
| 9.1.80 <sup>5/</sup> | 3                          | 3      | 6     |                              |
| 16.1                 | 15                         | 17     | 32    |                              |
| 23.1                 | 21                         | 20     | 41    |                              |
| 6.2                  | 35                         | 38     | 73    |                              |
| 13.2                 | 17                         | 16     | 33    |                              |
| 20.2                 | 12                         | 12     | 24    |                              |
| 5.3                  | 17                         | 19     | 36    |                              |
| 19.3                 | 8                          | 9      | 17    |                              |
| Sub-total            | 128                        | 134    | 262   | 1 : 1.2                      |
| Grand total          | 536                        | 616    | 1152  | 1 : 1.2                      |

1/, 2/, 3/, 4/ and 5/ = From 27th, 29th, 30th, 31st and 32nd crop respectively.

or plant nectaries, both of which have been shown to contain free amino acids. Currently, there is growing awareness of the essential role of these in the longevity and fecundity of insect species, and in recent years their importance to entomophagous forms (Braconidae in particular) have been indicated by findings of several workers (Wolcott, 1942; Vouëte, 1946; Hagen, 1950, 1953; Gyoerfi, 1951, 1962; Kopvillem, 1960; Leius, 1960, 1961a, b, 1963, 1967; Gulii, 1963; van Emden, 1963a, b; Hsiao & Holdaway, 1966; Syme, 1966, 1974, 1975, 1977; Hassan, 1967; Koehler & Kolk, 1969; Judd, 1970; Esbjerg, 1972; Kevan, 1973). The present studies therefore seek to explore the response by A. plutellae to such adult foods. In particular, emphasis was devoted to (i) search for natural food sources, (ii) determining their effects on adult longevity and fecundity, and (iii) identifying and confirming on the components responsible, such as floral and extrafloral nectaries.

#### 5.7.1 Longevity, oviposition pattern and reproductive capacity of A. plutellae when prevented or given access to honey solution

In the studies on the influence of foods on survival and reproduction of A. plutellae, several related aspects were considered. Initially, the longevity, oviposition pattern and reproductive capacity of the parasite were examined in relation to full access to honey or without, using freshly-emerged and mated adults. All the females were individually confined within the 'breeding jar' (Plate 2.1) until their death. In all cases, water was provided through a wick. For treatments having access to

Table 5.6.3

Sex ratio of Apanteles plutellae Kurdj. emerging from parasite cocoons collected from unsprayed cabbage crops in Tanah Rata, Cameron Highlands.

| Date                   | No. of <u>A. plutellae</u> emerging |        |       | Sex ratio<br>(Male : Female) |
|------------------------|-------------------------------------|--------|-------|------------------------------|
|                        | Male                                | Female | Total |                              |
| 20.12.78 <sup>1/</sup> | 1                                   | 2      | 3     |                              |
| 27.12                  | 3                                   | 5      | 8     |                              |
| 3.1.79                 | 2                                   | 3      | 5     |                              |
| 10.1                   | 4                                   | 4      | 8     |                              |
| 24.1                   | 5                                   | 7      | 12    |                              |
| 31.1                   | 8                                   | 10     | 18    |                              |
| 14.2                   | 0                                   | 2      | 2     |                              |
| 21.2                   | 1                                   | 3      | 4     |                              |
| Sub-total              | 24                                  | 36     | 60    | 1 : 1.5                      |
| 9.8.79 <sup>2/</sup>   | 1                                   | 0      | 1     |                              |
| 16.8                   | 0                                   | 0      | 0     |                              |
| 22.8                   | 0                                   | 1      | 1     |                              |
| 29.8                   | 1                                   | 1      | 2     |                              |
| 12.9                   | 0                                   | 0      | 0     |                              |
| 19.9                   | 1                                   | 1      | 2     |                              |
| 3.10                   | 1                                   | 1      | 2     |                              |
| 10.10                  | 3                                   | 4      | 7     |                              |
| 17.10                  | 8                                   | 10     | 18    |                              |
| Sub-total              | 15                                  | 18     | 33    | 1 : 1.2                      |
| 2.11.79 <sup>3/</sup>  | 1                                   | 0      | 1     |                              |
| 7.11                   | 0                                   | 1      | 1     |                              |
| 22.11                  | 3                                   | 5      | 8     |                              |
| 28.11                  | 3                                   | 4      | 7     |                              |
| 5.12                   | 1                                   | 2      | 3     |                              |
| 19.12                  | 8                                   | 9      | 17    |                              |
| 26.12                  | 11                                  | 13     | 24    |                              |
| Sub-total              | 27                                  | 34     | 61    | 1 : 1.3                      |
| Grand total            | 66                                  | 88     | 154   | 1 : 1.3                      |

1/, 2/ and 3/ = From 27th, 30th and 31st crop respectively.

honey (30%), the latter was similarly provided. In studies on fecundity and pattern of oviposition, 30 2nd-instar DBM larvae were also provided daily. This was continued until the female died. Following each exposure, all the larvae were immediately dissected to determine the number of parasite eggs deposited. Also, upon death of the parasite it was dissected for counts of unlaidd eggs in the ovaries, oviduct or vagina.

The developmental process of both matured and immatured eggs in the ovaries of female parasites was also investigated. For this study freshly-emerged females were immediately separated into 2 groups, the first

fed with 30% honey and water and the second water only. Everyday 14 to 34 females in the 1st group were dissected and the number of matured and developing eggs (oocytes) determined under a binocular microscope. In the 2nd group 22 to 43 females were dissected daily. In either case host larvae were not provided to restrain oviposition.

For investigation on effect of partial starvation on longevity and survival of the parasite, newly-emerged males and females were separated into different groups and with-held initially from feeding on honey for different periods of 12 hrs, 1, 2 and 3 days, after which honey was provided until their death. A total of 213 adults (144 males + 69 females) was considered for the 12-hr group, 204 adults (116 males + 88 females) for the 1-day group, 184 adults (112 males + 72 females) for the 2-day group, and 162 adults (105 males + 57 females) for the 3-day group.

Fig. 5.7.1 presenting the comparative survival of the parasite in both the presence and absence of honey food source clearly shows that both male and female A.plutellae were able to live longer when there was access to honey. The vast difference observed points to the importance of food in the survival of A.plutellae. In general, where oviposition opportunity was not provided, the mean longevity of females were slightly greater than that of the males. However, the reverse was obtained when egg laying by the females occurred (Fig. 5.7.1), suggesting that oviposition activity must have probably demanded substantial energy and could shorten the lifespan.

Access to adult food in the form of honey has also been observed to affect both the ovipositional pattern and reproductive capacity of the parasite. When fed on diluted honey, females deposited a much higher mean number of eggs/day/female than those not given honey (Fig. 5.7.2). However, the mean number of eggs deposited declined gradually with female age, until its death. When the percentage eggs deposited per day was considered, it was initially much higher in adults not given honey. This was mainly because the females had shorter lifespan, hence reduced number of eggs deposited; and being so, the percentage daily egg production when considered over the reduced total would inevitably be increased.

Pertaining to oviposition period, this was noted to vary remarkably between individuals, being 1 day in the shortest and 16 days in the longest for the group given honey. In those not given food it varied from 1 day to 5 days. Generally, larger females oviposited a larger number of eggs daily and had longer oviposition period. Individually, the highest number of eggs deposited by a female ( $n = 39$ ) was 829 eggs, and the greatest number deposited in 1 day was 190 eggs. This was recorded from only the females given access to honey. For those ( $n = 40$ ) not

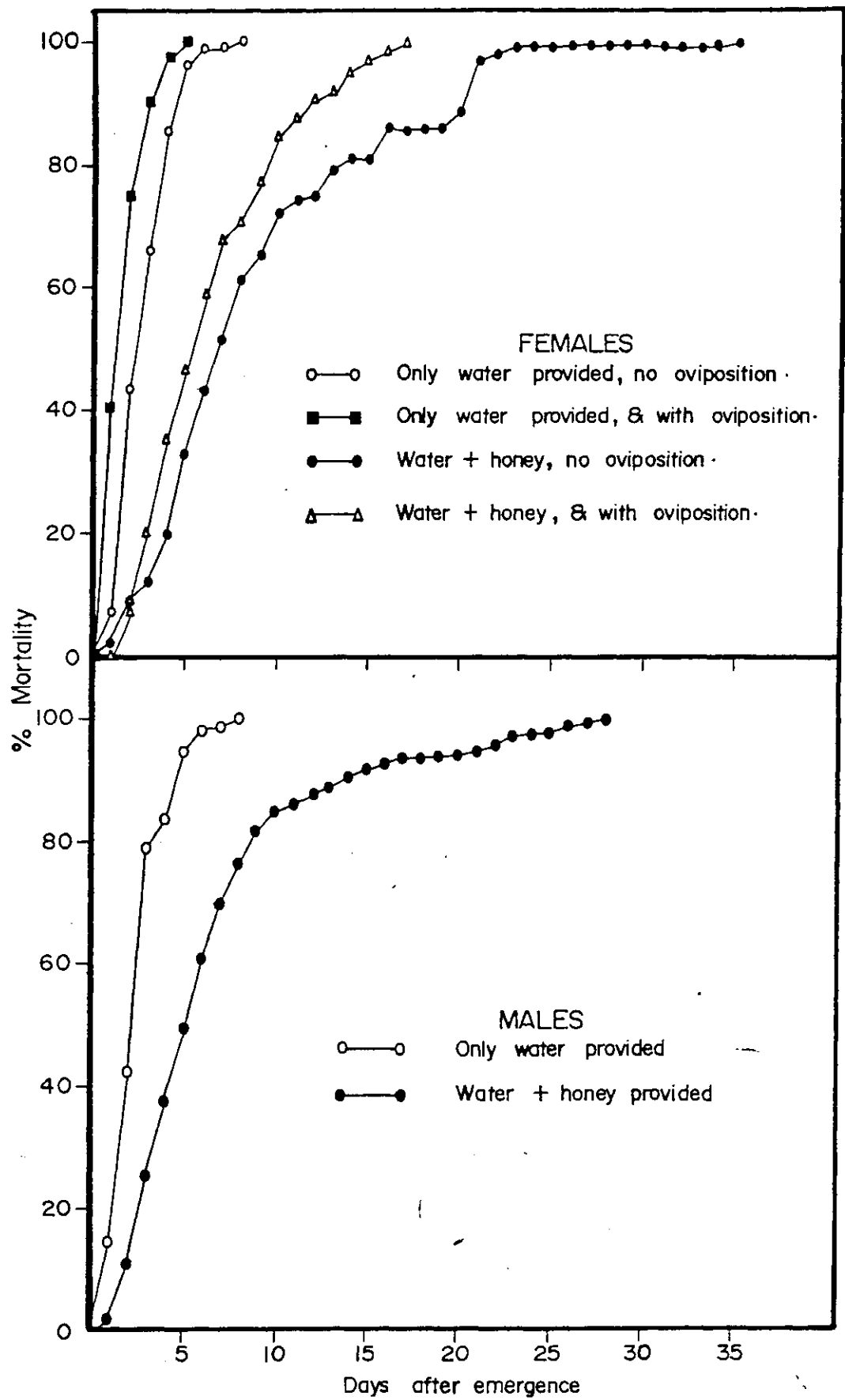


Figure 5-7-1 Longevity of *Apanteles plutellae* Kurdj. adults in relation to food (honey) and oviposition.

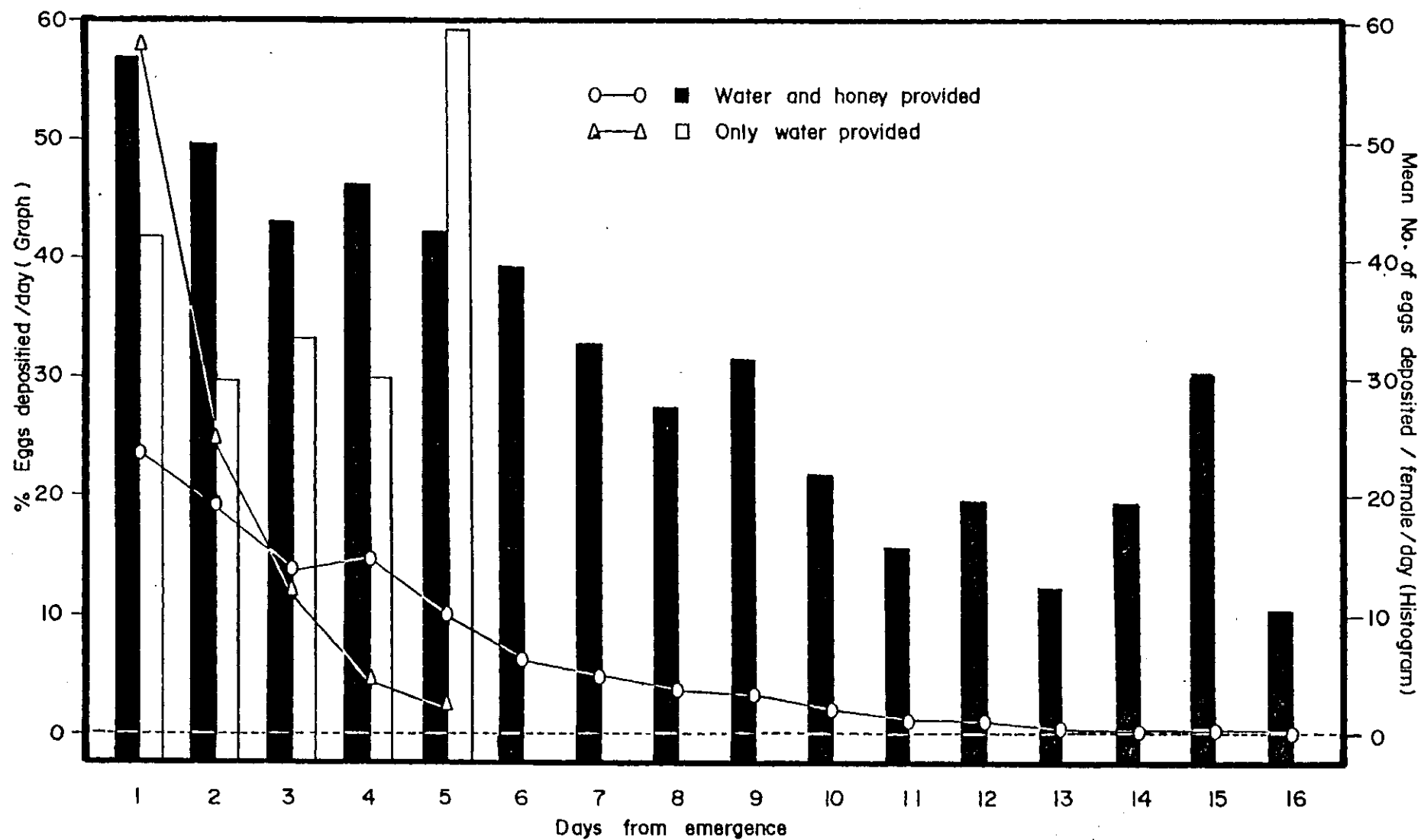


Figure 5.7.2 Ovipositional pattern in *Apanteles plutellae* Kurdj.

given food, the maximum number was 261 eggs, while 125 eggs was the highest number deposited per day. In general, the effect of honey on the overall egg production of the parasite is better demonstrated in Fig. 5.7.3 which shows the accumulated number of eggs laid per female plotted against time. This affords a direct comparison of the fecundity of the parasite under both the absence and availability of food in the form of honey. Under the latter situation about 494 eggs were deposited while only 193 eggs were obtained in the former. Largely, this is attributed to the vast difference in lifespans of females in the 2 groups since the total number of eggs deposited by A. plutellae was highly dependent on its longevity; more will be laid when the lifespan was increased. The relationship has a regression equation of  $y = 35.57x + 34.99$  when females had access to honey and  $y = 49.28x - 25.50$  when restrained from food (Fig. 5.7.4). Furthermore, since egg deposition was less erratic and less variable for females in the presence of honey, the food probably had some stabilizing effects, perhaps by way of reducing the time spent in searching for food. As with Orgillus obscurator Nees (Hym: Braconidae) (Syme, 1977), a starved A. plutellae is likely to spend more time searching for food than consistently searching and attacking more hosts.

When the relation between the number of matured eggs deposited and those remained in the ovaries of the dead female was examined, it was seen that the latter was usually very few (Fig. 5.7.5). Likewise, the number of developing eggs or oocytes was also found to be negligible. Such a condition was apparently maintained by the developing eggs being continuously transformed into matured eggs which were rapidly released through oviposition. This resulted in the percentage number of eggs deposited against the estimated total number of ovarian eggs ( $\equiv$  total number of eggs deposited plus those remained in the ovaries) to be more than 74.4% on average. Because egg-maturing process occurred continuously until eventual death of the female, more eggs could be expected for each additional day of survival. Moreover, exploitation of the potential number of available eggs would increase further since the percentage number of eggs deposited against the estimated ovarian eggs was observed to rise with female age; these being 34.1%, 59.1%, 78.5%, 86.5%, 93.7% and 94.7% in females living for 2, 3, 4, 5, 6 and 16 days respectively.

When the same features (i.e. both matured and developing eggs in the ovaries) were considered in females that were not allowed to oviposit, it was noted that the fully-developed eggs increased in number to about 125 eggs within the first 2 days of adult emergence (Fig. 5.7.6) for both starved females and those given honey. This was maintained for about 4 days in fed females, until after the 6th day when the number

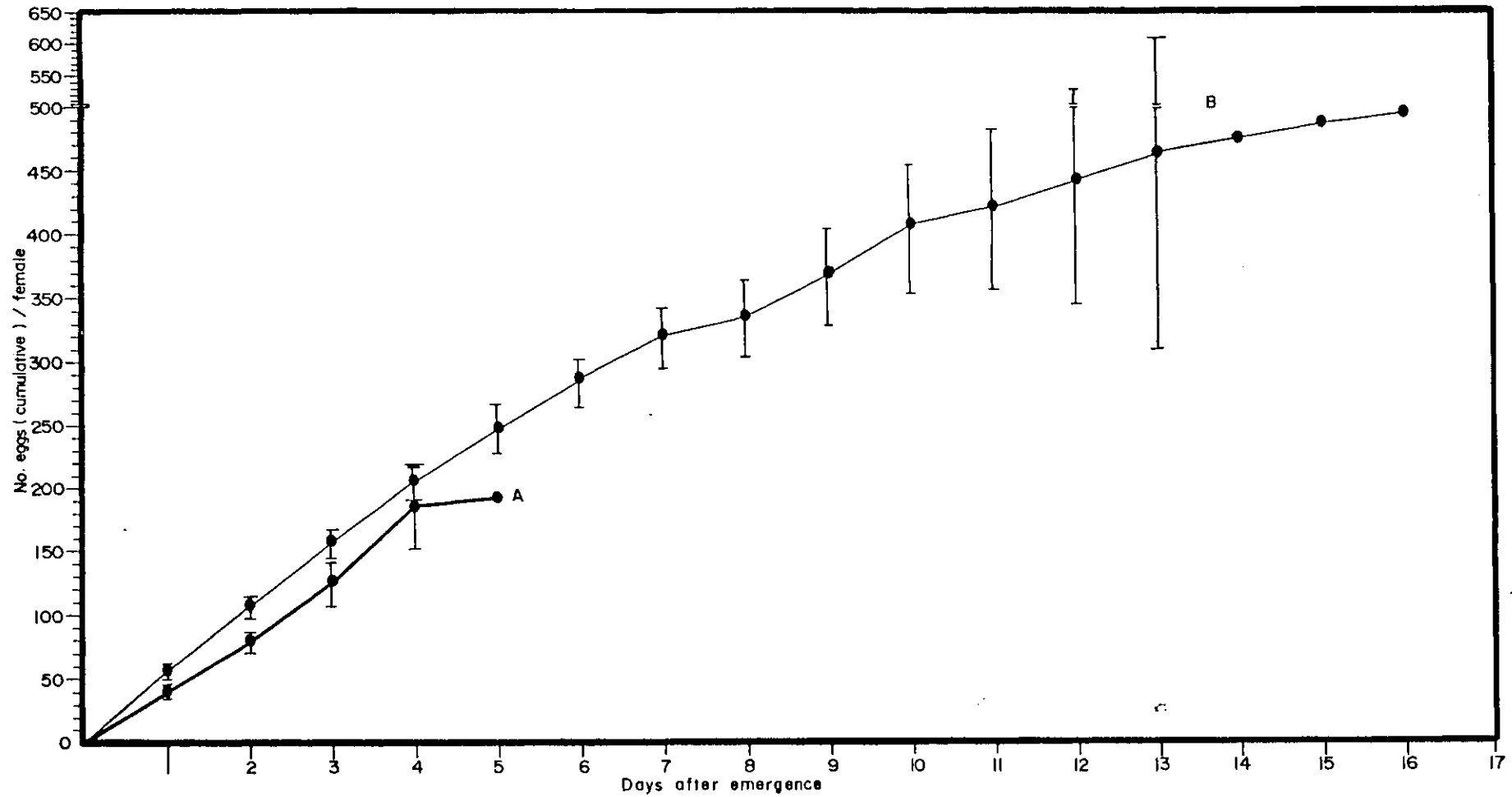


Figure 5-7-3 Mean number of eggs (cumulative total) laid by each female *Apanteles plutellae* Kurdj. when given water only (A) or also provided with honey as food (B).



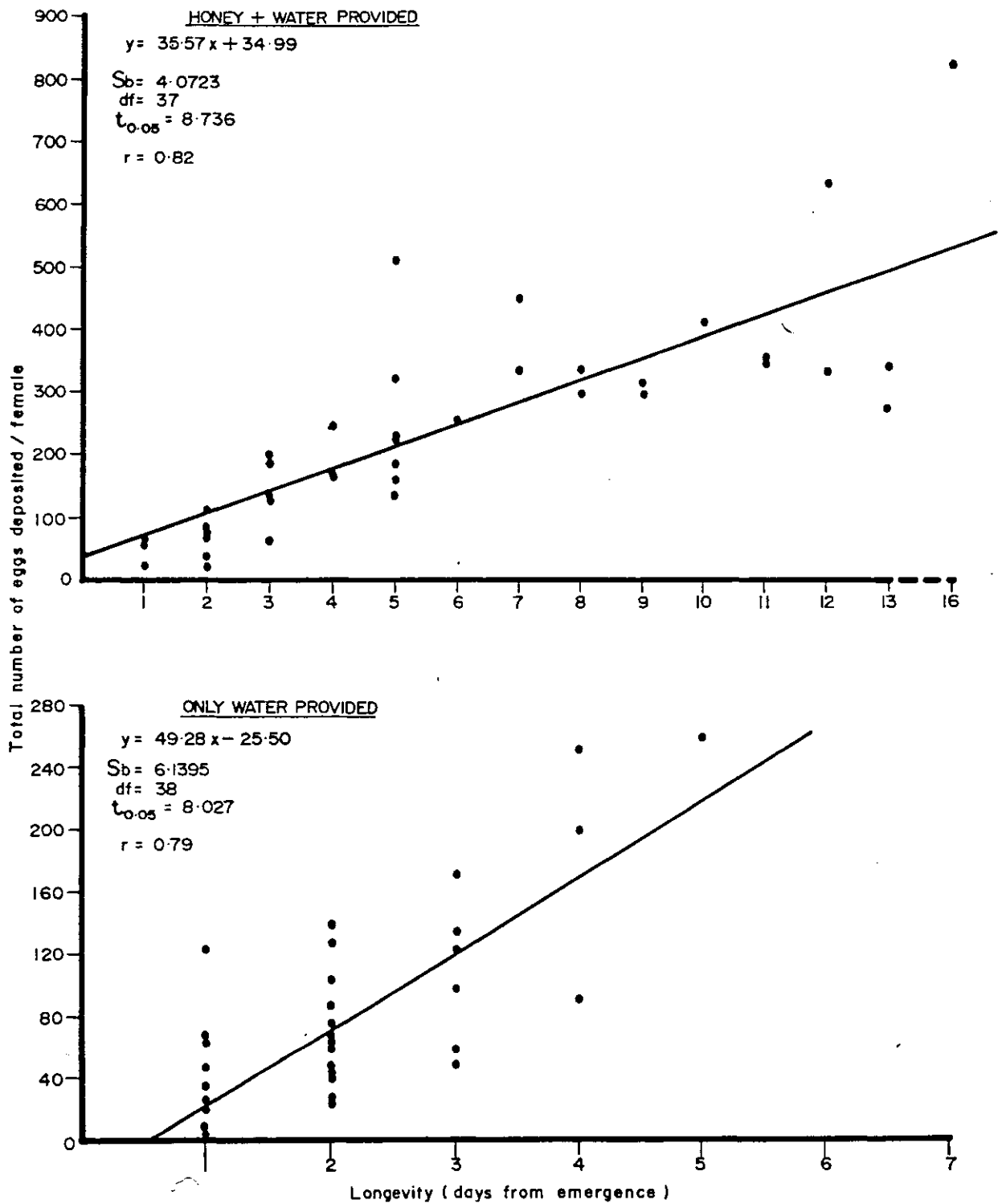


Figure 5.7.4 Regression between the longevity of *Apanteles plutellae* Kurdj. and the number of eggs laid by each female.

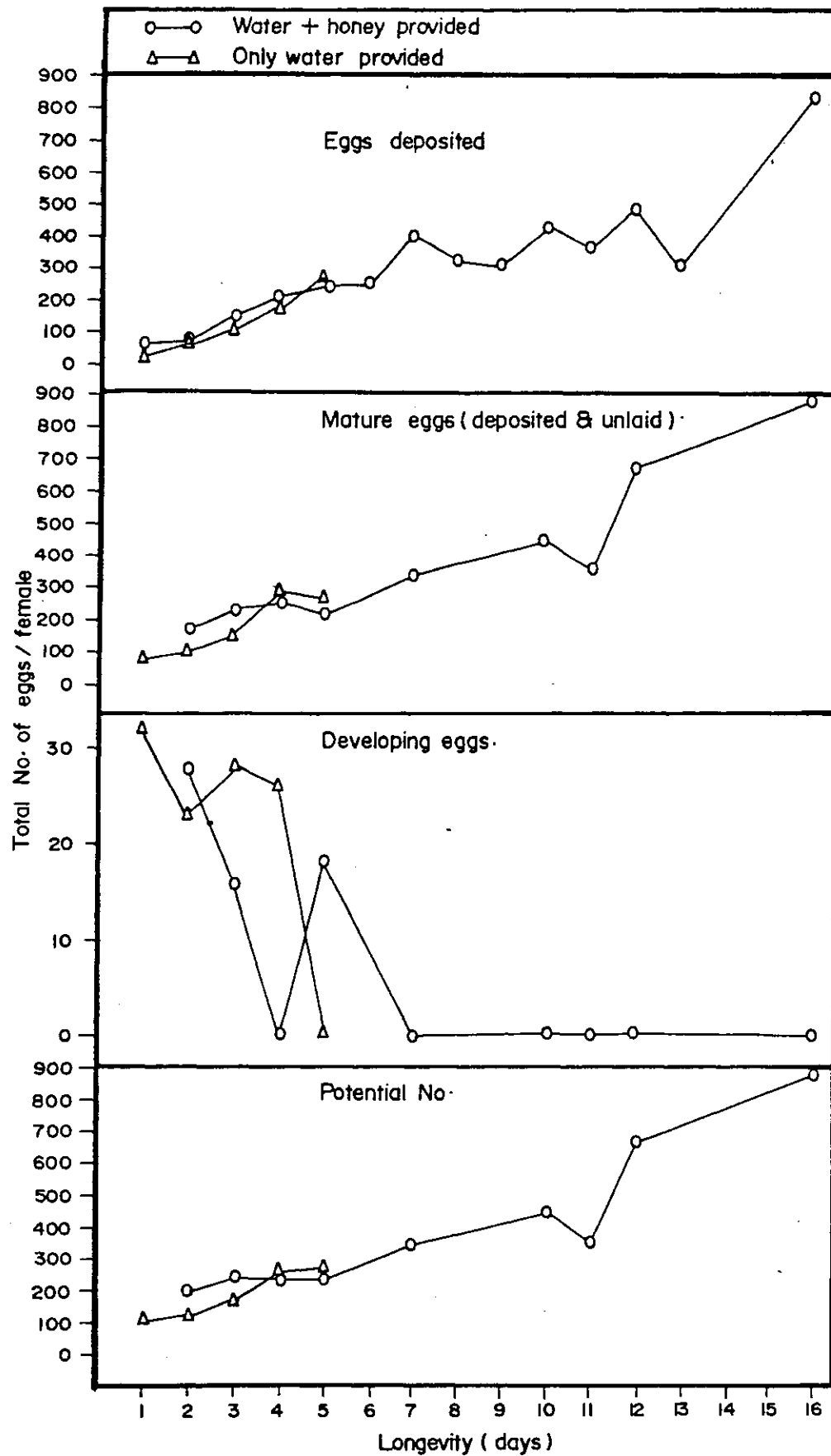


Figure 5-7-5 Egg production capacity in relation to longevity of *Apanteles plutellae* Kurdj.

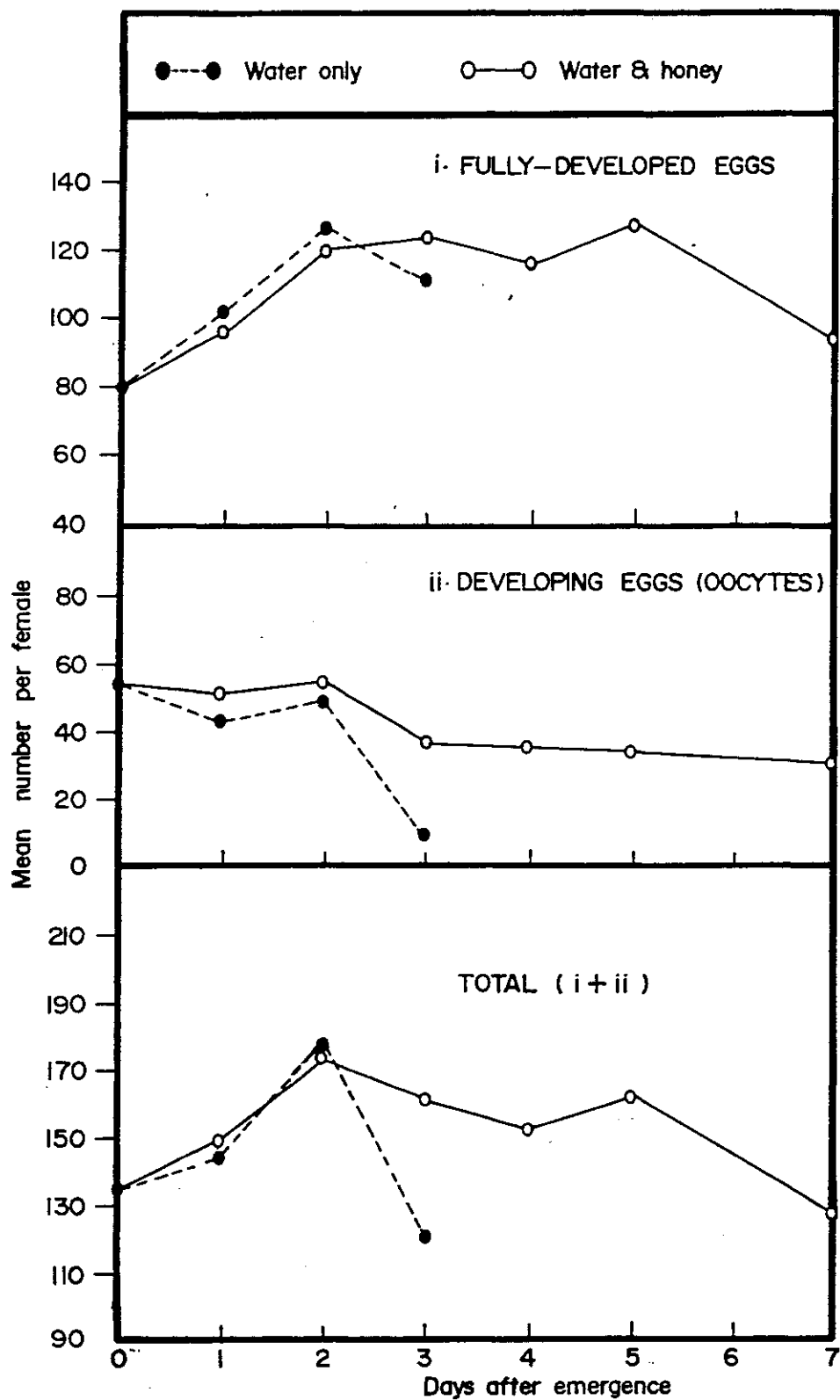


Figure 5-7-6 Comparative egg potential and egg development of *Apanteles plutellae* given water only or together with food (30% honey).

declined to about 90 eggs, suggesting that oosorption had probably set in. It was not known whether there would be further decline had examination been made beyond the 7th day of emergence. Developing eggs, on the other hand, never increased (Fig. 5.7.6). These remained relatively constant for 2 days and then declined, gradually in the fed females but rapidly in the unfeds. In the latter, the oocytes degenerated to near completion just prior to death of the females which occurred in about 3 days. This was apparently due to lack of nutrients. Where honey was provided, sufficient nutrients were available to sustain some developing eggs as well as in preventing total oosorption of mature eggs. It appeared that the number of matured eggs produced by the 2nd day was probably the limit number (about 125 eggs) that might be produced by nutrients preserved at the time of emergence. Even if additional nutrients were to become available as in the case of fed females, this limit number of eggs would still not increase further as was evident in the present studies (Fig. 5.7.6). Egg production could only be further increased when oviposition also occurred to make way for other developing eggs that were awaiting to mature, thereby raising the fecundity of the female (Fig. 5.7.2).

At the time of emergence, adult females have been observed to possess some mature eggs (Fig. 5.7.6) whose development began in the 2-day old pupae (Table 5.7.1). Since these were already fully-developed and oosorption was only partial (Fig. 5.7.6), it thus explains why females were able (Fig. 5.7.2) to deposit some eggs for a few days even if they cannot find suitable diet. Nevertheless, if food continues to be unavailable to beyond the 3rd day, adult females would in general die with only a relatively small portion of the overall potential eggs deposited. Whether adult longevity would regain or still remain adversely affected should food then become available after the initial starvation period has never been reported. Present studies clearly revealed that longevity could only be partially regained (Fig. 5.7.7). By inference, this would also enhance reproductive capacity since fecundity in A. pluteellae was shown to be closely related to longevity (Fig. 5.7.4). In general, regain in longevity was greater as the initial starvation period was reduced. Nevertheless, even starvation period of as short as 12 hrs can have adverse effect.

In all the above feeding studies, the partake of food was noted to have a clear association with female reproduction. That it was not entirely related to egg production alone was, however, evident from the effect it had in increasing longevity of the males (Figs. 5.7.1 & 5.7.7). Perhaps through a longer lifespan a greater aid is afforded to favour mating so as to ensure the maintenance of a more favourable sex ratio.

Table 5.7.1 Mean ( $\pm$  SE) number of fully-developed and developing eggs in the ovaries and reproductive system of the pupae of Apanteles plutellae Kurdj.

| Cocoon age (days)* | Fully-developed eggs |                    |                    | Developing eggs    |                    |                    | Overall total       |
|--------------------|----------------------|--------------------|--------------------|--------------------|--------------------|--------------------|---------------------|
|                    | Left ovary           | Right ovary        | Total              | Left ovary         | Right ovary        | Total              |                     |
| 1                  | 0                    | 0                  | 0                  | 12.8<br>$\pm 0.17$ | 13.7<br>$\pm 0.19$ | 26.5<br>$\pm 0.35$ | 26.5<br>$\pm 0.35$  |
| 2                  | 0.2<br>$\pm 0.06$    | 0.3<br>$\pm 0.08$  | 0.4<br>$\pm 0.13$  | 45.8<br>$\pm 0.11$ | 44.2<br>$\pm 0.98$ | 89.9<br>$\pm 0.19$ | 90.4<br>$\pm 0.19$  |
| 3                  | 27.9<br>$\pm 0.12$   | 28.9<br>$\pm 0.12$ | 56.8<br>$\pm 0.23$ | 38.0<br>$\pm 0.90$ | 38.9<br>$\pm 0.80$ | 76.9<br>$\pm 0.16$ | 133.7<br>$\pm 0.28$ |
| 4                  | 32.6<br>$\pm 0.23$   | 30.3<br>$\pm 0.19$ | 62.9<br>$\pm 0.42$ | 31.5<br>$\pm 0.92$ | 32.1<br>$\pm 0.91$ | 63.6<br>$\pm 0.17$ | 126.4<br>$\pm 0.39$ |

\*The developing parasite pupae contained within these cocoons were dissected for determination of the developing and fully-developed eggs.

#### 5.7.2 Effects of various flowers on the longevity of A. plutellae

Besides the effect of diluted honey, natural food sources were also investigated, in particular floral and extrafloral nectaries. Sixteen species of flowers were examined by enclosing 100 freshly-emerged adult A. plutellae (x10 replications with 5 parasite pairs/replicate) to each flower source in 'breeding jars' (Plate 2.1) under the laboratory conditions (see 2b). Each cut flower stalk was maintained erect in plugged glass vial containing water, and was changed daily. Water for the parasites was also provided through a wick. As control checks, only water was provided in 1 set while 17% honey plus water in another. All treatments were examined daily and record made of any dead parasite.

The results (Table 5.7.2) clearly show that parasites enclosed with most of the flowers lived significantly longer than those provided with water only. In a few, either one or both of the sexes were found to be unaffected. The findings suggest that most of the flowers tested contained some valuable food and could serve as natural food sources. However, when compared to the 'honey' treatment, all these were inferior. Even the best flower source (Malastoma malabathricum) was only about half as effective as the 'honey' treatment. This may be due to honey containing more of the essential nutrients or the physiology of the flowers adversely affected through detachment (see 5.7.6). Nevertheless, in the field their presence could still prove useful and desirable, at least as supplements

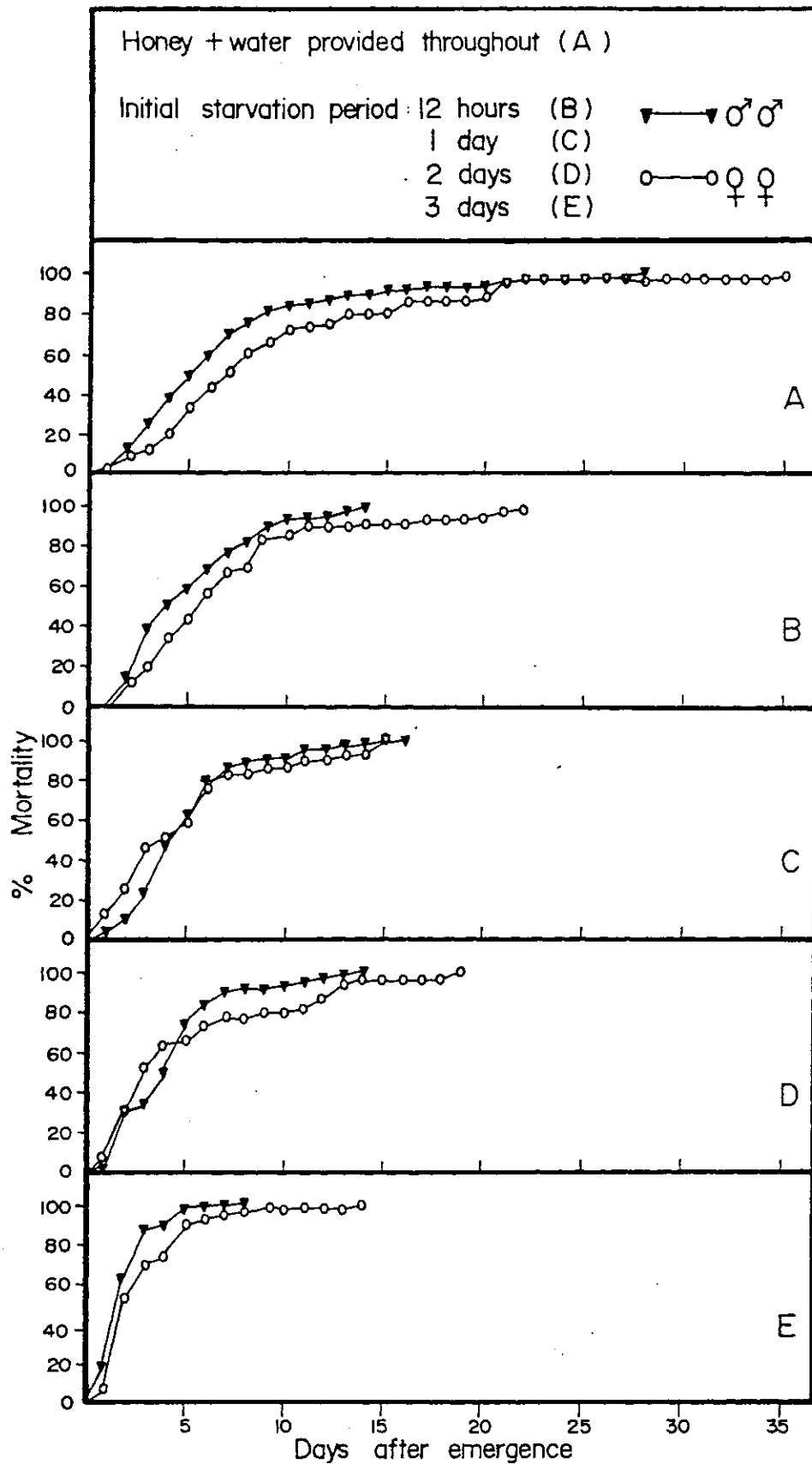


Figure 5.7.7 Longevity of male and female *Apanteles plutellae* Kurdj. adults in relation to varying initial starvation periods.

Table 5.7.2 Mean longevity ( $\pm$  SE) of newly-emerged adult *Apanteles plutellae* surj. exposed to various foods. Comparisons of paired means<sup>1,2/</sup> and their significance<sup>2/</sup> relate to that of individual flower source as measured against the "water" control on "honey" treatment.

| Food source          | Days      | n  | Significance <sup>2/</sup> when measured against: |                   |
|----------------------|-----------|----|---------------------------------------------------|-------------------|
|                      |           |    | "Water" control                                   | "Honey" treatment |
| <u>Malastoma</u>     |           |    |                                                   |                   |
| <u>malabathricum</u> |           |    |                                                   |                   |
| Male                 | 6.14+0.63 | 50 | **                                                | **                |
| Female               | 7.88+0.61 | 50 | **                                                | **                |
| <u>Crotalaria</u>    |           |    |                                                   |                   |
| <u>striata</u>       |           |    |                                                   |                   |
| Male                 | 4.04+0.51 | 50 | **                                                | **                |
| Female               | 6.08+0.60 | 50 | **                                                | **                |
| <u>Crotalaria</u>    |           |    |                                                   |                   |
| Male                 | 3.90+0.37 | 50 | **                                                | **                |
| Female               | 3.42+0.35 | 50 | **                                                | **                |
| <u>Cleome</u>        |           |    |                                                   |                   |
| <u>rutidosperma</u>  |           |    |                                                   |                   |
| Male                 | 4.52+0.72 | 50 | **                                                | **                |
| Female               | 4.58+0.57 | 50 | **                                                | **                |
| <u>Hibiscus</u>      |           |    |                                                   |                   |
| <u>rosa-sinensis</u> |           |    |                                                   |                   |
| Male                 | 3.02+0.24 | 50 | **                                                | **                |
| Female               | 3.22+0.22 | 50 | **                                                | **                |
| <u>Imperata</u>      |           |    |                                                   |                   |
| <u>cylindrica</u>    |           |    |                                                   |                   |
| Male                 | 1.60+0.09 | 50 | ns                                                | -                 |
| Female               | 2.00+0.10 | 50 | **                                                | -                 |
| <u>Passiflora</u>    |           |    |                                                   |                   |
| <u>foetida</u>       |           |    |                                                   |                   |
| Male                 | 1.86+0.14 | 50 | **                                                | **                |
| Female               | 1.76+0.13 | 50 | **                                                | **                |
| <u>Antigonon</u>     |           |    |                                                   |                   |
| <u>leptopus</u>      |           |    |                                                   |                   |
| Male                 | 1.44+0.11 | 50 | ns                                                | -                 |
| Female               | 1.70+0.11 | 50 | **                                                | -                 |
| <u>Wedelia</u> sp.   |           |    |                                                   |                   |
| Male                 | 1.26+0.08 | 50 | ns                                                | -                 |
| Female               | 1.58+0.10 | 50 | *                                                 | -                 |
| <u>Eupatorium</u>    |           |    |                                                   |                   |
| <u>oderatum</u>      |           |    |                                                   |                   |
| Male                 | 1.48+0.08 | 50 | ns                                                | -                 |
| Female               | 1.46+0.07 | 50 | ns                                                | -                 |
| <u>Citrus</u>        |           |    |                                                   |                   |
| <u>aurantifolia</u>  |           |    |                                                   |                   |
| Male                 | 1.20+0.06 | 50 | *                                                 | -                 |
| Female               | 1.36+0.07 | 50 | ns                                                | -                 |

Table 5.7.2 (continued)

| Food Source                              | Days       | n   | Significance when measured against: |                   |
|------------------------------------------|------------|-----|-------------------------------------|-------------------|
|                                          |            |     | "Water" control                     | "Honey treatment" |
| <u>Ageratum conyzoides</u>               |            |     |                                     |                   |
| Male                                     | 2.10±0.14  | 50  | **                                  | **                |
| Female                                   | 2.02±0.17  | 50  | **                                  | **                |
| <u>Acacia auriculi-</u><br><u>formis</u> |            |     |                                     |                   |
| Male                                     | 2.30±0.18  | 50  | **                                  | **                |
| Female                                   | 2.40±0.16  | 50  | **                                  | **                |
| <u>Mimosa pudica</u>                     |            |     |                                     |                   |
| Male                                     | 1.64±0.09  | 50  | *                                   | -                 |
| Female                                   | 1.28±0.07  | 50  | ns                                  | -                 |
| <u>Ipomea reptans</u>                    |            |     |                                     |                   |
| Male                                     | 1.80±0.13  | 50  | **                                  | **                |
| Female                                   | 2.14±0.23  | 50  | **                                  | **                |
| <u>Ipomea cairica</u>                    |            |     |                                     |                   |
| Male                                     | 1.86±0.18  | 50  | **                                  | **                |
| Female                                   | 2.18±0.23  | 50  | **                                  | **                |
| Honey (17%)                              |            |     |                                     |                   |
| Male                                     | 11.66±0.60 | 279 | **                                  | -                 |
| Female                                   | 12.66±0.62 | 166 | **                                  | -                 |
| Control (Water alone)                    |            |     |                                     |                   |
| Male                                     | 1.40±0.09  | 233 | -                                   | -                 |
| Female                                   | 1.32±0.07  | 83  | -                                   | -                 |

1/ Mean difference  $d = \frac{x_1 - x_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$  between individual flower source and

the "water" control, or "honey" treatment. The latter was made only for flowers showing significant difference from the "water" control in both the sexes.

- 2/ \* = significant at the 5% level, \*\* = significant at the 1% level, ns = not significant. Against the "water" control a one-tailed test was employed, while a two-tailed test was used when measured against "honey".



along with other non-flower sources such as insect honeydew and leaf exudates. Moreover, under natural conditions there is also much greater variety of choice, of which some may be substantially better.

#### 5.7.3 Effects of *C.striata* and *C.rutidosperma* on the fecundity of *A.plutellae*

Although most of the flowers could increase significantly the parasite's lifespan, for them to enhance the effectiveness of the parasite they must also be able to increase the parasite's ability to attack hosts. Tests are thus conducted to ascertain their effect on fecundity or ability to oviposit. For the study, flowers of two commonly-occurring plant species [*Crotalaria striata* L. (Plate 5.7.3) and *Cleome rutidosperma* D.C.] which had significant influence were used. The check treatments were again honey (30%) plus water, and water alone. For determination of the eggs deposited, 30 2nd-instar larvae of DBM were provided daily to each parasite for 24 hrs, and on removal, immediately dissected for counts of the parasite's eggs. This was continued until death of each female. For each treatment, 9-40 females were evaluated.

The comparative data in Table 5.7.3 revealed that of the 2 flowers studied only *C.striata* resulted in significantly higher production of eggs than the 'water' control. Although the total egg production was lower than that of the 'honey' treatment, the difference was not significant ( $P > 0.01$ ). It was, however, significantly different ( $t_{0.05} = 2.694$ ) from the flower *C.rutidosperma*, which, although able to increase the parasite's longevity (Table 5.7.2), still failed to produce any significant effect on its fecundity or ability to oviposit. Of the 2 flowering plants, evidently *C.striata* is more useful in the environment of the parasite.

#### 5.7.4 Comparative effects of the flowers, flower stalk's axil, and leaves of *C.striata* on the longevity of *A.plutellae*

The effects of various parts (flowers, flower stalk's axil and leaves) of *C.striata* on the longevity of the parasite were also evaluated and compared. In this study, 30-100 adult parasites (15-50 males + 15-50 females) were used for each treatment. A treatment involving the flower stalk's axil and the flowers together was also included. As in previous studies, the control checks consisted of honey (17%) + water, and water alone.

The results (Table 5.7.4) clearly show that except for the flower treatment, other treatments involving flower stalks, flower stalk + flowers, and the leaves were significantly ( $P < 0.01$ ) better than the treatment with water alone, be they for males or females. However, all

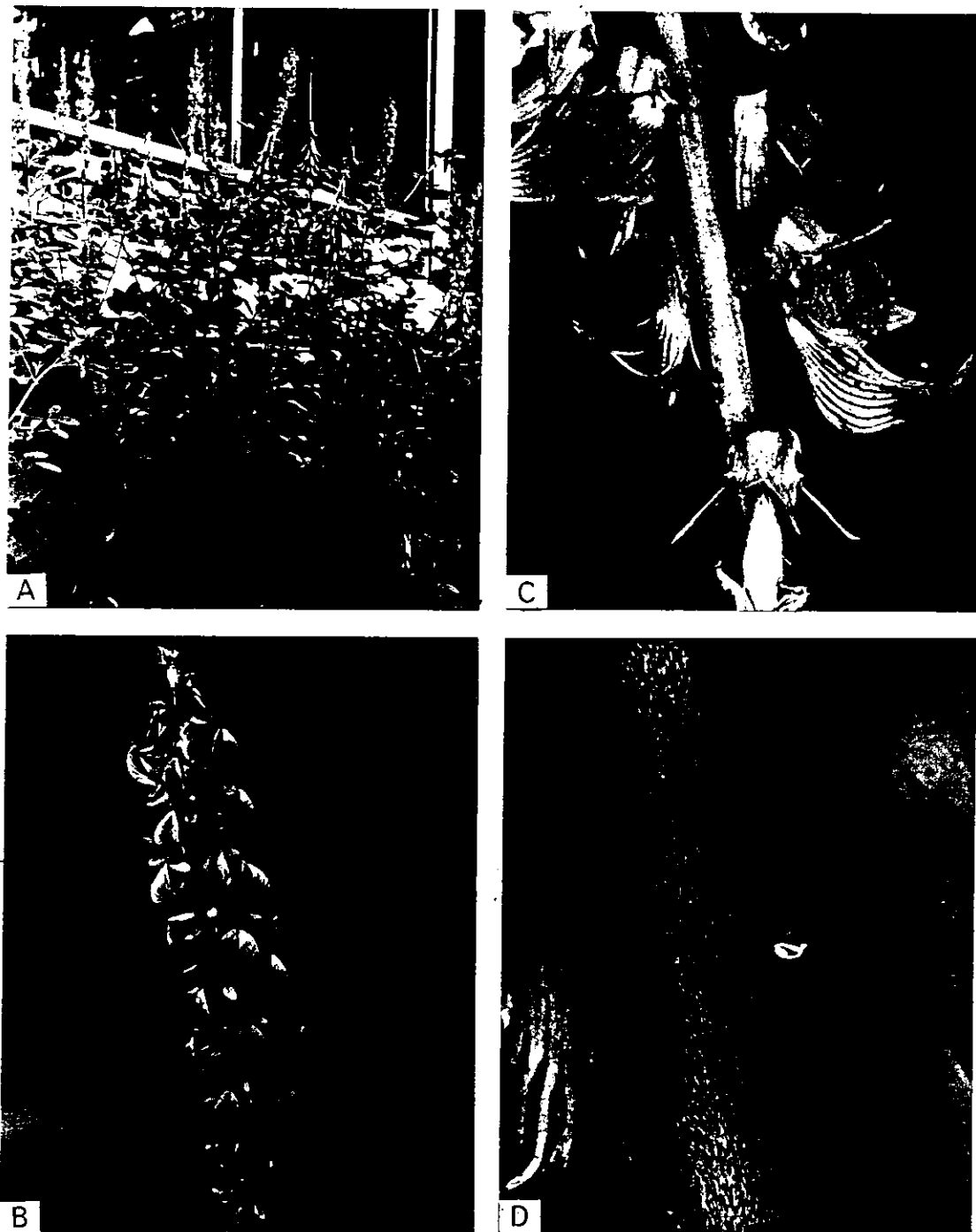


PLATE 5.7.3

Crotalaria striata L., a flowering plant evaluated as possible food source for the adults of Apanteles plutellae Kurdj. (A. Mature plants, B. Inflorescence, C. Buds and extrafloral secretions, D. Close-up of a secretion droplet from the axil of a flower stalk).

TABLE 5.7.3 Mean fecundity ( $\pm$  SE) of newly-emerged adult Apanteles plutellae Kurdj. exposed to various foods. Comparisons of paired means<sup>1,2/</sup> and their significance<sup>2/</sup> relate to that of individual flower source as measured against the "water" control or "honey" treatment.

| Food source                              | No. of eggs        | n  | Significance <sup>2/</sup> when measured against: |                   |
|------------------------------------------|--------------------|----|---------------------------------------------------|-------------------|
|                                          |                    |    | "water" control                                   | "Honey treatment" |
| <u>Crotalaria striata</u> <sup>3/</sup>  | 180.07 $\pm$ 23.30 | 15 | **                                                | ns                |
| <u>Cleome rutidosperma</u> <sup>3/</sup> | 86.89 $\pm$ 9.39   | 9  | ns                                                | -                 |
| Honey (17%)                              | 243.87 $\pm$ 27.54 | 39 | **                                                | -                 |
| Control(water alone)                     | 71.83 $\pm$ 10.31  | 40 | -                                                 | -                 |

1/ Mean difference  $d = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$  between individual flower source and

the "water" control, or "honey" treatment. The latter was made only for C. striata which showed significant difference from the "water" control.

2/ \*\* = significant at the 1% level, ns = not significant. Against the "water" control a one-tailed test was employed, while a two-tailed test was used when measured against "honey".

3/ According to the two-tailed test C. striata was significantly different ( $t_{0.05} = 2.694$ ) from C. rutidosperma.

the treatments were significantly less than that of honey, except the treatment involving females for flower stalk + flowers. Of the remaining treatments, that which contained the flower stalks were noted to be generally superior to either the treatment for the leaves or flowers alone, suggesting that secretions from flower stalks were quite important as a food source to A. plutellae. This was especially so for the females whose longevity was increased to almost that of honey treatment, particularly when flowers were also provided together. Evidently, all the parts when present together, would probably contribute significantly towards the survival of the parasite.

#### 5.7.5 Extrafloral nectar from flower stalk's axils as food of A. plutellae

Plant nectaries constitute an important food source to parasites (Doutt, 1964) and their abundance could have a favourable influence as was observed by Allen and Smith (1958) for the braconid Apanteles

TABLE 5.7.4 Mean longevity ( $\pm$  SE) of newly-emerged adult Apanteles plutellae Kurdj. exposed to honey (17%), water and various parts of Crotalaria striata L.

| Food source(treatment)                            | Longevity<br>(days) | Mean difference and significance <sup>1/</sup> |                   |                   |                   |                   |
|---------------------------------------------------|---------------------|------------------------------------------------|-------------------|-------------------|-------------------|-------------------|
| <u>MALES</u>                                      |                     |                                                |                   |                   |                   |                   |
| Treatments:                                       |                     | 5                                              | 2                 | 4                 | 3                 | 1                 |
| Honey 17% (5)                                     | 11.8                | -                                              | -                 | -                 | -                 | -                 |
| Flower stalk axils(2)                             | 6.3                 | 5.5**                                          | -                 | -                 | -                 | -                 |
| Flower stalk axils<br>+flowers <sup>2/</sup> (4)  | 6.2                 | 5.6**                                          | 0.1 <sup>ns</sup> | -                 | -                 | -                 |
| Flowers <sup>3/</sup> (3)                         | 3.6                 | 8.2**                                          | 2.7 <sup>ns</sup> | 2.6 <sup>ns</sup> | -                 | -                 |
| Leaves <sup>4/</sup> (1)                          | 3.1                 | 8.7**                                          | 3.2**             | 3.1**             | 0.5 <sup>ns</sup> | -                 |
| Water (6)                                         | 1.4                 | 10.4**                                         | 4.9**             | 4.8**             | 2.2 <sup>ns</sup> | 1.7*              |
| <u>FEMALES</u>                                    |                     |                                                |                   |                   |                   |                   |
| Treatments:                                       |                     | 5                                              | 4                 | 2                 | 1                 | 3                 |
| Honey 17% (5)                                     | 13.8                | -                                              | -                 | -                 | -                 | -                 |
| Flower stalk axils<br>+ flowers <sup>2/</sup> (4) | 11.9                | 1.9 <sup>ns</sup>                              | -                 | -                 | -                 | -                 |
| Flower stalk axils(2)                             | 5.6                 | 8.2**                                          | 6.3**             | -                 | -                 | -                 |
| Leaves <sup>4/</sup> (1)                          | 3.9                 | 9.9**                                          | 8.0**             | 1.7 <sup>ns</sup> | -                 | -                 |
| Flowers <sup>3/</sup> (3)                         | 3.3                 | 10.5**                                         | 8.6**             | 2.3 <sup>ns</sup> | 0.6 <sup>ns</sup> | -                 |
| Water (6)                                         | 1.6                 | 12.2**                                         | 10.3**            | 4.0**             | 2.3**             | 1.7 <sup>ns</sup> |

1/ ns = not significant, \* = significant at the 5% level, \*\* = significant at the 1% level.

2/ A total of 30 flowers were provided throughout.

3/ A total of 26 flowers were provided throughout.

4/ 3 leaves having a total of 9 leaflets were provided throughout.

medicaginis Mues. (Hym: Braconidae). Evaluation of different parts of C.striata has also indicated that extrafloral secretions produced by leaves and flower stalk's axil could increase longevity of A.plutellae (see 7.5.4). To confirm this, secretions of flower stalk's axil (Plate 5.7.3) were collected and further evaluated directly as feeds to the parasites. These secretions were selected as the droplets were generally larger and more easily collected. They were collected with micropipette and then diluted with water into concentrations of strength 50% and 10%. Together with undiluted nectaries, these were evaluated against undiluted honey and honey diluted to 17%. Also included was a control treatment with water alone. The test foods were provided through 'feeding wicks' in glass vials to the parasites. As with the 'water control', a 'water' wick was also included. Test parasites consisted of both newly-emerged males and females. These were evaluated in groups of 10 per treatment (5 pairs) and replicated 8 times.

The study shows conclusively that the secretion was responsible for the increased longevity when parasites were enclosed with the flower stalk's axil in the earlier study. Among the 3 concentrations evaluated, that of 50% dilution had the maximum effect in both the sexes (Table 5.7.5). In the males, this was almost comparable to 'honey' treatment. However, for females the 'honey' treatments were significantly ( $P < 0.01$ ) superior. In either case, the 'water' controls were immensely less, suggesting that when detached portions were utilized the smaller differences observed (see 5.7.6) had been largely due to the lack of cyclic replenishment of the nectar.

#### 5.7.6 Comparative effects of detached and intact leaves of C.striata on the longevity of A.plutellae

One factor not accounted for in previous experiments described here was that some flower species have a daily cycle of nectar production (Park, 1930). If this was true for any of the species tested, the immediate history of visitation to the flower by insects, relative to its nectar-production cycle, would be critical. This is especially so with respect to the time of picking when the investigations were made. Wykes (1950, 1951) has shown that either ringing could stop translocation, or nectar secretion reduced by defoliation of the shoot. With combination of these treatments, nectar production could stop entirely. This may also occur when flowers of some plants are picked. However, when the picked flowers were kept standing in 15-20% sugar solution, nectar secretions were maintained proportionately (Wykes, 1950, 1951) while longevity and fecundity of parasitic test species [e.g. Hyssopus thymus Girault (Hym: Eulophidae)] increased significantly (Syme, 1975). In determining whether nectar avail-

TABLE 5.7.5 Mean longevity ( $\pm$  SE) of newly emerged adult Apanteles plutellae Kurdj. provided with various concentrations of honey and flower axil secretions of Crotalaria striata as foods. (No. insects evaluated per treatment per sex = 40).

| Food source                       | Days             | Significance*<br>(F = 0.01) |
|-----------------------------------|------------------|-----------------------------|
| FEMALE                            |                  |                             |
| Flower axil secretion (undiluted) | 5.78 $\pm$ 0.53  | c                           |
| Flower axil secretion (50%)       | 8.23 $\pm$ 0.69  | b                           |
| Flower axil secretion (10%)       | 5.48 $\pm$ 0.55  | c                           |
| Honey (undiluted)                 | 12.68 $\pm$ 1.31 | a                           |
| Honey (17%)                       | 11.08 $\pm$ 1.20 | a                           |
| Control (water alone)             | 2.0 $\pm$ 0.11   | d                           |
| MALE                              |                  |                             |
| Flower axil secretion (undiluted) | 5.65 $\pm$ 0.52  | c d                         |
| Flower axil secretion (50%)       | 7.35 $\pm$ 0.68  | b c                         |
| Flower axil secretion (10%)       | 4.28 $\pm$ 0.46  | d                           |
| Honey (undiluted)                 | 8.90 $\pm$ 0.98  | a b                         |
| Honey (17%)                       | 9.85 $\pm$ 1.30  | a                           |
| Control (water alone)             | 1.95 $\pm$ 0.12  | e                           |

\*Means having the same alphabets against them are not significantly different according to the New Duncan's Multiple Range Test (Snedecor & Cochran, 1967).

ability in C.striata could be adversely affected due to separation of plant parts, a study was made to compare the effects of detached and intact leaves of the plant. Leaves were selected as they were not only readily available but had also earlier been found to produce extrafloral secretions suitable as insect food (see 5.7.4). In the study, the longevity of 50 parasite pairs was considered per treatment. To each replicate of 5 pairs, 8 leaves (detached or intact, and possessing ca 24 leaflets) were provided along with a 'water wick'. Again, honey (17%) + water or water alone acted as the controls.

From Table 5.7.6, it is evident that longevity of A.plutellae enclosed on both intact and detached leaves was significantly ( $P < 0.01$ ) higher than that of 'water' control but less than the 'honey' treatment. Between both intact and detached leaves, the former was significantly

TABLE 5.7.6 Mean longevity ( $\pm$  SE) of newly-emerged adult Apanteles plutellae Kurdj. when provided with foods in the form of honey (17%) and leaves (intact and detached) of Crotalaria striata L. Comparisons of paired means<sup>1,2/</sup> and their significance<sup>2/</sup> relate to that of individual food source as measured against the "water" control or "honey" treatment.

| Food source                                           | Days                    | n  | Significance <sup>2/</sup> when measured against: |                   |
|-------------------------------------------------------|-------------------------|----|---------------------------------------------------|-------------------|
|                                                       |                         |    | "Water" control                                   | "Honey" treatment |
| Detached leaves <sup>3/</sup><br>of <u>C. striata</u> |                         |    |                                                   |                   |
| Male                                                  | 2.52 <sub>±</sub> 0.19  | 50 | **                                                | **                |
| Female                                                | 3.02 <sub>±</sub> 0.22  | 50 | **                                                | **                |
| Intact leaves <sup>3/</sup><br>of <u>C. striata</u>   |                         |    |                                                   |                   |
| Male                                                  | 4.72 <sub>±</sub> 0.44  | 50 | **                                                | **                |
| Female                                                | 5.32 <sub>±</sub> 0.45  | 50 | **                                                | **                |
| Honey (17%)                                           |                         |    |                                                   |                   |
| Male                                                  | 10.48 <sub>±</sub> 0.79 | 50 | **                                                | -                 |
| Female                                                | 12.30 <sub>±</sub> 0.79 | 50 | **                                                | -                 |
| Control (water alone)                                 |                         |    |                                                   |                   |
| Male                                                  | 1.58 <sub>±</sub> 0.08  | 50 | -                                                 | -                 |
| Female                                                | 1.82 <sub>±</sub> 0.10  | 50 | -                                                 | -                 |

1/ Mean difference  $d = \bar{X}_1 - \bar{X}_2$  between individual food source and the

$$\sqrt{\frac{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}{1 + \frac{1}{n_1} + \frac{1}{n_2}}}$$

"water" control, or "honey" treatment.

2/ \*\* significant at the 1% level. Against the "water" control a one-tailed test was employed, while a two-tailed test was used when measured against "honey".

3/ According to the two-tailed test the intact leaves were significantly greater ( $P < 0.01$ ) than the detached leaves;  $d$  (females) = 4.586 and  $d$  (males) = 4.541.

( $P < 0.01$ ) higher, suggesting that production of extrafloral secretions in detached leaves was probably more rapidly depleted. With intact leaves a higher level appeared to be maintained, probably through further production in the daily cycle.

#### 5.7.7 Survey of insects visiting C. striata

Since C. striata produces nectar that could enhance longevity

(see 5.7.2) and fecundity (see 5.7.3) of A. plutellae under laboratory conditions, an investigation was conducted to determine if the plant would also attract the parasite and serve as a food source under natural situation. This was studied in Serdang where potted and naturally grown bushes of C. striata were periodically observed for visiting insects. Prior to their collection for taxonomic identification, any insect noted would first be closely watched on their behaviour, particular the feeding activity. Such a study was initiated in 1979 and continued through to September, 1980.

From Table 5.7.7, it is noted that many arthropod species periodically visited C. striata; the most common among these were Diptera and Hymenoptera. Included in the latter was also A. plutellae. This species, like many others, moved actively over the plant to feed on the flower nectar as well as extrafloral secretions, in particular from flower axils. The large number of insects observed feeding on the plant strongly suggested that C. striata is probably a good food source. Evidently, with supporting evidence obtained from previous studies (see 5.7.2 - 5.7.6), it is now clear that C. striata would play an important role in the conservation of A. plutellae.

## 5.8 ALTERNATIVE HOSTS OF A. PLUTELLAE

Although development of insecticide-resistant population has been suspected to be a contributory factor towards the abundance of A. plutellae in the Cameron Highlands, contributions through reservoirs of alternative hosts could not be totally discounted. To determine this, a series of investigations was conducted, covering a number of aspects.

### 5.8.1 Oviposition by A. plutellae on some common Lepidoptera

In an attempt to identify alternative hosts of A. plutellae locally, several lepidopteran species commonly found associated with DBM on cabbages were evaluated for possible oviposition by the parasite. These included Agrotis ypsilon Rott. (Lep: Noctuidae), Crocidolomia binotalis Zell. (Lep: Pyralidae), Hellula undalis F. (Lep: Pyralidae), Spodoptera pecten F. (Lep: Noctuidae) and S. litura F. (Lep: Noctuidae). The silkworm Bombyx mori L. (Lep: Bombycidae) was also tested for possible utilization as a mass-rearing medium, while DBM included for comparison.

In the study, early-stage larvae (1st or/and 2nd instar) were exposed in groups within 'oviposition jars' (Plate 2.1) to equal numbers of male and female parasites for period of either 24 hrs or 48 hrs as shown in Table 5.8.1. Immediately following exposure, the larvae were dissected for egg counts.



TABLE 5.7.7 Arthropod species observed visiting the flowering plant, Crotalaria striata L. at Serdang, Malaysia (1979-80).

| Visiting insect                                      |                |                 |             | Plant part collected from | Remarks                                               |
|------------------------------------------------------|----------------|-----------------|-------------|---------------------------|-------------------------------------------------------|
| Name                                                 | Collection No. | Collection Date | File No.    |                           |                                                       |
| HYMENOPTERA                                          |                |                 |             |                           |                                                       |
| <u>Eurytoma</u> sp.(Eurytomidae)                     | M 2284         | 22.11.79        | CP.74/01/22 | Pod                       | Possibly parasitising <u>Araecerus fasciculatus</u> . |
| <u>Macrocentrus</u> sp.(Braconidae)                  | M 2299         | 17.12.79        | CP.74/01/29 | Pod                       |                                                       |
| <u>Bracon</u> sp. (Braconidae)                       | M 2300         | 17.12.79        | CP.74/01/29 | Pod                       |                                                       |
| <u>Eurytoma</u> sp.(Eurytomidae)                     | M 2301         | 17.12.79        | CP.74/01/29 | Pod                       | Possibly parasitising <u>A. fasciculatus</u> .        |
| <u>Bracon greeni</u> Ashmead (Braconidae)            | M 2345         | 15.1.80         | CP.74/01/26 | Pod                       |                                                       |
| <u>Leptobatopsis indica</u> Cameron (Ichneumonidae)  | M 2480         | 27.2.80         | CP.74/01/26 | Leaf                      |                                                       |
| <u>Camponotus</u> sp.(Formicidae)                    | M 2484         | 28.2.80         | CP.74/01/26 | Leaf                      |                                                       |
| <u>Disophrys?albopilosellus</u> Cameron (Braconidae) | M 2489         | 28.2.80         | CP.74/01/26 | Leaf                      |                                                       |
| <u>Scelio</u> sp.(Scelionidae)                       | M 2491         | 28.2.80         | CP.74/01/26 | Leaf                      |                                                       |
| <u>Camponotus</u> sp.(Formicidae)                    | M 2501         | 15.5.80         | CP.74/01/26 | Leaf                      |                                                       |
| <u>Pison</u> sp. (Sphecidae)                         | M 2538         | 20.5.80         | CP.74/01/26 | Leaf                      | Observed to feed on exudate.                          |
| <u>Pison</u> sp. (Sphecide)                          | M 2550         | 22.5.80         | CP.74/01/26 | Flower                    |                                                       |
| <u>Pithitis</u> sp. (Xylocopidae)                    | M 2551         | 22.5.80         | CP.74/01/26 | Flower                    |                                                       |
| <u>Odynerus</u> sp.(Eumenidae)                       | M 2552         | 22.5.80         | CP.74/01/26 | Flower                    |                                                       |
| <u>Pison</u> sp. (Sphecidae)                         | M 2553         | 22.5.80         | CP.74/01/26 | Leaf                      |                                                       |
| <u>Chelonus</u> sp.(Braconidae)                      | M 2554         | 21.5.80         | CP.74/01/26 | Leaf                      | Observed to feed on exudate.                          |
| <u>Apanteles plutellae</u> (Braconidae)              | -              | 15.1.80         | -           | Leaf                      | Observed to feed on exudate.                          |
|                                                      | -              | 16.1.80         | -           | Leaf                      | Observed to feed on exudate.                          |
|                                                      | -              | 25.1.80         | -           | Leaf                      | Observed to feed on exudate.                          |

TABLE 5.7.7 (continued 1).

| Visiting insect                                            |                   |                    |             | Plant part<br>collected from | Remarks                      |
|------------------------------------------------------------|-------------------|--------------------|-------------|------------------------------|------------------------------|
| Name                                                       | Collection<br>No. | Collection<br>Date | File No.    |                              |                              |
| COLEOPTERA                                                 |                   |                    |             |                              |                              |
| <u>Araecerus fasciculatus</u> (Degeer)<br>(Anthribidae)    | M 2283            | 22.11.79           | CP.74/01/22 | Pod                          |                              |
| <u>Colposcelis signata</u> (Mots.)<br>(Eumolpinae)         | M 2477            | 27.2.80            | CP.74/01/26 | Leaf                         |                              |
| <u>Oenopia luteopustulata</u> Muls.<br>(Coccinellidae)     | M 2478            | 27.2.80            | CP.74/01/26 | Leaf                         |                              |
| <u>Longitarsus birmanicus</u> Jacoby<br>(Halticinae)       | M 2482            | 27.2.80            | CP.74/01/26 | Leaf                         |                              |
| DICTYOPTERA                                                |                   |                    |             |                              |                              |
| <u>Megamareta</u> sp.(Blattellidae)                        | M 2496            | 8.5.80             | CP.74/01/26 | Leaf                         |                              |
| LEPIDOPTERA                                                |                   |                    |             |                              |                              |
| <u>Etiella behri</u> Zell.(Pyralidae)                      | M 2279            | 19.11.79           | CP.74/01/22 | Pod                          |                              |
| DIPTERA                                                    |                   |                    |             |                              |                              |
| <u>Rivellia?basilaris</u> (Wiedemann)<br>(Platystomatidae) | M 2479            | 27.2.80            | CP.74/01/26 | Leaf                         |                              |
| <u>Dacus dorsalis</u> Hendel(Tephri-<br>tidae)             | M 2488            | 28.2.80            | CP.74/01/26 | Leaf                         |                              |
| <u>Eumerus</u> sp. (Syrphidae)                             | M 2534            | 20.5.80            | CP.74/01/26 | Leaf                         | Observed to feed on exudate, |
| <u>Cosmina bicolor</u> Walker<br>(Calliphoridae)           | M 2535            | 20.5.80            | CP.74/01/26 | Leaf                         | Observed to feed on exudate, |
| <u>Chysomya megacephala</u> Fabricius<br>(Calliphoridae)   | M 2536            | 20.5.80            | CP.74/01/26 | Leaf                         | Observed to feed on exudate, |
| <u>Paragus crenulatus</u> Thomson<br>(Syrphidae)           | M 2544            | 21.5.80            | CP.74/01/26 | Leaf                         | Observed to feed on exudate, |
| <u>Cosmina bicolor</u> Walker<br>(Calliphoridae)           | M 2545            | 20.5.80            | CP.74/01/26 | Leaf                         | Observed to feed on exudate, |

TABLE 5.7.7 (continued 2).

| Visiting insect                            |                   |                    |             | Plant part<br>collected from | Remarks                                                         |
|--------------------------------------------|-------------------|--------------------|-------------|------------------------------|-----------------------------------------------------------------|
| Name                                       | Collection<br>No. | Collection<br>Date | File No.    |                              |                                                                 |
| HEMIPTERA                                  |                   |                    |             |                              |                                                                 |
| <u>Aphis craccivora</u> Koch(Aphididae)    | M 2289            | 5.12.79            | CP.74/01/22 | Leaf                         |                                                                 |
| <u>Bemisia tabaci</u> (Genn.)(Aleyrodidae) | M 2556            | 8.5.80             | CP.74/01/26 | Leaf                         |                                                                 |
| THYSANOPTERA                               |                   |                    |             |                              |                                                                 |
| Thrip                                      | M 2933            | 20.9.80            | CP.74/01/26 | Flower                       |                                                                 |
| UNIDENTIFIED SPECIES                       |                   |                    |             |                              |                                                                 |
| ?                                          | M 2481            | 27.2.80            | CP.74/01/26 | Leaf                         |                                                                 |
| ?                                          | M2533             | 20.5.80            | CP.74/01/26 | Flower                       | Observed feeding on flower axil<br>secretion and flower nectar, |
| ?                                          | M 2539            | 21.5.80            | CP.74/01/26 | Leaf                         |                                                                 |
| ?                                          | M 2540            | 21.5.80            | CP.74/01/26 | Leaf                         |                                                                 |
| ?                                          | M 2541            | 21.5.80            | CP.74/01/26 | Leaf                         |                                                                 |
| ?                                          | M 2542            | 21.5.80            | CP.74/01/26 | Leaf                         |                                                                 |
| ?                                          | M 2546            | 21.5.80            | CP.74/01/26 | Leaf                         | Observed feeding on exudate.                                    |
| ?                                          | M 2549            | 22.5.80            | CP.74/01/26 | Flower                       |                                                                 |
| Braconidae                                 | M 2791            | 19.8.80            | CP.74/01/26 | Leaf                         | Observed feeding on exudate.                                    |
| Hymenoptera                                | M 2905            | 10.9.80            | CP.74/01/26 | Leaf                         | Observed feeding on exudate.                                    |
| Hymenoptera                                | M 2906            | 13.9.80            | CP.74/01/26 | Leaf                         | Observed feeding on exudate.                                    |
| Aranea (Oxyopidae)                         | M 2543            | 21.5.80            | CP.74/01/26 | Leaf                         |                                                                 |

TABLE 5.8.1. Ovipositional pattern and number of eggs deposited by Apanteles plutellae Kurdj. on the larvae of different lepidopteran test species.

| Test species exposed                            |              |     |                   | No. of para-<br>sites used |        | No. of test larvae containing the following number<br>of parasite eggs* |    |    |   |   |   |   |   |   |   |    |    |    |    |    |    |                    |      |      | Parasi-<br>tised |                          | Eggs deposited         |  |  |
|-------------------------------------------------|--------------|-----|-------------------|----------------------------|--------|-------------------------------------------------------------------------|----|----|---|---|---|---|---|---|---|----|----|----|----|----|----|--------------------|------|------|------------------|--------------------------|------------------------|--|--|
| Name                                            | Ins-<br>tar  | No. | Period<br>(Hours) | Male:                      | Female | 0                                                                       | 1  | 2  | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | More<br>than<br>15 | No.  | %    | To-<br>tal       | Mean No.<br>Per-<br>host | Per Female<br>Parasite |  |  |
| 1. <u>Agrotis ypsilon</u>                       | 2nd          | 50  | 48                | 10 :                       | 10     | 43                                                                      | 0  | 1  | 2 | 2 | 0 | 1 | 0 | 0 | 0 | 0  | 1  | 0  | 0  | 0  |    | 7                  | 14.0 | 33   | 0.7              | 3.3                      |                        |  |  |
| 2. <u>Bombyx mori</u>                           | 1st          | 63  | 24                | 9 :                        | 9      | 49                                                                      | 5  | 3  | 3 | 2 | 1 |   |   |   |   |    |    |    |    |    |    | 14                 | 22.2 | 33   | 0.5              | 3.7                      |                        |  |  |
| 3. <u>Crocido-<br/>lomia<br/>binota<br/>lis</u> | 1st          | 56  | 24                | 8 :                        | 8      | 35                                                                      | 9  | 4  | 1 | 1 | 3 | 2 | 0 | 0 | 0 | 1  |    |    |    |    |    | 21                 | 37.5 | 61   | 1.1              | 7.6                      |                        |  |  |
|                                                 | 1st &<br>2nd | 10  | 48                | 2 :                        | 2      | 4                                                                       | 3  | 0  | 2 | 1 |   |   |   |   |   |    |    |    |    |    |    | 6                  | 60.0 | 13   | 1.3              | 6.5                      |                        |  |  |
| 4. <u>Hellula undalis</u>                       | 1st &<br>2nd | 19  | 48                | 8 :                        | 8      | 10                                                                      | 2  | 2  | 1 | 2 | 1 | 1 |   |   |   |    |    |    |    |    |    | 9                  | 47.4 | 28   | 1.5              | 3.5                      |                        |  |  |
|                                                 | 1st &<br>2nd | 10  | 48                | 4 :                        | 4      | 1                                                                       | 4  | 2  | 2 | 0 | 0 | 0 | 0 | 1 |   |    |    |    |    |    |    | 9                  | 90.0 | 22   | 2.2              | 5.5                      |                        |  |  |
| 5. <u>Plutella xylostella</u>                   | 1st          | 70  | 24                | 10 :                       | 10     | 12                                                                      | 21 | 17 | 7 | 2 | 3 | 2 | 0 | 2 | 0 | 1  | 0  | 1  | 0  | 1  | 0  | 1(24)              | 58   | 82.9 | 187              | 2.7                      | 18.7                   |  |  |
| 6. <u>Spodop-<br/>tera<br/>litura</u>           | 1st &<br>2nd | 41  | 48                | 8 :                        | 8      | 25                                                                      | 7  | 6  | 2 | 1 |   |   |   |   |   |    |    |    |    |    |    | 16                 | 39.0 | 39   | 1.0              | 4.9                      |                        |  |  |
| 7. <u>Spodop-<br/>tera<br/>pecten</u>           | 1st          | 35  | 24                | 5 :                        | 5      | 19                                                                      | 11 | 4  | 0 | 0 | 1 |   |   |   |   |    |    |    |    |    |    | 16                 | 45.7 | 24   | 0.7              | 4.8                      |                        |  |  |

\*Where the number of parasite eggs is more than 15, this is indicated in the bracket.

From Table 5.8.1 all the lepidopteran species exposed were observed oviposited upon by A. plutellae. For DBM, the mean number of eggs deposited per host or per female parasite was highest, indicating it to be most preferred. All the other species, however, appeared to be potentially capable of serving as alternative hosts to A. plutellae.

#### 5.8.2 Success in parasitism by A. plutellae in some common Lepidoptera

The previous study revealed that A. plutellae would readily oviposit on a number of lepidopteran species. Whether such oviposition would eventually result in successful parasitization was investigated. The procedure was as described in the previous study, except that parasitized hosts were reared until pupation or death, or parasite emergence.

In the study, parasite emergence was recorded only from A. ypsilon and C. binotalis (Table 5.8.2), indicating these to be possible alternative hosts. In the latter, out of a total of 135 exposed, only 4 adult parasites (3 males + 1 female) were obtained. Also, 2 late-stage larvae which died just prior to their pupation (or parasite emergence?) were found to contain the advanced parasite larvae upon dissection. For A. ypsilon, only 1 male parasite emerged out of a total of 50 hosts exposed.

In general, except for the above few successful parasitism, most of the remaining larvae died within 2-7 days, apparently being adversely affected by the parasite's oviposition or stinging. Only for H. undalis and S. pecten were there some successful host pupation attained. Evidently, significant host mortality could be inflicted by A. plutellae even if full parasite development to reach successful emergence may not be achieved.

#### 5.8.3 Ovipositional preference by A. plutellae between DBM and C. binotalis

Among the Lepidoptera successfully parasitized by A. plutellae, the DBM seemed most preferred (see 3.3 & 5.8.2). To confirm this, a preference study was carried out between DBM and C. binotalis, using equation (2) (Murdoch, 1969; Cock, 1978), and in the same manner earlier employed for the preference study between the various larval instars of DBM (see 5.2.2). However, in this study, only 2nd instar larvae of both test species were compared. As before, each of the various combinations of the two host larvae were exposed to a pair of freshly emerged parasite for 24 hrs and then dissected for counts of the total number of eggs deposited. The combinations included 2,4,6,8,10,12,14,16 and 18 larvae of C. binotalis together with the corresponding number of DBM which made up a total of 20 larvae for each combination. Each test combination was replicated 4 times.

Following Murdoch's (1969) graphical display of preference (Fig. 5.8.1) where the ratio of the hosts attacked was plotted against the ratio at which they were present (i.e. illustrating equation (2)),

TABLE 5.8.2 Evaluation of some common Lepidopteran larvae as alternate hosts to Apanteles plutellae Kurdj.  
(Exposure period = 48 hours).

| Test species                   | Test |          | Stage and no. exposed |     | No. of parasites used |          | Parasite cocoon formed |                     | Pupation of test species |                     | Mortality before test species reaching pupation |       |
|--------------------------------|------|----------|-----------------------|-----|-----------------------|----------|------------------------|---------------------|--------------------------|---------------------|-------------------------------------------------|-------|
|                                | No.  | Date     | Instar                | No. | Male                  | : Female | No.                    | Days after exposure | No.                      | Days after exposure | No.                                             | %     |
| <u>Agrotis ypsilon</u>         | 1    | 6.8.80   | 2nd                   | 50  | 10                    | : 10     | 1                      | 14                  | 0                        | -                   | 50                                              | 100.0 |
| <u>Bombyx mori</u>             | 1    | 18.4.75  | 1st                   | 100 | 8                     | : 8      | 0                      | -                   | 0                        | -                   | 100                                             | 100.0 |
|                                | 2    | 24.4.75  | 2nd                   | 80  | 7                     | : 6      | 0                      | -                   | 0                        | -                   | 80                                              | 100.0 |
| <u>Crociodolomia binotalis</u> | 1    | 15.10.79 | 1st & 2nd             | 40  | 10                    | : 10     | 0                      | -                   | 0                        | -                   | 40                                              | 100.0 |
|                                | 2    | 19.3.80  | 1st & 2nd             | 15  | 10                    | : 10     | 1                      | 7                   | 0                        | -                   | 15                                              | 100.0 |
|                                | 3    | 20.3.80  | 1st & 2nd             | 15  | 10                    | : 10     | 0                      | -                   | 0                        | -                   | 15                                              | 100.0 |
|                                | 4    | 21.3.80  | 1st & 2nd             | 15  | 10                    | : 10     | 1                      | 7                   | 0                        | -                   | 14                                              | 93.0  |
|                                | 5    | 27.3.80  | 1st                   | 50  | 10                    | : 10     | 2                      | 8                   | 0                        | -                   | 50                                              | 100.0 |
| <u>Hellula undalis</u>         | 1    | 28.12.79 | 1st & 2nd             | 7   | 5                     | : 5      | 0                      | -                   | 0                        | -                   | 7                                               | 100.0 |
|                                | 2    | 10.1.80  | 1st & 2nd             | 6   | 5                     | : 5      | 0                      | -                   | 0                        | -                   | 6                                               | 100.0 |
|                                | 3    | 5.2.80   | 1st & 2nd             | 20  | 10                    | : 10     | 0                      | -                   | 3                        | 7 - 8               | 17                                              | 85.0  |
| <u>Spodoptera litura</u>       | 1    | 25.3.80  | 2nd                   | 15  | 10                    | : 10     | 0                      | -                   | 0                        | -                   | 15                                              | 100.0 |
|                                | 2    | 28.3.80  | 1st & 2nd             | 30  | 10                    | : 10     | 0                      | -                   | 0                        | -                   | 30                                              | 100.0 |
| <u>Spodoptera pecten</u>       | 1    | 11.1.75  | 1st                   | 50  | 2                     | : 3      | 0                      | -                   | 21                       | 23 - 26             | 29                                              | 58.0  |
|                                | 2    | 18.1.75  | 1st                   | 80  | 7                     | : 5      | 0                      | -                   | 19                       | 21 - 26             | 61                                              | 76.3  |
|                                | 3    | 23.1.75  | 1st                   | 100 | 8                     | : 9      | 0                      | -                   | 47                       | 19 - 23             | 53                                              | 53.0  |
|                                | 4    | 18.2.75  | 1st                   | 30  | 2                     | : 2      | 0                      | -                   | 15                       | 21 - 24             | 15                                              | 50.0  |
|                                | 5    | 20.1.75  | 2nd                   | 100 | 8                     | : 9      | 0                      | -                   | 42                       | 18 - 22             | 58                                              | 58.0  |
|                                | 6    | 21.1.75  | 2nd                   | 100 | 8                     | : 8      | 0                      | -                   | 47                       | 21 - 24             | 53                                              | 53.0  |
|                                | 7    | 22.1.75  | 2nd                   | 100 | 8                     | : 9      | 0                      | -                   | 53                       | 20 - 23             | 47                                              | 47.0  |
|                                | 8    | 24.1.75  | 2nd                   | 100 | 5                     | : 8      | 0                      | -                   | 46                       | 18 - 24             | 54                                              | 54.0  |
|                                | 9    | 28.1.75  | 3rd                   | 80  | 5                     | : 5      | 0                      | -                   | 31                       | 14 - 30             | 49                                              | 61.3  |

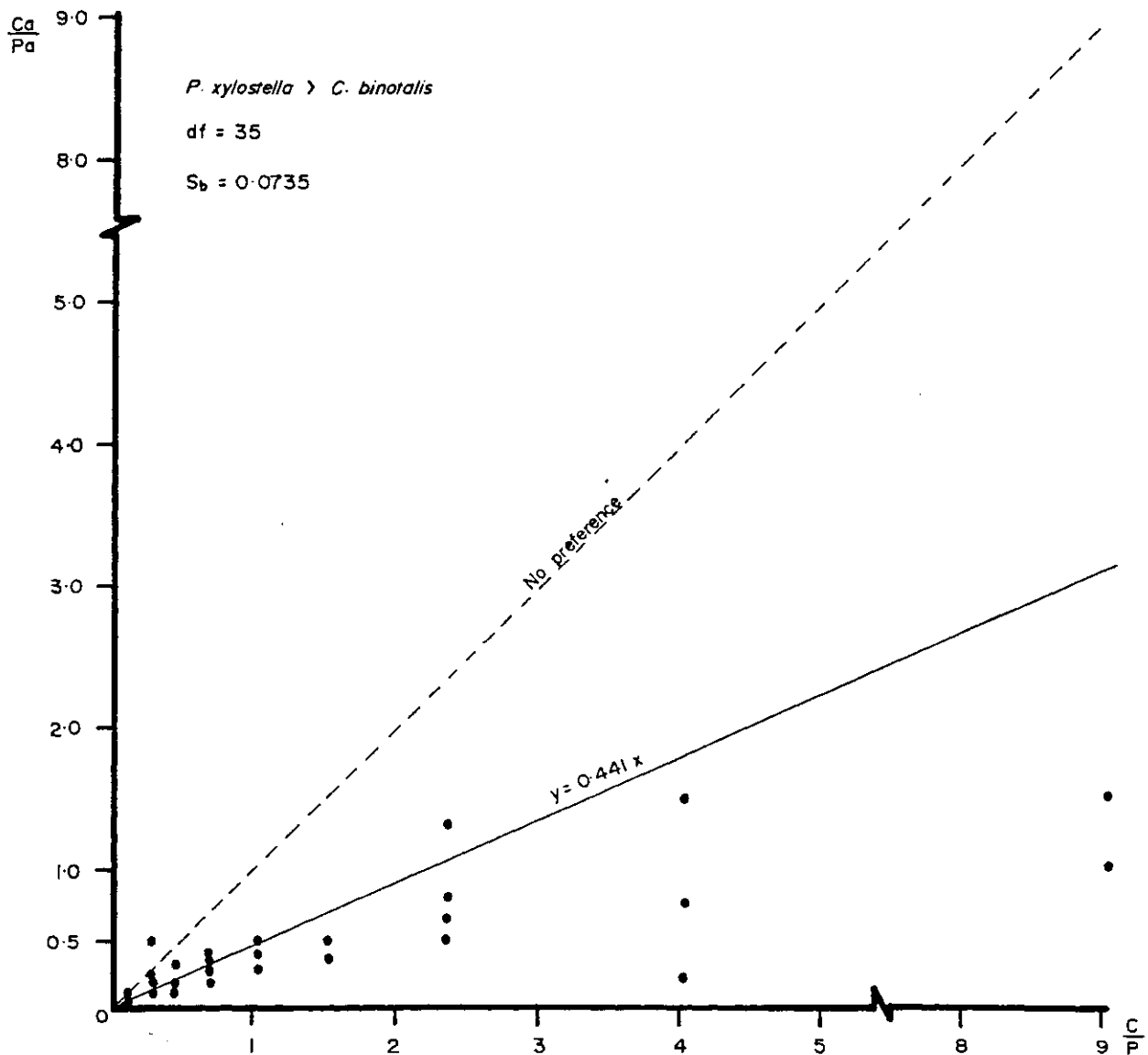


Figure 5-8-1 Parasitism of *Crociodolomia binotalis* Zell. and *Plutella xylostella* (L.) by *Apanteles plutellae* Kurdj. when the two host larvae of the 2nd-instar were presented together.  $C_a$  and  $P_a$  are the respective number of *C. binotalis* and *P. xylostella* parasitised or "attacked", and  $C$  and  $P$  the respective numbers presented.

a slope with deviation significantly ( $b = 0.44$ ,  $S_b = 0.0735$ ,  $df = 35$ ,  $P < 0.01$ ) different from unity was obtained, showing that A. plutellae had distinct preference between the 2 hosts. That DBM was preferred to C. binotalis was noted from the negative preference exhibited ( $y = 0.4411x$ , Fig. 5.8.1) when the ratio of C. binotalis over DBM was used. The preference for DBM was also borne out by field data (see 3.3 & 5.8.5) where only DBM was found to be parasitized by A. plutellae.

#### 5.8.4 Effects of ovipositional 'attack' by A. plutellae on the survival of some Lepidoptera commonly found associated with DBM

Survival of the lepidopteran species evaluated appeared to be adversely affected following 'attacks' by A. plutellae. To what extent this may actually occur was examined for some species commonly found occurring with DBM, viz: A. ypsilon, C. binotalis, H. undalis and S. litura. In the study, survival in a parasitized population was directly compared with that of a corresponding unparasitized one, involving a total of 40-90 individuals per test species. Every parasitized individual was subject to 2 ovipositional 'attacks' by A. plutellae in order to ensure positive parasitism while avoiding excessive stinging which could cause high host mortality (see 5.5.4).

Table 5.8.3 shows that in all the species evaluated a 100% host mortality was inflicted when oviposited upon. With unparasitized populations the mortality was significantly lower, being respectively 15.0%, 30.0%, 40.0% and 42.2% for C. binotalis, S. litura, H. undalis and A. ypsilon.

#### 5.8.5 Survey for alternative hosts of A. plutellae under natural field conditions

Although C. binotalis and A. ypsilon have been firmly established (see 5.8.1 to 5.8.2) as possible alternative hosts to A. plutellae in the laboratory, it is still not certain if these also constitute as such under natural field conditions. To explore into this, as well as, to seek for other alternative host species which may exist but so far unevaluated, a field survey involving periodic collections of lepidopteran larvae for parasite emergence was initiated in 1979 and conducted through to July, 1980. The collections were made from both cabbage crops and other plants found in the vicinity, while the surveyed sites encompassed different regions in the Cameron Highlands, as well as, Kg. Kelambu (Banting) in the lowlands. During the investigation, whatever lepidopteran larvae found were collected along with their food plants and individually reared in 'breeding jars' (Plate 2.1) until the adult host themselves or their parasites have emerged. To facilitate pupation for some species a plastic vial containing fine sand (ca 1.5cm deep) was also provided. Confirmation



TABLE 5.8.3. Effects of ovipositional "attack" by Apanteles plutellae Kurdj. on the survival of some lepidopterans commonly found associated with Plutella xylostella (L.).

| Test species                  | Test |        | Stage and no. exposed |     | Treatment* | Parasite cocoon formed |                     | Adult parasite obtained |      | Pupation of test species |                     | Mortality before test species reaching pupation |       |
|-------------------------------|------|--------|-----------------------|-----|------------|------------------------|---------------------|-------------------------|------|--------------------------|---------------------|-------------------------------------------------|-------|
|                               | No.  | Date   | Instar                | No. |            | No.                    | Days after exposure | No.                     | Sex  | No.                      | Days after exposure | No.                                             | %     |
| <u>Agrotis ypsilon</u>        | 1    | 8.8.80 | 2nd                   | 15  | P          | 0                      | -                   | 0                       | -    | 0                        | -                   | 15                                              | 100.0 |
|                               |      |        | 2nd                   | 15  | U          | 0                      | -                   | 0                       | -    | 9                        | 21 - 23             | 6                                               | 40.0  |
|                               | 2    | 16.9   | 2nd                   | 30  | P          | 4                      | 14 - 15             | 1                       | Male | 0                        | -                   | 30                                              | 100.0 |
|                               |      |        | 2nd                   | 30  | U          | 0                      | -                   | 0                       | -    | 17                       | 20 - 23             | 13                                              | 43.3  |
| <u>Crocidolomia binotalis</u> | 1    | 4.8    | 2nd                   | 10  | P          | 1                      | 9                   | 0                       | -    | 0                        | -                   | 10                                              | 100.0 |
|                               |      |        | 2nd                   | 10  | U          | 0                      | -                   | 0                       | -    | 8                        | 11 - 12             | 2                                               | 20.0  |
|                               | 2    | 22.8   | 2nd                   | 30  | P          | 4                      | 11                  | 1                       | Male | 0                        | -                   | 30                                              | 100.0 |
|                               |      |        | 2nd                   | 30  | U          | 0                      | -                   | 0                       | -    | 26                       | 11 - 13             | 4                                               | 13.3  |
| <u>Hellula undalis</u>        | 1    | 24.7   | 2nd                   | 20  | P          | 0                      | -                   | 0                       | -    | 0                        | -                   | 20                                              | 100.0 |
|                               |      |        | 2nd                   | 20  | U          | 0                      | -                   | 0                       | -    | 12                       | 20                  | 8                                               | 40.0  |
| <u>Spodoptera litura</u>      | 1    | 5.8    | 2nd                   | 20  | P          | 0                      | -                   | 0                       | -    | 0                        | -                   | 20                                              | 100.0 |
|                               |      |        | 2nd                   | 20  | U          | 0                      | -                   | 0                       | -    | 12                       | 23 - 27             | 8                                               | 40.0  |
|                               | 2    | 6.8    | 2nd                   | 10  | P          | 0                      | -                   | 0                       | -    | 0                        | -                   | 10                                              | 100.0 |
|                               |      |        | 2nd                   | 10  | U          | 0                      | -                   | 0                       | -    | 9                        | 23                  | 1                                               | 10.0  |

\*P = Host larvae exposed to 2 oviposition "attacks" by A. plutellae; U = Unexposed and unparasitised larvae.

TABLE 5.8.4. Parasites obtained from Lepidopteran larvae collected from cabbage crops and other plants in their vicinity.

| Lepidopteran larvae collected                            |                                          |         |                                                              |              |                      |                 | Emerging parasites                                                                  |                                  |
|----------------------------------------------------------|------------------------------------------|---------|--------------------------------------------------------------|--------------|----------------------|-----------------|-------------------------------------------------------------------------------------|----------------------------------|
| Species                                                  | Locality                                 | Date    | Plant                                                        | Total number | No. emerged as adult | No. parasitised | Species                                                                             | Type                             |
| <u>Agrotis segetum</u> Schiff.<br>(Lepidop:Noctuidae)    | 33rd mile,<br>Ringlet<br>(C. Highlands)  | 21.5.80 | <u>Brassica ole-<br/>racea</u> L.<br>(Cruciferae)<br>cabbage | 2            | 2                    | 0               | -                                                                                   | -                                |
| <u>Agrotis ypsilon</u><br>Rott.<br>(Lepidop:Noctuidae)   | 47th mile, Kg.<br>Raja (C. Highlands)    | 5.3.80  | <u>B.oleracea</u>                                            | 3            | 1                    | 0               | -                                                                                   | -                                |
|                                                          | Brinchang<br>(C. Highlands)              | 10.7.80 | <u>B.oleracea</u>                                            | 66           | 8                    | 6               | 1) Unidentified<br>M2789 (Dipteran)                                                 | Endo-larval, grega-<br>rious.    |
|                                                          |                                          |         |                                                              |              |                      |                 | 2) <u>Ichneumon</u> sp.<br>(I.D. Gauld det.)<br>(Hymenop: Ichne-<br>umonidae)       | Endo, larval-pupal,<br>solitary. |
|                                                          |                                          |         |                                                              |              |                      |                 | 4) Unidentified<br>M 2786 (Dip :<br>Tipulidae)                                      | Endo-larval,<br>solitary,        |
| <u>Chloridea assulta</u><br>Guen.<br>(Lepidop:Noctuidae) | Kg. Kelambu<br>(Banting)                 | 27.2.80 | <u>B.oleracea</u>                                            | 4            | 2                    | 0               | -                                                                                   | -                                |
|                                                          | 47th Mile,<br>Kg. Raja<br>(C. Highlands) | 5.3.80  | <u>B.oleracea</u>                                            | 1            | 0                    | 0               | -                                                                                   | -                                |
|                                                          | Tanah Rata<br>(C. Highlands)             | 5.3.80  | <u>B.oleracea</u>                                            | 9            | 2                    | 1               | 1) <u>Litomastix</u> sp.<br>(B.R. Subba<br>Rao det.)<br>(Hymenop: Encyrti-<br>dae). | Endo, larval-pupal<br>gregarious |
|                                                          | Tanah Rata<br>(C. Highlands)             | 9.5.80  | <u>Brassica</u><br><u>chinensis</u> L.                       | 3            | 3                    | 0               | -                                                                                   | -                                |
|                                                          | Tanah Rata<br>(C. Highlands)             | 10.7.80 | <u>B.oleracea</u>                                            | 4            | 3                    | 0               | -                                                                                   | -                                |
|                                                          | Bertam Valley<br>(C. Highlands)          | 10.7.80 | <u>B.oleracea</u>                                            | 3            | 2                    | 0               | -                                                                                   | -                                |

TABLE 5.8.4 (continued 1).

| Lepidopteran Larvae collected                                       |                                              |         |                   |           |                      |                 | Emerging parasites                                                                       |                                 |
|---------------------------------------------------------------------|----------------------------------------------|---------|-------------------|-----------|----------------------|-----------------|------------------------------------------------------------------------------------------|---------------------------------|
| Species                                                             | Locality                                     | Date    | Plant             | Total No. | No. emerged as adult | No. parasitised | Species                                                                                  | Type                            |
| <u>Crocidolomia</u><br><u>binotalis</u> Zell<br>(Lepidop:Pyralidae) | 42nd&45th Mile,<br>Kg.Raja<br>(C. Highlands) | 27.9.79 | <u>B.oleracea</u> | 95        | 69                   | 5               | 3) <u>Bessa</u> sp.(K.M.<br>Harris det.)<br>(Dip:Tachinidae)                             | Endo,larval-pupal,<br>solitary. |
|                                                                     |                                              |         |                   |           |                      |                 | 2) <u>Eriborus argen-</u><br><u>teopilosus</u> (Came-<br>ron)(Hymenop:<br>Ichneumonidae) | Endo,larval-pupal,<br>solitary. |
|                                                                     | Kg.Kelambu<br>(Banting)                      | 27.2.80 | <u>B.oleracea</u> | 12        | 11                   | 0               | -                                                                                        | -                               |
|                                                                     | 47th Mile,<br>Kg.Raja<br>(C.Highlands)       | 5.3.80  | <u>B.oleracea</u> | 1         | 0                    | 0               | -                                                                                        | -                               |
|                                                                     | Tanah Rata,<br>(C.Highlands)                 | 5.3.80  | <u>B.oleracea</u> | 73        | 56                   | 0               | -                                                                                        | -                               |
|                                                                     | Tanah Rata<br>(C.Highlands)                  | 9.5.80  | <u>B.oleracea</u> | 10        | 7                    | 1               | 1) <u>Peribaea orbata</u><br>Wiedemann.<br>(Dip:Tachinidae)                              | Endo,larval-pupal<br>solitary.  |
|                                                                     | Tanah Rata<br>(C.Highlands)                  | 21.5.80 | <u>B.oleracea</u> | 65        | 42                   | 1               | 1) <u>E.argenteopilosus</u>                                                              | Endo,larval-pupe<br>solitary.   |
|                                                                     | Tanah Rata<br>(C.Highlands)                  | 4.6.80  | <u>B.oleracea</u> | 68        | 8                    | 0               | -                                                                                        | -                               |
|                                                                     | Brinchang<br>(C.Highlands)                   | 10.7.80 | <u>B.oleracea</u> | 6         | 5                    | 0               | -                                                                                        | -                               |
|                                                                     | Bertam Valley<br>(C.Highlands)               | 10.7.80 | <u>B.oleracea</u> | 4         | 2                    | 0               | -                                                                                        | -                               |

TABLE 5.8.4 (continued 2).

| Lepidopteran larvae collected                                           |                                   |         |                                                      |           |                      |                 | Emerging parasites                                                          |                             |
|-------------------------------------------------------------------------|-----------------------------------|---------|------------------------------------------------------|-----------|----------------------|-----------------|-----------------------------------------------------------------------------|-----------------------------|
| Species                                                                 | Locality                          | Date    | Plant                                                | Total No. | No. emerged as adult | No. parasitised | Species                                                                     | Type                        |
| <u>Hellula undalis</u> F.<br>(Lepidop:Pyralidae)                        | Kg. Kelambu (Banting)             | 27.2.80 | <u>B. oleracea</u>                                   | 12        | 12                   | 0               | -                                                                           | -                           |
|                                                                         | 33rd Mile, Ringlet (C.Highlands)  | 21.5.80 | <u>B. chinensis</u>                                  | 274       | 30                   | 0               | -                                                                           | -                           |
|                                                                         | Bertam Valley (C.Highlands)       | 10.7.80 | <u>B. oleracea</u>                                   | 3         | 2                    | 0               | -                                                                           | -                           |
| <u>Ochyrotica concur-</u><br><u>sa</u> Walk.<br>(Lepidop:Pterophoridae) | 44th Mile, Kg. Raja (C.Highlands) | 25.1.80 | <u>Ipomoea batatas</u> Lam.<br>(Convolvulaceae)      | 10        | 10                   | 0               | -                                                                           | -                           |
|                                                                         | 47th Mile, Kg. Raja (C.Highlands) | 5.3.80  | <u>Polygonum malai-</u><br><u>cum</u> (Polygonaceae) | 54        | 21                   | 28              | 28) <u>Apanteles ater</u><br>gp. (I.D. Gauld det.)<br>(Hymenop: Braconidae) | Endo-larval,<br>solitary.   |
|                                                                         | Tanah Rata (C.Highlands)          | 20.3.80 | <u>P. malaicum</u>                                   | 43        | 19                   | 19              | 19) <u>A. ater</u> gp.                                                      | Endo-larval,<br>solitary.   |
|                                                                         | Tanah Rata (C.Highlands)          | 1.4.80  | <u>P. malaicum</u>                                   | 9         | 6                    | 3               | 3) <u>A. ater</u> gp.                                                       | Endo-larval,<br>solitary.   |
|                                                                         | 44th Mile, Kg. Raja (C.Highlands) | 25.1.80 | <u>Citrus</u> sp.                                    | 5         | 1                    | 4               | 4) <u>Pteromalus puparum</u> L.<br>(Hymenop: Pteromalidae)                  | Endo-larval,<br>gregarious. |
| <u>Plusia chalcites</u><br>Esp.<br>(Lepidop:Noctuidae)                  | 44th Mile, Kg. Raja (C.Highlands) | 25.1.80 | <u>B. oleracea</u>                                   | 2         | 1                    | 1               | 1) <u>Euplectrus</u> sp.<br>(Z. Boucek det.)<br>(Hymenop: Eulophidae).      | Endo-larval,<br>gregarious. |

TABLE 5.8.4 (continued 3).

| Lepidopteran larvae collected                                  |                                                  |         |                                                 |           |                      |                 | Emerging parasites                                                 |                                  |
|----------------------------------------------------------------|--------------------------------------------------|---------|-------------------------------------------------|-----------|----------------------|-----------------|--------------------------------------------------------------------|----------------------------------|
| Species                                                        | Locality                                         | Date    | Plant                                           | Total No. | No. emerged as adult | No. parasitised | Species                                                            | Type                             |
| <u>Plusia intermixta</u> Warr.<br>(Lepidop:Noctuidae)          | 44th Mile,<br>Kg. Raja<br>(C.Highlands)          | 25.1.80 | <u>B. oleracea</u>                              | 4         | 3                    | 1               | 1) <u>Compsilura concinnata</u><br>Meigen. (Dip.Tachinidae)        | Endo, larval-pupa<br>solitary.   |
| <u>Psara</u> sp.<br>(Lepidop:Pyraustidae)                      | 47th Mile,<br>Kg. Raja<br>(C.Highlands)          | 5.3.80  | <u>Trema orientalis</u> ,<br>Blume (Urticaceae) | 38        | 15                   | 0               | -                                                                  | -                                |
| <u>Spilosoma sumat-<br/>rana</u> Swinh.<br>(Lepidop:Arctiidae) | 47th Mile,<br>Kg. Raja<br>(C.Highlands)          | 5.3.80  | <u>B. oleracea</u>                              | 6         | 0                    | 3               | 3) <u>Apanteles</u> sp.<br>(Hymenop: Braconidae)                   | Endo-larval,<br>gregarious.      |
| <u>Spodoptera litura</u> F.<br>(Lepidop:Noctuidae)             | 42nd and 45th<br>Mile, Kg. Raja<br>(C.Highlands) | 27.9.79 | <u>B. oleracea</u>                              | 27        | 6                    | 6               | 4) <u>Coboldia fuscipes</u><br>Meigen<br>(Dip: Scatopsidae)        | Endo, larval-pupal,<br>solitary. |
|                                                                |                                                  |         |                                                 |           |                      |                 | 2) Unidentified M2466<br>(Dipteran)                                | Endo-larval,<br>gregarious.      |
|                                                                | 44th Mile,<br>Kg. Raja<br>(C.Highlands)          | 25.1.80 | <u>B. oleracea</u>                              | 4         | 1                    | 0               | -                                                                  | -                                |
|                                                                | Kg. Kelambu<br>(Banting)                         | 27.2.80 | <u>B. oleracea</u>                              | 41        | 10                   | 0               | -                                                                  | -                                |
|                                                                | 47th Mile,<br>Kg. Raja<br>(C.Highlands)          | 5.3.80  | <u>B. oleracea</u>                              | 20        | 11                   | 0               | -                                                                  | -                                |
|                                                                | Tanah Rata<br>(C.Highlands)                      | 5.3.80  | <u>B. oleracea</u>                              | 17        | 5                    | 1               | 1) <u>Bracon</u> sp.<br>(I.D. Gauld det.)<br>(Hymenop: Braconidae) | Endo-larval,<br>solitary.        |

TABLE 5.8.4 (continued 4).

| Lepidopteran larvae collected                                          |                                          |         |                                                        |           |                      | Emerging parasites |                                                                                          |                                                            |
|------------------------------------------------------------------------|------------------------------------------|---------|--------------------------------------------------------|-----------|----------------------|--------------------|------------------------------------------------------------------------------------------|------------------------------------------------------------|
| Species                                                                | Locality                                 | Date    | Plant                                                  | Total No. | No. emerged as adult | No. parasitised    | Species                                                                                  | Type                                                       |
|                                                                        | Tanah Rata<br>(C. Highlands)             | 12.4.80 | <u>Fragaria vers</u><br>L.<br>(Strawberry)<br>Rosaccae | 29        | 10                   | 8                  | 8) <u>Microplitis</u> sp.<br>(Hymenop <sup>i</sup> Braconidae)                           | Endo-larval, solitary.                                     |
|                                                                        | Tanah Rata<br>(C.Highlands)              | 16.4.80 | <u>F. vesca</u>                                        | 20        | 5                    | 8                  | 8) <u>Microplitis</u> sp.                                                                | Endo-larval, solitary.                                     |
|                                                                        | Tanah Rata<br>(C.Highlands)              | 21.4.80 | <u>F. vesca</u>                                        | 28        | 8                    | 5                  | 5) <u>Microplitis</u> sp.                                                                | Endo-larval, solitary.                                     |
|                                                                        | Tanah Rata<br>(C.Highlands)              | 9.5.80  | <u>F. vesca</u>                                        | 103       | 18                   | 38                 | 37) <u>Microplitis</u> sp.<br>1) <u>Peribaea orbata</u><br>Wiedemann.<br>(Dip.Tachnidae) | Endo-larval, solitary.<br>Endo, larval-pupal,<br>solitary. |
|                                                                        | Tanah Rata<br>(C.Highlands)              | 21.5.80 | <u>F. vesca</u>                                        | 72        | 20                   | 15                 | 10) <u>Microplitis</u> sp.<br>5) Unidentified M2466<br>(Dipteran)                        | Endo-larval, solitary.<br>Endo-larval, gregarious          |
|                                                                        | Tanah Rata<br>(C.Highlands)              | 4.6.80  | <u>F. vesca</u>                                        | 84        | 5                    | 3                  | 3) <u>Microplitis</u> sp.                                                                | Endo-larval, solitary.                                     |
|                                                                        | Bertam Valley<br>(C.Highlands)           | 10.7.80 | <u>B. oleracea</u>                                     | 57        | 36                   | 0                  | -                                                                                        | -                                                          |
| <u>Tiracola plagia-</u><br><u>ta</u> Walk.<br>(Lepidop:Noctui-<br>dae) | 42nd Mile,<br>Kg. Raja<br>(C. Highlands) | 27.9.79 | <u>B. oleracea</u>                                     | 1         | 1                    | 0                  | -                                                                                        | -                                                          |
|                                                                        | Tanah Rata<br>(C.Highlands)              | 21.5.80 | <u>B. oleracea</u>                                     | 1         | 1                    | 0                  | -                                                                                        | -                                                          |

TABLE 5.8.4. (continued 5).

| Lepidopteran larvae collected                           |                                         |          |                                      |           |                      | Emerging parasites |                                                                        |                           |
|---------------------------------------------------------|-----------------------------------------|----------|--------------------------------------|-----------|----------------------|--------------------|------------------------------------------------------------------------|---------------------------|
| Species                                                 | Locality                                | Date     | Plant                                | Total No. | No. emerged as adult | No. parasitised    | Species                                                                | Type                      |
| <u>Venessa cardui</u> L.<br>(Lepidop:Nymphalidae)       | 44th Mile,<br>Kg. Raja<br>(C.Highlands) | 25.1.80  | <u>Artemisia</u> sp.<br>(Compositae) | 22        | 16                   | 0                  | -                                                                      | -                         |
|                                                         | 47th Mile,<br>Kg. Raja<br>(C.Highlands) | 5.3.80   | <u>Artemisia</u> sp.                 | 34        | 28                   | 0                  | -                                                                      | -                         |
| <u>Xanthorhoe saturata</u> Gn.<br>(Lepidop:Geometridae) | Tanah Rata<br>(C. Highlands)            | 27.11.79 | <u>Camellia thea</u><br>L.(Theaceae) | 12        | 0                    | 2                  | 2) <u>Apanteles vitripennis</u><br>Wilkinson.<br>(Hymenop: Braconidae) | Endo-larval,<br>solitary. |
|                                                         | Tanah Rata<br>(C. Highlands)            | 26.12.79 | <u>C. thea</u>                       | 24        | 1                    | 4                  | 4) <u>A. vitripennis</u>                                               | Endo-larval,<br>solitary. |
|                                                         | Tanah Rata<br>(C. Highlands)            | 22.1.80  | <u>C. thea</u>                       | 57        | 1                    | 5                  | 5) <u>A. vitripennis</u>                                               | Endo-larval,<br>solitary. |
|                                                         | Tanah Rata<br>(C. Highlands)            | 25.1.80  | <u>C. thea</u>                       | 55        | 0                    | 5                  | 5) <u>A. vitripennis</u>                                               | Endo-larval,<br>solitary. |

were smaller. It might be expected, therefore, that these related factors would affect the size of the cephalic skeleton and hence the inapplicability of Dyar's law for the developing larvae of A. plutellae as observed in the present investigations.

Among the different larval stadia of A. plutellae the 2nd was rather amorphous. According to Allen (1958), in such an amorphous state the great increase in size probably does not require a moult. This was strongly supported by Clausen (1940) who reported that this increase in size is not uncommon in many parasitic Hymenoptera. Subsequent study by Boling & Pitre (1970) on A. marginiventris also lent firm support to this. Although Allen (1958) further suggested that such larval stadium may actually be 2 instars, this has never been shown by workers with any Apanteles species and it did not appear to be so with A. plutellae. Evidently, only 3 distinct larval instars exist in A. plutellae as have been also noted by others (Delucchi et al, 1954; Fan & Ho, 1971; Chiu & Chien, 1972; Ho & Chio, 1972).

On host stage preferences it was clearly demonstrated that A. plutellae is an endo-larval parasite of DBM and it prefers most the host's 2nd larval instar. This was consistently indicated by the several approaches employed, including the analytical method of Murdoch (1969) and Cock (1978). Although the preference index of Lawton et al (1974) which uses the Random Predator Equation would prove more yielding (Cock, 1978), it however also assumes a more complex variable that is dependent upon  $T_s$  (= time available for searching) which itself is dependent upon the numbers of each prey type eaten, the handling times ( $T_h$ ) and the search efficiencies. But in the current context relating to A. plutellae this exploitation model does not appear necessary while that of Murdoch (1969) and Cock (1978) appears to suffice. This is because all the basic assumptions involving such analytical techniques are generally well-satisfied. For instance, the prey densities have remained constant throughout and have not gradually become less as with exposures to true predators wherein the preys would be either consumed or destroyed. Moreover, since the total exposure period did not exceed 24 hrs all 'attacked' larvae would still have an equal chance of being 'reattacked' since none of the eggs deposited would have hatched by then (see 5.1.7) to elicit successful host discrimination by the parasite (see 9.3.2.3). As such, the 'switch' or exploitation effect would be either absent or insignificant. Otherwise, the exploitation model of Lawton et al (1974) would be necessary and more appropriate.

The ability of A. plutellae to exhibit distinct preference for the 2nd larval instar of DBM may be due to a variety of reasons. Host



palatability, which could constitute an important governing factor among predators, is unlikely to be involved here, since the host larva serves only as oviposition medium while the adult parasite never exhibits host feeding. However, the size of the host 'attacked' may be a contributory influence, as with prey sizes which can greatly affect the a' and Th values of predators (Thompson, 1975; Hassell et al, 1976). Since both these parameters have major influence on the outcome of the Random Predator Equation which itself is the basis of a highly versatile preference index (Lawton et al, 1974), obviously the size of the host could not be totally overlooked. With A. plutellae, this is perhaps closely related to the violent 'jerking' behaviour of the host when it encounters the parasite. For larger hosts, successful oviposition is less likely because of more effective 'warding off' of the 'attacking' parasite, hence the lower preference for the 3rd and 4th instars. With the smaller 2nd instar larvae, they are easily subdued and oviposited upon, thus resulting in the highest number of successful 'attacks'. Pertaining to 1st instar, locating the larvae could perhaps pose a limitation, leading to lower rates of 'attacks'. However, behavioural 'warding off' does not appear to be a sole governing factor. This is clearly suggested from the unequal developmental biology of the parasite when initial oviposition occurred on different larval instars. For instance, a 1:1 sex ratio was obtained only when parasitism occurred during the 2nd instar stage (see 5.3). When later instars were oviposited upon there were usually less females. This is probably related to the shorter developmental biology of the males. Being generally smaller, male parasites would require less developmental time and adjustment, and can therefore better develop within the later host larvae. From these, it appears that achieving a balanced sex ratio is also an important factor that governs the differential preference of host stages by the parasite.

Another important factor is the parasite's survival potential. For some reasons, a lower mortality was obtained when oviposition occurred on the 2nd host instar which offers optimal development to the parasite. Conversely, the poorer survival obtained when oviposition occurred in the 4th instar is similarly related with this stage being least preferred.

In general, it seems that whatever may be the explanations for the relative stage preference, all have a common basis that eventually aim to enhance the survival value of the parasite. That this is so is evident from the different host and parasite developmental periods which have resulted from parasite oviposition at the different host stages. When oviposition first occurred in the 1st instar, no difference in host's developmental period was observed from that of unparasitized individuals,

suggesting that the normal life cycle period of the host is sufficient to encompass that of the parasite. But when egg deposition occurred over the later stages, the overall host developmental period was extended to accomodate that of the parasite; this increase was progressively greater as the ovipositional stage becomes later. The adjustment is clearly an important adaptation of the parasite which somehow is able to delay the host's development to suit its own. This seems so as the overall developmental period of the parasite (egg - adult) was observed to remain relatively unaffected throughout. Ecologically, this synchronization has relevance to natural field conditions where all stages of host may occur together. It is also considered an important attribute of a good control agent (van Lenteren, 1980), and for A. plutellae may have contributed to its relatively high parasitism rates and widespread occurrence in the Cameron Highlands (see 3.3).

Internal synchronization in development has also been observed in some other host-parasite species. While the developing stage between the 3rd moult of the host to parasite cocooning acted as the main 'waiting' stage in DBM, that for some may encompass all the larval stages as with C. inantius (Rechav & Orion, 1975). Yet in others, the developing parasites may also serve as the 'waiting' phase as was noted for Chelonus texanus Cresson (Hym: Braconidae) (Buttler, 1966) and D. eucero-phaga (Ooi, 1980). In all these cases the internal synchronization is essentially also to enhance the survival of the parasites concerned.

To date, no comprehensive experimental study has been conducted to explain the internal synchrony existing between A. plutellae and DBM. For some parasites, internal synchronization may be explained by assuming that the parasites interact with the hormonal changes in the host haemolymph (Salt, 1938; Corbet, 1968). This has been thoroughly discussed with special reference to Chelonus annulipes Wesmeal. (Hym: Braconidae) by Bradley & Arbuthnot (1938). Also, the response of the host to both external and internal stimulations is expressed similarly in changes in the amount of haemolymph components. Any change, likewise, would create relevant reactions in the host and parasite, thereby permitting appropriate adjustment to achieve internal synchronization.

The successful evolution of behavioural adaptations for host detection (and hence successful oviposition) in A. plutellae is undoubtedly also responsible for the widespread occurrence of the parasite. Its ability to avoid ovipositing on dead hosts evidently constitutes an important adaptation to overcome wastage of eggs as well as in reducing handling time. The importance of host movement in eliciting ovipositional

response has perhaps led further to the evolution of the 'silk-tracking' behaviour, which proves to be a highly effective method of parasitizing an escaping host. This adaptation overcomes the host's escape mechanism of strong wriggling and abrupt dropping off on its silk thread whenever roughly handled. In A. plutellae, oviposition 'attack' is necessarily rapid, as otherwise, egg deposition may not succeed due to the violent jerking and vigorous 'fighting back' of the host. Under such a situation the parasite would generally be unable to maintain its hold for sufficient duration to ensure egg transfer. Since each ovipositor insertion generally permits deposition of only one egg, egg-utilization is simultaneously economised because superparasitism will not yield more than one parasite adult.

Under laboratory conditions, large numbers of eggs may be readily found per host, being largely due to multiple oviposition. Because of this, host mortality is greatly increased beyond that based on parasite emergence alone, particularly at high parasite density where multiple oviposition could rise sharply. This has also been reported for A. marginiventris (Kunnalaca & Mueller, 1979). Such a phenomenon has probably arisen out of unnatural conditions of the laboratory since in the field extreme high parasite: host ratio normally never exists. This is borne out by the fact that larvae of DBM collected from the field usually contain only one developing parasite larva or egg, and never exceeding 3 (for eggs). Besides, field parasitism of the parasite is also usually well below 100%.

The sex ratio of a parasite population has always constituted an important consideration in the assessment of the parasite's usefulness. In obligatory thelytokous species there is no problem associated with sex ratio since males are virtually unknown. Similarly, neither is there in practical work any concern expressed over the occasional appearance of the few exceptional males in deuterotokous species. However, as in other arrhenotokous parasites, the variable sex ratios of A. plutellae may cause difficulty, particularly in relation to its regulatory capability over DBM. Aspects of especial concern are its mass production in insectary culture and its colonization. However, the wide fluctuations in sex ratios may perhaps be something that arises under laboratory conditions for in the field a balanced ratio of 1:1 was generally obtained. This has also been found for numerous other species of Apanteles (Ford, 1943). Contrariwise, arrhenotoky in species such as A. plutellae may in nature have great survival value. Accordingly to White (1954), it has probably been evolved to provide greater adaptability and to allow more flexibility to adjust the sex ratio to more variable field situations. If so, arrhenotoky

toky in A. plutellae would have tremendous advantage to the parasite, since in an ephemeral cabbage environment with widely influencing factors its sex ratio can well develop accordingly to the 'best' requirements of reproduction. This could be critical as the occurrence and abundance of both crop and host are usually highly variable. Perhaps, the variable sex ratios manifested over the different growth stages in a crop is a reflection of the adjustment capability of the parasite. This flexibility may have enable A. plutellae to fit into rather diverse environment and partly accounts for its current widespread occurrence as well as its rapid establishment in release projects (Bennett & Yaseen, 1972; Yaseen, 1974, 1978). With respect to the latter, it was the only one which became firmly established among 2 other exotic parasites (A. vestalis and T. collaris) that were released together in Trinidad and the Lesser Antilles. Evidently, these successes with A. plutellae have lent further support to discrediting the presumption that colonization of arrhenotokous species is likely to suffer failure because of the inconsistent sex ratios (Doutt, 1964).

In arrhenotokous species a satisfactory sex ratio could best be maintained by habits which favour mating soon after emergence. This is aided by males having a shorter developmental period and preceding the females to the adult stage by 1 or 2 days. Some other factors (Flanders, 1946) would include the effect of the density of oviposition hosts on: (a) differential mortality during development; (b) the premating period after emergence; (c) excessive mating; (d) possible difference in oviposition response before and after mating; (e) the availability of preferred oviposition hosts; and (f) the rate of oviposition. Presently, most of these aspects are still little understood. Undoubtedly, the problem of sex determination is fundamental to sex ratio, and to date, this is not as yet fully explained for many species, including A. plutellae.

From the studies on pattern of egg laying and egg development, it was confirmed that A. plutellae is not a 'proovigenic' species (Flanders, 1950) where the adult emerges with a complete complement of ripe eggs attained entirely from stored nutrients from the larval stage. Rather, like most other Hymenoptera (Doutt, 1964) it is 'synovigenic' (Flanders, 1950) with egg production being continuous and dependent on adult feeding. If adult food is unavailable for an extended period, then the ripe eggs still within in the ovarioles are usually absorbed (Flanders, 1942, 1945). According to Doutt (1964), this conservation of reproductive material emphasizes the economy of parasitism, and is usually correlated with a high searching capacity. Such parasite species with long-lived females are generally regarded as effective agents in biological control, mainly because they are capable of searching in low host densities and yet con-

serve their eggs to oviposit in sites (hosts) suitable for development of their progeny (Flanders, 1947). In this regard, the effectiveness of A. plutellae as a biological control agent could accordingly increase if female lifespan can somehow be extended in the field.

Since A. plutellae does not partake in host feeding, evidently the food sources would necessarily be supplied from naturally-occurring honeydew or plant nectaries (Doutt, 1964). The former has however not been evaluated, while the latter found to be potentially useful. Out of a total of 16 plant species studied, the floral nectaries from at least 10 species were found capable of increasing significantly the longevity of A. plutellae. The essential role of plant nectaries cannot be over-emphasized for their usefulness has been well-demonstrated under many other situations and on numerous occasions. For instance, Wolcott (1942) described how a parasite, Larra americana Saussure, introduced from Brazil to Puerto Rico to control the mole cricket (Scapteriscus vicinus Scudder) became established only in the presence of two weeds, Borreria verticillata and Hyptis atrorubens. These served as nectar supplies for the adult wasp and, where they were absent or scarce, the wasps failed to survive. In 1946, Voûte claimed that a lack of flowers was fatal to many species of ichneumonids, while Gyoerfi in subsequent studies (1951, 1962) discussed the importance of a well-developed understory in woodlands to serve as a reservoir of alternative hosts for parasites of forest pests and as a source of food for the adult parasites. He listed Daucus carota L., Pastinaca sativa L., Medicago sativa L., and Trifolium pratense L. as important food sources. In 1960, Kopvillem found up to 94% of cabbage cutworm larvae on a crop were parasitized when umbelliferous flowers were established near the crop plants in a ratio of 1:400. For DBM, the proximity between cabbage plants and extensive patches of flowering herbs and bushes enabled its parasites to exert a controlling influence much earlier than that in situations devoid of flowering plants. Investigations by Leius (1960, 1961a, b, 1963, 1967) on the attractiveness of several foods to adults of hymenopterous parasites and the effects of some of them on longevity and fecundity have clearly revealed that flowers of the family Umbelliferae were often preferred. The parasite O. obscurator was noted to feed only on flowers of this family, selecting wild parsnip, P. sativa, above all others. Pollens were also found to have significant effects on fecundity or longevity of some parasitic species but the effect varied considerably between the different consumers and different pollens. In O. obscurator, the longevity was increased by a factor of 5 when wild carrot, D. carota, was also present (Syme, 1966). Because of the immense benefits that may be derived, Leius (1967) strongly urged the encourage-

ment of food sources in areas where releases are contemplated. Gulii (1963) suggested planting nectar-producing plants such as Euphorbia villosa Waldst. & Kit., E. macroceras F. & M., Pastinaca intermedia F. & M., and Prunus avium L. as a promising measure to increase the efficiency of parasites of the European pine shoot moth, Rhyacionia buoliana (Schifferrmueller). The value of this was also indicated by studies of van Emden (1963 a, b, 1964) who found more carnivores in unmanaged hedgerows with abundant flowers than in managed hedgerows or cultivated lands. He also obtained much higher trap catches of parasites in crops or cultivated land when flowers were present. Moreover, catches could be increased by adding flowers to the area. In Germany, Hassan (1967) also found hymenopterous parasites to visit more frequently flowers within forests.

In study on the influence of food on fecundity of Chrysopa carnea Stephens, Sundby (1967) showed that some pollens were more effective than others. On the other hand, by artificially disseminating honey throughout plantations harbouring R. buoliana, Koehler & Kolk (1969) were able to increase the numbers of parasites with some success. Judd (1970), in a study of the insects associated with flowering wild carrot, recorded 5 species of Coccinellidae, 9 of Syrphidae, and 7 of parasitic Hymenoptera and Diptera that frequent these blooms. More recently, Esbjerg (1972) recommended sowing umbelliferous flowers in pine plantations to promote parasite populations, while Kevan (1973), in a study with parasitic Hymenoptera frequenting Arctic flowers, stressed the importance of the latter to these insects as a source of sugars for fuel in flight, mating, and host finding. Later on, following extensive investigations on the effects of natural foods on 3 parasite species (Exeristes comstockii Cresson (Hym: Ichneumonidae), H. thymus and O. obscurator) of R. buoliana, Syme (1975, 1977) strongly urged the establishment and encouragement of flowering plants in pine plantations, particularly the species D. carota, Fagopyrum esculentum Moench, Asclepias syriaca L. and Nepeta cataria L. These were recommended to be established within the bounds of local weed control legislation.

Evidently, from all the above case studies which together constitute a substantial amount of evidence to establish and confirm on the essential role of natural adult foods, it seems clear that many of the plant species evaluated in the present studies could similarly have a strong effect towards promoting the beneficial role of A. pluteellae for the control of DBM. That these plants could satisfactorily serve as possible food sources is well borne out by the frequent observations of their attractiveness to the parasite (and also many other insects) under natural conditions. In particular, A. pluteellae (as well as D. eucero-phaga

and T.collaris), have often been found wandering actively among the flowers of Crotalaria spp. and many other cultivated legumes (e.g. beans and green peas) in the Cameron Highlands.

On a brassica crop, although DBM are usually present, suitable host stage or preferred instars may not always be immediately available to the parasite which thus has to wait. Without a suitable food supply, under such a situation, its expected lifespan of about 3 days could result in extremely low frequency of host attack. Moreover, immediate access to food upon emergence can be critical to A.plutellae since even a mere initial starvation of only 12 hrs could have adverse effect on its longevity and survival. In this may perhaps lie the crucial explanation between the relatively higher abundance of the parasite in the Cameron Highlands as compared to the scarcity in the lowlands. Under conditions of the latter, cabbages are generally cultivated on flat and vast open land. Where flowering bushes are present, these are usually more distantly located. In contrast, the close valley system of the Cameron Highlands is relatively much richer in flowering vegetations which are also closer to the cultivated crops. This condition evidently allows for more rapid and freer movements of A.plutellae between the crops and adult food sources, thereby preserving better the parasites. Further improvement may however be expected if the food plants are brought still closer to the crops. It thus seems worth considering having plant species such as Crotalaria either bordering the crops or interspersed as interrows, particularly since such habitat management is not too cumbersome for farmers to adopt. That Crotalaria might also attract pest species to the cabbage crop is unlikely because they both have quite different pest range.

Regarding alternative hosts of A.plutellae, only a few have so far been recorded (Delucchi et al, 1954; Wang et al, 1972; Chiu et al, 1974; Chiu & Chou, 1976). Even among these, some are noted to be unnatural hosts while few have actually been confirmed as true hosts through proper breeding studies. In general, it seems obvious that A.plutellae is oligophagous. Except for DBM, other species that are recorded as alternative hosts have not been found infesting brassicas in Malaysia (Yunus & Ho, 1970b). Evidently, its range of alternative host species under the Malaysian conditions is restricted only to A.ypsilon and C.binotalis, both of which are also observed to be poorly exploited by the parasite. As such, A.plutellae is almost wholly confined to DBM locally, thus ruling out the possibility that its apparent abundance may be due to regular supply from reservoirs in alternative hosts. Besides, because of the more equable climate and the ever-presence of DBM in an environment of staggered cropping, alternate hosts even if present, will not constitute

any importance in manner similar to Swammerdamia lutaria on hawthorn wherein the alternate host (S.lutaria) serves to bridge an overwintering larval generation of Diadegma fenestralis Grav. which is an important parasite of DBM in Britain (van Emden, 1965).

From the foregoing considerations, it is evident that A.plutellae has a number of attributes desirable of a good biological control agent (van Lenteren, 1980), viz: (i) host specificity, (ii) great reproductive potential (short generation time, high fecundity), (iii) good internal synchronization with development of host, (iv) well-adapted to a fairly wide range of conditions occupied by the host and (v) is density responsive to changes in host population. Many of the basic features governing the latter are, however, still not fully understood and some of these [functional response ( $a'$  &  $T_h$ ), host discrimination, interference and competition] will be examined in Section 9. Nevertheless, it may be concluded thus far that A.plutellae is an important parasite of DBM and its exploitation in the management of the moth should be given serious and full consideration. Ensuring easy access of suitable food sources to the parasite should not be overlooked. This is because the total number of parasite eggs that may be deposited is dependent on its longevity; more will be laid when the lifespan is increased. In turn, the latter is governed by food availability which could increase the reproductive capacity of the parasite, and perhaps their abundance and overall effectiveness as a biological control agent. In view of such possibilities, any natural food sources that could increase the lifespan of A.plutellae should be strongly encouraged.



## 6. OCCURRENCE AND SPATIAL DISTRIBUTION OF DBM AND A. PLUTELLAE ON THE CABBAGE PLANT AT DIFFERENT AGES

Like most other insects, the occurrence and spatial distribution of DBM over its host plant are not uniform, with certain parts or surfaces usually preferred to others. Likewise, the occurrence and distribution of its parasite, A. plutellae, may also closely follow it, as it is largely governed by the presence of the host(s). An understanding into these features could prove useful, particularly if chemicals are to be used rationally for efficient moth control while affecting minimally its parasite(s).

### 6.1 MATERIALS AND METHODS

In one of two studies carried out on transplanted crops, the oviposition pattern of DBM on potted cabbage plants (variety K-K Cross) at 3 different ages [4, 7 and 10 weeks after transplanting (WAT)] was investigated. At each growth stage, 10 plants were individually enclosed with 5 pairs of 2-day old DBM adults in 46.5 cm x 61.5 cm x 61 cm netted cages. Three days after, each plant was removed for record of all eggs deposited. The egg distribution was classified according to whether the eggs were deposited on the upper or lower leaf surface, or on young leaves (& shoots), moderately old leaves, or old leaves. Separation of the different leaf categories was arbitrarily considered as follows; (i) young leaves (& shoots) being those which are tender and yellowish-green, as well as, generally in the process of emerging and to a large extent still folded; (ii) moderately old leaves being light green in colour, of moderately hardened texture, and are fully opened as well as firmly held up; and (iii) old leaves being dark green, well hardened, and the leaves fully opened, spread out or drooping. Categorising separately eggs that were laid on stems and petioles was not attempted as eggs deposited on these parts were negligible. Harcourt (1957) recorded less than 1% of eggs laid on these portions.

In the 2nd study, the occurrence of larvae and pupae of DBM and its parasite cocoons were examined. These were made on unsprayed transplanted cabbages (variety Constanta F.1 Danish) taken at random from a 0.18-ha planting. The field was sub-divided into 3 lots, from each of which was taken 27 plants for DBM and parasite counts at 4-5, 6-7, 9-10 and 12-13 WAT. Their occurrence was similarly categorised according to whether they were on the upper or lower leaf surface, or on young leaves (& shoots), moderately old leaves, or old leaves.

Investigations on the occurrence of DBM, its parasites, and other arthropod species within the cabbage heads covered 3 aspects.

The first aimed to determine if any of the species could be found within the heads, and if so, their respective positions. In this study, freshly harvested cabbages ready for marketing were used; 30 heads taken randomly from an unsprayed crop in the MARDI Research Station, and 15 heads from a farmer's crop in Tanah Rata where insecticides were applied every 2-3 days. Beginning from the outermost of each head, all the leaves were peeled off individually and examined for the presence of any arthropod species.

The second study also utilized freshly-harvested cabbage heads but these were obtained from 3 different localities; 24 heads from an unsprayed crop in the MARDI Research Station, while 15 heads and 25 heads, respectively, from heavily-sprayed fields of farmers in Brinchang and Kg. Raja. These were individually enclosed for 2 weeks under laboratory conditions in wooden frame cages (38.1 cm x 38.1 cm x 38.1 cm) overlaid with white nylon netting. All arthropods emerging from the heads were determined. Subsequently, the cabbage heads from Brinchang and Kg. Raja were peeled for determination of the status of those still remaining within. This determination constituted the third aspect of investigations on the cabbage heads.

## 6.2 RESULTS

### 6.2.1 Distribution of the eggs of DBM on transplanted cabbage plant

The differential deposition of eggs by DBM between the abaxial and adaxial surface of cabbage leaves was distinctly in favour of the former only when the plants were young (Table 6.1). At 4 WAT eggs deposited on abaxial surface was 2.4 times that of the adaxial and this increased to about 3 folds at 7 WAT. By then, the difference was clearly evident and highly significant ( $t = 4.291$ ,  $df = 18$ ). However, by 10 WAT the difference was insignificant ( $t = 0.704$ ,  $df = 18$ ). This was also observed when egg population for all the plant ages was pooled ( $t = 1.657$ ,  $df = 4$ ) (Table 6.1). In general, there is a tendency for eggs to be deposited on the abaxial leaf surface as indicated by their consistent preponderance there.

In relation to total egg deposition with respect to leaf age, a significantly ( $P < 0.05$ ) higher number was found on moderately old leaves for all the plant stages studied. Between old and young leaves (& shoots) there was, however, no significant difference (Table 6.2).

Table 6.1 Differential deposition of the eggs of Plutella xylostella (L.) on the adaxial and abaxial leaf surfaces of cabbages (variety K-K Cross) at different times after transplanting.

| Plant age<br>(weeks after<br>transplanting) | Mean number of eggs/plant <sup>1/</sup> |         |                               |
|---------------------------------------------|-----------------------------------------|---------|-------------------------------|
|                                             | Leaf<br>surface:                        | Abaxial | Adaxial                       |
| 4                                           |                                         | 11.6    | 4.8                           |
| 7                                           |                                         | 25.9    | 8.7                           |
| 10                                          |                                         | 21.0    | 17.2                          |
| Total                                       |                                         | 195.0   | 102.3                         |
|                                             |                                         |         | Mean difference <sup>2/</sup> |
|                                             |                                         |         | *(t=2.396, df=18)             |
|                                             |                                         |         | *** (t=4.291, df=18)          |
|                                             |                                         |         | ns(t=0.704, df=18)            |
|                                             |                                         |         | ns(t=1.657, df=4)             |

1/ Replicated 10 times.

2/ ns = no significant difference, \* = significant at 5% level, and \*\*\* = significant at 0.1% level.

Table 6.2 Differential deposition of the eggs of Plutella xylostella (L.) on cabbage leaves of different ages. (Cabbage variety planted = K-K Cross).

| Plant age<br>(weeks after<br>transplanting)         | Category of<br>leaves <sup>1/</sup> : | Mean number of eggs/plant <sup>2/</sup> |         |         |
|-----------------------------------------------------|---------------------------------------|-----------------------------------------|---------|---------|
|                                                     |                                       | YL (S)                                  | MOL     | OL      |
| 4                                                   |                                       | 0.80 a                                  | 11.60 b | 4.00 a  |
| 7                                                   |                                       | 1.80 a                                  | 30.00 b | 3.90 a  |
| 10                                                  |                                       | 6.70 a                                  | 25.20 b | 6.30 a  |
| All plant ages<br>considered together <sup>3/</sup> |                                       | 9.10 a                                  | 66.80 b | 13.80 a |

1/ YL (S) = Young leaves (& shoots) which are tender and yellowish-green. These are generally in the process of emerging and to a large extent still folded; MOL = Moderately old leaves which are light green, moderately hardened, and fully opened as well as firmly held up; OL = Old leaves which are hardened, dark green, and fully opened, spread out or drooping.

2/ Means followed by similar letter for each plant age are not significantly different ( $P = 0.05$ ) based on the Duncan's Multiple Range Test.

3/ The mean population considered in this group is for a total of 30 plants.

#### 6.2.2 Occurrence of larvae and pupae of DBM and the cocoons of A. pluteillae on transplanted cabbage plant

Since the spatial distributions of immature stages of DBM on brassica plant approximate the negative binomial (Harcourt, 1960; Chua & Lim, 1977, 1979) and a  $\log(x + 1)$  transformation found satisfactory

(Harcourt, 1960) this was employed in the present analysis. Although larval populations recorded on the under surface of leaves were relatively higher in all the plant stages studied (Fig. 6.1) none was significantly different (Table 6.3). Of 3248 larvae, 55.9% occurred on the adaxial leaf surface.

Both pupae of DBM and cocoons of A. plutellae were also found in greater numbers on the underside. However, differences in populations on upper and lower surface were highly significant only for some of the plant stages (Table 6.3). With host pupae, 29.3% of 208 was recorded on the upper surface, while 74.2% of 469 parasite cocoons occurred on the underside.

In relation to distribution among the different leaf categories, that of A. plutellae cocoons and pupae of DBM showed no significant difference (Table 6.4). There was, however, a tendency for cocoons to be higher on both old and moderately old leaves; the total amounting to 71.6%. For larvae and pupae of DBM, the reverse was true (Table 6.4). Of 3248 larvae and 208 pupae, only 23.2% and 22.1% respectively were on old leaves. In both, nearly 40% were on the shoots and young tender leaves.

#### 6.2.3 Location of DBM and its parasite A. plutellae within marketable cabbage heads

Since previous studies on the occurrence of DBM and its parasites on cabbages have exclusively involved transplanted crops, investigations were made to clarify their possible presence within the cabbage heads. It is hoped that such knowledge could prove useful in the control and better understanding on the dispersal ecology of the moth.

In spite of the rather tight and closed conditions of the cabbage heads, both DBM and its parasites were readily located within when the leaves were gradually peeled off (Tables 6.5 & 6.6). The stages observed have included both larvae and pupae of DBM, and cocoons of the parasite. Although most were recorded from the first 15 outer leaves, some were found as far in as the 27th leaf. It is probable that they were trapped within as the younger leaves on which they had concentrated began to fold over one another to become compacted into the head. In unsprayed treatment 46.7% of the heads had infestations within, while that of sprayed heads 80%. Evidently, insecticides in the latter could not reach within the heads to kill the larvae.

#### 6.2.4 Insects emerging from harvested and cleaned marketable cabbage heads

Although both DBM and its parasite occurred within the cabbage heads (see 6.2.3), it was not certain as to what would be their fate.

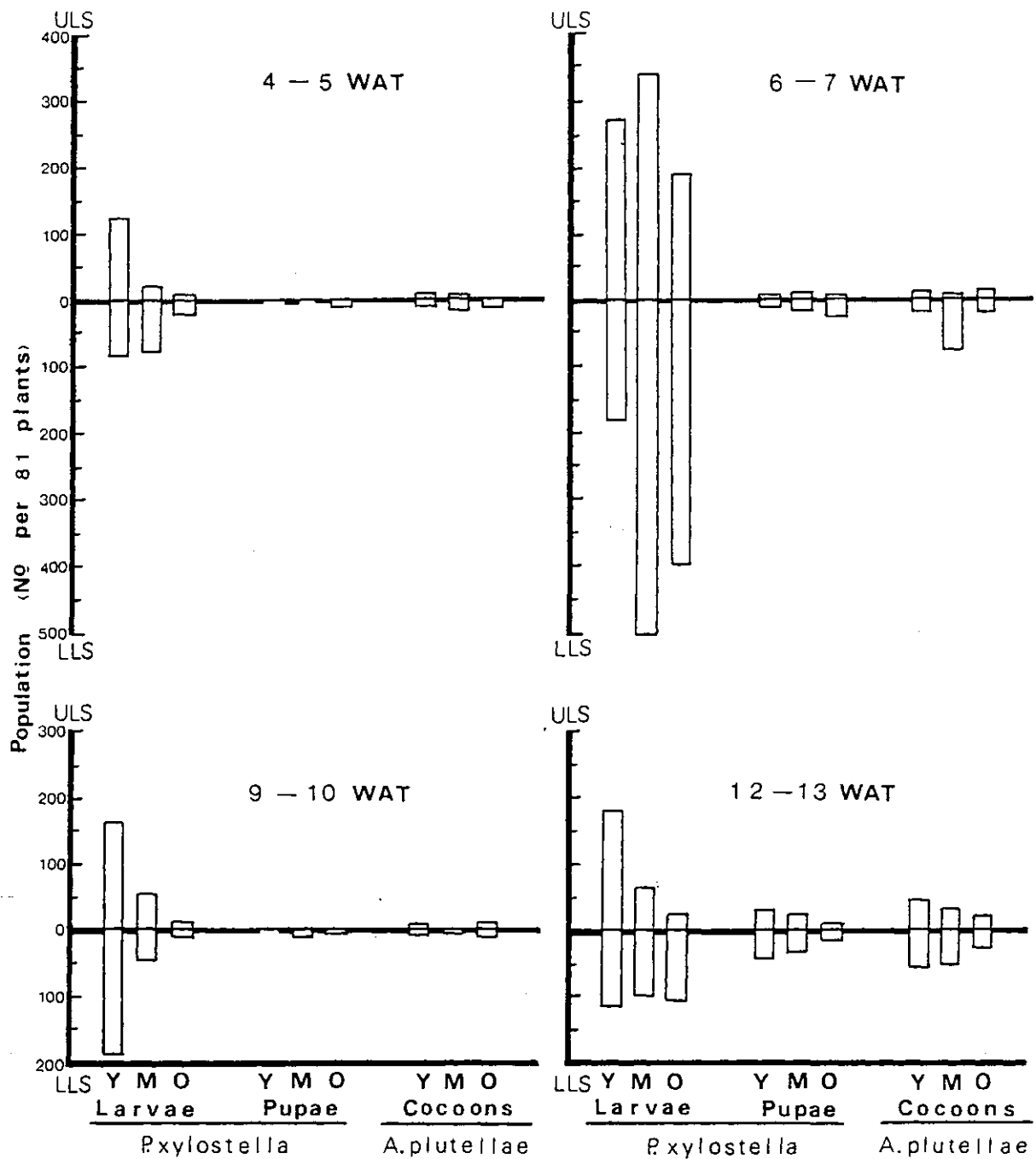


FIGURE 6.1 Occurrence and distribution of the larvae and pupae of *Plutella xylostella* (L.) and the cocoons of *Apanteles plutellae* Kurdj. on cabbages at different plant age. (WAT = Weeks after transplanting; ULS = Upper leaf surface, LLS = Lower leaf surface; Y = Young leaves/shoots, M = Moderately old leaves, O = Old leaves).

Table 6.3 Occurrence of the larvae and pupae of Plutella xylostella (L) and the cocoons of Apanteles plutellae Kurdj. on the different leaf surfaces of cabbages (variety Constanta Fl) at different times after transplanting.

| Plant age<br>(WAT) <sup>2/</sup> | Mean population/27 plants <sup>1/</sup> |         |                               |         |         |                               |                     |         |                               |
|----------------------------------|-----------------------------------------|---------|-------------------------------|---------|---------|-------------------------------|---------------------|---------|-------------------------------|
|                                  | <u>P. xylostella</u>                    |         |                               |         |         |                               | <u>A. plutellae</u> |         |                               |
|                                  | Larvae                                  |         |                               | Pupae   |         |                               |                     |         |                               |
|                                  | Abaxial                                 | Adaxial | Mean difference <sup>3/</sup> | Abaxial | Adaxial | Mean difference <sup>3/</sup> | Abaxial             | Adaxial | Mean difference <sup>3/</sup> |
| 4 - 5                            | 54.33                                   | 57.67   | ns(t=1.190,<br>df=4)          | 0.00    | 0.33    | 4/                            | 2.00                | 5.67    | 4/                            |
| 6 - 7                            | 267.33                                  | 360.00  | ns(t=0.373,<br>df=4)          | 3.00    | 15.00   | *** (t=26.320,<br>df=4)       | 11.00               | 59.67   | *** (t=195.451,<br>df=4)      |
| 9 - 10                           | 71.00                                   | 79.67   | ns(t=0.469,<br>df=4)          | 0.00    | 1.33    | 4/                            | 0.67                | 2.00    | 4/                            |
| 12 - 13                          | 85.00                                   | 107.67  | ns(t=1.294,<br>df=4)          | 17.33   | 32.33   | *** (t=53.766,<br>df=4)       | 26.67               | 48.67   | *** (t=120.196,<br>df=4)      |
| Total                            | 119.42                                  | 151.25  | ns(t=0.647,<br>df=22)         | 5.08    | 12.25   | ns(t=1.086,<br>df=22)         | 10.08               | 29.00   | ns(t=1.673,<br>df=22)         |

1/ Replicated 3 times.

2/ WAT = Weeks after transplanting.

3/ ns = no significant difference, \*\*\* = significantly different at 0.1% level.

4/ Statistical analysis not carried out as the population levels were too low.

Table 6.4 Occurrence of the larvae and pupae of Plutella xylostella (L.) and the cocoons of Apanteles plutellae Kurdj. on cabbage leaves of different ages. (Cabbage variety planted = Constanta F.1 Danish).

| Plant age<br>(weeks after<br>transplan-<br>ting)       | Category of<br>leaves <sup>1/</sup> | Mean population/27 plants <sup>2,3/</sup> |         |                               |
|--------------------------------------------------------|-------------------------------------|-------------------------------------------|---------|-------------------------------|
|                                                        |                                     | <u>P.xylostella</u>                       |         | <u>A.plutellae</u><br>cocoons |
|                                                        |                                     | Larvae                                    | Pupae   |                               |
| 4 - 5                                                  | YL (S)                              | 67.67 a                                   | 0.00)   | 1.33 a                        |
|                                                        | MOL                                 | 36.33 ab                                  | 0.00)   | 4.00 a                        |
|                                                        | OL                                  | 8.00 b                                    | 0.33)   | 2.33 a                        |
| 6 - 7                                                  | YL (S)                              | 149.33 a                                  | 3.00 a  | 9.00 a                        |
|                                                        | MOL                                 | 280.00 a                                  | 6.00 a  | 27.00 a                       |
|                                                        | OL                                  | 198.00 a                                  | 9.00 a  | 34.67 a                       |
| 9 - 10                                                 | YL (S)                              | 114.67 a                                  | 0.00)   | 1.00)                         |
|                                                        | MOL                                 | 32.67 b                                   | 1.00)   | 0.33)                         |
|                                                        | OL                                  | 3.33 b                                    | 0.33)   | 1.33)                         |
| 12 - 13                                                | YL (S)                              | 96.67 a                                   | 24.00 a | 33.00 a                       |
|                                                        | MOL                                 | 54.00 a                                   | 20.00 a | 27.00 a                       |
|                                                        | OL                                  | 42.00 a                                   | 5.67 a  | 15.33 a                       |
| All plant ages<br>considered<br>together <sup>4/</sup> | YL (S)                              | 428.33 a                                  | 27.00 a | 44.33 a                       |
|                                                        | MOL                                 | 403.00 a                                  | 27.00 a | 58.33 a                       |
|                                                        | OL                                  | 251.33 b                                  | 15.33 a | 53.67 a                       |

1/ YL (S) = Young leaves (& shoots) which are tender and yellowish-green. These are generally in the process of emerging and to a large extent still folded; MOL = Moderately old leaves which are light green, moderately hardened, and are fully opened as well as firmly held up; OL = Old leaves which are hardened, dark green, and fully opened, spread out or drooping.

2/ Replicated 3 times.

3/ Means followed by similar letter in the same column are not significantly different ( $P = 0.05$ ) based on the Duncan's Multiple Range Test.

4/ The mean population considered in this group is for a total of 108 plants.

5/ Statistical analysis not attempted because the population obtained was too low.

Whether they would continue to remain within and die was investigated through confinement of the cabbage heads for observation of possible emergence. From such a study, it was revealed that both DBM and its parasites (A. plutellae and D.eucerothaga) could somehow survive to emerge (Table 6.6). The emergence, however, may be of a different nature. In some, the adult DBM and parasites would first emerge within and later crawl out of the head. Alternatively, larvae of DBM may move out to pupate, and if parasitized, the parasites then emerge to pupate. Generally, by the 12th day

Table 6.5 Location of Plutella xylostella (L) and its parasite Apanteles plutellae Kurj. within marketable cabbage heads obtained from sprayed and unsprayed fields in Tanah Rata, Cameron Highlands.

| Leaf No. 1/ | No. of <u>P. xylostella</u> and <u>A. plutellae</u> |   |   |                                  |   |   |
|-------------|-----------------------------------------------------|---|---|----------------------------------|---|---|
|             | <u>Within 15 sprayed heads</u>                      |   |   | <u>Within 30 unsprayed heads</u> |   |   |
|             | L                                                   | P | C | L                                | P | C |
| 1           | 0                                                   | 1 | 1 | 0                                | 3 | 0 |
| 2           | 1                                                   | 1 | 1 | 0                                | 1 | 2 |
| 3           | 1                                                   | 0 | 0 | 3                                | 0 | 2 |
| 4           | 1                                                   | 0 | 1 | 3                                | 1 | 1 |
| 5           | 3                                                   | 0 | 0 | 3                                | 0 | 0 |
| 6           | 3                                                   | 0 | 0 | 2                                | 0 | 0 |
| 7           | 1                                                   | 0 | 0 | 0                                | 0 | 0 |
| 8           | 2                                                   | 1 | 0 | 3                                | 0 | 1 |
| 9           | 1                                                   | 1 | 0 | 1                                | 0 | 0 |
| 10          | 2                                                   | 0 | 0 | 2                                | 0 | 0 |
| 11          | 0                                                   | 0 | 0 | 0                                | 1 | 0 |
| 12          | 2                                                   | 0 | 0 | 1                                | 0 | 0 |
| 13          | 2                                                   | 0 | 0 | 0                                | 1 | 0 |
| 14          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 15          | 1                                                   | 0 | 0 | 0                                | 0 | 0 |
| 16          | 0                                                   | 0 | 0 | 1                                | 0 | 0 |
| 17          | 1                                                   | 0 | 0 | 0                                | 0 | 0 |
| 18          | 1                                                   | 0 | 0 | 0                                | 0 | 0 |
| 19          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 20          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 21          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 22          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 23          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 24          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 25          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 26          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 27          | 0                                                   | 0 | 0 | 1                                | 0 | 0 |
| 28          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 29          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 30          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 31          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 32          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 33          | 0                                                   | 0 | 0 | 0                                | 0 | 0 |
| 34          |                                                     |   |   | 0                                | 0 | 0 |
| 35          |                                                     |   |   | 0                                | 0 | 0 |
| 36          |                                                     |   |   | 0                                | 0 | 0 |
| 37          |                                                     |   |   | 0                                | 0 | 0 |
| 38          |                                                     |   |   | 0                                | 0 | 0 |
| 39          |                                                     |   |   | 0                                | 0 | 0 |

1/ Beginning from the outermost on a marketable head.

2/ L, P = Respectively larva and pupa of P. xylostella, C = Cocoon of A. plutellae



Table 6.6 Insects emerging from cabbage heads (cleaned and marketable) purchased from Brinchang <sup>1/</sup> and Kg. Raja (50th mile) <sup>4/</sup> and others harvested from MARDI Research Station (Tanah Rata) <sup>2/</sup> in the Cameron Highlands.

| Nature of emergence <sup>3/</sup>            | Total No. of heads | No. of insects emerging at following days after harvesting |   |   |   |   |   |   |   |   |    |    |    |    |                 | Total |
|----------------------------------------------|--------------------|------------------------------------------------------------|---|---|---|---|---|---|---|---|----|----|----|----|-----------------|-------|
|                                              |                    | 1                                                          | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14              |       |
| A. CABBAGES SPRAYED WITH INSECTICIDES        |                    |                                                            |   |   |   |   |   |   |   |   |    |    |    |    |                 |       |
| i. <u>Brinchang</u> <sup>1/</sup>            | 15                 |                                                            |   |   |   |   |   |   |   |   |    |    |    |    |                 |       |
| Pl                                           |                    | -                                                          | 2 | 4 | - | - | 4 | 2 | - | 1 | -  | -  | -  | -  | -               | 13    |
| Ap                                           |                    | -                                                          | - | - | - | - | - | - | - | - | -  | -  | -  | -  | -               | -     |
| Da                                           |                    | -                                                          | - | - | - | - | 2 | 1 | - | - | -  | -  | 3  | -  | -               | 6     |
| Dp                                           |                    | -                                                          | - | - | - | - | - | 2 | - | - | -  | -  | -  | -  | -               | 2     |
| Others                                       |                    | -                                                          | - | - | - | - | - | - | - | - | -  | -  | -  | -  | -               | -     |
| ii. <u>50th mile, Kg. Raja</u> <sup>1/</sup> | 25                 |                                                            |   |   |   |   |   |   |   |   |    |    |    |    |                 |       |
| Pl                                           |                    | -                                                          | - | - | 4 | - | - | 2 | - | - | -  | -  | 1  | -  | -               | 7     |
| Ap                                           |                    | -                                                          | - | - | - | - | - | - | - | 2 | -  | -  | 1  | -  | -               | 3     |
| Aa                                           |                    | -                                                          | - | - | - | - | - | 2 | - | 1 | -  | -  | 1  | -  | -               | 4     |
| Ha                                           |                    | -                                                          | - | - | 2 | - | - | 1 | - | 1 | -  | -  | -  | -  | -               | 4     |
| Others                                       |                    | -                                                          | - | - | - | - | - | - | - | - | -  | -  | -  | -  | 1 <sup>4/</sup> | 1     |
| B. UNSPRAYED CABBAGES <sup>2/</sup>          |                    |                                                            |   |   |   |   |   |   |   |   |    |    |    |    |                 |       |
|                                              | 24                 |                                                            |   |   |   |   |   |   |   |   |    |    |    |    |                 |       |
| Pl                                           |                    | -                                                          | - | 4 | - | 6 | 2 | - | 1 | - | -  | 1  | 1  | -  | -               | 15    |
| Ap                                           |                    | -                                                          | - | 1 | - | - | - | - | - | - | -  | -  | 2  | -  | -               | 3     |
| Aa                                           |                    | -                                                          | - | - | - | 1 | - | - | 1 | - | -  | -  | -  | -  | -               | 2     |
| Hp                                           |                    | -                                                          | - | - | - | 1 | 2 | - | - | - | -  | -  | -  | -  | -               | 3     |
| Others                                       |                    | -                                                          | - | - | - | - | - | - | - | - | -  | -  | -  | -  | -               | -     |

<sup>1/</sup> The pre-harvest cabbages were subjected to regular insecticidal sprays at 2 - 3 days interval with mixtures of chemicals, particularly Tameron<sup>®</sup> and Dipel<sup>®</sup>.

<sup>2/</sup> The cabbage heads were obtained from crops cultivated successively without any insecticidal treatment.

<sup>3/</sup> Pl = Plutella xylostella larva emerging to the outer leaves to pupate; Ap = P.xylostella emerging as adult; Aa = Apanteles plutellae emerging as adult; Ha = Host larvae emerging to outer leaves, followed by emergence of the parasite (A.plutellae) larvae; Da = Diadegma eucerothaga emerging as adult; Dp = Host larvae emerging to outer leaves, followed by emergence of the parasite D.eucerothaga

<sup>4/</sup> Dipteran adult.

all would have completely emerged. From one of the heads, however, a dipteran adult also emerged on the 14th day.

When cabbage heads from Kg. Raja were peeled open at the end of the observational period, there was found only a dead larva of S.litura under the 6th leaf of one of the heads, as well as, a dead adult of DBM under the 3rd leaf of another (Table 6.7).

Table 6.7 Insects species found remaining within the cabbage heads purchased from Brinchang and Kg. Raja (50th mile) in the Cameron Highlands.

| Insect species              | Leaf no. <sup>1/</sup> on which insect species<br>was found              |          | Total |
|-----------------------------|--------------------------------------------------------------------------|----------|-------|
|                             | Location: <sup>2/</sup> Brinchang                                        | Kg. Raja |       |
| <u>Diadegma eucrophaga:</u> |                                                                          |          |       |
| Empty pupal case            | 2nd, 4th, 5th(x2),<br>6th, 7th(x2), 9th,<br>10th, 12th.                  | -        | 10    |
| Dead adult                  | 4th, 5th.                                                                | -        | 2     |
| Dead flea beetle            | 4th, 5th(x3), 6th(x3),<br>7th(x3), 8th(x2), 9th,<br>10th, 12th, 13th(x2) | -        | 17    |
| <u>Plutella xylostella:</u> |                                                                          |          |       |
| Dead larva                  | 2nd(x3), 3rd(x22),<br>12th(x4)                                           | -        | 29    |
| Dead pupa                   | 9th                                                                      | -        | 1     |
| Empty pupal case            | 6th                                                                      | -        | 1     |
| Dead adult                  | 3rd, 4th, 7th, 12th                                                      | 3rd      | 4     |
| <u>Spodoptera litura:</u>   |                                                                          |          |       |
| Dead larva                  | -                                                                        | 6th      | 1     |

1/ The outermost leaf on a head was considered the 1st leaf. When more than one specimen were recorded on a particular leaf, the numbers are indicated within brackets.

2/ The total number of cabbages considered for Brinchang was 15 while that for Kg. Raja was 25.

Apparently, only a very small percentage of the insects initially trapped within these heads fail to emerge. Although leaves of cabbages generally overlay upon one another rather tightly, most of the insects are still able to survive and find their exit to the exterior. Perhaps they move

out as the leaves tighten up. However, in cabbage heads collected from Brinchang, substantial numbers of different insect species died within (Table 6.7). Some were noted as far in as the 12th leaf. For DBM, most were in the larval stage. Although not confirmed from pathogen isolates, many were suspected to have succumbed to disease as indicated by their watery, foul and disintegrated appearance. This is not unexpected as hearted brassica plants can promote conditions which encourage diseases (Way et al, 1951). Largely, this occurs through the compact leaves holding wet insect faeces in pockets of stagnant air of increased humidity which favours diseases (Gunn, 1917; Smith, 1931; Way et al, 1951; Present studies, Section 5).

### 6.3 DISCUSSION

From investigation on differential oviposition by DBM on cabbages, it is evident that the abaxial leaf surface received more eggs, amounting to 65.6%. This finding, however, does not agree with those of many other workers. For example, Marsh (1917), Muggeridge (1930), Robertson (1939), Kanervo (1936), Miles (1924) and Salinas (1972) stated that the eggs are laid principally on the lower leaf surface. Only the results of Gunn (1917), Harcourt (1957) and Chua & Lim (1977, 1979) support the present finding. Although eggs were principally found on the undersides of leaves in most of the reports, many of these have either been based on laboratory rearing in small enclosures or on limited observations in the field. Harcourt (1957) noted that when closely confined the moth does not oviposit normally. Under such conditions, the moth lays more eggs on the stem than in the field, and often lays large numbers on the sides or bottoms of containers. Other major factors are, perhaps, the variety and the age of the plants in use during the assessment. The latter, for example, resulted in higher numbers being deposited on the upper surface when younger stages were used. The proportion laid declined from 70.7% at 4 WAT and 74.9% at 7 WAT to about 55.0% at 10 WAT (Table 6.1).

Why more eggs are usually laid on upper leaf surface during early growth stages is not clear. Perhaps, the texture in younger leaves may have a significant influence. A higher egg deposition on lower surface at later stages (e.g. 10 WAT) could be due to increase in concavities as more leaves become mature and have better developed veins which are more pronounced. That this appears so is in part supported by the findings of Gupta & Thorsteinson (1960) and Salinas (1972) who found that eggs of DBM were preferentially laid in concavities of leaves and stem, and significantly more on a pebbled, grooved or pitted polyethylene surface than on a smooth substrate of the same material. However, this

factor could not entirely account for the significantly higher number of eggs recorded on moderately old leaves. In this case, the greater abundance was also due to a relatively higher number of such leaves (averaging 48.5%). As such, the apparent differences could not be considered as reflecting the moth's ovipositional preference. In any case, this study does not aim to unravel such differential preferences, but merely to determine if any relative differences exist, and if so, how such understanding may help towards the proper and more effective use of pesticides.

Guided by the above finding, it appears that any employment of chemical ovicides for the management of DBM should ensure special effort in targeting the sprays over moderately old leaves, particularly the upper leaf surface in early growth stages. When plants exceed 10 weeks old, emphasis for the upper surface is not critical, but getting the chemical onto both leaf surfaces would seem desirable. However, since oviposition distribution may vary according to Brassica species and variety, caution is needed in relating these actions on crops other than the one evaluated.

For larvae and pupae, the situation is less simple. Although more are found on the adaxial surface, substantial numbers are also present on the upperside. As such, spraying of both surfaces are still essential. However, treatment of older leaves appears unnecessary as these contain relatively small numbers of the pest population. Using such spraying procedure, it would be possible to destroy at least 77% of the larval population while preserving about 34% of the parasite's cocoons, even if broad-spectrum insecticides are used. However, with narrower-spectrum materials, such 'target treatment' is likely to magnify further in favour of the parasite's survival.

As regard occurrence of DBM and its parasites within cabbage heads, the findings have notable implications for the management of the moth. Among the adjoining cabbage farms, pest survival within the heads between croppings will constitute a contributory factor in initiating and maintaining its presence in succeeding crops. A possible source would include cabbages retained by farmers for family consumption since these are usually uncovered in the homes. However, its relative importance with respect to other carry-over factors, such as, left-over crop residues and the survival on cruciferous weed hosts (Ullyett, 1947) is not known.

Another related aspect concerns their dispersal ecology. Unless totally exterminated by systemic insecticides which themselves are undesirable for reason of residues, the presence of these insects protected within the heads would constitute a reservoir of population. Potentially, they could be dispersed far and wide when the cabbage heads containing them are distributed via the marketing system. Ho (1965) suggested that

DBM probably came into Malaysia through importation of cruciferous vegetables, either legally or illegally via Thailand in the north or from Sumatra to the west, and via Singapore from Taiwan. Practically, this can happen since cabbage heads need to be despatched very rapidly to avoid deterioration, and normally this occurs well within the emergent period (ca 2 weeks) from the time of crop harvest. For DBM, involvement of such a dispersal mechanism is probably important only over time since the moth could easily migrate over long distances, e.g. from continental Europe (Russia) to England and Scotland in 1936 and 1958, respectively (Hardy, 1938; French & White, 1960; French, 1965 ; Johnson, 1969). Such a migrating flight of the moth has also been observed in North America (List, 1937). For its parasites, dispersal within cabbage heads is perhaps even less important. Otherwise, parasite species in the region should be rather similar and more common.

On the other hand, dispersal in cabbage heads may perhaps be more important within the country since cabbages are generally more actively distributed internally. For example, movements of cabbage heads occur from the Cameron Highlands to various parts of the country daily. This may possibly account for why A. plutellae has so quickly become widespread in West Malaysia.

In general, it appears that understanding of the occurrence and spatial distribution of both DBM and its parasites can be important for the management of the moth. These aspects, evidently, merit consideration when control guidelines are being developed.

## 7. FIELD ABUNDANCE OF DBM IN RELATION TO PLANTING AND NATURAL ENVIRONMENTAL FACTORS

Comprehensive studies on field abundance of DBM in relation to influencing factors are generally limited, being largely confined to studies by Hardy (1938), Ulliyett (1947), Vos (1953), Harcourt (1963, 1969), Oatman & Platner (1969) and Goodwin (1979). In many places where DBM is of concern the knowledge is largely from cursory observation and extended field experience. Where some data based on periodic samplings are available, these were normally not taken continuously for sufficient duration to enable the establishment of a meaningful pattern of its occurrence should trends exist. This is particularly true in the Cameron Highlands where knowledge of its abundance is confined mainly to vague impressions associating it with dry and low rainfall periods. Beyond this, except for some initial studies by Ooi (1979a), much information on its field abundance and the natural governing factors are lacking. The present investigations thus aimed to gather such knowledge, particularly on how population fluctuations may be affected by crop age, time of planting, seasonal changes and naturally-occurring biological control factors.

### 7.1 MATERIALS AND METHODS

Essentially, these studies are detailed analyses of various relating factors recorded over 32 continuous overlapping and unsprayed crops cultivated between 1973-80. The methodology has been described earlier in Section 4.

### 7.2 RESULTS AND DISCUSSION

An initial attempt to understand the population fluctuation of DBM in the field was to determine if the build-up is governed by the age of infested crop. In this regard, the population development of DBM for the first 30 crops were individually plotted against the developmental age (days after transplanting) of each crop. From Fig. 7.1, it is evident that the population fluctuations is unrelated to the age of infested crop. For some crops, a gradual build-up was observed, culminating in a single peak at the later age. With a few, infestation was high initially, but later declined either sharply or slowly. In yet others, there were two distinct peaks; a smaller build-up preceded by a larger one, or vice versa. Evidently, even if the age of the crop were to have any influence on the population fluctuations of DBM, it would not be an over-riding factor.

When parasitism rates of A. plutellae are superimposed over the fluctuations of DBM over each crop, there was generally an inverse rela-

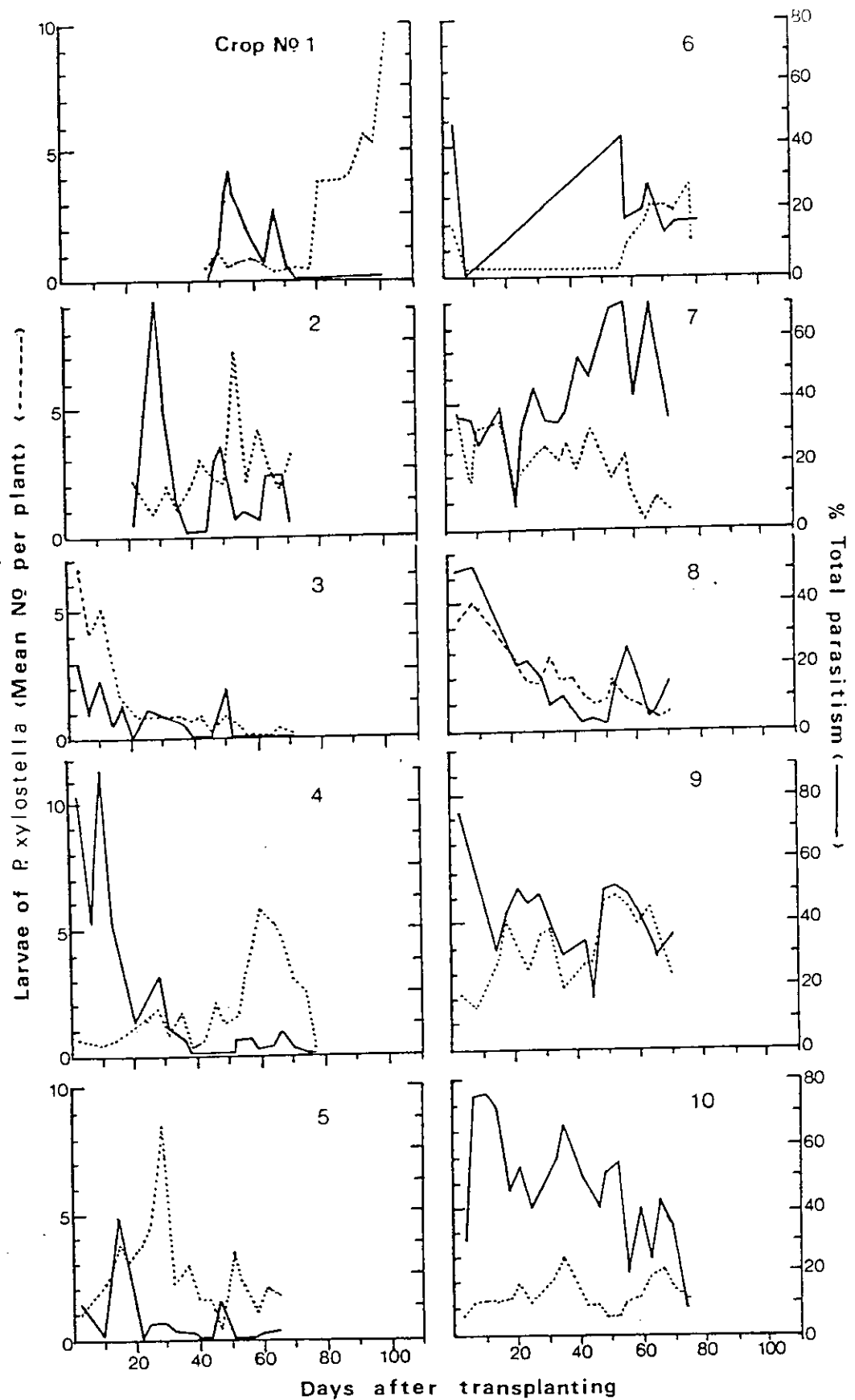


FIGURE 7.1 Population development of *Plutella xylostella* (L.) and its parasitization by *Apanteles plutellae* Kurdj. in relation to crop age. ( For each cabbage crop there was overlapping by a preceding and successive planting ).

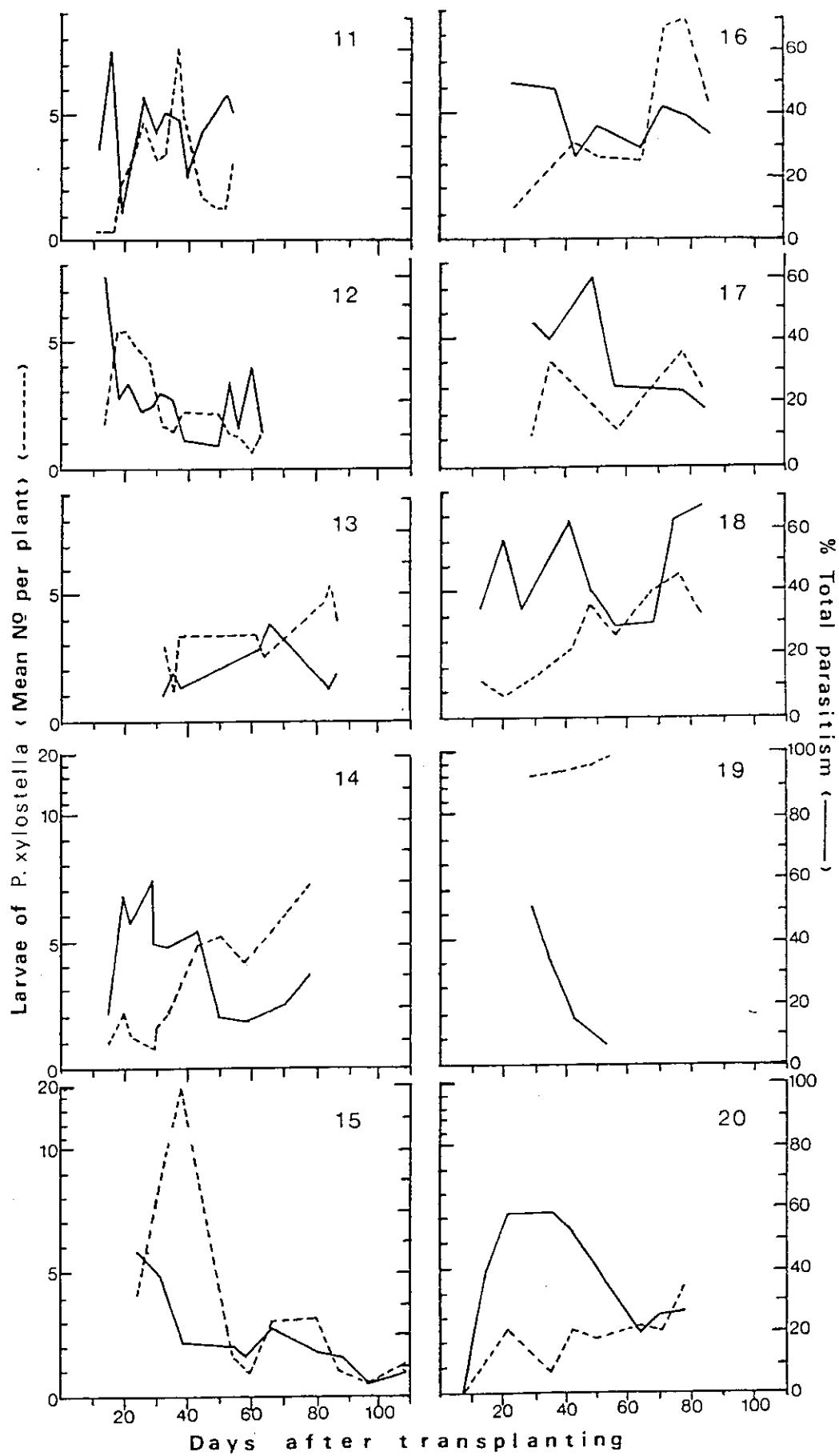


FIGURE 7.1 (Continued 1).



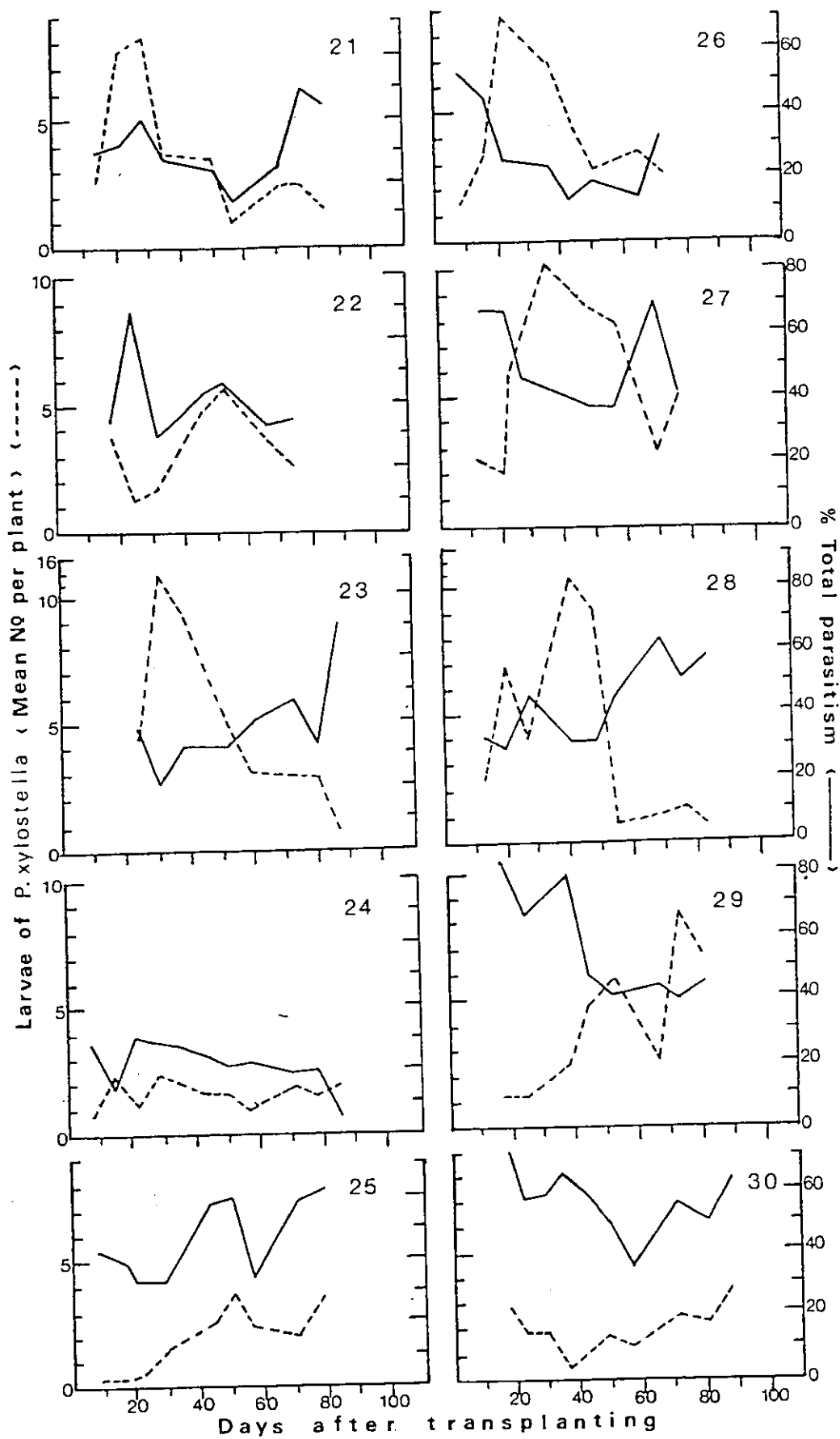


FIGURE 7.1 (Continued 2).

tionship (Fig. 7.1). A high parasitism is almost invariably associated with low host population, and vice versa. This general association is further indicative of the parasite's suppressive effect, and to some extent, its contribution in governing the moth's abundance and population fluctuations.

Since plant age has little or no influence, the DBM fluctuations were further examined in relation to seasonality. Fig. 7.2 shows the moth building up in two distinct parts of the year. The first, which is generally bigger, usually occurs over a narrower time period between the later part of January to April. Although it normally peaks in February, the peak may sometimes occur around March, or even as late as May. The latter, however, is not usual. In the 2nd build-up, the range of noticeable occurrence is often much wider, extending from June to October (Fig. 7.2). Peak occurrence normally is evident in August, though this may sometimes be slightly earlier at the end of July or much later in September/October.

Since the time of yearly build-up is fairly consistent, seasonal influence is believed responsible. In particular, rainfall appears a strong contributory factor. The long time impression that DBM infestations are generally low during periods of higher rainfall is well borne out by the present studies, except for the short period between January and August in 1977 where the reverse was observed (Fig. 7.2). For temperature and relative humidity, no clear pattern in their relationships was evident. Analyses showed the correlation to be insignificant ( $P > 0.05$ ) irrespective of whether data for the period January-August, 1977 were included (Fig. 7.3) or omitted (temperature:  $r = -0.2387$ ,  $df = 62$ ; RH:  $r = -0.1865$ ,  $df = 62$ ). For rainfall a significant negative correlation ( $0.01 < P < 0.02$ ) was, however, obtained (Fig. 7.3), when data for the mentioned period were excluded. It has a significant slope ( $P < 0.05$ ,  $t = 2.513$ ,  $df = 62$ ) and a regression equation of  $y = 4.659 - 0.0057x$ , suggesting an increase of one larva per plant for every 175 mm reduction in monthly precipitation. Such a climatic influence appears critical as the mean population per plant (see 4.5) at mean monthly rainfall of 192.00 mm is presently quite close to the economic threshold of 37 larvae/10 plants (Jusoh *et al.*, 1981). Especially during the dry spells, this population is likely to increase beyond the economic threshold.

Although rainfall may only occasionally be important (Hardy, 1938) in some temperate countries (e.g. England), it is evidently of substantial importance in the Cameron Highlands largely because precipitation is generally much greater there. During heavy rain (particularly tropical rainstorms), drowning of the larvae may constitute the main source of

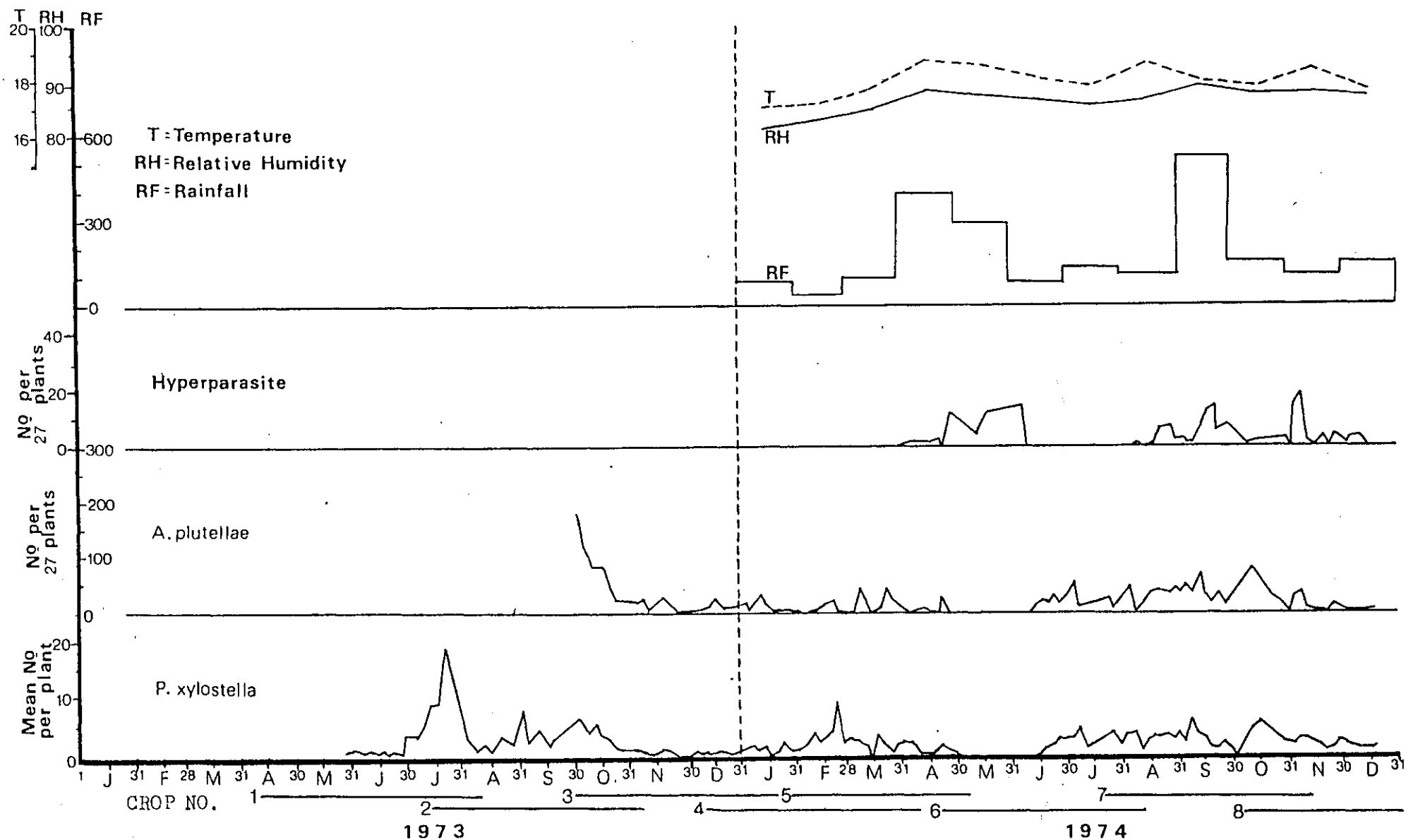


FIGURE 7.2 Seasonal occurrence of *Plutella xylostella* (L.), its parasite *Aranteles plutellae* Kurdj., and the hyperparasite activity in relation to various climatic parameters.

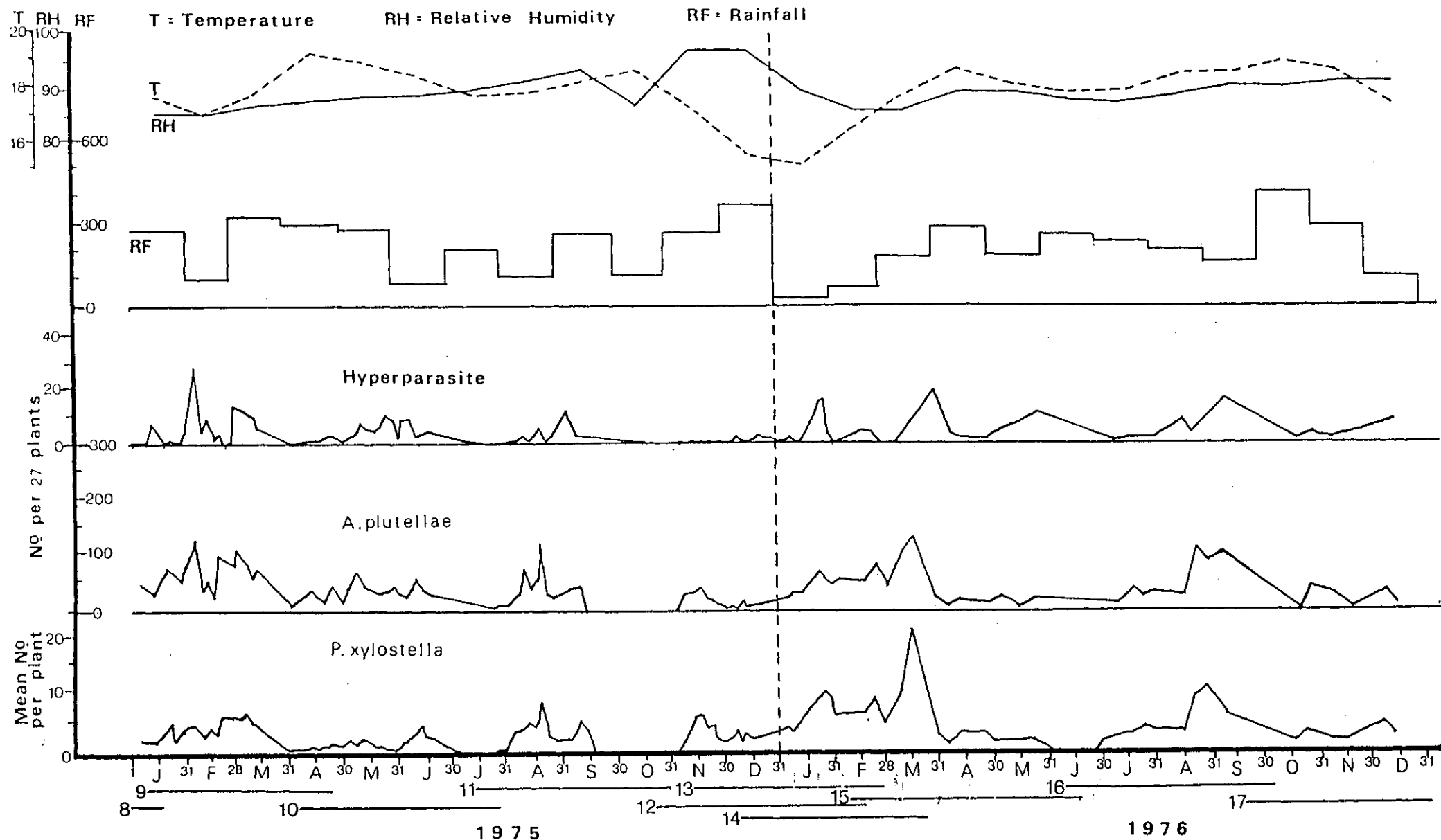


FIGURE 7.2 (Continued 1).

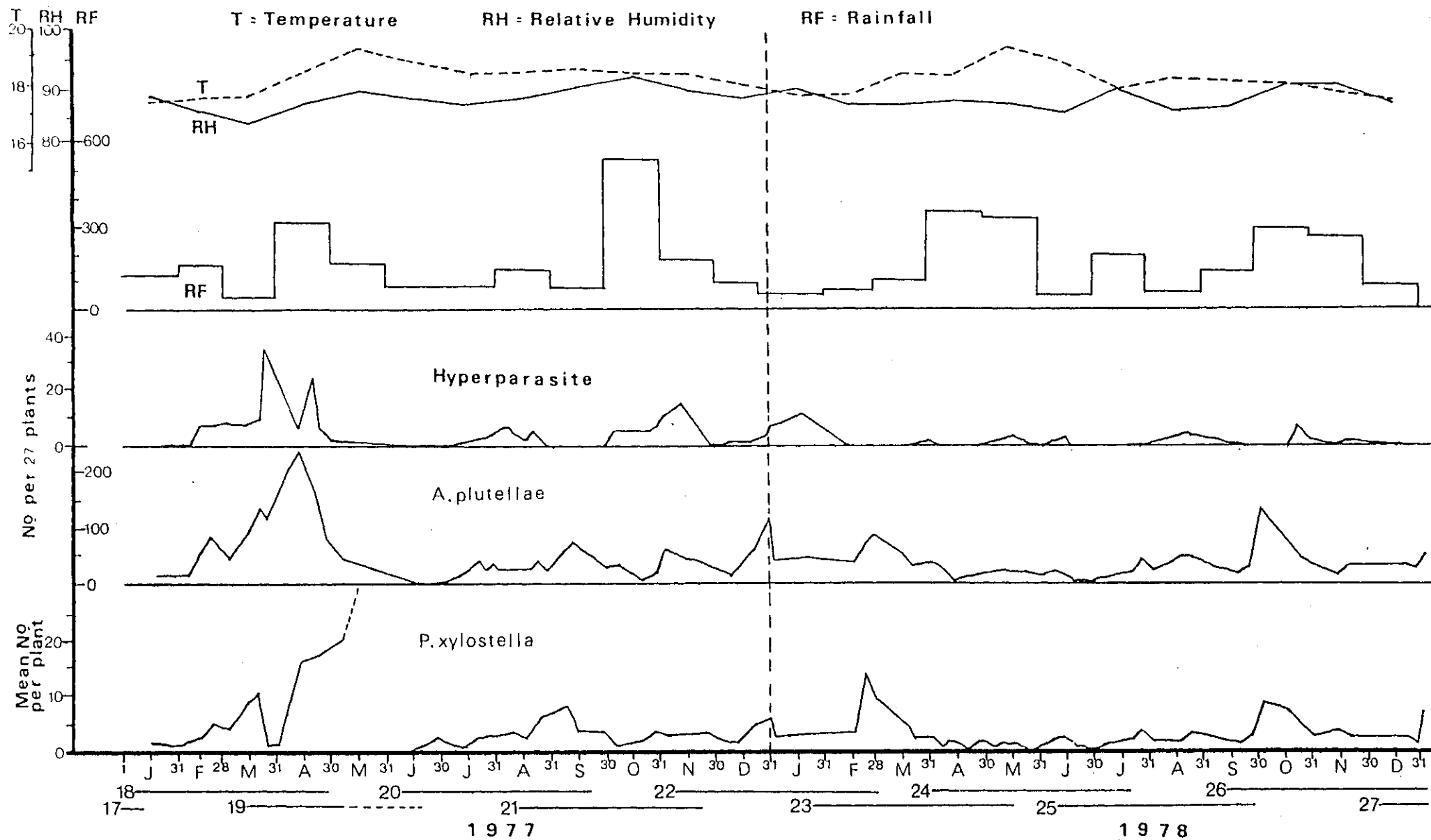


FIGURE 7.2 (Continued 2).

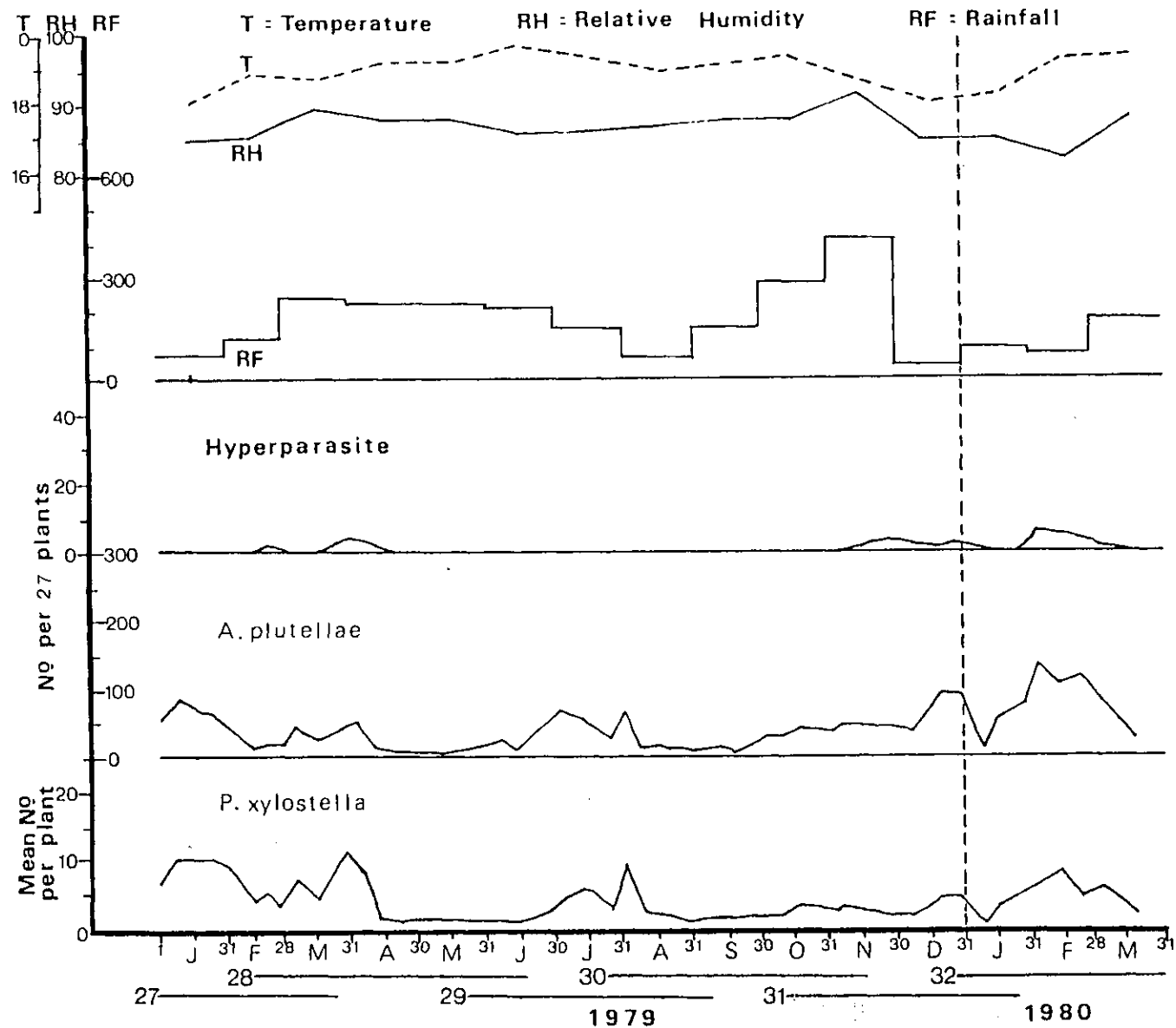


FIGURE 7.2 (Continued 3).

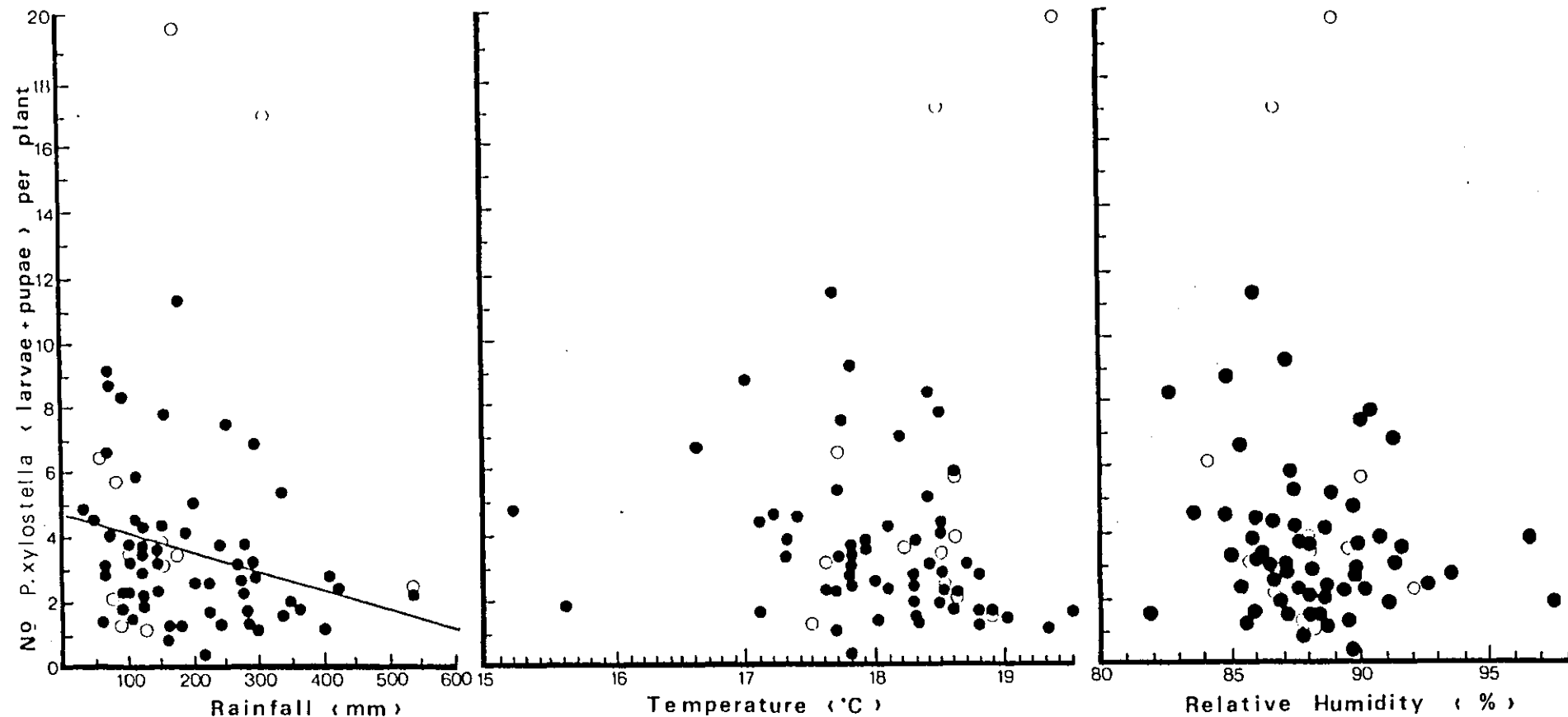


FIGURE 7.3 Relationships between the abundance of *Plutella xylostella* (L.) on successive and overlapping croppings of cabbages (variety Constanta F.1 Danish) and some climatic parameters in the Cameron Highlands. (Regression analyses when data (o) between Jan-August, 1977 are included: Rainfall,  $b=-0.00345$ ,  $a=4.5573$ ,  $r=-0.1165$  (ns),  $df=70$ ; Temperature,  $b=-0.49596$ ,  $a=12.870$ ,  $r=-0.1118$  (ns),  $df=70$ ; RH,  $b=-0.1487$ ,  $a=17.009$ ,  $r=-0.1235$  (ns),  $df=70$ ; and when data (o) excluded: Rainfall,  $b=-0.0057$ ,  $a=4.6519$ ,  $r=-0.3040$  (\*),  $df=62$ , regression equation  $y=4.6519-0.0057x$ ; Temperature,  $b=-0.7111$ ,  $a=16.3632$ ,  $r=-0.2387$  (ns),  $df=62$ ; RH,  $b=-0.1468$ ,  $a=16.4930$ ,  $r=-0.1865$  (ns),  $df=62$ ).

mortality. This was also noted by Harcourt (1963b) in Canada. Evidently, the status and fluctuations of DBM in the Cameron Highlands are, to some extent, reflecting this underlying association with precipitation. When the weather is drier, a higher infestation can be expected. This is further borne out by the severe DBM outbreak on the 19th crop in 1977 which had the lowest mean annual rainfall of 168.85 mm. Within the year itself, it was also generally drier during the earlier period wherein the mean monthly precipitation from January to August was only 140.56 mm. Based largely on the rainfall-infestation relationships, the overall climatic conditions would seem highly favourable for substantial build-up of the moth, at least for the first half year. However, during this period there was also a sudden increase in rainfall (317.4 mm) in April. That this coincided with the build-up seems contradictory to the general infestation-rainfall relationship. Nevertheless, when compared to the corresponding wet periods of other years this spell of rain was very brief and unable to suppress effectively the build-up. By May which had become drier, the infestations had attained outbreak proportions.

During the outbreak period, the population pattern of A. plutellae was also inconsistent with that generally observed at other times. Normally, fluctuations of the parasite follow closely that of DBM (Fig. 7.2) until immediately preceding the outbreak. For instance, from January to end of March (1977), the parasite population climbed steadily after that of the host (Fig. 7.2). Soon after, and for 1-2 weeks, the host population 'crashed' abruptly before regaining rapidly to outbreak proportion during the brief period of higher rainfall in April. The parasite, however, continued to rise well beyond the 'crashing period' of the host into early April. Then, responding numerically, it also 'crashed' to negligible numbers, by which time the host had recovered to increase sharply. Why the host abruptly 'crashed', and why the parasite did not rebuild sufficiently to prevent the eventual outbreak can only be speculative. Several factors probably accounted for the latter, viz: (i) during the 'crash' host availability was obviously the limiting factor, (ii) following host recovery, suppression was ineffective because of asynchrony with preferred host stages (see 5.2), and (iii) at high parasite and low host density during the 'crash' and initial recovery stage, excessive superparasitism resulted in high host mortality (see 5.5.4) and preponderance of male parasites (see 5.6). Together, all these interrelating factors could well result in the parasite failing to respond sufficiently to cope with the numerical increase of the host.

As regard what might possibly cause the abrupt and near-complete 'crash' of the host, this can only be speculated from a somewhat parallel



situation earlier reported by Ulliyett (1947) in South Africa wherein the DBM upsurge was traced to an epizootic of E.sphaerosperma. In this instant, a sufficiently wet spell provided the favourable conditions that triggered off the epizootic which drastically decimated the Plutella hosts, whose 'crash' eventually resulted in extensive parasite reduction. In the present case, a similar effect of an E.sphaerosperma epizootic could not be totally ruled out, particularly since the fungus is also commonly present. However, as the incidence of the disease were unfortunately not recorded during the outbreak, its possible association can only be extrapolated from records of diseases in comparable studies made by Ooi (1979a, 1981) in other cabbage fields in the Cameron Highlands. Invariably, in all 3 separate sites (Tanah Rata 1, Tanah Rata 2 and Bertam Valley) sampled by him, the DBM population showed a distinct tendency to build up during February and March. When disease incidence increased considerably (averaging 20-30%), a sharp decline of DBM infestation was immediately evident. Although this phenomenon was common, there were variations among the sites in the actual time of disease build-up and the period such high incidence was maintained. Since the 19th crop in the present investigation was also cultivated during the same period it is highly probable that the sudden and sharp decline of DBM must have also been due to an upsurge of E.sphaerosperma. In the same manner as described by Ulliyett (1947) in South Africa, this may be responsible for the unusual parasite decline and the subsequent DBM outbreak. That similar outbreak did not also develop in the other 3 sites although the moth's build-up was unusually higher than at other times, clearly suggests that the causal factors involved are not so simply defined as above. Subtle variations among the different sites were possibly responsible for the different degrees of build-up, e.g. differences in disease inoculum, levels of parasite and host density, plant conditions, other cultural practices, etc. In addition, the right amount of rain has to be present (Ulliyett, 1947), i.e. the rainfall should not be exceptionally heavy on any one day but well distributed. This requirement is further borne out by the numerous occasions when disease incidence was not unusually high in spite of very high rainfall and to be closely followed by an increase in DBM. Clearly, for an outbreak to erupt, the necessary factors must also occur and interact in such a manner that not only are they present in the appropriate proportions but also their occurrence suitably timed and coinciding. Such well-harmonised conditions no doubt occurred only in the 19th crop where there was a resultant outbreak.

Apparently, outbreaks resulting from the chain-reaction described above are only rarely encountered when one considers that conditions

with sufficient rainfall are fairly common in the Cameron Highlands. Rather, the tendency is for higher build-up when conditions become drier, as was clearly evident from the long records of the present studies.

Since E.sphaerosperma can provide extensive kill of DBM it may also be exploited as a microbial control agent against the moth. However, since its 'catastrophic effects' could also induce outbreaks (Ulliyett, 1947; present studies), there thus appears uncertainties about its usefulness. Nevertheless, Kelsey (1966) advocated its use in New Zealand as it serves well in keeping DBM low. Although parasites within E.sphaerosperma-killed larvae were also destroyed, he still considers that on balance the advantages outweigh the disadvantages. In the Cameron Highlands, the fungus is also considered (Ooi, 1979a; 1981) an important mortality factor which is only sometimes density-dependent (Ulliyett, 1947). There, correlation with host population changes was clearly significant [ $r = 0.5951$  ( $P < 0.05$ ),  $df = 10$ ;  $a = 77.8150$ ,  $b = 1.7590$ ,  $t_{0.05} = 2.34^*$ ] as also with mortality from other diseases [ $r = 0.5918$  ( $P < 0.05$ ),  $df = 10$ ;  $a = 80.3682$ ,  $b = 2.6403$ ,  $t_{0.05} = 2.32^*$ ]. However, the correlation was insignificant [ $r = 0.3182$  ( $P > 0.05$ ),  $df = 10$ ] when all the diseases were considered together.

Pertaining to weather, Ooi (1979a) found the incidence to be independent of rainfall. In the present investigations there was also no significant correlation with the major climatic parameters [rainfall:  $r = 0.0739$  ( $P > 0.05$ ),  $df = 29$ ; RH:  $r = 0.095$  ( $P > 0.05$ ),  $df = 29$ ] except temperature [ $r = -0.4069$  ( $P < 0.05$ ),  $df = 29$ ;  $a = 377.7889$ ,  $b = -19.8135$ ,  $t_{0.05} = 2.4^*$ ]. However, for spore germination in E.sphaerosperma the conditions most favourable are darkness, a temperature near 20°C and more than 70% RH (Sawyer, 1931). As these conditions are more or less constantly available in the Cameron Highlands, a reasonable level of natural infection can usually be expected there. Periodic records (Fig. 7.2; Ooi, 1979a, 1981), have borne this out, lending further support to the view (Ulliyett & Schonken, 1940) that "in countries with abundant rainfall and high mean temperature the fungus forms a permanent member of the population of natural enemies associated with the host insect". In such a situation, a fairly stable 'equilibrium' most likely exists among the biological agents that make up the host-disease-parasite complex, and this probably helps in dampening any tendency of a large scale epizootic of E.sphaerosperma. Nonetheless, in exploiting the destructive potential of the fungus, consideration should be given to the warning of Kelsey (1966) on the possible adverse effects on parasites when infection occurred early in the cycle of DBM.

Presently, the relationships between E.sphaerosperma and parasites of DBM are still insufficiently known. From the meagre data available, there was noted a positive correlation only with D.eucerotheca [ $r = 0.6955$  ( $P < 0.05$ ),  $df = 8$ ,  $a = 7.3410$ ,  $b = 0.4157$ ,  $t_{0.05} = 2.74^*$ ]. Correlation with A.plutellae [ $r = -0.0164$  ( $P > 0.05$ ),  $df = 8$ ] or the two parasites together ( $r = 0.2667$  ( $P > 0.05$ ),  $df = 8$ ) was not significant. Evidently, more comprehensive research to unravel the complexities involved are desirable, so as to enable better exploitation of the fungus. However, its employment in manner similar to conventional insecticides using macerated infected-larvae should presently be explored, particularly in uninfected fields. This might prove beneficial since preliminary studies have shown such sprays to be effective substitutes for chemical insecticides with production costs greatly reduced (Kelsey, 1966). For the Cameron Highlands, it might also prove useful in overcoming the acute problems of insecticide resistance besides speeding up development of IPC programme for DBM.

The subject dealt with so far has revealed various mortality factors (both climatic and biological) that could influence the population pattern of DBM. Morris (1959) suggested that, although many variables may contribute to mortality in a population, the main fluctuations are caused by only a few, and the measurement of these could provide the key to predicting the subsequent population development. Moreover, there may often be only one factor that is responsible for the majority of the fluctuations in a particular index of population trend (Varley & Gradwell, 1960). In such a situation, it must, however, be stressed that 'the key factor' accounts only for the main fluctuations in population size and not the principal regulating or density-dependent factor(s) (Southwood, 1966). To date, ecological analysis to identify the respective role of the different factors that may influence population changes of DBM in the Cameron Highlands is only limited to a preliminary effort by Ooi (1979a). The further treatment attempted here not only amplifies on this, but hopefully, will also help towards the development of a more rational and predictive basis in the control.

Normally, the key factor analysis is carried out on a generation basis and has the underlying assumptions that similar stages measured in each successive and discrete generations are non-overlapping. However, for DBM in the Cameron Highlands, such assumptions could never be fulfilled as the moth breeds rapidly and continuously in the field, resulting in population of highly overlapped generations. In spite of this, the analysis is still attempted with a view of examining the feasibility of applying such a method. As the analysis could not possibly be done on

the generation basis, mortalities were therefore examined in relation to successive croppings. Under the existing circumstances, this appears most appropriate as each crop constitutes a fairly discrete unit with well-defined beginning and ending. Moreover, since the close succession of crops has made it possible for a continuous population to exist, the series of estimates made in successive croppings could well provide a meaningful population trend from crop to crop. In any case, it should be recognized that the key factor analysis attempted here is not similar to the method normally understood as that of Varley & Gradwell (1960, 1963a, b, 1965), but rather a modified one.

Figure 7.4 shows the  $k$ -values obtained for the various known mortality factors plotted against the successive croppings. From visual correlation it is evident that A. plutellae (or parasite as a whole) during Period I (prior to the introduction of D. eucerothaga) was never a key factor. The major mortality and fluctuations were effected largely by others ( $k_r$ ) which were probably made up of diseases and climatic factors. During Period 2 when there were further differentiation of the various mortalities, a rather different pattern was noticeable. The residual mortality ( $k_r$ ) had now become negligible (Fig. 7.4). As this essentially resulted from separating out  $k_D$  (disease mortality), the latter must have been largely responsible for  $k_r$  being the key factor during Period I. That  $k_D$  had all along been a key factor is also suggested by the high visual correlation between  $k_D$  and  $K$  during the first half of Period 2.

In the attempt to test for direct density dependence of the various  $k_s$ , the regression for each  $k$  against the log numbers ( $\log N_t$ ) entering the stage on which it acts was determined (Table 7.1) as outlined by Southwood (1966) for the method developed by Varley & Gradwell (1960, 1963a, b, 1965) and Varley (1963). However, only that for  $k_r$  and  $k_R$  are significant; thus density dependence for these may be suspected. But, as pointed out by Southwood (1966), the regression could be spurious due to sampling errors since the two variables are not independent but actually  $\log N_t$  and  $\log N_{t+1}$ . In view of this, further regressions of the log numbers entering the stage ( $\log N_t$ ) against the log number of survivors ( $\log N_{t+1}$ ), as well as the reverse ( $\log N_{t+1}$  on  $\log N_t$ ), were calculated as suggested by Southwood (1966). Since only one ( $\log N_t$  on  $\log N_{t+1}$ ) and not both the regression coefficients is found to depart significantly from 1.0 (Table 7.1), the density dependence earlier suspected cannot be taken as real (Watt, 1964; Southwood, 1966). Thus, based on the regression analyses (Table 7.1), it appears that the various  $k_s$  are not directly density dependent. This, however, should be viewed with reservation as

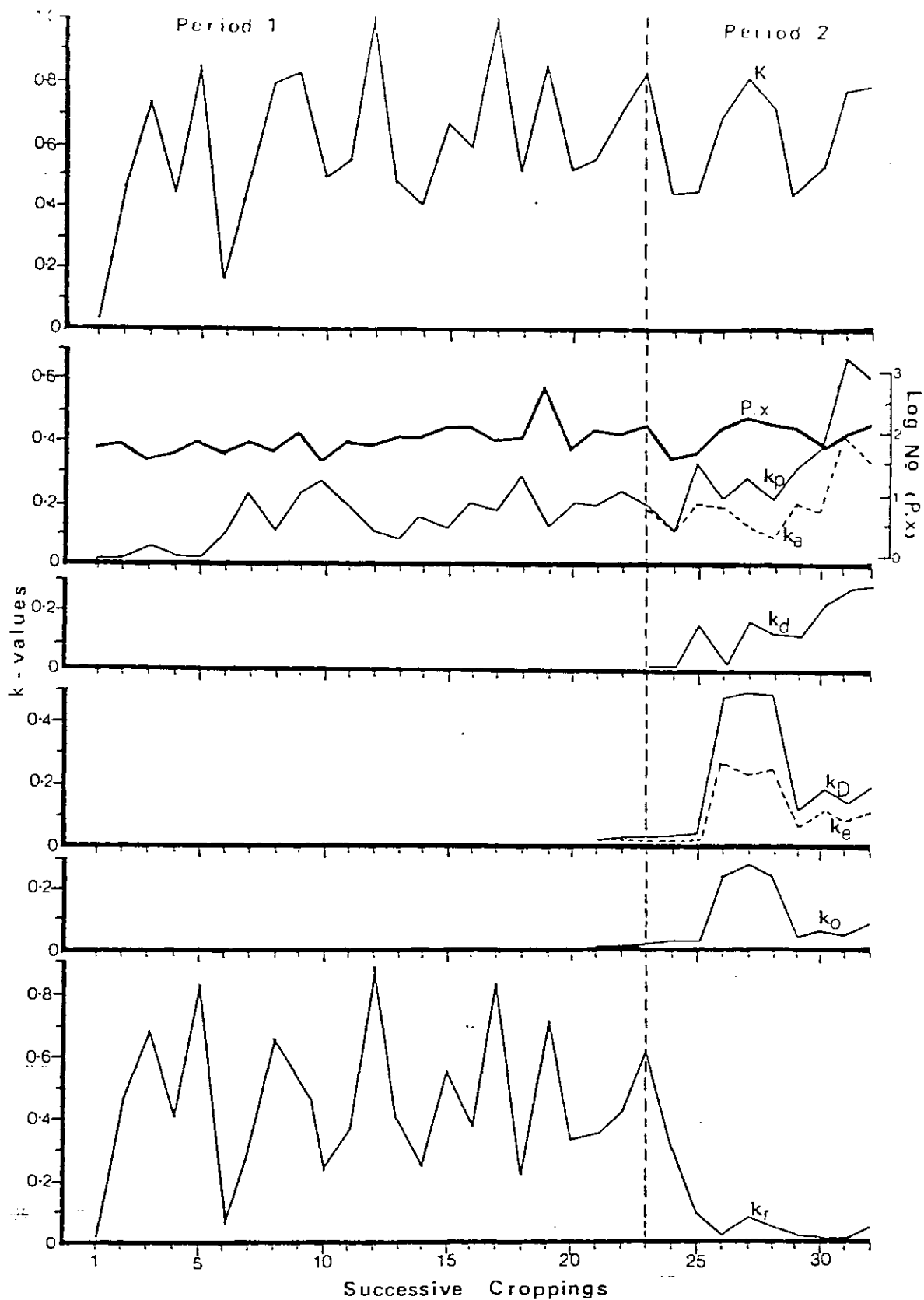


FIGURE 7.4 Partial key factor analysis for the larvae of *Plutella xylostella* (L.) on successive and overlapping crops of cabbages (variety Constanta F.1 Danish) in the Cameron Highlands. ( $P.x.$  = *P.xylostella*; K = Total mortality;  $k_r$  = Residual mortality;  $k_a$ ,  $k_d$ ,  $k_p$ ,  $k_e$ ,  $k_o$ ,  $k_p$  = Mortalities, respectively, due to *Apanteles plutellae*, *Diadegma eucerothaga*, total parasitization, *Entomophthora sphaerosperma*, diseases other than *E.sphaerosperma*, and diseases as a whole).

Table 7.1 Regressions between various  $k$  factors against the log density at the start of the stage on which it acts for determination of density dependence.

| Cropping Period | Regression                                                                    |                      |                            |
|-----------------|-------------------------------------------------------------------------------|----------------------|----------------------------|
|                 | Parameters                                                                    | Equation             | Significance <sup>1/</sup> |
| I(Crop 1-20)    | Log No. larvae entering stage against $k_a$ due to <u>A. plutellae</u> .      | $y=0.0317x + 0.0764$ | $t=0.3765$ , $df=18$ (ns)  |
|                 | Log No. larvae surviving $k_a$ against $k_r$ due to unknown factor.           | $y=0.3088x - 0.0871$ | $t=1.3107$ , $df=18$ (ns)  |
| II(Crop 21-32)  | Log No. larvae entering stage against $k_a$ due to <u>A. plutellae</u> .      | $y=0.2041 - 0.0086x$ | $t=0.0540$ , $df=10$ (ns)  |
| II(Crop 23-32)  | Log No. larvae surviving $k_a$ against $k_d$ due to <u>D. eucerothaga</u> .   | $y=0.3413 - 0.1214x$ | $t=0.8616$ , $df=8$ (ns)   |
|                 | Log No. larvae surviving $k_d$ against $k_e$ due to <u>E. sphaerosperma</u> . | $y=0.1761x - 0.1814$ | $t=1.7933$ , $df=8$ (ns)   |
|                 | Log No. larvae surviving $k_e$ against $k_o$ due to other diseases.           | $y=0.1082x - 0.0672$ | $t=0.7442$ , $df=8$ (ns)   |
|                 | Log No. larvae surviving $k_o$ against $k_r$ due to unknown factors.          | $y=0.6456x - 0.8091$ | $t=3.5259$ , $df=8$ (**)   |
| II(Crop 23-32)  | Log No. larvae entering stage against $k_p$ due to larval parasites (total).  | $y=0.3296 - 0.0094x$ | $t=0.0310$ , $df=8$ (ns)   |
|                 | Log No. larvae surviving $k_p$ against $k_d$ due to diseases (total).         | $y=0.3673x - 0.3961$ | $t=1.7796$ , $df=8$ (ns)   |
|                 | Log No. larvae surviving $k_d$ against $k_R$ due to unknown factors.          | $y=2.4647x - 3.4701$ | $t=2.8626$ , $df=8$ (*)    |
| II(Crop 23-32)  | Log No. larvae entering stage against Log No. surviving $k_o$ (& $k_D$ ).     | $y=0.3544x + 0.8091$ | $t=3.5259$ , $df=8$ (**)   |
|                 | Log No. larvae surviving $k_o$ (& $k_D$ ) against Log No. entering stage.     | $y=0.8991x + 0.2487$ | $t=0.2172$ , $df=8$ (ns)   |

<sup>1/</sup> ns = not significant, \* = significant at 5% level, and \*\* = significant at 1% level.

the demonstration of density-dependence from census data is presently fraught with difficulties, and in particular, failure to detect it in no way proves its absence (Southwood, 1966).

It is noted that following the introduction of D.eucero-phaga, the overall mortality due to parasite ( $k_p$ ) gradually increased while  $k_D$  parallelly declined. From this, it seems that  $k_p$  is gradually replacing  $k_D$  as a possible key factor and that parasites as a whole may soon assume an added importance. Whether this is truly so, and for how long, can only be ascertained through continual collection of such data. In any case, much more will still need to be done since the present consideration is only a partial key factor analysis confined strictly to the larval stage alone. Unless mortality assessment in other life stages are also available to help complete a total key factor analysis, it would not be possible to account or predict for the overall fluctuations in population size. The need for this is strongly suggested from Harcourt's (1963b) findings that adult mortality is the critical or 'key' factor in the population dynamics of DBM, and this has strong predictive value for species such as DBM which is multivoltine and whose life-cycle is short. Evidently, should additional data and deeper ecological understanding prove the present modified method of analysis to be reliably functional, perhaps some form of population forecast with respect to DBM outbreaks may then be realised.

## 8. INSECTICIDAL USAGE IN THE DBM-PARASITE ENVIRONMENT

As noted in Section 1.2 the control of DBM in the Cameron Highlands has been exclusively dependent on chemical insecticides. Other possibilities (mainly biological control) have only very recently been explored and it is doubtful that any effective substitutes to chemicals are likely to become fully available in the immediate future. Even if there are alternatives, chemical insecticides would still be required when suppressions from the non-chemical methods break down occasionally. Moreover, in developing an IPC programme for DBM, it is envisaged that chemical insecticides would still constitute a fair proportion of the relevant control tactics, at least initially. As such, a better understanding of the effects of chemical insecticides and how they may be judiciously employed, is essential. Since possible aspects to be considered are so numerous, in the present context only those that appear to have immediate relevance are examined.

### 8.1 MATERIALS AND METHODS

The full range of insecticides so far employed against DBM in the Cameron Highlands has been enormous (see 1.2, Fig. 1.2). Insecticidal mixtures, many locally concocted to make quick returns for pesticide salesmen, are unusually common. Often, many of these contained chemicals that are completely ineffective against DBM. In order to understand better what insecticidal components can still be employed, a full range of the insecticides presently available locally was screened against the major stages (eggs, larvae and pupae) of DBM (Appendix 3). Many of the chemicals were also evaluated for possible hazards to the parasite, A. plutellae.

In the insecticide screening of DBM, test insects from stock culture originating from the Mensum Valley in 1977 were used. The larvae were evaluated using treated B. rapa leaves as feeding substrate. Plants individually grown in polyethylene bags (23 cm x 15 cm diameter) were divided into different treatment groups at 3 weeks old and sprayed with 0.1% a.i. (unless otherwise stated) of the respective test chemicals. On the 1st, 3rd, 5th, 10th and 15th day after spraying, an excised leaf from each treated group was placed in a glass vial (74 cm x 23 cm diameter) containing water and held upright by cotton plug. Twenty 2nd-instar larvae were then introduced onto each leaf just prior to confinement within a 'breeding jar' (Plate 2.1). For the controls, untreated leaves were used. Each treatment was replicated 3 times and the larval mortality recorded daily until pupation. Throughout, the evaluation was made under laboratory



conditions while the sprayed plants maintained in ambient glasshouse conditions.

In the study on ovicidal effects, approximately 200 1-day old eggs which were still adhered to B.rapa leaves were submerged for 1 min in 0.1% a.i. solution (unless otherwise stated) of each test chemical. Following treatment, the leaves were air-dried and then separately kept overlying a moist filter paper in 16 cm x 2 cm glass petri dishes. Observations for egg eclosion were made daily, and upon emergence, all the larvae transferred onto untreated B.rapa leaves in separate petri dishes for daily record of mortality until attainment of the 2nd-instar stage. In the controls, the eggs were dipped in water only.

For evaluations of DBM pupae and A.plutellae cocoons, the individuals were dipped in the treatment solutions. Again, dipping in water constituted the controls. Upon air-dried following treatment, these were separately kept in their respective treatment groups in ventilated 'breeding jars'. To sustain the emerging adults, water and 30% honey solution were also provided. Everyday, adult emergence of both DBM and A.plutellae were recorded along with their subsequent mortality.

In past investigations on conventional insecticides for DBM control in West Malaysia (see 1.2), most were confined to laboratory and field screening of their toxicities (Henderson, 1957; Ho, 1965; Ho & Ng, 1970). Limited study has also shown that the use of sticker (Tenac Sticker<sup>R</sup>) is able to extend their effectiveness for about 7 days (Ho, 1965). More recently, investigations have revealed the optimum spraying interval to be 8 days in West Malaysia (Jusoh et al, 1981). Although treating at 16-day interval was still significantly better than the untreated control the yield was substantially reduced. With a view towards identifying further improvement in insecticidal usage, various treatment methods were therefore examined. Comparisons were made among 4 methods of insecticide application, viz (i) spraying onto upper and lower leaf surfaces of plants, (ii) spraying on young leaves and shoots only, (iii) applying only the undersurface of the leaves, and (iv) applying over the top of the plant as normally done by farmers. In addition, an untreated control was also included. The trial was conducted in the MARDI Research Station at Tanah Rata (Cameron Highlands) employing a randomised complete block design consisting of 5 treatments and 3 replications. Each replicate has 30 plants arranged in 2 rows of 15 plants/row. Except for the various chemical treatment, all planting and agronomic practices were similar to that of farmers (Appendix 1). The insecticide Hostathion<sup>R</sup> was applied weekly at 0.1% a.i. Periodically, both DBM and A.plutellae as well as crop damage were assessed, while the plot yields determined at harvest. In damage

assessment the same method described under 4.1 was employed.

Although field testings have shown B.t. to provide effective kill of DBM (Ho & Ng, 1970, see also 4.2.3), ~~only a moderate kill was~~ obtained from laboratory screening (see 8.2.2). The latter is probably due to mortality assessment being made for only 24 hrs after exposure and not continued thereafter. Since B.t. is generally slower than most conventional insecticides, following through with the cumulative mortality over a longer period might help to clarify the discrepancy. A study was thus made to trace the population development of DBM when given B.rapa leaves sprayed with 0.25 gm/500 ml Dipel<sup>R</sup>. An untreated set constituted the control. The study was conducted in 'breeding jars' (Plate 2.1) under laboratory conditions, beginning with 300 larvae of each instar and replicated 3 times. Every 24 hrs, all larvae surviving the exposure were recorded and transferred onto fresh leaves from the original stocks.

Since B.t. is capable of providing effective control of DBM (Creighton et al., 1970, 1972, 1973, 1974; Ho & Ng, 1970; Cadapan & Gabriel, 1973; Chuo, 1973; Suah & Ellis, 1974; Sudarwohadi & van den Oever, 1974; Gruner & Delplanque, 1974; Creighton & McFadden, 1975; Present Studies, Sections 4.2.3 & 8.2.6), further examination was made to gain deeper insight into the chemical's influence on feeding and consumption rate. For the study, air-dried leaves sprayed with 0.25 gm/500 ml. Dipel<sup>R</sup>, and untreated ones were provided in the form of feeding discs (5 cm diameter) to freshly-moulted 2nd-instar larvae of DBM. The experiment was replicated 5 times with 6 leaf discs to 150 larvae within a 250 ml flask. Every 24 hrs, the surviving larvae were transferred to fresh set of leaves while the dry weight (at 110°C) determined for those fed upon. Correspondingly, the dry weight of parallel sets of unfed checks were also determined daily. By this means, comparison was made for the amount consumed by both exposed and unexposed individuals.

Previous study (see 4.2.3) has shown that B.t. does not pose any direct hazard to developing parasites within the cocoons. Although it is also safe to the adult parasite, evidence is however not available on its indirect effect through the developing host larvae. In attempts to explore this, DBM larvae parasitized at the 1st-instar stage by A.plutellae were individually reared in glass vial (75 mm x 24 mm diameter) on unsprayed B.rapa leaves. Upon immediate entry into the 1st, 2nd, 3rd and 4th-instar stage, batches of 50 larvae/stage (replicated 3 times) were transferred and reared on leaves sprayed with 0.25 gm/500 ml Dipel<sup>R</sup>. For the controls which ran parallelly, use of the untreated leaves was continued. Throughout the study conducted under laboratory conditions (see 2b) detailed records were kept on the resultant progeny.

The abundance of A. plutellae in spite of heavy insecticidal inputs in the Cameron Highlands has prompted the suggestion (Ooi & Sudderuddin, 1978) that the parasite may have become resistant. An understanding of this is not only useful to explain its present abundance but could also provide the means for possible manipulation with resistant parasites. To investigate this, A. plutellae collected from the field in the Mensum Valley during January 1978 were compared with laboratory stock culture initiated in mid-1973 and bred through to 1978 when the test was made. Due to continuous breeding in conditions free of insecticidal pressure, it is assumed that the laboratory stock might by then be equivalent to a susceptible strain. In 1980, further collections were made for another evaluation. However, only the responses against malathion were compared simultaneously with that produced by the stock culture which was about 7 years old then. The others evaluated included lindane, fenvalerate and methamidophos.

In the biological assay, only male parasites between 0.5 - 0.8 mg (mean weight = 0.717 mg, n = 2160) were used. For those collected at the cocoon stage from the field, only the F<sub>1</sub> adults were evaluation. As to the toxicants, these were of analytical grade (95 - 99.5% purity) diluted in acetone to the appropriate concentrations (w/v). The controls, however, consisted of acetone only. Application was made topically with a micro-capillary tube; 1 ul being delivered dorsally onto the thorax of each parasite. However, prior to treatment the parasites were immobilised by chilling in a freezer for 5 mins. Every test concentration consisted of 40 exposed adults, this being replicated 4 times with 10 adults/replicate. Immediately following treatment, the parasites were confined in 'breeding jars' with water and 30% honey, and record of mortality was made hourly for the first 6 hrs and at 24 hrs. However, only the mortality at 6 hrs was considered in the probit analysis since beyond this there was wider variation in the control mortality. Moreover, between 5-16 hrs the mortality was relatively constant.

## 8.2 RESULTS

### 8.2.1 Effects of insecticides on the eggs of DBM

Of 44 chemicals evaluated, only 6 were found capable of preventing more than 90% egg hatching (Fig. 8.1). Among these, 3 were pyrethroids (decamethrin, fenvalerate and permethrin), 1 organophosphate (cyanofenphos), 1 organophosphate mixture (dichlorvos + phenthoate) and 1 carbamate (carbamate). For 4 other chemicals, moderate egg mortality ranging from 25-74% was obtained. From these, it is evident that eggs of DBM are generally

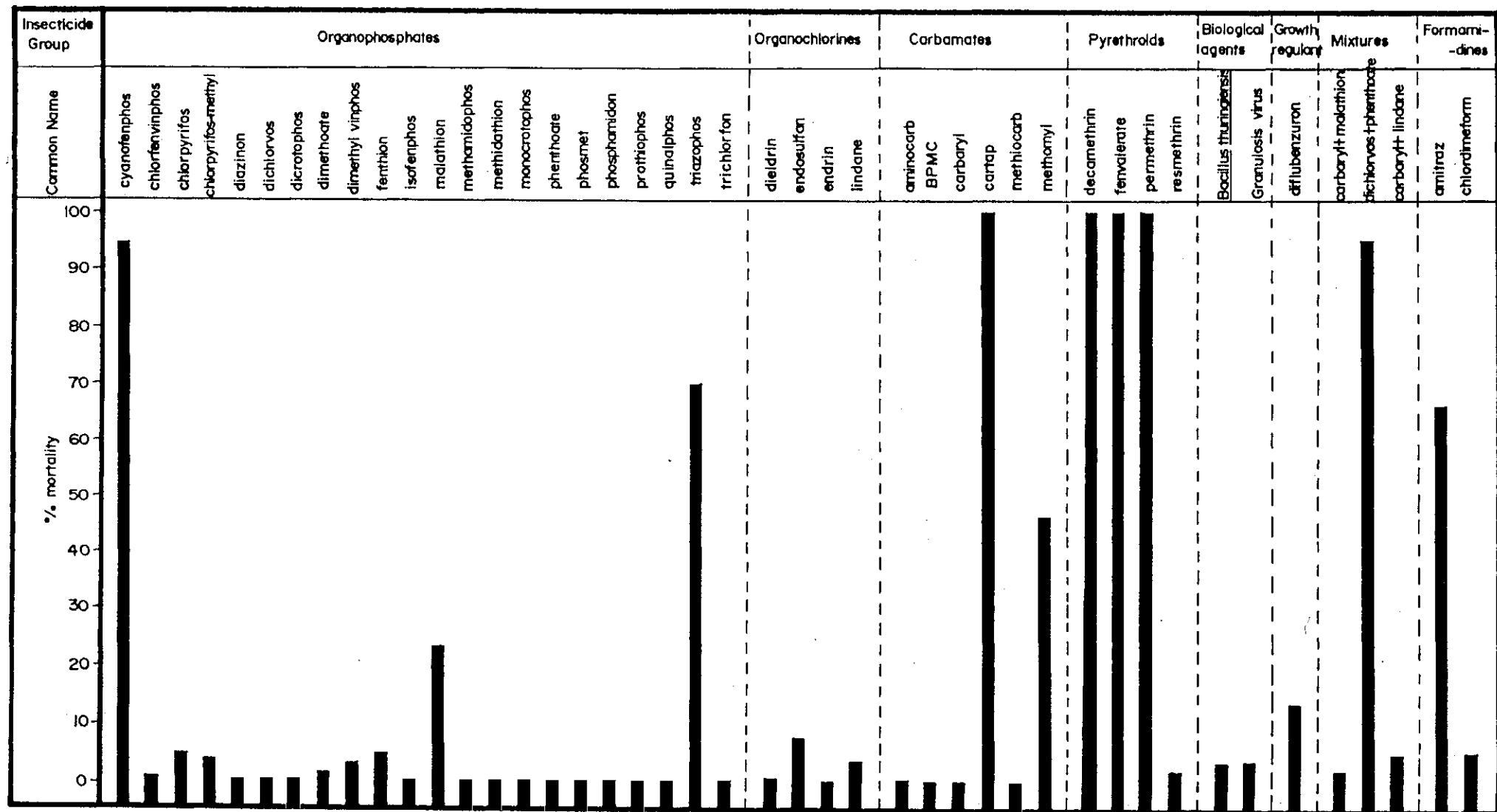


Figure 8-1 Effects of Insecticides on the hatching of the eggs of *Plutella xylostella* (L.). Test concentrations= 0.1 % a.i. except for *B. thuringiensis* and the granulosis virus which were evaluated at 1 gm/ 2 litres and 0.1 larva equivalent / ml, respectively.

resistant to insecticides. This was also found in earlier investigation by Ho (1965) and field survey in the current studies (see 3.3.5). In general, the pyrethroids (except for resmethrin) are superior as ovicides.

Although egg hatching was not prevented by most of the test chemicals, mortality of the resultant larvae was considerable in nearly half of the insecticides, largely among the organophosphates (Fig. 8.2). Except for methiocarb (carbamate), resmethrin (pyrethroid) and chlordimeform (formamidine) which effected 100% kill, mortality for most non-organophosphates was, in general, less. It thus appears that, although many organophosphates were poor ovicides, they nevertheless could compensate by effecting a higher kill over the young larvae that emerged.

#### 8.2.2 Effects of insecticides on the larvae of DBM

Unlike the ovicidal evaluation, more of the chemicals were found to perform better as larvicides (Fig. 8.3). Of 39 insecticides screened, 16 produced at least 90% larval mortality. The pyrethroids were consistently superior while the degree in effectiveness of others varied considerably.

In general, chemicals which exhibited high initial toxicity also tended to have a longer residual toxicity (Fig. 8.4). For a few, this was however not so, e.g. resmethrin. Among those that may be included in the former category were: fenthion, phosmet, profenophos and triazophos among the organophosphates, lindane among the organochlorines, cartap and methiocarb among the carbamates, decamethrin, fenvalerate and permethrin among the pyrethroids, and cyhexatin among the organo-tins.

#### 8.2.3 Effects of insecticides on the pupae of DBM

The effects of insecticides on adult emergence from treated pupae were similar to that for eggs. Generally, pupal survival was little affected (Fig. 8.5) as was also noted from the field survey (see 3.3.5). The highly effective insecticides capable of causing more than 90% pupal mortality were 2 organophosphates (chlorfenvinphos and methidathion) and the 4 pyrethroids (decamethrin, fenvalerate, permethrin and resmethrin).

When longevity of the emerged adults was considered for a period of up to 7 days, it was observed that with the exception of cartap there was little difference between the treated and untreated. For cartap, the cumulative adult mortality reached 100% within 1 day after emergence while that of the control increased only gradually and never exceeded 30%.

It is evident from the study that DBM pupae, like the eggs (see 8.2.1), are generally resistant to most insecticides. Unless the more potent ones are employed, in most situations the pupae will survive the

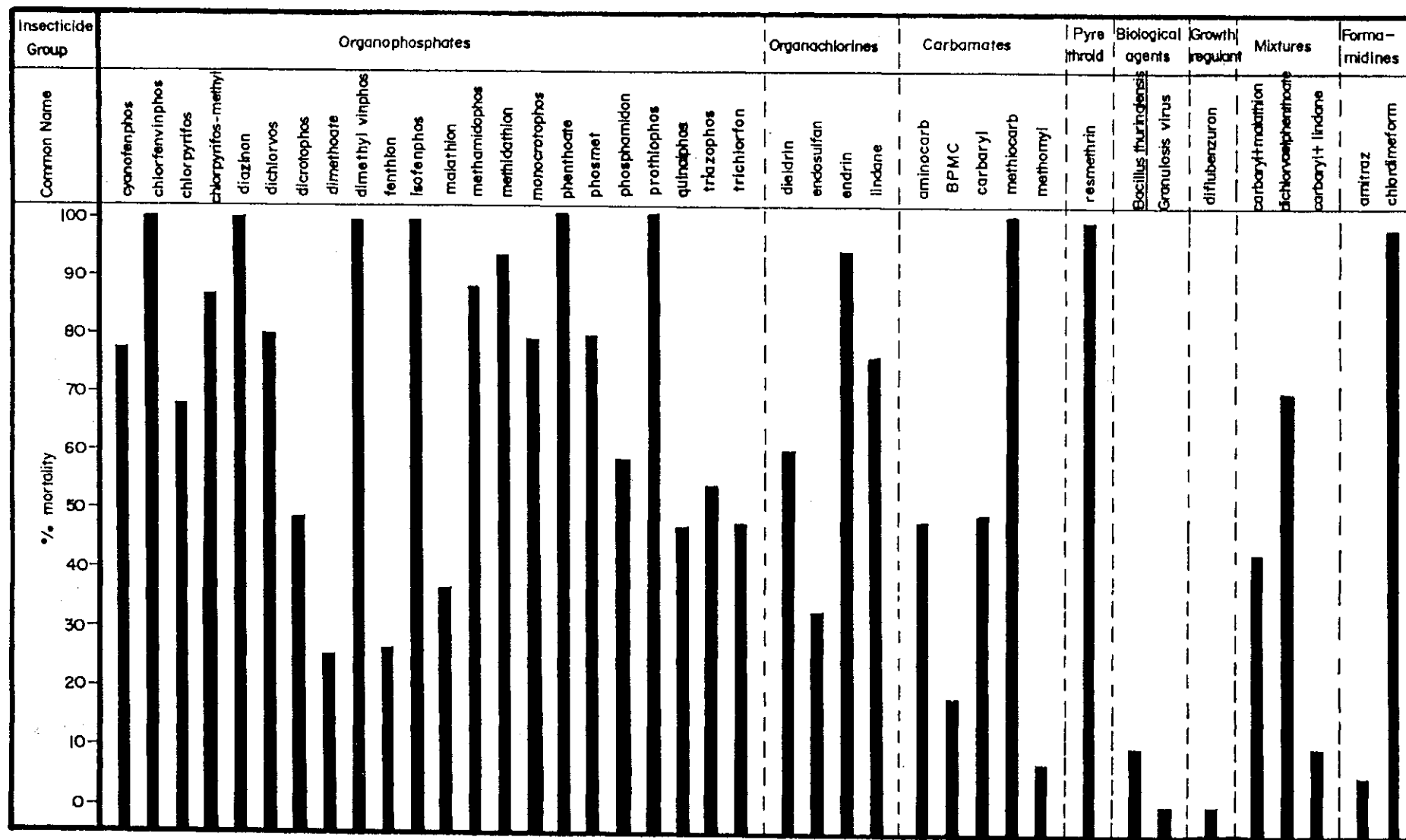


Figure 8-2 Mortality of *Plutella xylostella* (L.) larvae (up to 2nd-instar stage) emerging from eggs treated with different insecticides. Test concentrations = 0.1% a.i. except for *B. thuringiensis* and the granulosis virus which were evaluated at 1 gm/2 litres and 0.1 larva equivalent / ml, respectively.

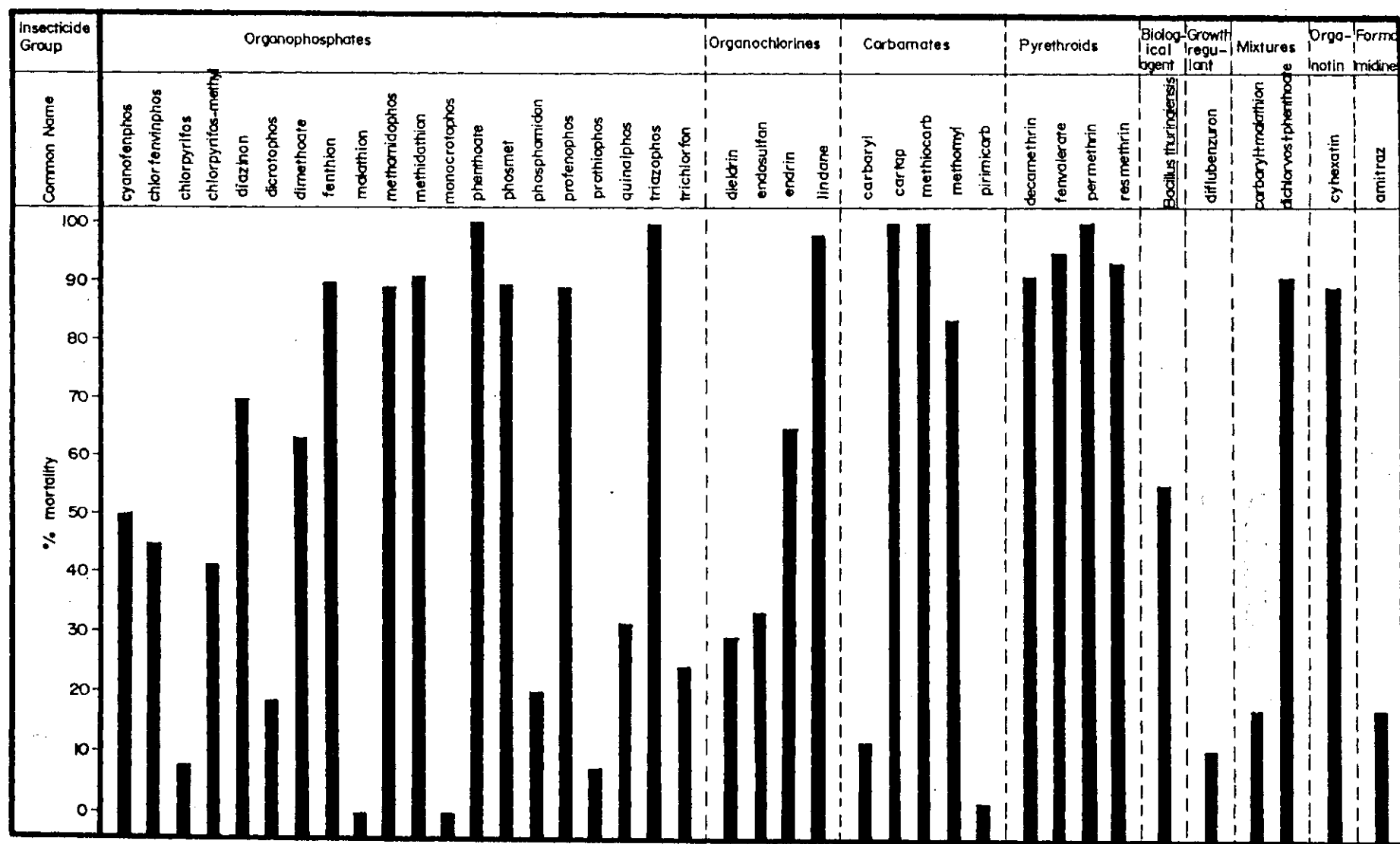


Figure 8-3 Effects of insecticides on the larvae of *Plutella xylostella* (L.) at 24 hours after treatment. Test concentrations = 0-1% a.i. except for *B. thuringiensis* which was evaluated at 1 gm / 2 litres.

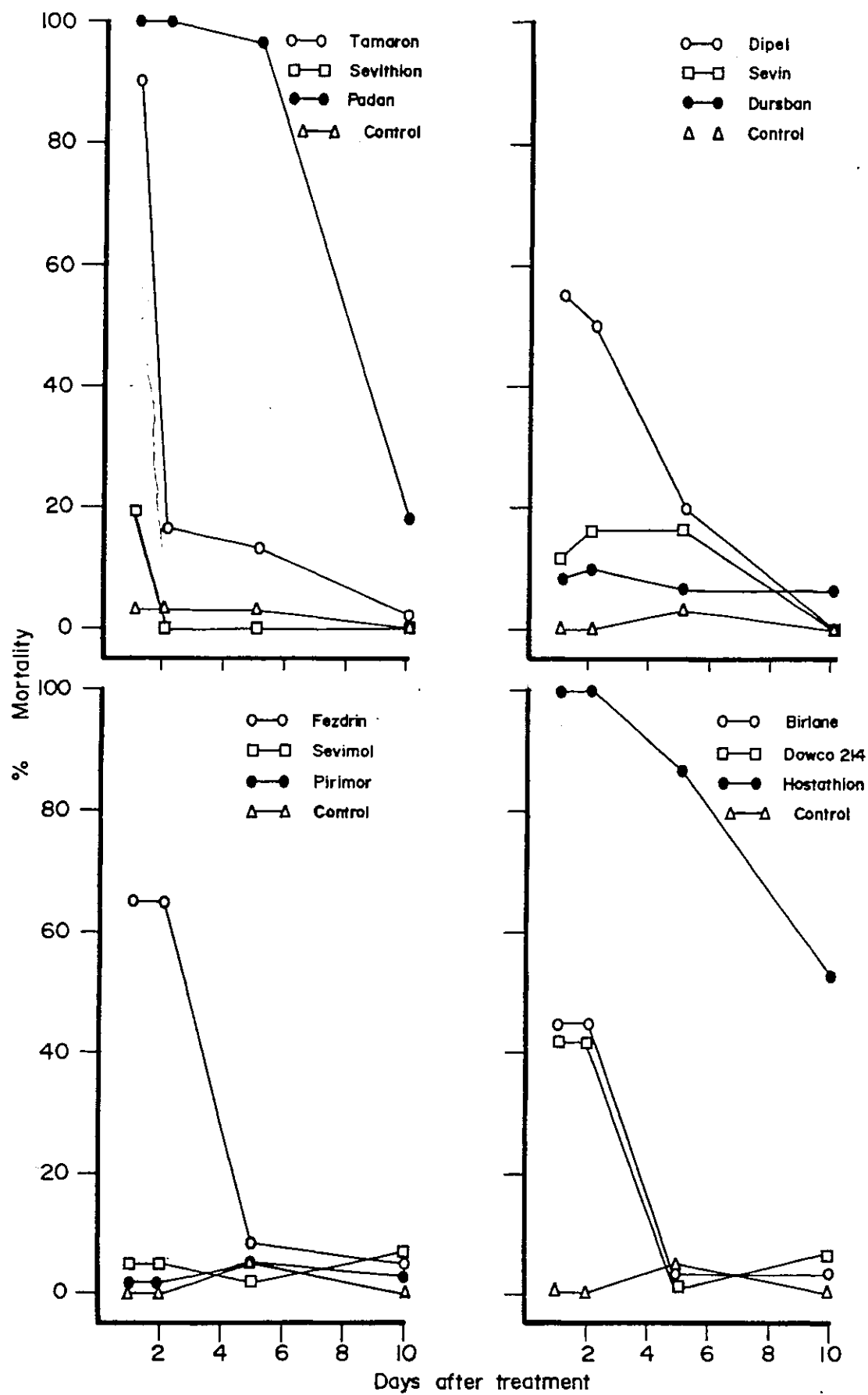


Figure 8-4 Residual toxicity of various insecticides to the 2<sup>nd</sup> instar larvae of *Plutella xylostella*(L.).



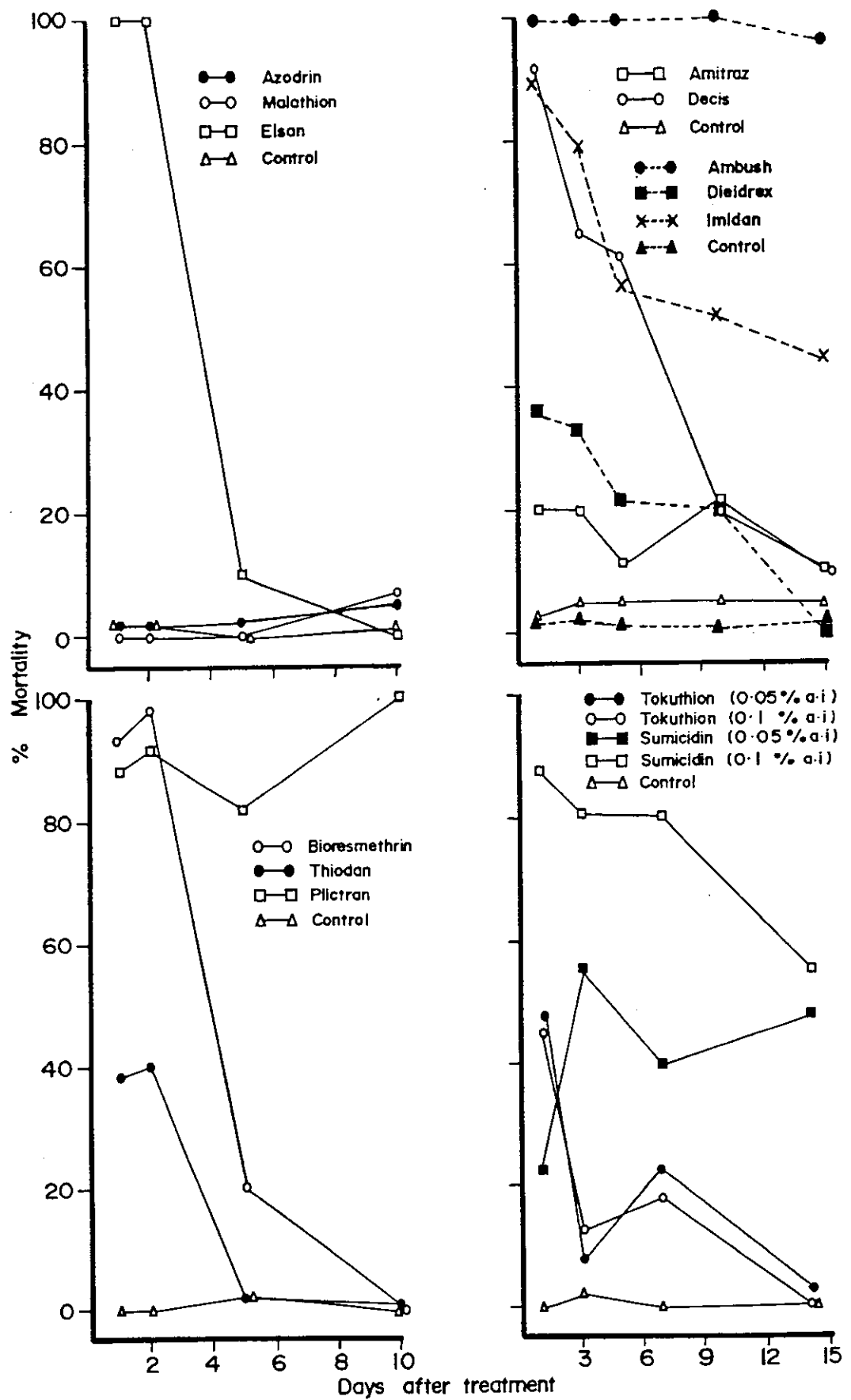


Figure 8.4 (Continued I). Residual toxicity of various insecticides to the 2<sup>nd</sup> instar larvae of *Plutella xylostella*(L.).

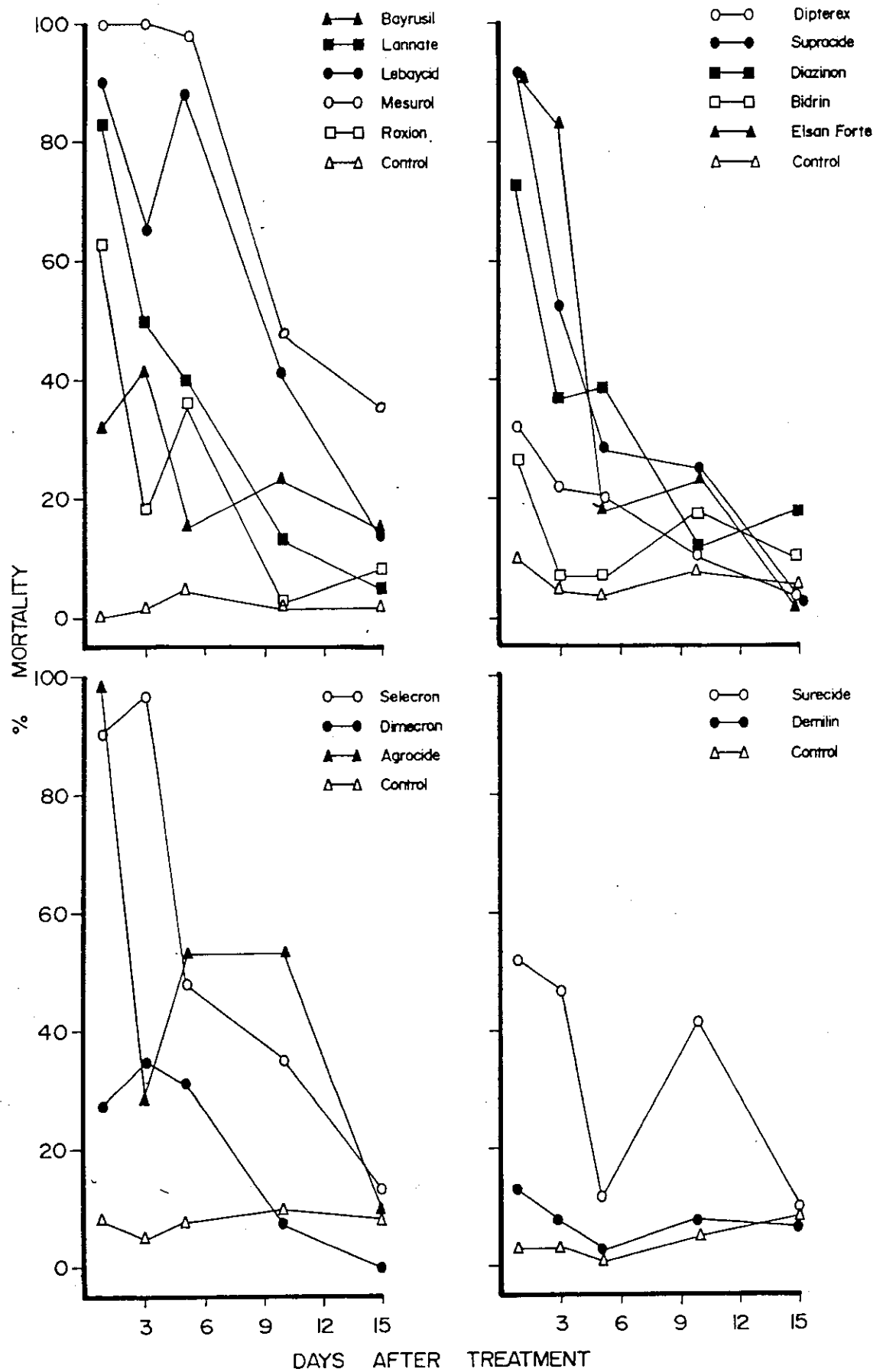


Figure 8.4 (Continued 2). Residual toxicity of various insecticides to the 2<sup>nd</sup> instar larvae of *Plutella xylostella*(L).

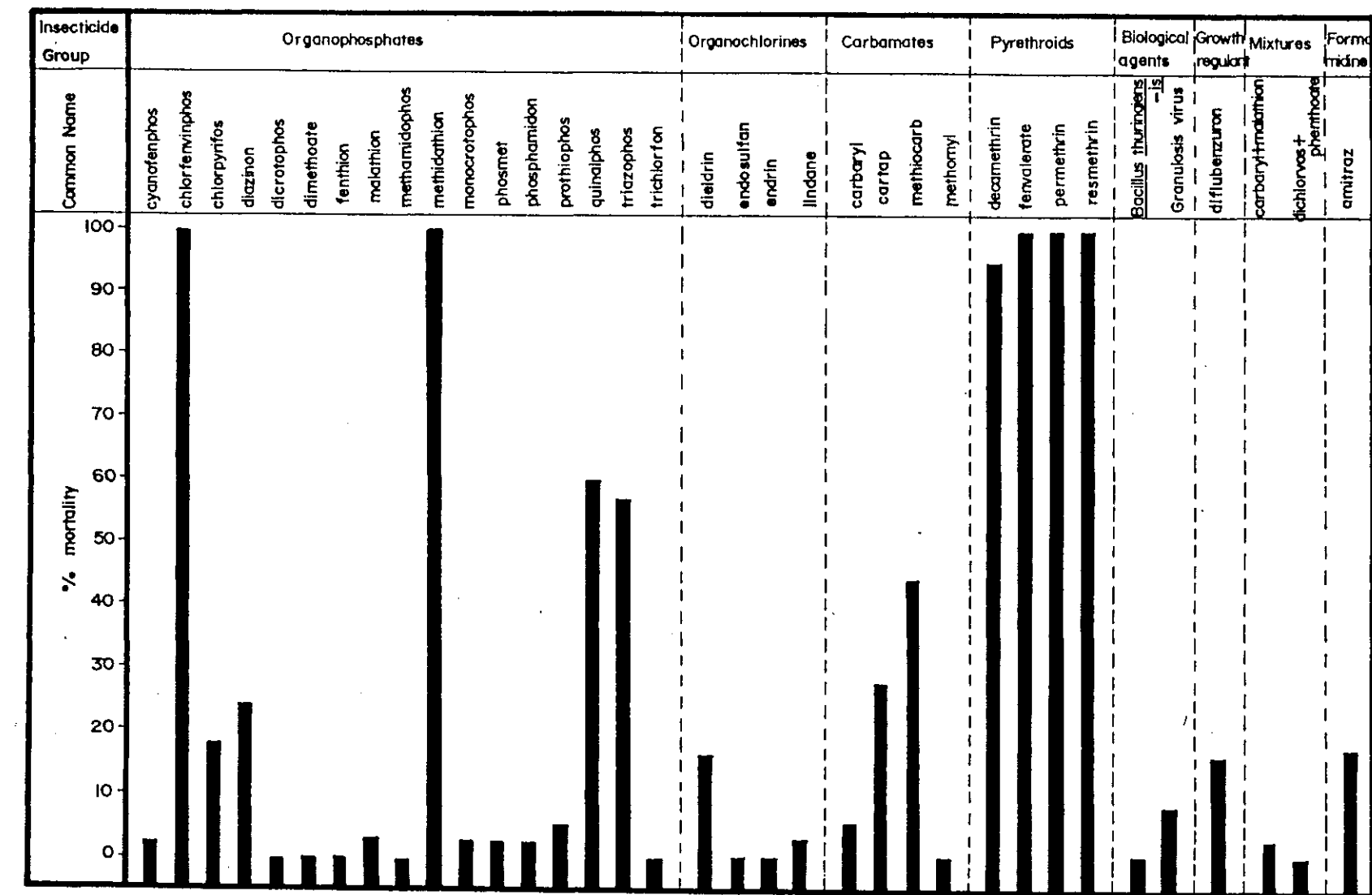


Figure 8-5 Adult emergence of *Plutella xylostella* (L.) from pupae treated with different insecticides. Test concentrations = 0.1 % a.i. except for *B. thuringiensis* and the granulosis virus which were evaluated at 1 gm/2 litres and 0.1 larva equivalent/ml, respectively.

chemical treatment.

#### 8.2.4 Effects of insecticides on the cocoons of *A. plutellae*

In this study, no distinct pattern was observed between parasite emergence from chemically-exposed cocoons and the major insecticide groupings. Where sufficient numbers of chemicals in each group were evaluated, both hazardous and relatively safe toxicants were found (Fig. 8.6). In some treatments, although parasite emergence was little affected, survival of adult parasites was, however, greatly reduced relative to that of the unexposed controls (Fig. 8.7). Over a period of 1-week some suffered mortality as high as 100%, e.g. with chlorpyrifosmethyl, dichlorvos, dimethoate, phosmet, prothiophos and tetrachlorvinphos among the organophosphates, endosulfan among the organochlorines, and decamethrin among the pyrethroids. In general, the overall findings appear encouraging in that specificity does occur among some of the chemicals. An example may be seen in fenvalerate which was highly toxic to DBM (Fig. 8.3) but seems relatively safe to *A. plutellae* (Fig. 8.6).

#### 8.2.5 Evaluation of different spraying methods in the control of DBM

Among the various treatments evaluated, spraying made on both surfaces of the leaves was found to provide the highest yield while that of the untreated control the least (Table 8.1). Except for treatment involving spray on the upper surface only, all others had significantly ( $P < 0.05$ ) higher yields than the control. However, the yield difference for treatment following farmers' practice and that of the untreated plots was only marginally insignificant. In the control the yield was at least 29.72% less.

In general, it is clear (Table 8.1) that the method of application currently adopted by most farmers is not completely satisfactory. To some extent, the poor control of DBM on some occasions is probably due to this and not entirely to resistance development. Evidently, the need for improvement on the existing control method should receive serious consideration.

#### 8.2.6 Survival of DBM as affected by exposure of the different larval instars to *B. thuringiensis*

Fig. 8.8 shows the initial kill of DBM by *B.t.* as generally slow. For most of the larval stages exposed, not more than 60% mortality was effected within 24 hrs. However, when the mortality was cumulated, it was evident that larval survival could be severely affected. Except for larvae exposed at the 4th instar, all others suffered complete mortality.

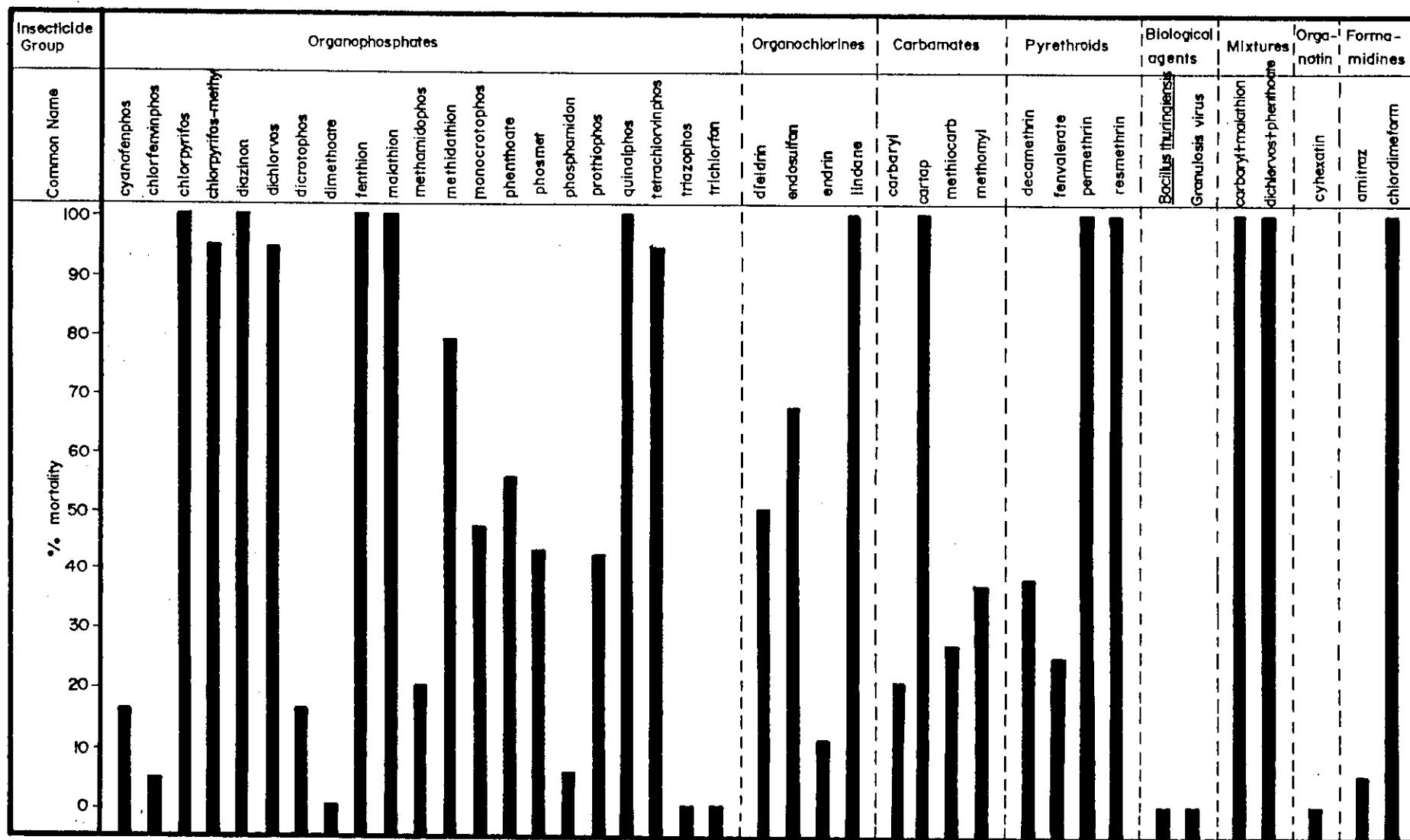


Figure 816 Adult emergence of *Apanteles plutellae* Kurdj. from cocoons treated with different insecticides. Test concentrations = 0.1 % a.i. except for *B. thuringiensis* and the granulosis virus which were evaluated at 1gm / 2litres and 0.1 larva equivalent / ml, respectively.

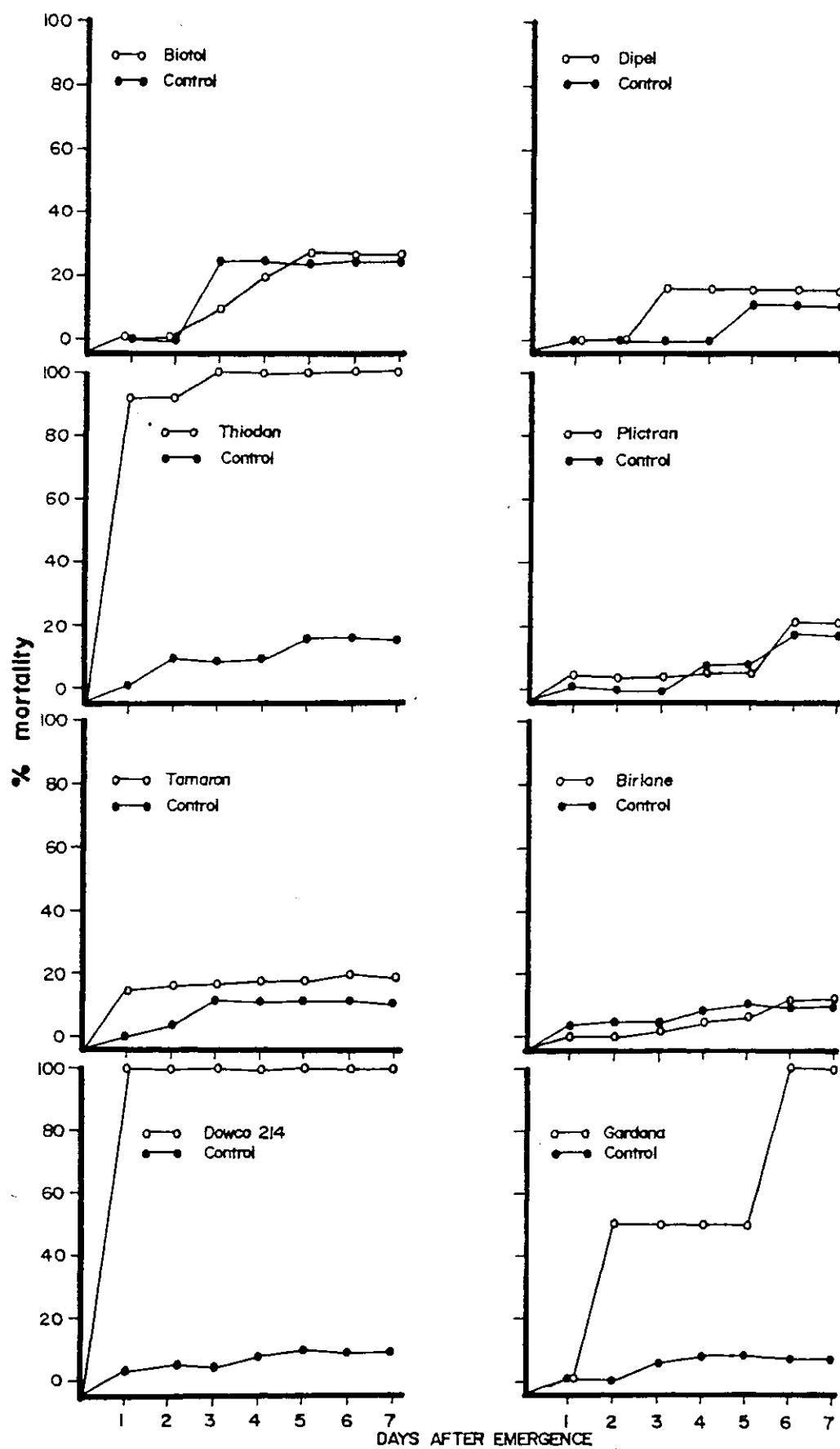


Figure 8-7 Cumulative mortality of adult *Apanteles plutellae* Kurdj. following emergence from cocoons that were treated with various insecticides.

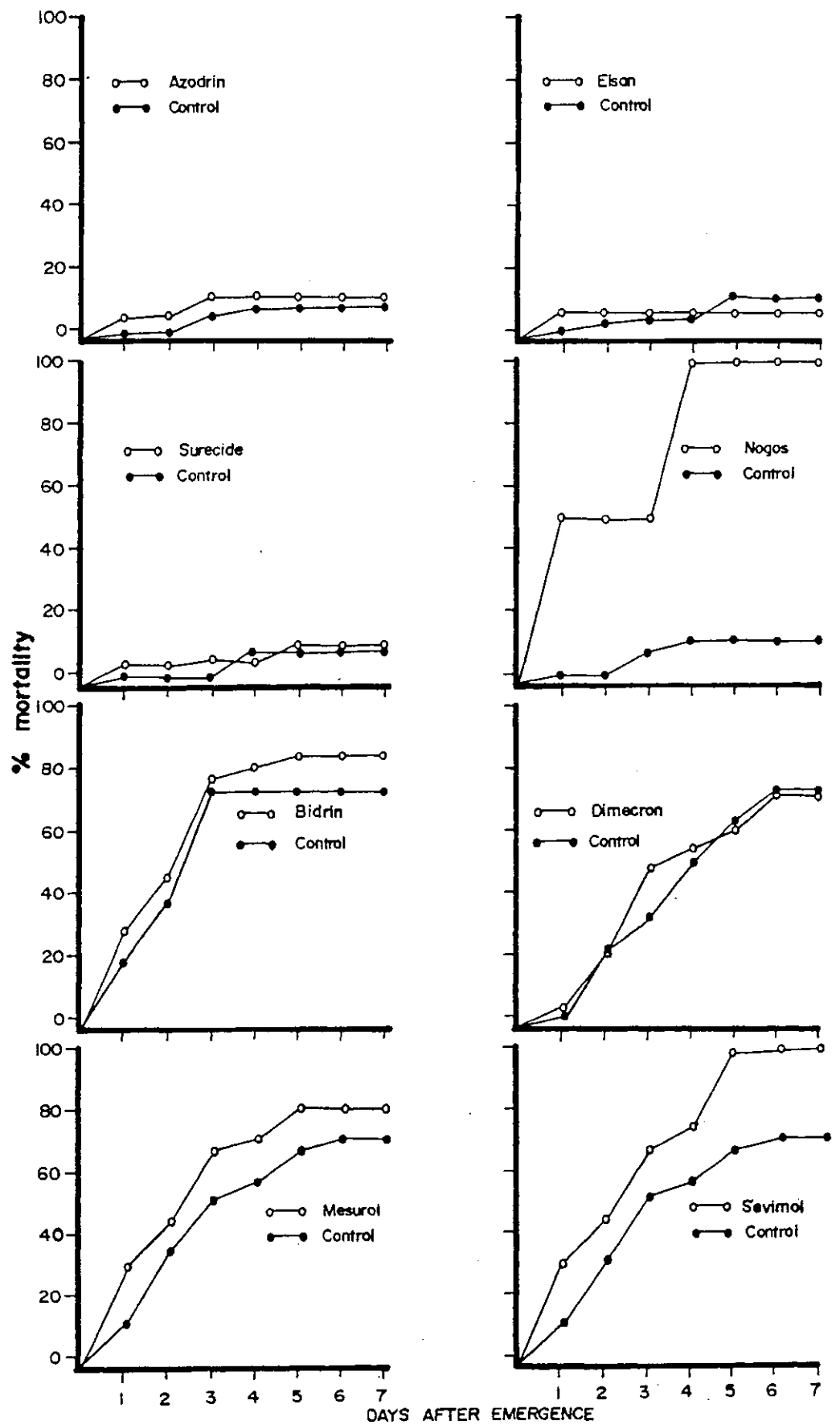


Figure 8-7 (Continued). Cumulative mortality of adult *Apanteles plutellae* Kurdj. following emergence from cocoons that were treated with various insecticides.

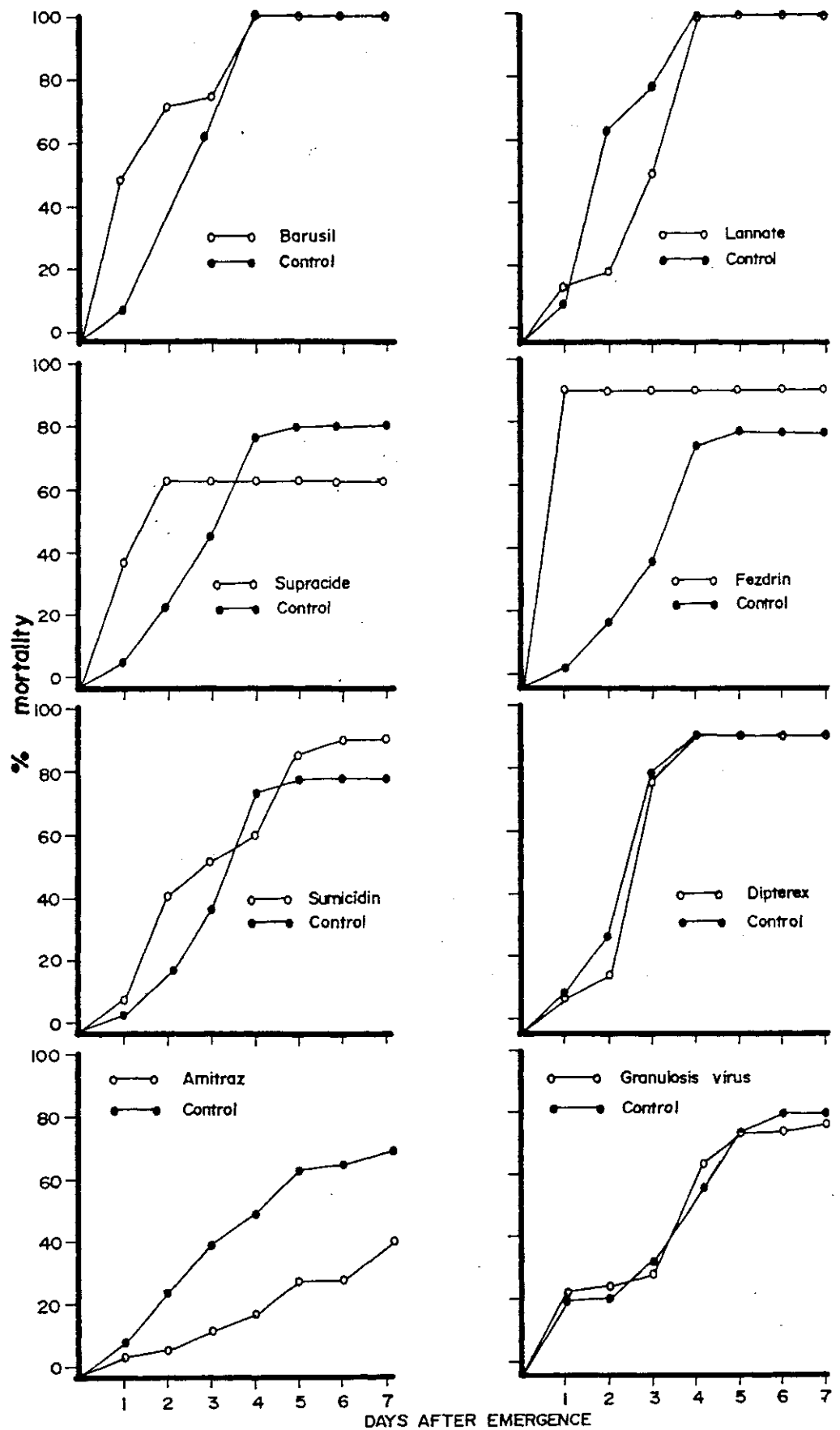


Figure 8-7. (Continued 2). Cumulative mortality of adult *Apanteles plutellae* Kurdj. following emergence from cocoons that were treated with various insecticides.



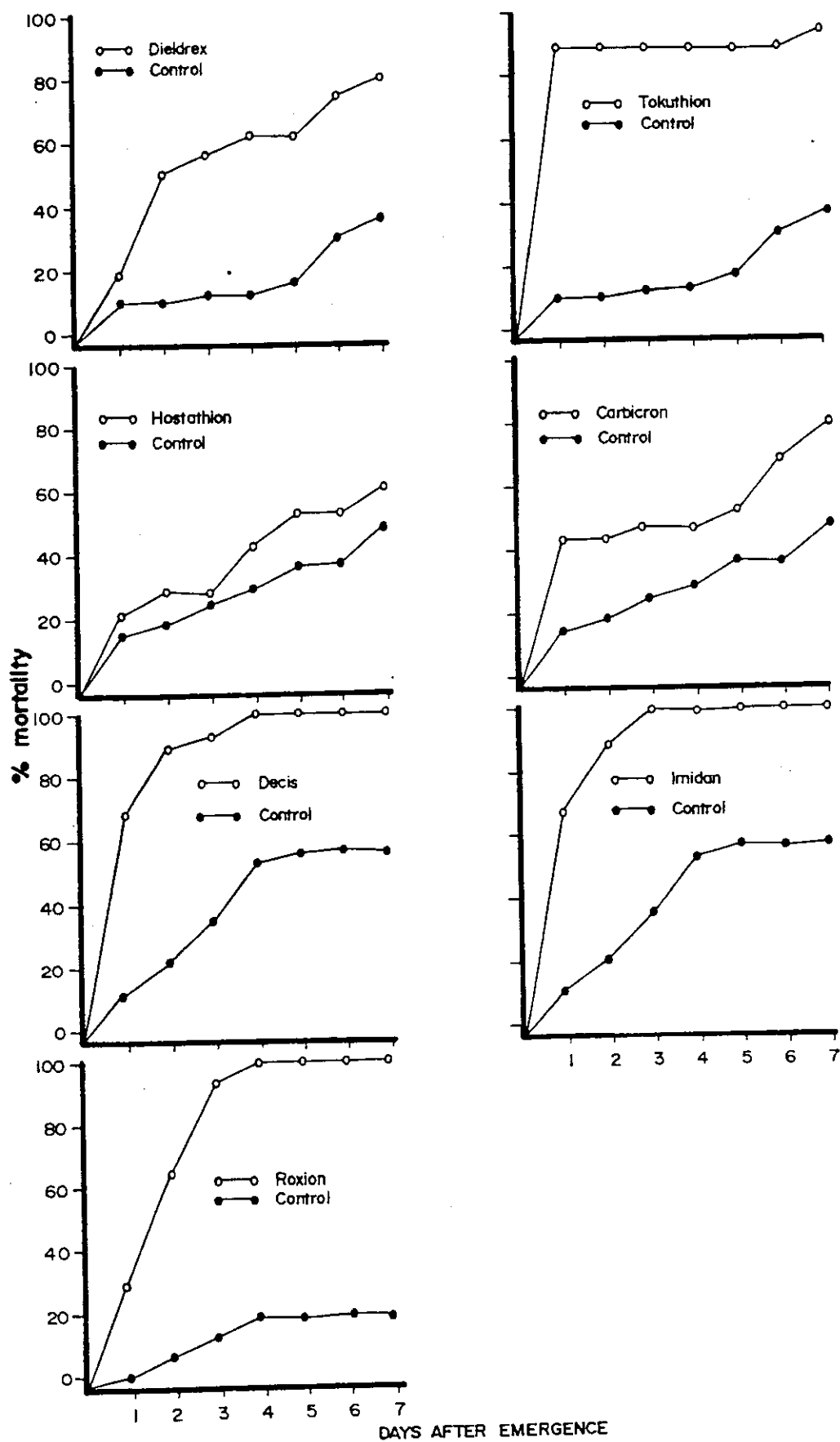


Figure 8-7 (Continued 3). Cumulative mortality of adult *Apanteles plutellae* Kurdj. following emergence from cocoons that were treated with various insecticides.

Table 8.1

Effects of different spraying methods — on the infestations of Plutella xylostella (L.) and the resultant cabbage yields.

| Method of application                              | Mean number/15 sampled plants/treatment <sup>2/</sup> |       |       |                                | Plant damage index (%) <sup>3/</sup> | Marketable heads/plot <sup>5/</sup> |                         |
|----------------------------------------------------|-------------------------------------------------------|-------|-------|--------------------------------|--------------------------------------|-------------------------------------|-------------------------|
|                                                    | <u>P. xylostella</u>                                  |       |       | <u>A. plutellae</u><br>cocoons |                                      | No.                                 | Yield(kg) <sup>2/</sup> |
|                                                    | Larvae                                                | Pupae | Total |                                |                                      |                                     |                         |
| Over both surfaces of leaves                       | 113                                                   | 10    | 123   | 16                             | 5.50                                 | 81                                  | 156.7a                  |
| On young leaves & shoots only                      | 126                                                   | 11    | 140   | 28                             | 6.50                                 | 73                                  | 143.7a                  |
| On undersurface only                               | 135                                                   | 5     | 137   | 19                             | 7.46                                 | 70                                  | 139.5a                  |
| On uppersurface only<br>(Normal farmers' practice) | 137                                                   | 12    | 149   | 15                             | 7.26                                 | 68                                  | 126.2ab                 |
| Untreated control                                  | 198                                                   | 11    | 209   | 15                             | 8.20                                 | 62                                  | 88.7b                   |

1/ The insecticide used was Hostathion<sup>R</sup> applied weekly at 0.1% a.i.

2/ Based on 4 samplings made on 29.6.77, 13.7.77, 27.7.77 and 10.8.77. Each sample consisted of 5 plants taken at random from each of the 3 replicates in each treatment.

3/ Based on 6 visual scorings made on 21.7.77, 27.7.77, 3.8.77, 10.8.77, 18.8.77 and 23.8.77. Each scoring was made on 45 sampled plants treatment, with 15 plants from each of the 3 replicates.

4/ Each treatment plot consisted of 3 replications (beds), with each bed having 30 plants.

5/ Yields followed by the same letter are not significantly different at the 5% level according to the Duncan's Multiple Range Test.

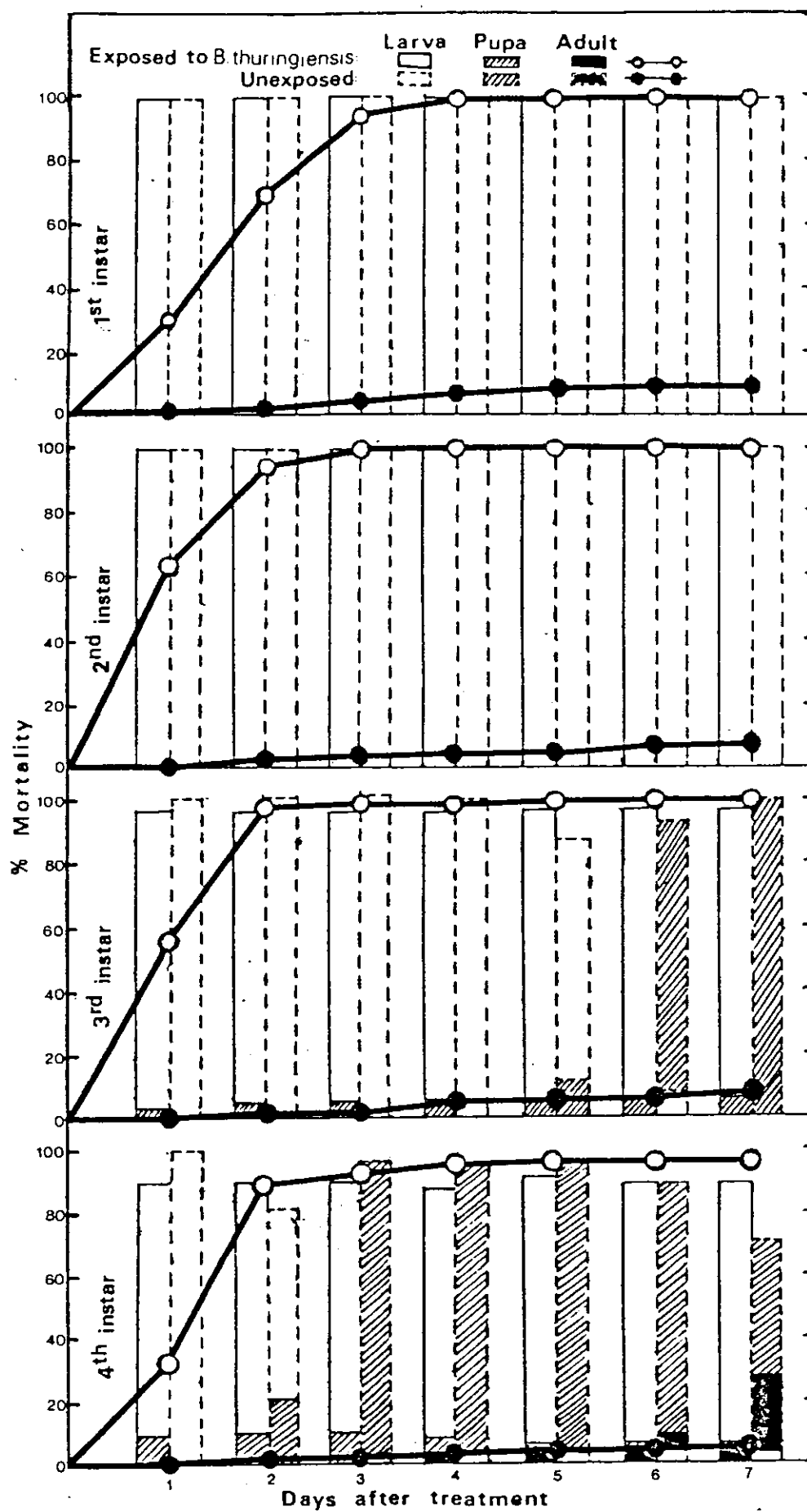


FIGURE 8.8 Survival of *Plutella xylostella* (L.) when exposed to *Bacillus thuringiensis* Berlinger (0.25 gm/500 ml Dipel®) at the different larval stages.

Although some pupation occurred from among the 3rd-instar exposure, none of the resultant pupae produced live adults. Only in the 4th-instar exposure was there a small proportion of adults obtained (Fig. 8.8). When compared to the corresponding unexposed larvae pupation was observed to occur earlier in the exposed individuals, suggesting the latter to be under stress. Perhaps through less intake of B.t. because of faster development and reduced leaf consumption induced by the pathogen such larvae were able to complete their development up to the adult stage.

In general, the findings have confirmed that although B.t. is slow to act against DBM, it is still highly effective as a controlling agent. That this is so is also well borne out by its good field performance.

#### 8.2.7 Effect of *B.thuringiensis* on leaf consumption by DBM

The comparative study on leaf consumption between DBM exposed to B.t. and unexposed individuals has clearly shown that exposed larvae not only suffered extensive mortality but also fed less prior to their death. For instance, the amount of B.rapa leaves consumed by an exposed 2nd-instar larva was, respectively, 0.096 mg, 0.232 mg, 0.609 mg and 0.732 mg by the end of the 24th, 48th, 72nd and 96th hr after exposure, as opposed to the corresponding consumptions of 1.012 mg, 0.500 mg, 1.118 mg and 2.402 mg in the unexposed individual. The overall difference between the unexposed (5.032 mg) and the exposed individual (1.669 mg) was about 3 fold. Given sufficient larval infestation, this difference in consumption would probably account for considerable portion of the vast difference in crop damage often observed between treated and unsprayed crops. Evidently, even though live larvae may still be present for some period after Dipel<sup>R</sup> treatment, considerable protection from feeding damage has already been afforded by the applied chemical since feeding by the exposed larvae would have already been reduced substantially.

#### 8.2.8 Effect of *B.thuringiensis* on parasitized larvae of DBM

Results of this investigation showed that out of 600 parasitized larvae of DBM, only 3.3% produced adult A.plutellae when the hosts were exposed to B.t. (Table 8.2). However, from unexposed larvae, as high as 70% emergence was obtained showing that the bacteria have an adverse effect on the parasite. Apparently, much of the mortality of the parasite probably resulted from starvation due to premature death of the host larvae. This is further indicated by the fact that should sufficient food be available for the developing parasites to reach the cocooning stage, further mortality observed thereon differed little between those

Table 8.2 Development and survival of Apanteles plutellae Kurdj. from parasitized hosts [Plutella xylostella (L.)], the latter are exposed to Bacillus thuringiensis Berlinger (0.25 gm/500ml Dipel<sup>R</sup>) at the different instar stages.

| Host stage when first exposed to <u>B. thuringiensis</u> | Treatment: unexposed (-), or exposed (+) to Dipel <sup>R</sup> | Test Individuals (No.) | Developmental stage(s) attained by <u>A. plutellae</u> and survivors |      |        |      |
|----------------------------------------------------------|----------------------------------------------------------------|------------------------|----------------------------------------------------------------------|------|--------|------|
|                                                          |                                                                |                        | Cocoons                                                              |      | Adults |      |
|                                                          |                                                                |                        | (No.)                                                                | (%)  | (No.)  | (%)  |
| FIRST                                                    | -                                                              | 150                    | 140                                                                  | 93.3 | 131    | 87.3 |
|                                                          | +                                                              | 150                    | 0                                                                    | 0.0  | 0      | 0.0  |
| SECOND                                                   | -                                                              | 150                    | 106                                                                  | 70.7 | 101    | 67.3 |
|                                                          | +                                                              | 150                    | 0                                                                    | 0.0  | 0      | 0.0  |
| THIRD                                                    | -                                                              | 150                    | 139                                                                  | 92.7 | 122    | 81.3 |
|                                                          | +                                                              | 150                    | 10                                                                   | 6.7  | 0      | 0.0  |
| FOURTH                                                   | -                                                              | 150                    | 118                                                                  | 78.7 | 105    | 70.0 |
|                                                          | +                                                              | 150                    | 51                                                                   | 34.0 | 20     | 13.3 |
| TOTAL                                                    | -                                                              | 600                    | 503                                                                  | 83.8 | 459    | 76.5 |
|                                                          | +                                                              | 600                    | 61                                                                   | 10.2 | 20     | 3.3  |

of the control (mean 7.3%) and the exposed individuals (mean 6.9%). In any case, it seems clear that with the exception of parasitized larvae which have already attained the 4th-instar stage, any exposure of all other larval stages to B.t. may prove disastrous to the parasite. From a practical standpoint, targeting the application of B.t. with respect to safeguarding parasites still developing within the hosts is likely to prove difficult.

#### 8.2.9 Development of insecticide resistance in *A. plutellae*

Among the 4 insecticides evaluated for possible resistance development, only slight changes in the LD<sub>50</sub> values were obtained for the different populations of *A. plutellae* examined during 1973-80 (Fig. 8.9). With the organochlorine lindane, the resistance ratio (RR) was 2.4 fold in 1980, while RRs of 2.9 and 2.7 were obtained for the pyrethroid fenvalerate, during 1978 and 1980 respectively. In spite of the small ratios, the LD<sub>50</sub> values were found to be significantly different based on the non-overlap of the 95% confidence limits. In the case of fenvalerate, the difference between that for 1978 and 1980 was, however, not significant.

As regard the 2 organophosphates, some differences were, however, observed between malathion and methamidophos. In the former insecticide, there was hardly any change at all in the LD<sub>50</sub> values and the difference was insignificant, suggesting that no resistance whatsoever had developed between 1973 to 1980. With methamidophos, a progressive increase in the RR values was distinctly apparent; these being 2.7 for the population collected in 1978 and 3.9 for those obtained in 1980. The LD<sub>50</sub> values for both these comparisons were clearly significant. Although that between 1978 and 1980 was insignificant, it was, however, only marginally so. Should the present trend persist, this difference could be expected to become significant after some period.

From the findings, it is evident that the development of insecticide resistance by *A. plutellae*, if any, is very limited for all the 3 major groups of insecticides so far considered.

### 8.3 DISCUSSION

In the toxicity screening of insecticides, it was evident that various combinations of toxic responses may be evoked by the different chemicals in both DBM and its *A. plutellae* parasite (Table 8.3). Although categorization of the responses is invariably arbitrary, it nevertheless constitutes a useful guide towards more appropriate decisions on their employment. Insecticides that are completely ineffective would become

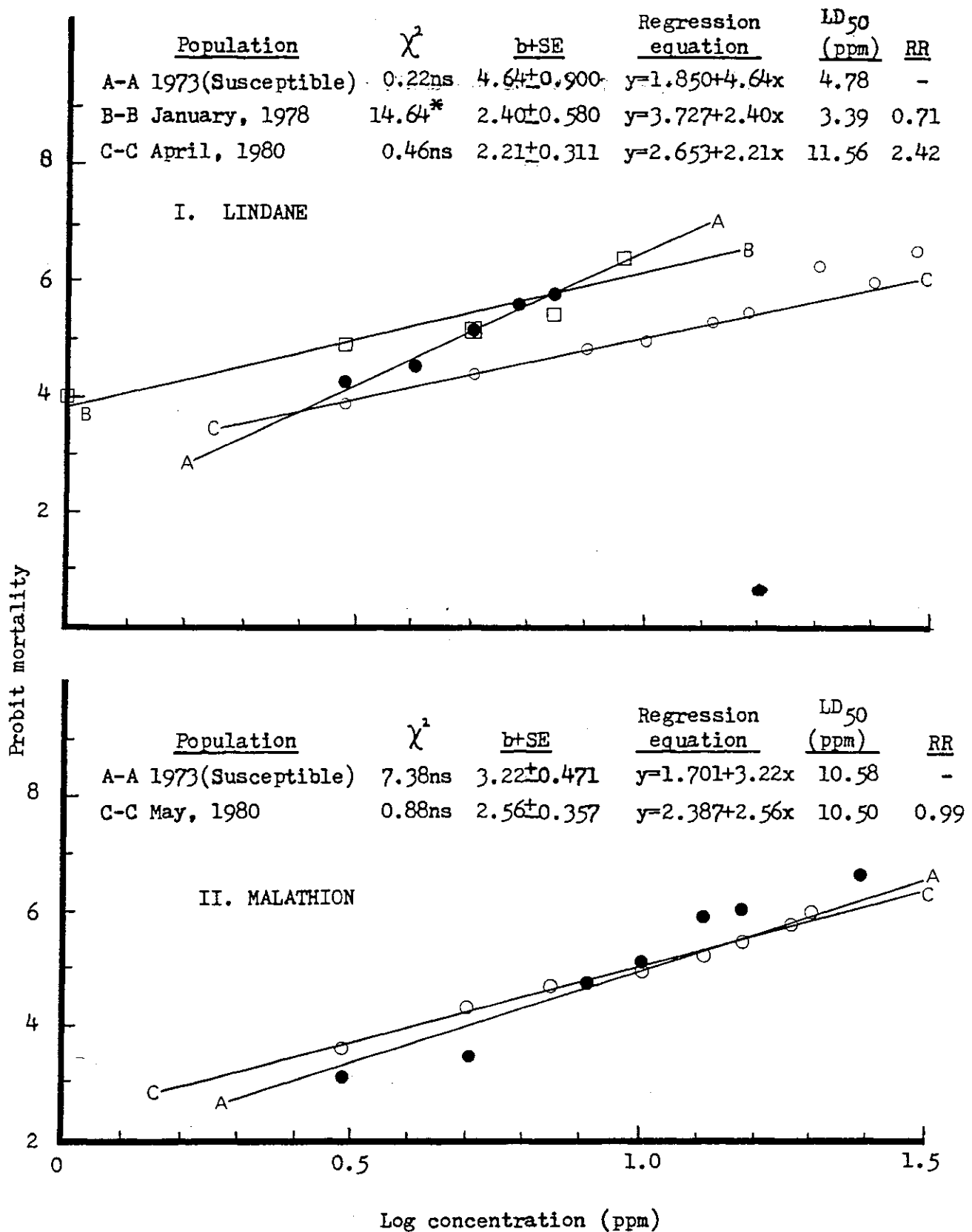
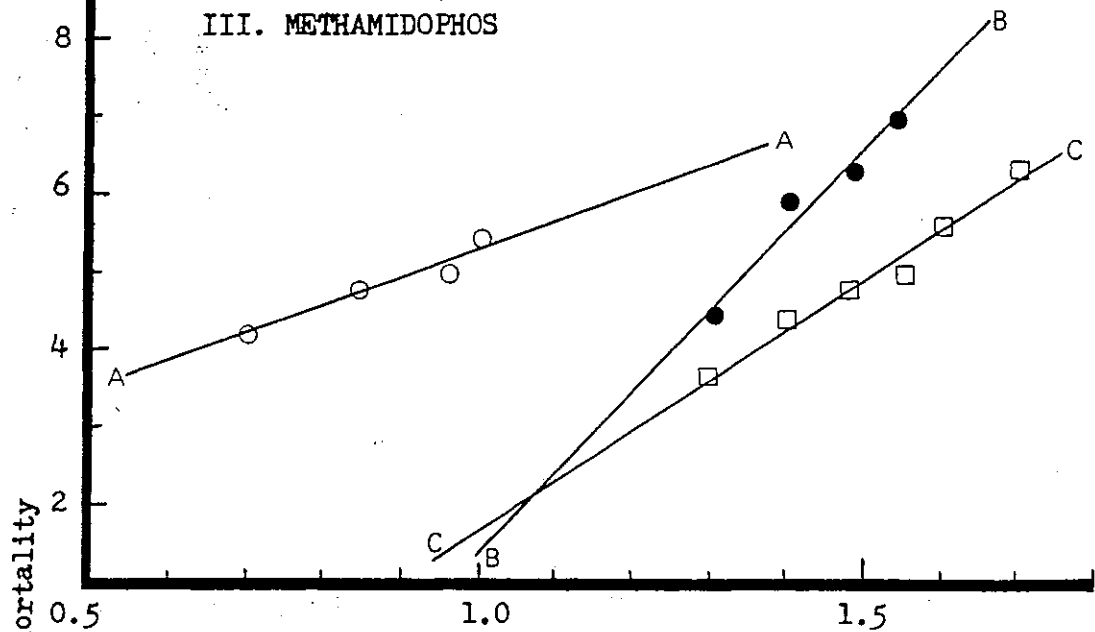


FIGURE 8.9 Dosage-mortality regressions for different field populations of male *Apanteles plutellae* Kurdj. in relation to different insecticide (I. Lindane, II. Malathion, III. Methamidophos and IV. Fenvalerate). RR = Resistance ratio.

| Population            | $\chi^2$ | b+SE        | Regression equation | LD <sub>50</sub> (ppm) | RR   |
|-----------------------|----------|-------------|---------------------|------------------------|------|
| A-A 1973(Susceptible) | 0.36ns   | 3.56±1.001  | y=1.702+3.56x       | 8.45                   | -    |
| B-B January 1978      | 0.55ns   | 10.46±1.695 | y=10.46x-9.140      | 22.50                  | 2.66 |
| C-C January 1980      | 1.38ns   | 6.38±0.969  | y=6.38x-4.711       | 33.25                  | 3.94 |



| Population            | $\chi^2$ | b+SE       | Regression equation | LD <sub>50</sub> (ppm) | RR   |
|-----------------------|----------|------------|---------------------|------------------------|------|
| A-A 1973(Susceptible) | 0.58ns   | 3.77±0.484 | y=1.516+3.77x       | 8.39                   | -    |
| B-B January 1978      | 2.31ns   | 8.27±1.343 | y=8.27x-6.420       | 23.91                  | 2.85 |
| C-C February 1980     | 2.13ns   | 3.58±0.536 | y=3.720+3.58x       | 22.80                  | 2.72 |

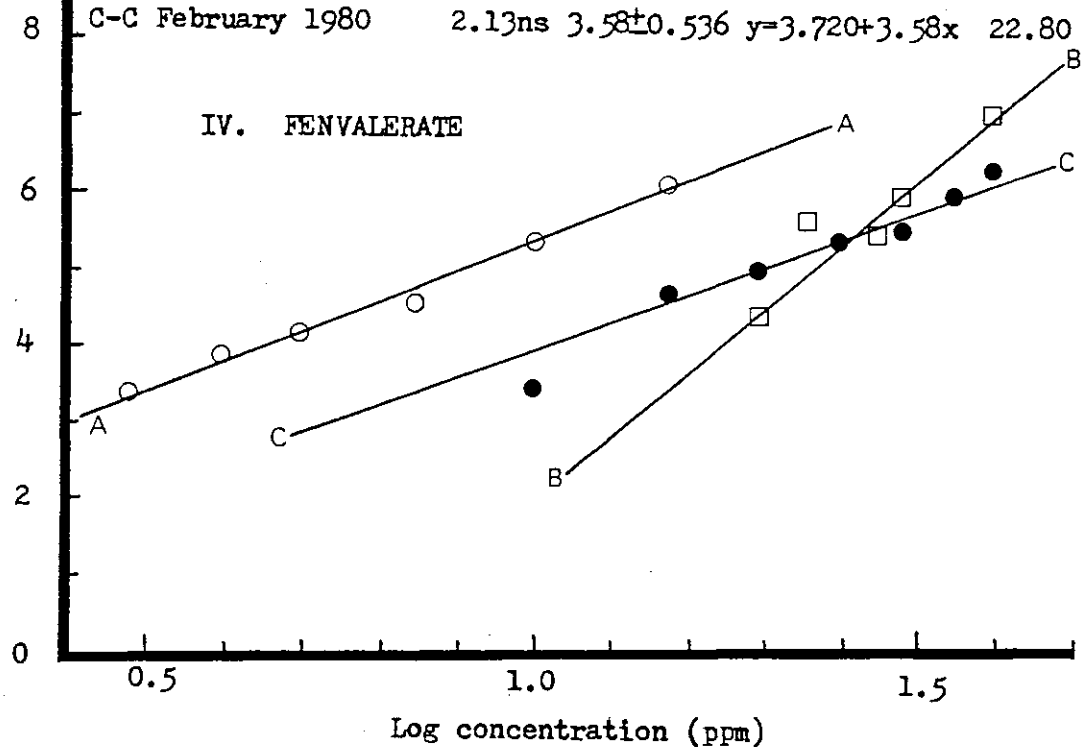


FIGURE 8.9 (Continued).



Table 8.3 Relative effectiveness of various insecticides to the different stages of *Plutella xylostella* (L.) and their relative hazards to its parasite *Apanteles plutellae* Kurdj.

| Chemical insecticide | Toxicity to <i>P.xylostella</i> |                 |                                                                |                                     |                          | On treated pupae        |                                     | Relative over-all effectiveness of pupal control <sup>γ</sup><br>g = (e+f) | Toxicity to <i>A.plutellae</i> on treated cocoons |                                         | Relative over-treat hazard to para-site <sup>δ</sup><br>J=(h+i) |  |
|----------------------|---------------------------------|-----------------|----------------------------------------------------------------|-------------------------------------|--------------------------|-------------------------|-------------------------------------|----------------------------------------------------------------------------|---------------------------------------------------|-----------------------------------------|-----------------------------------------------------------------|--|
|                      | On treated eggs*                |                 | Overall effectiveness of egg control <sup>γ</sup><br>c = (a+b) | On treated leaves exposed to larvae |                          | Adult emergence*<br>(e) | Emergent adults <sup>λ</sup><br>(f) |                                                                            | Mortality in para-site emergence*<br>(h)          | Emergent para-sites <sup>λ</sup><br>(i) |                                                                 |  |
|                      | Hatching                        | Emergent larvae |                                                                | At 24 hrs*                          | Persistence <sup>β</sup> |                         |                                     |                                                                            |                                                   |                                         |                                                                 |  |
|                      | (a)                             | (b)             |                                                                |                                     |                          |                         |                                     |                                                                            |                                                   |                                         |                                                                 |  |
| I.ORGANOPHOSPHATES   |                                 |                 |                                                                |                                     |                          |                         |                                     |                                                                            |                                                   |                                         |                                                                 |  |
| cyanofenphos         | VH                              | M               | Good                                                           | M                                   | S                        | VL                      | C                                   | Poor                                                                       | VL                                                | C                                       | Safe                                                            |  |
| chlorfenvinphos      | VL                              | VH              | Good                                                           | L                                   | S                        | VH                      | -                                   | Good                                                                       | VL                                                | C                                       | Safe                                                            |  |
| chlorpyrifos         | VL                              | M               | Moderate                                                       | VL                                  | S                        | VL                      | C                                   | Poor                                                                       | VH                                                | -                                       | Very harm)                                                      |  |
| chlorpyrifos-methyl  | VL                              | H               | Good                                                           | L                                   | S                        | -                       | -                                   | -                                                                          | VH                                                | a                                       | -ful                                                            |  |
| diazinon             | VL                              | VH              | Good                                                           | M                                   | S                        | VL                      | C                                   | Poor                                                                       | VH                                                | -                                       | V.harmful                                                       |  |
| dichlorvos           | VL                              | H               | Good                                                           | -                                   | -                        | -                       | -                                   | -                                                                          | VH                                                | a                                       | V.harmful                                                       |  |
| dicrotophos          | VL                              | L               | Poor                                                           | VL                                  | S                        | VL                      | C                                   | Poor                                                                       | VL                                                | b                                       | M.harmful                                                       |  |
| dimethoate           | VL                              | VL              | Poor                                                           | M                                   | S                        | VL                      | C                                   | Poor                                                                       | VL                                                | a                                       | V.harmful                                                       |  |
| dimethyl vinphos     | VL                              | VH              | Good                                                           | -                                   | -                        | -                       | -                                   | -                                                                          | -                                                 | -                                       | -                                                               |  |
| fenthion             | VL                              | VL              | Poor                                                           | H                                   | Lg                       | VL                      | C                                   | Poor                                                                       | VH                                                | -                                       | -                                                               |  |
| isofenphos           | VL                              | VH              | Good                                                           | -                                   | -                        | -                       | -                                   | -                                                                          | -                                                 | -                                       | -                                                               |  |
| malathion            | VL                              | L               | Poor                                                           | VL                                  | S                        | VL                      | C                                   | Poor                                                                       | VH                                                | -                                       | -                                                               |  |
| methamidophos        | VL                              | H               | Good                                                           | H                                   | S                        | VL                      | C                                   | Poor                                                                       | VL                                                | C                                       | Safe                                                            |  |
| methidathion         | VL                              | VH              | Good                                                           | VH                                  | S                        | VH                      | -                                   | Good                                                                       | H                                                 | C                                       | M.harmful                                                       |  |
| monocrotophos        | VL                              | H               | Good                                                           | VL                                  | S                        | VL                      | C                                   | Poor                                                                       | L                                                 | C                                       | Safe                                                            |  |
| phenthoate           | VL                              | VH              | Good                                                           | VH                                  | Md                       | -                       | -                                   | -                                                                          | M                                                 | C                                       | M.harmful                                                       |  |
| phosmet              | VL                              | H               | Good                                                           | H                                   | Md                       | VL                      | C                                   | Poor                                                                       | L                                                 | b                                       | M.harmful                                                       |  |
| phosphamidon         | VL                              | M               | Moderate                                                       | VL                                  | S                        | VL                      | C                                   | Poor                                                                       | VL                                                | c                                       | Safe                                                            |  |
| profenophos          | -                               | -               | -                                                              | H                                   | Md                       | -                       | -                                   | -                                                                          | -                                                 | -                                       | -                                                               |  |
| prothiophos          | VL                              | VH              | Good                                                           | VL                                  | S                        | VL                      | C                                   | Poor                                                                       | L                                                 | b                                       | M.harmful                                                       |  |
| quinalphos           | VL                              | L               | Poor                                                           | L                                   | S                        | M                       | C                                   | Moderate                                                                   | VH                                                | c                                       | V.harmful                                                       |  |
| tetrachlorvinphos    | -                               | -               | -                                                              | -                                   | -                        | -                       | -                                   | -                                                                          | VH                                                | a                                       | V.harmful                                                       |  |
| triazophos           | H                               | M               | Moderate                                                       | VH                                  | Lg                       | M                       | C                                   | Moderate                                                                   | VL                                                | c                                       | Safe                                                            |  |
| trichlorfon          | VL                              | L               | Poor                                                           | VL                                  | S                        | VL                      | C                                   | Poor                                                                       | VL                                                | c                                       | Safe                                                            |  |
| II.ORGANOCHLORINES   |                                 |                 |                                                                |                                     |                          |                         |                                     |                                                                            |                                                   |                                         |                                                                 |  |
| dieldrin             | VL                              | M               | Moderate                                                       | L                                   | S                        | VL                      | C                                   | Poor                                                                       | M                                                 | b                                       | M.harmful                                                       |  |
| endosulfan           | VL                              | L               | Poor                                                           | L                                   | S                        | VL                      | C                                   | Poor                                                                       | M                                                 | a                                       | V.harmful                                                       |  |
| endrin               | VL                              | VH              | Good                                                           | M                                   | Md                       | VL                      | C                                   | Poor                                                                       | VL                                                | c                                       | Safe                                                            |  |
| lindane              | VL                              | H               | Good                                                           | VH                                  | S                        | VL                      | C                                   | Poor                                                                       | VH                                                | -                                       | V.harmful                                                       |  |
| III. CARBAMATES      |                                 |                 |                                                                |                                     |                          |                         |                                     |                                                                            |                                                   |                                         |                                                                 |  |
| aminocarb            | VL                              | L               | Poor                                                           | -                                   | -                        | -                       | -                                   | -                                                                          | -                                                 | -                                       | -                                                               |  |
| BPMC                 | VL                              | VL              | Poor                                                           | -                                   | -                        | -                       | -                                   | -                                                                          | -                                                 | -                                       | -                                                               |  |
| carbaryl             | VL                              | L               | Poor                                                           | VL                                  | S                        | VL                      | C                                   | Poor                                                                       | VL                                                | b                                       | M.harmful                                                       |  |
| cartap               | VH                              | -               | Good                                                           | VH                                  | Md                       | VL                      | a                                   | Good                                                                       | VH                                                | -                                       | V.harmful                                                       |  |
| methiocarb           | VL                              | VH              | Good                                                           | VH                                  | Lg                       | L                       | C                                   | Poor                                                                       | VL                                                | c                                       | Safe                                                            |  |
| methomyl             | L                               | VL              | Poor                                                           | H                                   | S                        | VL                      | C                                   | Poor                                                                       | L                                                 | c                                       | Safe                                                            |  |
| pirimicarb           | -                               | -               | -                                                              | VL                                  | S                        | -                       | -                                   | -                                                                          | -                                                 | -                                       | -                                                               |  |
| IV.PYRETHROIDS       |                                 |                 |                                                                |                                     |                          |                         |                                     |                                                                            |                                                   |                                         |                                                                 |  |
| decamethrin          | VH                              | -               | Good                                                           | VH                                  | S                        | VH                      | C                                   | Good                                                                       | L                                                 | b                                       | M.harmful                                                       |  |
| fenvalerate          | VH                              | -               | Good                                                           | VH                                  | Lg                       | VH                      | -                                   | Good                                                                       | VL                                                | c                                       | Safe                                                            |  |
| permethrin           | VH                              | -               | Good                                                           | VH                                  | Lg                       | VH                      | -                                   | Good                                                                       | VH                                                | -                                       | V.harmful                                                       |  |
| resmethrin           | VL                              | VH              | Good                                                           | VH                                  | Md                       | VH                      | -                                   | Good                                                                       | VH                                                | -                                       | V.harmful                                                       |  |

Table 8.3 (Continued 1).

| Chemical insecticide        | Toxicity to <i>P.xylostella</i> |                     |                                                           | On treated pupae  |                          |                                               |                     | Relative over-<br>all effective-<br>ness of pupal<br>control<br>g = (e+f) | Toxicity to <i>A.plutellae</i> on<br>treated cocoons |                                                 | Relative<br>overall<br>hazard to<br>parasite <sup>δ</sup><br>j=(h+i) |  |
|-----------------------------|---------------------------------|---------------------|-----------------------------------------------------------|-------------------|--------------------------|-----------------------------------------------|---------------------|---------------------------------------------------------------------------|------------------------------------------------------|-------------------------------------------------|----------------------------------------------------------------------|--|
|                             | On treated eggs*                |                     | Overall effect-<br>iveness of egg<br>control<br>c = (a+b) | On treated leaves |                          | Adult<br>emergence*adults <sup>λ</sup><br>(e) | Emerg-<br>ed<br>(f) |                                                                           | Mortality<br>in para-<br>site emer-<br>gence*<br>(h) | Emerg-<br>ed para-<br>sites <sup>λ</sup><br>(i) |                                                                      |  |
|                             | Hatching                        | Emerg-<br>ed larvae |                                                           | exposed to larvae |                          |                                               |                     |                                                                           |                                                      |                                                 |                                                                      |  |
|                             | (a)                             | (b)                 |                                                           | At 24<br>hrs*     | Persistence <sup>β</sup> |                                               |                     |                                                                           |                                                      |                                                 |                                                                      |  |
| V.BIOLOGICAL AGENTS         |                                 |                     |                                                           |                   |                          |                                               |                     |                                                                           |                                                      |                                                 |                                                                      |  |
| <i>B.thuringiensis</i>      | VL                              | VL                  | Poor                                                      | M                 | S                        | VL                                            | C                   | Poor                                                                      | VL                                                   | c                                               | Safe                                                                 |  |
| Granulosis virus            | VL                              | VL                  | Poor                                                      | -                 | -                        | VL                                            | C                   | Poor                                                                      | VL                                                   | c                                               | Safe                                                                 |  |
| VI.GROWTH REGULANT          |                                 |                     |                                                           |                   |                          |                                               |                     |                                                                           |                                                      |                                                 |                                                                      |  |
| diiflubenzuron              | VL                              | VL                  | Poor                                                      | VL                | S                        | VL                                            | C                   | Poor                                                                      | -                                                    | -                                               | -                                                                    |  |
| VII.MIXTURES                |                                 |                     |                                                           |                   |                          |                                               |                     |                                                                           |                                                      |                                                 |                                                                      |  |
| carbaryl+malathion          | VL                              | L                   | Poor                                                      | VL                | S                        | VL                                            | C                   | Poor                                                                      | VH                                                   | -                                               | V.harmful                                                            |  |
| dichlorvos +<br>phenothoate | VH                              | H                   | Good                                                      | VH                | Md                       | VL                                            | C                   | Poor                                                                      | VH                                                   | -                                               | V.harmful                                                            |  |
| carbaryl+lindane            | VL                              | VL                  | Poor                                                      | -                 | -                        | -                                             | -                   | -                                                                         | -                                                    | -                                               | -                                                                    |  |
| VIII.ORGANO-TIN             |                                 |                     |                                                           |                   |                          |                                               |                     |                                                                           |                                                      |                                                 |                                                                      |  |
| cyhexatin                   | -                               | -                   | -                                                         | H                 | Lg                       | -                                             | -                   | -                                                                         | VL                                                   | c                                               | Safe                                                                 |  |
| IX.FORMAMIDINES             |                                 |                     |                                                           |                   |                          |                                               |                     |                                                                           |                                                      |                                                 |                                                                      |  |
| amitraz                     | H                               | VL                  | Good                                                      | VL                | S                        | VL                                            | -                   | Poor                                                                      | VL                                                   | b                                               | M.harmful                                                            |  |
| chlordimeform               | VL                              | VH                  | Good                                                      | -                 | -                        | -                                             | -                   | -                                                                         | VH                                                   | -                                               | V.harmful                                                            |  |

\* VH=Very high (90% mortality and above), H=High (70% mortality and above, but less than 90%), M=Moderate (50% mortality and above but less than 70%), L=Low (30% mortality and above but less than 50%), and VL=Very low (less than 30% mortality).

β Lg=Long (Effecting more than 70% mortality for more than 7 days), Md=Medium (Effecting more than 70% mortality for more than 3 days but less than 7 days), and S=Short (Effecting more than 70% mortality for less than 3 days).

λ a=Difference in cumulative mortality from untreated control at 7 days after emergence > 60%, b=Difference greater than 30% but less than 60%, and c=Difference less than 30%.

γ Good=Possessing high toxicity (70% mortality and above) with respect to either hatching or on the subsequent survival of the hatched larvae up to the 2nd-instar stage, Moderate=Toxicity exhibited ranged from 50% mortality and above, but less than 70%, and Poor=Toxicity exhibited less than 50% mortality.

δ Safe=Mortality in parasite emergence less than 50% or difference in cumulative mortality from untreated control at 7 days after emergence < 30%, Moderately harmful = Parasite emergence mortality more than 50% but less than 70%, and difference in cumulative mortality from control is more than 30% but less than 60%, and Very harmful = Parasite emergence mortality more than 70% and difference in cumulative mortality from control is more than 60%.

immediately evident, as with Group Ih in Table 8.4. Moreover, specificity in relation to individual or combinations of different host stages is also apparent (Table 8.4, Groups Ia-g). Pertaining to insecticides capable of providing simultaneous and effective control against all immature stages of DBM these are limited, being restricted to those in Group Ig. This has special significance since the different life stages of DBM in the Cameron Highlands are usually present together, and such a situation generally demands the use of 'wide-spectrum' chemicals. That insecticides of such a nature are so few (Group Ig), as well as not always adequately available or properly utilized, probably also accounts for many of the failures in control of DBM.

From Table 8.4 there appears a fairly wide choice of chemicals for use against DBM, particularly when those possessing stage specificity are also considered and employed in conjunction with peak occurrence of a stage, of which the nature is now partially known from the stage distribution studies in Section 6.2. However, when considered from an IPC viewpoint in which insecticides that are less harmful to parasites would be most desirable, the available choice is restrictive, and is limited essentially to the following: cyanofenphos, chlorfenvinphos, methamidophos, monocrotophos, phosphamidon, triazophos and trichlorfon among the organophosphates, endrin among the organochlorines, methiocarb and methomyl among the carbamates, fenvalerate among the pyrethroids, B.t. and granulosis virus among the biological insecticides, and cyhexatin among the organotins (Table 8.3). A few other chemicals have, however, moderately harmful effects, viz dicrotophos, methidathion, phenthoate, phosmet, prothiophos, dieldrin, carbaryl, decamethrin and amitraz. Although all these appear preferable to many others that have extreme toxicity to the parasite (Table 8.3), not all can provide effective DBM control. Those found capable of satisfying both these requirements are thus further reduced to chemicals in Groups II & III (Table 8.4). Among these, fenvalerate appears the best choice, being highly effective against all the immature stages of DBM while relatively safe to A.plutellae (Tables 8.3 & 8.4). However, in those valleys where significant resistance development to DBM has been confirmed (Sudderuddin & Kok, 1978), its status needs to be further reviewed.

In general, the chemicals in the present investigations have been evaluated at dosages closely following that of commercial recommendations and farm use. It is well recognized that for many, the concentrations far exceed minimum effective dose and the excessive use is largely due to the 'play safe' factor. Further tests to identify lower concentrations would clearly be desirable if unwarranted excess in application of the

Table 8.4 Grouping of insecticides in relation to their effectiveness against the different stage(s) of Plutella xylostella (L.) and their hazards on its parasite, Apanteles plutellae Kurdj.

| Stage(s) of<br><u>P.xylostella</u>                                  | Eggs                       | Larvae                     | Pupae                          | Eggs +<br>larvae           | Eggs +<br>pupae                | Larvae +<br>pupae     | Eggs + larvae + pupa  |                                    |
|---------------------------------------------------------------------|----------------------------|----------------------------|--------------------------------|----------------------------|--------------------------------|-----------------------|-----------------------|------------------------------------|
| Response:                                                           | +                          | +                          | +                              | +                          | +                              | +                     | +                     | -                                  |
| + = effective                                                       |                            |                            |                                |                            |                                |                       |                       |                                    |
| - = ineffective                                                     |                            |                            |                                |                            |                                |                       |                       |                                    |
| -----                                                               |                            |                            |                                |                            |                                |                       |                       |                                    |
| Grouping based on the relative toxicity to <u>P.xylostella</u> only |                            |                            |                                |                            |                                |                       |                       |                                    |
| GROUP:                                                              | Ia                         | Ib                         | Ic                             | Id                         | Ie                             | If                    | Ig                    | Ih                                 |
| (Effective-<br>ness good)                                           | amitraz<br>cartap          | cartap<br>cyhexatin        | cartap<br>chlorfenvin-<br>phos | cartap<br>decamethrin      | cartap<br>chlorfenvin-<br>phos | cartap<br>decamethrin | cartap<br>decamethrin | carbaryl<br>carbary +<br>malathion |
|                                                                     | chlordimeform              | decamethrin                | decamethrin                    | dichlorvos +<br>phenthoate | decamethrin                    | fenvalerate           | fenvalerate           | dicroto-<br>phos                   |
|                                                                     | chlorfenvin-<br>phos       | dichlorvos +<br>phenthoate | fenvalerate                    | fenvalerate                | fenvalerate                    | methidathion          | methidath-<br>ion     | difluben-<br>zuron                 |
|                                                                     | chlorpyrifos-<br>methyl    | fenthion                   | methidathion                   | lindane                    | methidathion                   | permethrin            | permethrin            | endosulfan                         |
|                                                                     | cyanofenphos               | fenvalerate                | permethrin                     | methamidophos              | permethrin                     | resmethrin            | resmethrin            | malathion                          |
|                                                                     | decamethrin                | lindane                    | resmethrin                     | methidathion               | resmethrin                     |                       |                       | trichlorfon                        |
|                                                                     | diazinon                   | methamidophos              |                                | methiocarb                 |                                |                       |                       |                                    |
|                                                                     | dichlorvos                 | methidathion               |                                | permethrin                 |                                |                       |                       |                                    |
|                                                                     | dichlorvos +<br>phenthoate | methiocarb                 |                                | phenthoate                 |                                |                       |                       |                                    |
|                                                                     | dimethyl-<br>vinphos       | methomyl                   |                                | phosmet                    |                                |                       |                       |                                    |
|                                                                     | endrin                     | permethrin                 |                                | resmethrin                 |                                |                       |                       |                                    |
|                                                                     | fenvalerate                | phenthoate                 |                                |                            |                                |                       |                       |                                    |
|                                                                     | isofenphos                 | phosmet                    |                                |                            |                                |                       |                       |                                    |
|                                                                     | lindane                    | profenophos                |                                |                            |                                |                       |                       |                                    |
|                                                                     | methamidophos              | resmethrin                 |                                |                            |                                |                       |                       |                                    |
|                                                                     | methidathion               | triazophos                 |                                |                            |                                |                       |                       |                                    |
|                                                                     | methiocarb                 |                            |                                |                            |                                |                       |                       |                                    |

Table 8.4 (Continued 1).

| Stage(s) of<br><u>P.xylostella</u> | Eggs | Larvae | Pupae | Eggs +<br>larvae | Eggs +<br>Pupae | Larvae +<br>pupae | Eggs + larvae + pupa |   |
|------------------------------------|------|--------|-------|------------------|-----------------|-------------------|----------------------|---|
| Response:                          | +    | +      | +     | +                | +               | +                 | +                    | - |
| + = effective                      |      |        |       |                  |                 |                   |                      |   |
| - = ineffective                    |      |        |       |                  |                 |                   |                      |   |

Grouping based on the relative toxicity to P.xylostella only

| GROUP:                      | Ia                                                                                | Ib                                                               | Ic                       | Id                                 | Ie         | If | Ig         | Ih |
|-----------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------|--------------------------|------------------------------------|------------|----|------------|----|
| (Effective-<br>ness good)   | monocrotophos<br>permethrin<br>phenthoate<br>phosmet<br>prothiophos<br>resmethrin |                                                                  |                          |                                    |            |    |            |    |
| (Effectiveness<br>moderate) | chlorpyrifos<br>dieltrin<br>phosphamidon<br>triazophos                            | <u>B.t.*</u><br>cyanofenphos<br>diazinon<br>dimethoate<br>endrin | triazophos<br>quinalphos | cyanofenphos<br>diazinon<br>endrin | triazophos |    | triazophos |    |

Regrouping of Group Ia-g above with exclusions of insecticides found very harmful to A.plutellae

| GROUP:                    | IIa                  | IIb           | IIc                  | IId           | IIe                  | IIf          | IIg          |
|---------------------------|----------------------|---------------|----------------------|---------------|----------------------|--------------|--------------|
| (Effective-<br>ness good) | amitraz              | cyhexatin     | chlorfenvin-<br>phos | decamethrin   | chlorfenvin-<br>phos | decamethrin  | decamethrin  |
|                           | chlorfenvin-<br>phos | decamethrin   | decamethrin          | fenvalerate   | decamethrin          | fenvalerate  | fenvalerate  |
|                           | cyanofenphos         | fenthion      | fenvalerate          | methamidophos | fenvalerate          | methidathion | methidathion |
|                           | decamethrin          | fenvalerate   | methidathion         | methidathion  | methidathion         |              |              |
|                           | dimethyl-<br>vinphos | methamidophos |                      | methiocarb    |                      |              |              |
|                           | endrin               | methidathion  |                      | phenthoate    |                      |              |              |
|                           | fenvalerate          | methiocarb    |                      | phosmet       |                      |              |              |

Table 8.4 (Continued 2).

| Regrouping of Group Ia-g above with exclusions of insecticides found very harmful to <u>A.plutellae</u> |                                                                                                                    |                                                                |            |                        |            |      |            |
|---------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|------------|------------------------|------------|------|------------|
| GROUP:                                                                                                  | IIa                                                                                                                | IIb                                                            | IIc        | IIId                   | IIe        | IIIf | IIg        |
| (Effective-<br>ness good)                                                                               | isofenphos<br>methamidophos<br>methidathion<br>methiocarb<br>monocrotophos<br>phenthoate<br>phosmet<br>prothiophos | methomyl<br>phenthoate<br>phosmet<br>profenophos<br>triazophos |            |                        |            |      |            |
| (Effectiveness<br>moderate)                                                                             | dielddrin<br>phosphamidon<br>triazophos                                                                            | <u>B.t.*</u><br>endrin                                         | triazophos | cyanofenphos<br>endrin | triazophos |      | triazophos |

| Regrouping of Group IIA-g above with exclusions of insecticides found moderately harmful to <u>A.plutellae</u> |                                                                                                                                                      |                                                                                                                  |                                     |                                                |                                     |             |             |
|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|-------------------------------------|------------------------------------------------|-------------------------------------|-------------|-------------|
| GROUP:                                                                                                         | IIIa                                                                                                                                                 | IIIb                                                                                                             | IIIc                                | IIId                                           | IIIe                                | IIIIf       | IIIg        |
| (Effective-<br>ness good)                                                                                      | chlorfenvin-<br>phos<br>cyanophenphos<br>dimethyl-<br>vinphos<br>endrin<br>fenvalerate<br>isofenphos<br>methamidophos<br>methiocarb<br>monocrotophos | cyhexatin<br>fenthion<br>fenvalerate<br><br>methamidophos<br>methiocarb<br>methomyl<br>profenophos<br>triazophos | chlorfenvin-<br>phos<br>fenvalerate | fenvalerate<br><br>methamidophos<br>methiocarb | chlorfenvin-<br>phos<br>fenvalerate | fenvalerate | fenvalerate |
| (Effectiveness<br>moderate)                                                                                    | phosphamidon<br>triazophos                                                                                                                           | <u>B.t.*</u><br>endrin                                                                                           | triazophos                          | cyanophenphos<br>endrin                        | triazophos                          |             | triazophos  |

B.t.\* = B.thuringiensis

toxicants is to be avoided or minimised. The scope of achieving this seems not unrealistic when one considers that pyrethroids are often effective at extremely low concentrations (Elliott, 1976). Moreover, at sub-lethal dosages some may cause 'irritancy' as was recently found (K.H.Tan, 1981, pers. comm.) for cypermethrin and permethrin on Pieris brassicae. When the temperature declines to below 20°C an exposed larva would show 'irritancy' whereupon it stops feeding, wriggles vigorously and regurgitates before falling off the plant. Upon recovery when the temperature rises above the 'irritancy' threshold feeding is resumed by the larva after ascending the plant. However, the overall consumption is greatly reduced with the developmental period lengthened and the resultant pupa and adult much smaller. Should this phenomenon also occur in DBM, the practical implications with respect to its integrated control development can be far-reaching. Not only can lower rates of chemicals be utilized with attendant reduction in chemical selection pressure but also feeding damage to the crop reduced. Besides, the longer availability of host larval stages provides for better chance of parasite survival. In the Cameron Highlands, the 'irritancy' effect could prove critical since the temperature is well below 20°C most of the time. However, the benefits envisaged should also be carefully weighed against any possible forced dispersal of the affected larvae that might elicit more rapid resistance development to the pyrethroid itself.

In some instances, upon removal or reduction of the selection pressure by insecticides, susceptibility has been regained in resistant arthropods (Brown, 1958; Brown & Pal, 1971). Such 'reversion' has also been suggested in the present case with DBM where methamidophos and methomyl, earlier noted to be resistant (Fig. 1.2, Sudderuddin & Kok, 1978), are now found capable of effecting acceptable kill (Fig. 8.3). On the other hand, malathion which had resistant factor of 2,096 (Sudderuddin & Kok, 1978), has remained highly resistant (Fig. 8.3). These observations correspond well with the contention of Croft (1980) that 'reversion' from a high resistance level is normally rare, while it is more common if selection is discontinued during the initial phase of resistance development or before multiple resistance mechanisms are involved. Since new insecticides for replacement of resistant ones (Fig. 1.2) are becoming less readily available, efforts should be devoted to seeking additional 'reversions' so that re-use for some can be considered. The rotational use of appropriate chemicals with due consideration to minimising resistance development should also be examined.

Since the intensive use of chemicals appears likely to continue for some period, an important countermeasure for resistance would include

systematic checking on the development of resistance based on standard susceptibility tests. Such testing, as suggested by Brown (1958), will ensure that the use of a chemical be extended until such time as the tests make it evident that a control failure will result. This would eliminate the practical danger of control failure due to unsuspected resistance (Brown & Pal, 1971) and allow replacement by another before the selection pressure has firmly established the resistant condition.

In the Cameron Highlands, insecticides which showed signs of becoming resistant over a fairly wide area will generally be withdrawn from the market as soon as a new and more effective chemical becomes available. But some of the chemicals withdrawn could still be used effectively in some of the localities, suggesting that resistance development was not uniform for the different regions. For example, DBM found resistant to methomyl in the Mensum Valley during mid-1970 was still susceptible to the same chemical in Kampong Raja. In 1978, a parallel situation was again noted with fenvalerate. Field resistance was evident in Kea Farm and the Mensum Valley, while in Brinchang DBM remained relatively susceptible. Even from only these two cases which are probably under-representation of the actual situation, it is evident that the various agricultural valleys are subtly dissimilar in their DBM make-up; hence, their control strategies involving insecticides should be considered separately according to each valley ecosystem. Unfortunately, considering the Cameron Highlands as a whole is currently the general practice, and quite obviously needs to be reviewed. As regards the different pattern of resistance development observed in the different valleys it merely constitutes further evidence in support of the view (see 1.2) that there is little movement of DBM from one valley to another. That little immigration occurs is also indicated by the extremely rapid build-up of resistance often encountered within each valley itself.

From comparative studies on different methods of insecticidal spraying it is evident that more effective control of DBM can be effected through improved means of chemical application. Largely, this is due to higher capability of these methods in getting the chemicals onto areas where most of the pest individuals normally concentrate, i.e. young leaves and shoots, and on the undersurface (see also 6.2). Although spraying over both upper and lower surfaces is superior in terms of control efficiency, this procedure will not be readily adopted because of frequent need to invert the spray lance to get at the undersurface of every leaf. Likewise, treating only the underside would also face similar difficulty. In contrast, although thorough spraying of young leaves and shoots is not the most effective, it is however most practical and will more readily



be adopted. By this means less chemical is generally needed yet achieving better control than the average farmers. Moreover, this is acceptable economically and preferred ecologically because less chemical is applied while hazards to parasites greatly reduced due to concentration of the latter on moderately old leaves (see 6.2). As such, it would seem desirable to encourage farmers to pay particular attention in ensuring more thorough spraying of the young leaves and shoots. Such a tactic would constitute an important step towards the development of IPC against DBM. However, since targeting chemicals onto the undersurface of leaves could also produce significant improvement, the possible employment of the electro-dyne system (Coffee, 1980a, b) which has the unique feature of 'electric-field wrap-around', should also be seriously explored. With such a system the extra effort of inverting the spray lance is not required.

B.t. has consistently been found capable of controlling DBM under varied conditions in Canada (Cass, 1963), the Caribbeans (Suah & Ellis, 1974; Gruner & Delplanque, 1974), Finland (Rautapaa, 1967), Indonesia (Sudarwohadi & van den Oever, 1974), Malaysia (Ho & Ng, 1970), Mexico (Carillo, 1971), New Zealand (Helson, 1960), the Philippines (Cadapan & Gabriel, 1973), Singapore (Chuo, 1973), USA (Creighton et al., 1970; Creighton et al., 1973, 1974; Creighton et al., 1972; Creighton & McFadden, 1975), and the USSR (Adashkevich, 1966; Shchepetilnikova et al., 1968; Zurabova, 1972). Essentially, the insecticidal activity is largely due to (i) a crystalline delta endotoxin produced by the bacteria, and (ii) the bacteria spores. Initially, it was thought that the ingestion of the spores led to a bacterial population in the gut which eventually caused disease, followed by death of the insect. More recent knowledge (Luthy, 1973), however, indicates that the high gut pH and digestive enzymes of susceptible insects (pH 9.0+) cause dissolution of the crystalline endotoxin into toxic components which then block the enzyme system that protects the larva's gut from its own digestive juices. Following damage of the gut wall, the bacterial spores then invade the insect haemocoel through the perforated gut walls and produce a septicemia which kills the insect. This whole process is noted to govern the time interval between ingestion of the bacteria and the death of insect, and this period can vary from one to several days, with the caterpillar not resuming feeding at all (Luthy, 1973). In the present case with DBM 4 days appear to be needed to ensure maximum kill while feeding was not completely curtailed though drastically reduced (see 8.2.7).

Pertaining to natural enemy safety, B.t. is not totally selective in favour of the primary parasite, A.plutellae. Although relatively safer than most conventional chemical insecticides, it still could inflict

substantial parasite mortality when the parasitized hosts were exposed to B.t. prior to the developing parasites attaining the cocoon stage. Since parasite mortality is largely a result of starvation, other endo-larval parasites (e.g. D.eucero-phaga) could similarly be affected. Nevertheless, B.t. is still advantageous over other chemical insecticides.

In the Cameron Highlands and many other localities, the inability of B.t. to effect a quick kill has been a major drawback to its ready acceptance and wide adoption by farmers. Incompatibility with some other pesticides (Heimpel, 1967; Sutter et al, 1971; Hamilton & Attia, 1977) in spray tank mixing can also render it ineffective, thereby further aggravating its acceptability. The latter factor is believed to have significant influence since spray mixing is a very common practice in the Cameron Highlands (Ooi & Sudderuddin, 1978). Evidently, further research to minimise such incompatibility problem is desirable.

Concerning resistance development in A.plutellae, although changes in LD<sub>50</sub> values were generally small, some differences could still be detected in the developmental trends shown by the different chemicals. These differences are probably related to their historical usage or that of other closely-allied chemicals in the field. Lindane, for instance, was once widely employed against DBM in the Cameron Highlands but now only moderately used to control other pests, e.g. flea beetles in the nurseries and in poisoned baits against A.ypsilon. Evidently, the reduction in selection pressure for lindane over the years is not likely to generate a high RR, hence only a value of 2.4. With malathion the selection pressure is however even more reduced. Except for possible induction through cross-resistance, any direct inducement from malathion usage is expected to be negligible since it is now no longer in use on the cabbage crops. Moreover, even its employment on other miscellaneous crops (beans, ornamentals, peas, etc) has been drastically reduced and is nothing comparable to that applied earlier on brassicas. As such, it is not unexpected that resistance development by A.plutellae to malathion was not evident. Another possible explanation may closely relate to the extremely high level of resistance recorded for malathion to its host (Sudderuddin & Kok, 1978). With a 2,096 fold resistance, the host must, evidently, possess some highly effective means of detoxifying the insecticide. Although the actual pathway has not been determined, it is not unreasonable to assume that the processes involved have rather complex relationships with an internal parasite as reported by Tamashiro & Sherman (1955), Lingappa et al (1972) and Croft (1977a). In such a situation, toxicant transfer from the external is mediated through the physiology of the host. The survival of a resistant host may result in a 'chemotherapeutic' effect (Croft, 1977a) wherein the

endo-parasite is killed and the pest freed from its enemy. This is however not so with A. plutellae since parasitized host larvae surviving heavy doses of malathion have been observed to produce viable parasites. Moreover, the 'chemotherapeutic' effect is mostly found among relatively large lepidopteran hosts (Taylor, 1954 ; Thurston & Fox, 1972). In contrast, the survival of a resistant host may detoxify a pesticide (Croft, 1977a) resulting in a non-toxic environment for the endo-parasite. With A. plutellae, such a situation not only has afforded protection for its eggs and larvae from any external malathion, but also would remove the selection pressure for resistance development to the chemical. As such, the failure to find any resistance with malathion is thus not unexpected.

Methamidophos, however, has a slightly different pattern of development. Like the others, it is also reflected by its field usage. Once extensively used against both DBM and A. ypsilon, it has in recent years been employed as spray mixtures against only the latter species on brassicas. This is mainly because DBM has become resistant to it (RR = 6.2, Sudderuddin & Kok, 1978) while control of the cutworm is still satisfactory. As such, due to the continuous presence of methamidophos in the environment, it is thus not unexpected to find a steady and progressive increase in the RR values. Within about 3 years from 1978-80, the LD<sub>50</sub> increased by nearly 50%, from 22.5 ppm to 33.3 ppm. This higher rate of increase is perhaps also due to a greater selection pressure that is conferred through the host's lower level of resistance. Such a case with methamidophos has provided further evidence in support of the contention of Croft & Morse (1979) that resistance has always appeared in natural enemies of pests which first acquired resistance, but in crops on which the chemical continues in use for control of another pest. With this, indications are thus beginning to emerge among which natural enemies one might expect resistance to be developed most readily.

Fenvalerate, a pyrethroid introduced in early 1976 for the control of DBM has a RR value of 2.9 by 1978. Although the slight decline to 2.7 in 1980 may not be significant, it could, however, be indicative of the reduced selection pressure resulting from the drastic fall in use of fenvalerate by 1979. Whether the RR would decline further or otherwise increase is likely to be governed by possible occurrence of cross-resistance that may be conferred through heavy use of more recently introduced pyrethroids, such as, permethrin and decamethrin.

In all the chemicals examined, it is evident that the parasite has consistently a lower RR value than its host (Sudderuddin & Kok, 1978; Present studies, 8.2.9), indicating higher susceptibility. This conforms well to the general findings by Croft & Brown (1975) in a survey on res-

ponses of arthropod natural enemies to insecticides. The factors known to influence the rate at which resistance is acquired and the degree to which it is maintained in an arthropod population are numerous. In 1977, Georgiou & Taylor listed 21 major ones affecting pests grouped into categories of genetic, biological and operational factors. The latter are essentially those under the control of an operator or pest manager. In addition, two major hypotheses (Croft & Brown, 1975) have also emerged to account for the differential frequency of resistance which was 281 among agricultural arthropod pests (FAO, 1977) versus 9 among their entomophagous enemies (Croft, 1977b). The first relates to the density dependency of natural enemies upon their host for survival and multiplication following an insecticide application. More specifically, even though the chemical may similarly select out resistant genotypes of both groups, usually their differential multiplication following treatment would result in very different courses of development with respect to resistance selection. Whereas the pest usually has an unlimited food supply available on which to reproduce, the beneficial insect must survive the treatment and find its prey or host which is generally scarce. More usually, the selected natural enemies would fail and die from starvation or do not reproduce. Where they are highly mobile, they may also migrate out of the sprayed area, there to interbreed with another population resulting in the resistance factor becoming diluted or eventually lost (Huffaker, 1971b; Croft, 1972; Georgiou, 1972; Newsom, 1974; Croft & Brown, 1975). More recent study by Morse (1978) who studied resistance development to azinphosmethyl in susceptible strains of the predaceous mite Amblyseius fallacis Garman and its prey Tetranychus urticae Koch, has provided further support to this hypothesis. His data, in a critical analysis by Croft (1980), have confirmed indirectly that different food levels following selection by insecticides may be a significant factor limiting the development of predator resistance as compared to prey.

The second hypothesis to explain the discrepancy between pest and natural enemies in relation to resistance development relates to possible differences between each group in their ability to detoxify conventional pesticides. Accordingly, the increase in susceptibility and reduced ability to acquire resistance to pesticides (measured by concentration levels) as generally witnessed in pests, predators and parasites (Croft & Brown, 1975) are basically due to their retention, respectively, of a higher, intermediate and lower oxidative detoxification potential which, correspondingly, are governed by their phytophagous, mixed, and entomophagous habit. In the foremost, the higher and generalised tolerance is believed to be due to adjustment by natural selection to detoxify

secondary compounds produced by plants such as alkaloids, rotenoids and cyanides, etc. (Krieger et al, 1971) while the specialized parasite has become limited in its adaptation to these chemical stresses, and the predators taking an intermediate position.

It has been pointed out by Croft & Morse (1979) that no single explanation among the two hypothesis is likely to provide the complete answer to the differences observed among the 3 arthropod groups. More probably, both are in some way complementary, with each requiring to fill in partially on the other where limitations exist. Furthermore, drawing from the situation of A. plutellae and in particular the case of malathion, another possible explanation may involve 'shielding by a highly resistant host'. This, however, is relevant only to endo-parasites and specifically to the stages within the host. With this is clarified further the questions of differential responses of hosts and parasites to pesticides that have been asked since synthetic organic products were first introduced. Hopefully, additional research in the future will provide further answers which could allow much more to be done in terms of pesticide management based on natural enemy selectivity and effective chemical pest control.

## 9. THE ESTABLISHMENT, EFFECTS AND RELATIVE IMPORTANCE OF THE IMPORTED PARASITES

### 9.1 INTRODUCTION

Although A.plutellae can contribute substantially towards the suppression of DBM in the Cameron Highlands (see Sections 3 & 4), it is unable to maintain the host adequately at subeconomic levels on many occasions because of certain self-limiting characteristics (e.g. excessive superparasitism and multiple oviposition which can reduce progeny survival) or other extrinsic factors (e.g. the absence of natural foods and indiscriminate use of insecticides). While the latter extreneous influence might be overcome or reduced through proper environmental management, the intrinsic limitations are much less amenable and possibly not feasible in practice. As such, and because of the notable successes achieved with other parasites (Muggeridge, 1930, 1939; Hardy 1938; Ulliyett, 1947; Vos, 1953; Goodwin, 1979), several species were considered for introduction with the object of supplementing the existing contribution of A.plutellae.

Between 1975-77 and under the FAO/UNDP Technical Aid Programme, several shipments of the following parasites were imported (Ooi, 1979a): Macromalon orientale (Hym: Ichneumonidae), Tetrastichus sokolowskii Kurdj. (Hym: Eulophidae), T.collaris (Hym: Ichneumonidae) and D.eucero-phaga. Only the last two species have become firmly established. During 1977 they were consistently recovered only from unsprayed, overlapping cabbage crops specially prepared to help in their initial establishment at the MARDI Research Station in Tanah Rata (Ooi, 1979a).

Following parasite establishment, several research objectives have become relevant. An initial interest concerned their possible spread from the establishment site to major cabbage farms in the Cameron Highlands. With D.eucero-phaga, other studies were also made since it occurred more abundantly and its beneficial effect was relatively more apparent. Moreover, being also a larval endo-parasite, its possible competition and effects on the 'endemic' A.plutellae merited closer investigation. These were attempted to assess its role relative to A.plutellae in the control of DBM.

### 9.2 MATERIALS AND METHODS

In the survey of occurrence and spread of the parasites, periodic visits were made to various cabbage farms to collect both larvae and pupae of DBM as well as cocoons of D.eucero-phaga. Collected pupae and cocoons were kept for adult emergence while the larvae either dissected or reared to adult emergence for confirmation of parasitism. In dissections, the presence of D.eucero-phaga was considered positive when either the parasite

egg or the developing larva was obtained.

The interaction and competition between A.plutellae and D.eucero-phaga, and the subsequent effects on their relative contributions, were investigated in a series of studies in the Conviron<sup>R</sup> (see 2b). Initially, 3 experiments were designed to determine the competitive ability of the two parasites in locating and successfully ovipositing in the host larvae over a fixed period of time. Second instar host larvae were used and parasites 2 days old. In the 1st experiment, each host larva was confined with 2 female A.plutellae in a 'breeding jar' (Plate 2.1) for different periods (0.5, 1, 2, 4, 6, 16, 24 and 36 hrs), with each exposure time replicated 15 times. All the larvae were then dissected for egg counts immediately following exposure. With the 2nd and 3rd experiments the procedure was similar except that instead of confining with A.plutellae, the parasites involved were, respectively, D.eucero-phaga alone and both parasite species together.

Quantitative studies on competitive host searching were also conducted; in particular the functional response and the determination of Th (handling time) and a' (attack coefficient or attack rate) values for both parasites. Along with other known attributes it was hoped that these biological characteristics (Th and a') would help indicate their relative usefulness. For the investigations, 2nd-instar host larvae at different densities (5, 10, 30, 50, 100, 200 and 300 for D.eucero-phaga and 5, 10, 20, 30, 40, 50, 100, 200 and 250 for A.plutellae) were, respectively, provided for 24 hrs on a leaf of B.rapa (ca 180 cm<sup>2</sup>) to each 2-day old mated female parasite within a 'breeding jar' (Plate 2.1) arena. The parasites were given access to water and 10% honey, and each density replicated 4-5 times. Immediately following exposures, all the host larvae were dissected for parasite egg counts.

From previous studies of this experimental series D.eucero-phaga was found to detect hosts faster and parasitize them more successfully than A.plutellae (see 9.3.2.1 & 9.3.2.2). However, this need not necessarily be advantageous unless also accompanied by discrimination needed to avoid excessive superparasitism. Among solitary parasites, the ability to distinguish and avoid a parasitized host has particular adaptive significance. One with a perfect discrimination and restraint would avoid wastage of eggs, and through non-random selection of the hosts, is able to parasitize more host individuals. Under competitive situations with other species, such discriminatory capacity might often prove critical in governing its superiority, as might perhaps be so with D.eucero-phaga which is endowed with this faculty (Lloyd, 1940). Whether A.plutellae can exhibit

similar discriminatory ability, both intra- and inter-specific, was not certain. To explore these possibilities, four experiments were conducted. The first two (A & B) were designed to examine the intra-specific discriminatory ability of A.plutellae; A being replicated 6 times and B 10 times. All the parasites used were 3 days old and the test hosts were 2nd-instar stage which had been subjected first to single parasite oviposition. For the 2nd oviposition exposure (24 hrs) using 2 parasite females/host, a 24-hr lapse from 1st exposure was allowed in experiment A; while that for B was 4 days. Under these conditions, all the host larvae would contain parasite larvae in experiment B but eggs in A during the 2nd exposure, since egg-hatching in A.plutellae would normally require ca 3 days (Table 9.1). Following the 2nd exposure, the larvae were dissected for egg counts; this was made immediately in experiment B and 24 hrs later in A. By this means, all the eggs deposited during the 2nd oviposition can be readily distinguished as they would still remain unhatched, unlike those from the 1st oviposition exposure.

For the 3rd (C) and 4th (D) experiments the studies were on inter-specific discrimination to determine (i) whether females of each species (A.plutellae and D.eucero-phaga) are able to distinguish between unparasitized hosts and those parasitized by the other, and (ii) the degree of host discrimination at different intervals after parasitism by the other parasite. In experiment C, 20 host larvae at the 2nd-instar stage were first individually exposed to single oviposition by a 2-day old A.plutellae. At varying periods after this (0, 24, 48, 72, 96 and 120 hrs) different treatment groups with 20 larvae each were separately exposed to 10 mated females of D.eucero-phaga for 24 hrs within a 'breeding jar'. For the controls, healthy hosts unparasitized by A.plutellae were used. All the host larvae, immediately following the treatment exposures, were dissected for parasite egg and larval counts. In experiment D, the overall procedure was similar except that oviposition by D.eucero-phaga preceded that of A.plutellae.

In two other studies, the above experiments C and D were extended to determine the occurrence of inter-specific competition between the two parasite species by rearing the parasitized hosts in 'breeding jars' to adult emergence. The studies basically aimed to elucidate whether any one of the species is intrinsically superior to the other when oviposition of both species in the same host occurs at different time intervals. In general, the procedures were similar to that of experiments C and D except that only one 'attack' per host was permitted in the ovipositional exposure by the 2nd parasite and an additional treatment interval of 144 hrs between ovipositions was included. For the studies, the number of replicates was



Table 9.1 Egg incubation periods of Apanteles plutellae Kurdj. and Diadegma eucero-phaga Horstm. at  $20 \pm 3^{\circ}\text{C}$  and RH 75-85%.

| Parasite species       | Period after oviposition (hrs) | Stage of parasite upon dissection <sup>1/</sup> |   |   |   |   |   |   |   |   |    | Egg hatching <sup>2/</sup> |       |
|------------------------|--------------------------------|-------------------------------------------------|---|---|---|---|---|---|---|---|----|----------------------------|-------|
|                        |                                | Rep: 1                                          | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | (No.)                      | (%)   |
| <u>A. plutellae</u>    | 24                             | E                                               | E | E | E | E | E | E | E | E | E  | 0                          | 0.0   |
|                        | 36                             | E                                               | - | E | - | E | E | E | E | E | E  | 0                          | 0.0   |
|                        | 48                             | E                                               | E | E | E | E | E | - | E | E | E  | 0                          | 0.0   |
|                        | 50                             | E                                               | L | E | E | E | E | L | E | E | E  | 2                          | 20.0  |
|                        | 52                             | L                                               | E | L | L | E | E | L | - | E | L  | 5                          | 55.6  |
|                        | 54                             | L                                               | E | L | L | L | L | E | - | - | L  | 6                          | 75.0  |
|                        | 56                             | L                                               | L | L | L | L | - | L | L | L | L  | 9                          | 100.0 |
| <u>D. eucero-phaga</u> | 24                             | E                                               | E | E | E | E | - | E | E | E | E  | 0                          | 0.0   |
|                        | 36                             | E                                               | E | - | E | E | E | E | E | E | E  | 0                          | 0.0   |
|                        | 42                             | E                                               | E | E | E | E | E | E | - | E | E  | 0                          | 0.0   |
|                        | 44                             | L                                               | E | L | L | E | E | - | E | L | -  | 4                          | 50.0  |
|                        | 46                             | L                                               | L | L | - | - | L | E | L | L | L  | 7                          | 87.5  |
|                        | 48                             | L                                               | - | L | L | L | L | L | - | L | L  | 8                          | 100.0 |

1/ E = Egg, L = Larva, - = unparasitized

2/ Mean incubation period: A. plutellae = 54.00 hrs, D. eucero-phaga = 46.42 hrs.

also increased to 30.

### 9.3 RESULTS

#### 9.3.1 Dispersal and colonization by D. eucero-phaga and T. collaris

Among the 7 localities surveyed for the occurrence of the imported parasites, D. eucero-phaga was confirmed in 5 farming areas (Tanah Rata, Kg. Taman Sedia, Brinchang, Mensum Valley and Kea Farm) while T. collaris in Tanah Rata, Brinchang and Kea Farm (Table 9.2). Particularly with D. eucero-phaga, a general trend was apparent with respect to distances from the initial site of establishment (Tanah Rata) and the following features: (i) first occurrence reported on the parasite, (ii) consistency of its presence and (iii) levels of parasitism. In both (ii) and (iii) they tended to decrease with distance away from Tanah Rata while for (i) it progressively became later (Table 9.3, Fig. 3.1). For T. collaris, such a relationship was however not apparent. In any case, the survey findings clearly showed that not only were D. eucero-phaga and T. collaris found commonly at Tanah Rata but they had also gradually spread out over long distances to several other localities to become established there. On the other hand, the failure to find T. sokolowskii which was also released (Ooi, 1979a) has further

**Table 9.2 Recoveries of the imported parasites Diadegma eucrophaga Horstm. and Thyraeella collaris Grav. from Plutella xylostella (L.) in the Cameron Highlands.**

| No. plant sampled/No. <u>P.xylostella</u> larvae collected/No. (%) parasitized by <u>D.eucrophaga</u> <sup>1/</sup>                 |                               |             |     |                                 |                           |              |             |              |
|-------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|-------------|-----|---------------------------------|---------------------------|--------------|-------------|--------------|
| (No. of <u>D.eucrophaga</u> emerging from field collected cocoons/No. of <u>T.collaris</u> emerged from field collected host pupae) |                               |             |     |                                 |                           |              |             |              |
| Date                                                                                                                                | Locality <sup>2/</sup>        | TR          | KTS | B                               | MV                        | KF           | R           | KR           |
| 23.5.79                                                                                                                             | -                             | -           | -   | -                               | -                         | 328/105/0(0) | -           | 240/111/0(0) |
| 13.7.79                                                                                                                             | 84/28/11(39.3)                | -           | -   | 205/162/34(21.0)                | -                         | -            | -           | -            |
| 19.7.79                                                                                                                             | -                             | -           | -   | -                               | -                         | 150/21/0(0)  | -           | -            |
| 24.9.79                                                                                                                             | <u>305/41/0(0)</u><br>(59/0)  | -           | -   | -                               | -                         | -            | -           | -            |
| 26.9.70                                                                                                                             | <u>220/44/0(0)</u><br>(48/0)  | -           | -   | -                               | -                         | -            | -           | -            |
| 4.10.79                                                                                                                             | -                             | -           | -   | <u>214/35/0(0)</u><br>(87/0)    | -                         | -            | -           | 125/62/0(0)  |
| 8.10.79                                                                                                                             | -                             | -           | -   | -                               | -                         | -            | 158/70/0(0) | -            |
| 16.11.79                                                                                                                            | -                             | -           | -   | -                               | -                         | 198/61/0(0)  | -           | -            |
| 4.1.80                                                                                                                              | <u>60/14/2(14.3)</u><br>(2/0) | -           | -   | -                               | -                         | 142/36/0(0)  | -           | -            |
| 10.1.80                                                                                                                             | -                             | -           | -   | -                               | 144/6/1(16.7)             | -            | -           | -            |
| 9.4.80                                                                                                                              | -                             | 107/58/0(0) | -   | <u>167/57/10(17.5)</u><br>(0/4) | -                         | -            | -           | -            |
| 11.4.80                                                                                                                             | -                             | -           | -   | -                               | 212/186/0(0)              | 212/19/0(0)  | -           | -            |
| 15.4.80                                                                                                                             | <u>238/10/0(0)</u><br>(0/1)   | -           | -   | -                               | -                         | -            | -           | -            |
| 18.4.80                                                                                                                             | -                             | -           | -   | -                               | -                         | 472/45/0(0)  | -           | 96/45/0(0)   |
| 2.5.80                                                                                                                              | -                             | -           | -   | -                               | -                         | -            | 185/71/0(0) | -            |
| 12.5.80                                                                                                                             | -                             | 66/25/0(0)  | -   | <u>193/13/0(0)</u><br>(1/0)     | <u>90/1/0(0)</u><br>(2/0) | -            | -           | -            |

Table 9.2 (Continued 1).

| Date     | Locality: <sup>2/</sup> | TR | KTS                             | B                               | MV                             | KF                          | R           | KR          |
|----------|-------------------------|----|---------------------------------|---------------------------------|--------------------------------|-----------------------------|-------------|-------------|
| 26.5.80  |                         | -  | -                               | -                               | 105/25/0(0)                    | -                           | 159/25/0(0) | -           |
| 31.5.80  |                         | -  | -                               | -                               | -                              | <u>334/55/0(0)</u><br>(0/1) | -           | -           |
| 16.6.80  | 57/13/1(7.7)            | -  | -                               | -                               | -                              | -                           | -           | -           |
| 17.6.80  | -                       | -  | 168/47/0(0)                     | 190/12/4(33.3)                  | 162/33/0(0)                    | -                           | -           | -           |
| 25.6.80  | -                       | -  | -                               | -                               | -                              | -                           | 143/60/0(0) | -           |
| 26.6.80  | -                       | -  | -                               | -                               | -                              | 250/99/0(0)                 | -           | -           |
| 17.7.80  | 255/133/31(23.3)        | -  | -                               | -                               | -                              | -                           | -           | 101/76/0(0) |
| 18.7.80  | -                       | -  | <u>150/63/38(60.3)</u><br>(4/0) | <u>184/41/9(22.0)</u><br>(32/0) | 134/27/0(0)                    | -                           | -           | -           |
| 23.7.80  | -                       | -  | -                               | -                               | -                              | -                           | 98/35/0(0)  | -           |
| 29.7.80  | -                       | -  | -                               | -                               | -                              | 286/70/0(0)                 | -           | -           |
| 1.10.80  | -                       | -  | -                               | -                               | -                              | -                           | 150/5/0(0)  | -           |
| 8.10.80  | 108/32/8(50.0)          | -  | -                               | -                               | -                              | -                           | -           | -           |
| 30.10.80 | -                       | -  | <u>104/17/4(23.5)</u><br>(2/0)  | <u>149/25/4(16.0)</u><br>(1/0)  | <u>117/24/3(12.5)</u><br>(1/0) | -                           | -           | -           |
| 31.10.80 | -                       | -  | -                               | -                               | -                              | 386/31/2(6.5)               | -           | 67/49/0(0)  |

1/ Confirmed by dissections for the immature stages or from breeding until emergence of the adult parasites.

2/ TR = Tanah Rata, KTS = Kampong Taman Sedia, B = Brinchang, MV = Mensum Valley, KF = Kea Farm, R = Ringlet and KR = Kampong Raja.

confirmed the unsuccessful establishment of this species.

Table 9.3 Some features of parasitization in relation to the spread and colonization of Diadegma eucero-phaga Horstm. and Thyraeella collaris Grav. in the Cameron Highlands.

| Parasite species                    | Localities and their relative distance away from TR <sup>1/</sup> |         |         |         |          |      |      |
|-------------------------------------|-------------------------------------------------------------------|---------|---------|---------|----------|------|------|
|                                     | TR <sup>2/</sup>                                                  | KTS     | < B     | < MV    | < KF     | < R  | < KR |
| <u>DIADEGMA EUCEROPHAGA</u>         |                                                                   |         |         |         |          |      |      |
| First occurrence observed (date)    | 13.7.79                                                           | 18.7.79 | 13.7.79 | 10.1.80 | 31.5.80  | None | None |
| % Frequency of finding the parasite | 87.5                                                              | 40.0    | 100.0   | 42.9    | 10.0     | 0.0  | 0.0  |
| % parasitism                        | 16.8                                                              | 20.0    | 17.7    | 1.4     | 0.4      | 0.0  | 0.0  |
| <u>THYRAEELLA COLLARIS</u>          |                                                                   |         |         |         |          |      |      |
| First occurrence observed (date)    | 15.4.80                                                           | None    | 9.4.80  | None    | 31.10.80 | None | None |
| % Frequency of finding the parasite | 12.5                                                              | 0.0     | 28.6    | 0.0     | 10.0     | 0.0  | 0.0  |

1/ TR = Tanah Rata, KTS = Kampong Taman Sedia, B = Brinchang, MV = Mensum Valley, KF = Kea Farm, R = Ringlet and KR = Kampong Raja.

2/ Point of parasite release and initial establishment.

### 9.3.2 Competition and interaction between A.plutellae and D.eucero-phaga

#### 9.3.2.1 Competitive ability of A.plutellae and D.eucero-phaga in locating and successfully ovipositing on hosts in relation to exposure time

When DBM larvae were separately exposed for varying periods to A.plutellae and D.eucero-phaga the numbers of successful parasitisms increased with exposure time for both species (Table 9.4). However, in the former no parasitism occurred until after the first hour, while, in contrast, D.eucero-phaga parasitized at least 33% of the exposed larvae within the first half hour. This also occurred when both the species were exposed together (Table 9.4). The finding clearly indicates that D.eucero-phaga is able to detect its host within a much shorter time while the higher level

Table 9.4 Competitive ability of Diadegma eucerothaga Grav. and Apanteles plutellae Kurdj. in locating and successfully ovipositing on larvae of Plutella xylostella (L.) with relation to different periods of exposure.

| Host exposure 1/                                                  |              | % host parasitized by: |                       |              | % host superparasitized by: |                       | % host multiparasitized by <u>A. plutellae</u> and <u>D. eucerothaga</u> |            | Total egg deposition by: |                          |
|-------------------------------------------------------------------|--------------|------------------------|-----------------------|--------------|-----------------------------|-----------------------|--------------------------------------------------------------------------|------------|--------------------------|--------------------------|
| Condition                                                         | Period (hrs) | <u>A. plutellae</u>    | <u>D. eucerothaga</u> | Total        | <u>A. plutellae</u>         | <u>D. eucerothaga</u> |                                                                          |            | <u>A. plutellae</u>      | <u>D. eucerothaga</u> 2/ |
| To <u>A. plutellae</u> alone                                      | 0.5          | 0.0                    | -                     | 0.0          | 0.0                         | -                     | -                                                                        | -          | 0                        | -                        |
|                                                                   | 1            | 0.0                    | -                     | 0.0          | 0.0                         | -                     | -                                                                        | -          | 0                        | -                        |
|                                                                   | 2            | 6.7                    | -                     | 6.7          | 0.0                         | -                     | -                                                                        | -          | 1                        | -                        |
|                                                                   | 4            | 13.3                   | -                     | 13.3         | 6.7                         | -                     | -                                                                        | -          | 5                        | -                        |
|                                                                   | 6            | 20.0                   | -                     | 20.0         | 0.0                         | -                     | -                                                                        | -          | 3                        | -                        |
|                                                                   | 16           | 33.3                   | -                     | 33.3         | 13.3                        | -                     | -                                                                        | -          | 7                        | -                        |
|                                                                   | 24           | 20.0                   | -                     | 20.0         | 13.3                        | -                     | -                                                                        | -          | 10                       | -                        |
|                                                                   | 36           | 40.0 (16.7)*           | -                     | 40.0 (16.7)* | 20.0 (6.7)*                 | -                     | -                                                                        | -          | 40 (8.3)*                | -                        |
| To <u>D. eucerothaga</u> alone                                    | 0.5          | -                      | 33.3                  | 33.3         | -                           | 6.7                   | -                                                                        | -          | -                        | 7                        |
|                                                                   | 1            | -                      | 20.0                  | 20.0         | -                           | 6.7                   | -                                                                        | -          | -                        | 7                        |
|                                                                   | 2            | -                      | 46.7                  | 46.7         | -                           | 26.7                  | -                                                                        | -          | -                        | 16                       |
|                                                                   | 4            | -                      | 73.3                  | 73.3         | -                           | 20.0                  | -                                                                        | -          | -                        | 16                       |
|                                                                   | 6            | -                      | 53.3                  | 53.3         | -                           | 26.7                  | -                                                                        | -          | -                        | 13                       |
|                                                                   | 16           | -                      | 73.3                  | 73.3         | -                           | 33.3                  | -                                                                        | -          | -                        | 20                       |
|                                                                   | 24           | -                      | 93.3                  | 93.3         | -                           | 66.7                  | -                                                                        | -          | -                        | 34                       |
|                                                                   | 36           | -                      | 80.0 (59.1)*          | 80.0 (59.1)* | -                           | 40.0 (28.4)*          | -                                                                        | -          | -                        | 22 (16.9)*               |
| Both <u>A. plutellae</u> & <u>D. eucerothaga</u> present together | 0.5          | 0                      | 53.3                  | 53.3         | 0.0                         | 26.7                  | 0.0                                                                      | 0.0        | 0                        | 12                       |
|                                                                   | 1            | 0                      | 60.0                  | 60.0         | 0.0                         | 40.0                  | 0.0                                                                      | 0.0        | 0                        | 18                       |
|                                                                   | 2            | 13.3                   | 66.7                  | 80.0         | 0.0                         | 53.3                  | 13.3                                                                     | 13.3       | 2                        | 21                       |
|                                                                   | 4            | 0                      | 80.0                  | 80.0         | 0.0                         | 53.3                  | 0.0                                                                      | 0.0        | 0                        | 30                       |
|                                                                   | 6            | 6.7                    | 73.3                  | 80.0         | 0.0                         | 60.0                  | 6.7                                                                      | 6.7        | 1                        | 25                       |
|                                                                   | 16           | 6.7                    | 60.0                  | 66.7         | 0.0                         | 26.7                  | 6.7                                                                      | 6.7        | 1                        | 16                       |
|                                                                   | 24           | 13.3                   | 73.3                  | 86.7         | 0.0                         | 46.7                  | 13.3                                                                     | 13.3       | 2                        | 29                       |
|                                                                   | 36           | 40.0 (10.0)*           | 26.7 (61.7)*          | 66.7 (71.7)* | 6.7 (0.8)*                  | 0.0 (38.3)*           | 0.0 (5.0)*                                                               | 0.0 (5.0)* | 7 (1.6)*                 | 4 (19.4)*                |

1/ No. of hosts per exposure time = 15.

2/ No. of ovipositing females per exposure time = 30.

\* This indicates mean value.

of parasitism (59.1% alone and 61.7% when mixed) generally displayed by this species suggests it is functionally more efficient.

Superparasitism was distinctly higher (28.4%) in D.eucero-phaga (Table 9.4). This increased to 38.3% when it was exposed together with A.plutellae which exhibited an inverse situation, i.e. from 6.7% to 0.8%. On the other hand, multiparasitism involving the two parasites was contrastingly low (5.0%). For A.plutellae, the reduction in parasitism rate from 16.7% when alone to 10.0% in mixed exposures suggests that D.eucero-phaga has a tendency to deter A.plutellae from attacking hosts. That these are hosts largely taken by D.eucero-phaga was indicated by the low level of multiparasitism. Such deterrance may at first seem disadvantageous, apparently in suppressing A.plutellae. However, overall parasitism for mixed parasite species was much higher, averaging 71.7% against 59.2% and 16.7%, respectively, in the case with D.eucero-phaga and A.plutellae alone (Table 9.4). Since parasitism rate of D.eucero-phaga was little affected (from 59.1% to 61.7%), the overall parasitism increase in mixed exposures was probably achieved through A.plutellae being forced to seek out those hosts not already taken by D.eucero-phaga. Under varied field conditions, such a behavioural response may represent subtle differences in the niches of the two parasites, whereby through their combined activities a much fuller range of the host's habitat may be covered. From a control viewpoint these species would appear complementary, paradoxically arising through their competition.

#### 9.3.2.2 The functional response of A.plutellae and D.eucero-phaga

Many factors can influence the searching efficiency of a parasite, e.g. climate, alternative hosts, competitors, density and distribution of hosts and parasites. However, in a 'homogenous' environment as in the present investigation, it is essentially determined by the functional response (Solomon, 1969) which is the change in numbers of prey attacked in a fixed period of time by a single predator (parasitoid\* being a specialized predator) when the initial prey density is changed. This response may be expressed by the Random Parasite Equation (Royama, 1971; Rogers, 1972):

$$N_A = N \left[ 1 - \exp \left( \frac{-a' TP}{1 + a' Th N} \right) \right] \quad (4)$$

Where  $N_A$  = number of hosts attacked,  $P$  = number of parasites,

$N$  = host density,  $T$  = Total exposure time,

$a'$  = search efficiency or attack rate and

$Th$  = handling time.

\*In sensus strictus, A.plutellae is a parasitoid.

In the present case with A. plutellae the basic assumptions of the equation are generally well-satisfied, i.e. each host has equal probability of being encountered by the parasite, and each parasitized host may also be equally re-encountered. The latter is so since eggs in parasitized hosts would not have hatched in the study to elicit discrimination by the parasite (Table 9.1). With D. eucero-phaga the second assumption is, however, not so fully satisfied as some discrimination exists for parasitized hosts even when only eggs are within it (Lloyd, 1940).

The parameters  $\underline{a'}$  and  $\underline{Th}$  in equation (4) could be readily estimated by rearranging into a form suitable for linear regression analysis as follows (Rogers, 1972):

$$1/\ln S = - \frac{\underline{Th} N}{\underline{TP}} - \frac{1}{\underline{a'} \underline{TP}} \quad (5)$$

$$\text{where } S(\text{proportion of hosts surviving}) = \frac{N - N_A}{N}$$

Thus, in the experiment where  $T = 1$  and  $P = 1$ , the equation (5) would become:

$$1/\ln S = - \underline{Th} N - \frac{1}{\underline{a'}} \quad (6)$$

By regressing  $1/\ln S$  against the host density ( $N$ ), the slope of the line can be used to estimate  $\underline{Th}$  and the intercept the  $\underline{a'}$  value. Analysis of the data obtained (Table 9.5) shows the regression equations for both the parasite species to be as follows:

$$1/\ln S = 1.23 - 0.0115N \quad (\text{for } \underline{A. plutellae}) \quad (7)$$

$$1/\ln S = 0.53 - 0.0092N \quad (\text{for } \underline{D. eucero-phaga}) \quad (8)$$

It is evident from these search parameters that D. eucero-phaga has a much higher  $\underline{a'}$  (1.887 days<sup>-1</sup>) and lower  $\underline{Th}$  (0.0092 days) than A. plutellae ( $\underline{a'} = 0.813$  days<sup>-1</sup>,  $\underline{Th} = 0.0115$  days).

In the functional response, the number of attacks per parasite shows a decelerating increase to an upper asymptote in both species (Fig. 9.1), giving rise to Holling's 'type II' response (Holling, 1959b). Also, a good fit of the data was obtained (A. plutellae:  $F = 104.03$ ;  $df = 1, 7$ ;  $P < 0.01$ ; D. eucero-phaga:  $F = 22.66$ ;  $df = 1, 5$ ;  $P < 0.01$ ). In general, their response is similar to that commonly observed among insect parasites and invertebrate predators.

Table 9.5 Ovipositional attack of Apanteles plutellae Kurdj. and Diadegma eucero-phaga Horstm. in relation to varying host densities of Plutella xylostella (L.)

| Host density<br>(N) | No. of host larvae attacked |    |    |    |    |       |                        |    |    |    |    |       |
|---------------------|-----------------------------|----|----|----|----|-------|------------------------|----|----|----|----|-------|
|                     | <u>A. plutellae</u>         |    |    |    |    |       | <u>D. eucero-phaga</u> |    |    |    |    |       |
|                     | Rep: 1                      | 2  | 3  | 4  | 5  | Mean  | 1                      | 2  | 3  | 4  | 5  | Mean  |
| 5                   | 5                           | 5  | 2  | 3  | 1  | 3.20  | 3                      | 5  | 2  | 5  | 4  | 3.80  |
| 10                  | 8                           | 8  | 3  | 1  | 4  | 4.80  | 7                      | 8  | 8  | 9  | 7  | 7.80  |
| 20                  | 16                          | 18 | 4  | 12 | 2  | 10.40 | -                      | -  | -  | -  | -  | -     |
| 30                  | 16                          | 26 | 23 | 17 | 24 | 21.20 | 18                     | 25 | 27 | 23 | 26 | 23.80 |
| 40                  | 27                          | 10 | 5  | 13 | 32 | 17.40 | -                      | -  | -  | -  | -  | -     |
| 50                  | 18                          | 24 | 17 | 19 | 21 | 19.80 | 15                     | 34 | 15 | 32 | 35 | 26.20 |
| 100                 | 14                          | 12 | 32 | 34 | 24 | 23.20 | 60                     | 59 | 57 | 56 | 53 | 57.00 |
| 200                 | 54                          | 77 | 69 | 40 | 39 | 55.80 | 92                     | 63 | 76 | 85 | -  | 79.00 |
| 250                 | 44                          | 52 | 67 | 58 | -  | 55.25 | -                      | -  | -  | -  | -  | -     |
| 300                 | -                           | -  | -  | -  | -  | -     | 91                     | 89 | 39 | 72 | -  | 72.75 |

#### 9.3.2.3 Intra- and inter-specific discriminatory faculties of A. plutellae and D. eucero-phaga

Both experiments A and B on intra-specific discrimination showed that not all host larvae initially exposed to the 1st oviposition were successfully parasitized. This is evident from the absence of eggs or larvae in some of them (Tables 9.6 and 9.7). Where this happened the egg counts from these individuals along with their respective controls were excluded in the analyses.

Table 9.6 shows that, although the mean number of eggs deposited on 'unparasitized' control larvae was relatively higher than those where parasite eggs were already present, the difference was not significant ( $P > 0.05$ ). On average, the latter had 1.16 eggs/host while that of the control had 2.58 eggs/host. This small difference suggests that A. plutellae is unable to discriminate host larvae that contain the parasite eggs. The results of experiment B, however, were different. In this case, only 0.94 eggs/host were recorded for those which initially had parasite larvae within as opposed to 2.20 eggs/host in the controls (Table 9.7), and the difference was highly significant ( $P < 0.01$ ). It thus appears that A. plutellae is able to distinguish hosts only when parasite larvae are present within. However, the discrimination is only partial (imperfect) since many hosts containing parasite larvae were also superparasitized.



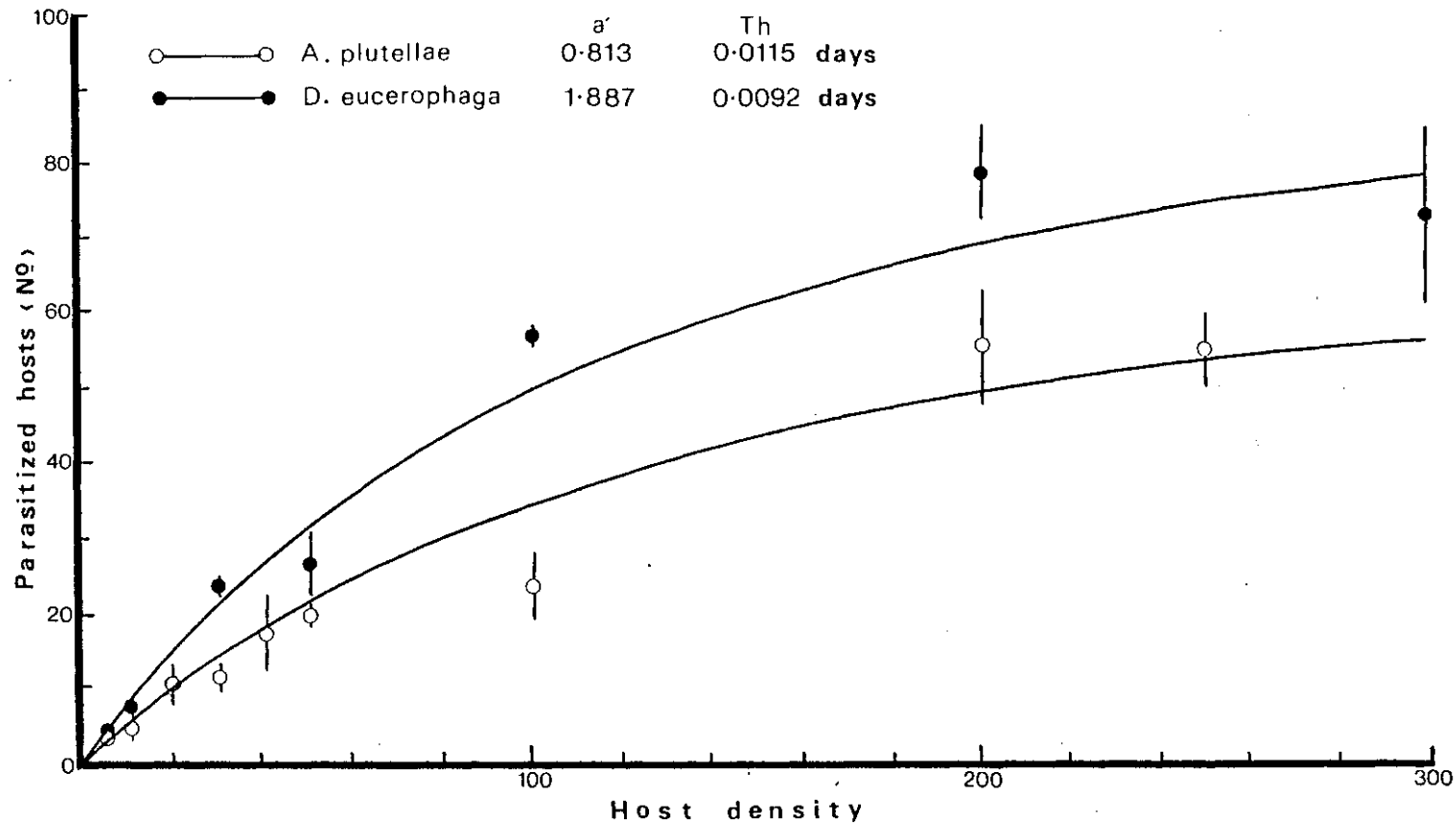


FIGURE 9.1 The functional response of Apanteles plutellae Kurdj. and Diadegma eucrophaga Horstm. on the host Plutella xylostella (L.)

Table 9.6 Oviposition of Apanteles plutellae Kurdj. in relation to the presence (+) and absence (-) of its own eggs within Plutella xylostella (L.) hosts (2nd-instar) which were reexposed to the parasite.

| Replicate | Condition of hosts | No. of parasite egg(s) and larva(e) per host |   |   |   |    |   |   |   |   |   | No. of host <sup>2/</sup> used | No. of eggs deposited |                         |      |
|-----------|--------------------|----------------------------------------------|---|---|---|----|---|---|---|---|---|--------------------------------|-----------------------|-------------------------|------|
|           |                    | Host larva Serial No:                        |   |   |   |    |   |   |   |   |   |                                | Total                 | Mean host <sup>-1</sup> |      |
|           |                    |                                              | 1 | 2 | 3 | 4  | 5 | 6 | 7 | 8 | 9 | 10                             |                       |                         |      |
| I         | +                  | 1/ PL:                                       | 1 | 0 | 1 | 1  | 0 | 1 | 1 | 1 | 1 | 1                              | 8                     | 14                      | 1.75 |
|           |                    | PE:                                          | 2 | 1 | 0 | 2  | 0 | 5 | 2 | 0 | 3 | 0                              |                       |                         |      |
|           | -                  | PE:                                          | 3 | 0 | 2 | 5  | 0 | 0 | 3 | 1 | 3 | 0                              | 8                     | 17                      | 2.13 |
| II        | +                  | PL:                                          | 1 | 1 | 1 | 1  | 1 | 1 | 0 | 0 | 0 | 0                              | 6                     | 9                       | 1.50 |
|           |                    | PE:                                          | 3 | 1 | 3 | 0  | 0 | 2 | 2 | 3 | 3 | 0                              |                       |                         |      |
|           | -                  | PE:                                          | 4 | 8 | 4 | 12 | 7 | 9 | 0 | 0 | 0 | 0                              | 6                     | 44                      | 7.33 |
| III       | +                  | PL:                                          | 0 | 1 | 0 | 1  | 1 | 1 | 0 | 1 | 1 | 0                              | 6                     | 13                      | 2.17 |
|           |                    | PE:                                          | 0 | 3 | 1 | 1  | 0 | 3 | 4 | 1 | 5 | 4                              |                       |                         |      |
|           | -                  | PE:                                          | 0 | 1 | 0 | 1  | 3 | 3 | 1 | 0 | 2 | 1                              | 6                     | 10                      | 1.67 |
| IV        | +                  | PL:                                          | 1 | 0 | 1 | 1  | 0 | 1 | 1 | 1 | 0 | 0                              | 6                     | 0                       | 0.00 |
|           |                    | PE:                                          | 1 | 0 | 1 | 1  | 0 | 1 | 1 | 1 | 0 | 0                              |                       |                         |      |
|           | -                  | PE:                                          | 0 | 2 | 1 | 0  | 0 | 0 | 2 | 1 | 0 | 0                              | 6                     | 4                       | 0.67 |
| V         | +                  | PL:                                          | 1 | 1 | 1 | 1  | 1 | 1 | 1 | 1 | 0 | 0                              | 8                     | 6                       | 0.75 |
|           |                    | PE:                                          | 2 | 0 | 2 | 0  | 0 | 1 | 0 | 2 | 1 | 0                              |                       |                         |      |
|           | -                  | PE:                                          | 3 | 2 | 1 | 2  | 2 | 1 | 3 | 2 | 0 | 0                              | 8                     | 16                      | 2.00 |
| VI        | +                  | PL:                                          | 1 | 1 | 1 | 1  | 1 | 1 | 1 | 1 | 0 | 9                              | 7                     | 0.78                    |      |
|           |                    | PE:                                          | 3 | 0 | 2 | 0  | 1 | 0 | 0 | 1 | 0 | 0                              |                       |                         |      |
|           | -                  | PE:                                          | 0 | 0 | 1 | 7  | 3 | 1 | 0 | 3 | 0 | 0                              | 9                     | 15                      | 1.67 |
| Total     | +                  | PE:                                          |   |   |   |    |   |   |   |   |   |                                | 43                    | 49                      | 1.16 |
|           | -                  | PE:                                          |   |   |   |    |   |   |   |   |   |                                | 43                    | 106                     | 2.58 |

1/ PE = Parasite egg(s), PL = Parasite Larva(e).

2/ Host larvae which did not contain any parasite larva(e) upon dissections were excluded from the analysis.

On inter-specific discrimination in A. plutellae and D. eucero-phaga, analyses using the ANOVA showed that although a lower mean number of eggs per host was generally deposited on hosts having immature stages of the other parasite species as compared to the controls (Tables 9.8 & 9.9), the difference was still not significant ( $F = 0.84$ ,  $P > 0.05$  for A. plutellae and  $F = 1.88$ ,  $P > 0.05$  for D. eucero-phaga). The mean number of eggs per host

Table 9.7 Oviposition of *Apanteles plutellae* Kurdj. in relation to the presence (+) and absence (-) of its own larvae within *Plutella xylostella* (L.) hosts (2nd-instar) which were reexposed to the parasite.

| Repli-<br>cate | Condit-<br>ion of<br>hosts | No. of parasite egg(s) and<br>larva(e) per host |   |   |   |   |   |   |   |   |   | No. of<br>hosts<br>consid-<br>ered <sup>2/</sup> | No. of eggs<br>deposited |       |                         |
|----------------|----------------------------|-------------------------------------------------|---|---|---|---|---|---|---|---|---|--------------------------------------------------|--------------------------|-------|-------------------------|
|                |                            | Host<br>larva<br>Serial<br>No:                  | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |                                                  | 10                       | Total | Mean host <sup>-1</sup> |
| I              | +                          | <sup>1/</sup> PL:                               | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1                                                | 9                        | 8     | 0.89                    |
|                |                            | PE:                                             | 0 | 3 | 0 | 0 | 1 | 1 | 0 | 2 | 1 | 0                                                |                          |       |                         |
|                | -                          | PE:                                             | 1 | 1 | 3 | 0 | 1 | 2 | 0 | 1 | 2 | 2                                                | 9                        | 13    | 1.44                    |
| II             | +                          | PL:                                             | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1                                                | 10                       | 12    | 1.20                    |
|                |                            | PE:                                             | 1 | 1 | 2 | 0 | 2 | 2 | 1 | 1 | 0 | 2                                                |                          |       |                         |
|                | -                          | PE:                                             | 0 | 6 | 4 | 0 | 3 | 5 | 2 | 0 | 2 | 1                                                | 10                       | 23    | 2.30                    |
| III            | +                          | PL:                                             | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1                                                | 8                        | 8     | 1.00                    |
|                |                            | PE:                                             | 1 | 1 | 1 | 0 | 1 | 2 | 1 | 1 | 0 | 1                                                |                          |       |                         |
|                | -                          | PE:                                             | 2 | 1 | 1 | 1 | 3 | 0 | 0 | 1 | 1 | 2                                                | 8                        | 9     | 1.13                    |
| IV             | +                          | PL:                                             | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1                                                | 8                        | 3     | 0.38                    |
|                |                            | PE:                                             | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1                                                |                          |       |                         |
|                | -                          | PE:                                             | 2 | 5 | 4 | 1 | 4 | 5 | 5 | 7 | 6 | 2                                                | 8                        | 35    | 4.38                    |
| V              | +                          | PL:                                             | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1                                                | 10                       | 5     | 0.50                    |
|                |                            | PE:                                             | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 3 | 0                                                |                          |       |                         |
|                | -                          | PE:                                             | 4 | 2 | 2 | 1 | 8 | 3 | 1 | 1 | 2 | 3                                                | 10                       | 27    | 2.70                    |
| VI             | +                          | PL:                                             | 1 | 0 | 2 | 0 | 1 | 0 | 0 | 1 | 0 | 0                                                | 4                        | 5     | 1.25                    |
|                |                            | PE:                                             | 1 | 0 | 2 | 0 | 1 | 0 | 0 | 1 | 0 | 0                                                |                          |       |                         |
|                | -                          | PE:                                             | 5 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1                                                | 4                        | 11    | 2.75                    |
| VII            | +                          | PL:                                             | 4 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1                                                | 9                        | 10    | 1.11                    |
|                |                            | PE:                                             | 0 | 0 | 4 | 2 | 1 | 1 | 1 | 0 | 0 | 1                                                |                          |       |                         |
|                | -                          | PE:                                             | 2 | 1 | 1 | 3 | 1 | 2 | 0 | 2 | 1 | 2                                                | 9                        | 14    | 1.56                    |
| VIII           | +                          | PL:                                             | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1                                                | 10                       | 9     | 0.80                    |
|                |                            | PE:                                             | 1 | 2 | 0 | 0 | 1 | 1 | 2 | 1 | 1 | 0                                                |                          |       |                         |
|                | -                          | PE:                                             | 1 | 5 | 1 | 2 | 1 | 2 | 0 | 4 | 1 | 2                                                | 10                       | 19    | 1.90                    |
| IX             | +                          | PL:                                             | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1                                                | 10                       | 10    | 1.00                    |
|                |                            | PE:                                             | 0 | 0 | 2 | 1 | 2 | 2 | 1 | 1 | 0 | 1                                                |                          |       |                         |
|                | -                          | PE:                                             | 6 | 1 | 2 | 2 | 5 | 3 | 2 | 1 | 1 | 1                                                | 10                       | 24    | 2.40                    |
| X              | +                          | PL:                                             | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0                                                | 7                        | 10    | 1.43                    |
|                |                            | PE:                                             | 1 | 2 | 1 | 1 | 2 | 1 | 1 | 3 | 1 | 2                                                |                          |       |                         |
|                | -                          | PE:                                             | 2 | 1 | 4 | 1 | 2 | 0 | 3 | 2 | 2 | 1                                                | 7                        | 12    | 1.71                    |
| Total          | +                          | PE:                                             |   |   |   |   |   |   |   |   |   |                                                  | 85                       | 80    | 0.94                    |
|                | -                          | PE:                                             |   |   |   |   |   |   |   |   |   |                                                  | 85                       | 187   | 2.20                    |

<sup>1/</sup> PE = Parasite egg(s), PL = Parasite larva(e). <sup>2/</sup> Dissected host larvae containing no parasite larva(e) were excluded from the analysis.

Table 9.8 Oviposition of Apanteles plutellae Kurdj. in relation to the presence(+) and absence(-) of the immature stages of Diadegma eucerothaga Horstm. within the host larvae of Plutella xylostella (L.).

| Exposure sequence and interval(hrs) in between 1/ | Condition of hosts | No. of hosts considered 2/ | No. of eggs deposited |           |                    | Hosts superparasitized by <u>A. plutellae</u> |       |
|---------------------------------------------------|--------------------|----------------------------|-----------------------|-----------|--------------------|-----------------------------------------------|-------|
|                                                   |                    |                            | Total                 | Mean/host | Mean difference 3/ | (No.)                                         | (%)   |
| D-0-A                                             | +                  | 19                         | 113                   | 5.95      |                    | 16                                            | 84.21 |
| A                                                 | -                  | 19                         | 149                   | 7.84      | $t = 1.146(ns)$    | 17                                            | 89.47 |
| D-24-A                                            | +                  | 20                         | 98                    | 4.90      |                    | 15                                            | 75.00 |
| A                                                 | -                  | 20                         | 102                   | 5.10      | $t = 0.210(ns)$    | 16                                            | 80.00 |
| D-48-A                                            | +                  | 17                         | 38                    | 2.24      |                    | 10                                            | 58.82 |
| A                                                 | -                  | 17                         | 50                    | 2.94      | $t = 1.176(ns)$    | 13                                            | 76.47 |
| D-72-A                                            | +                  | 15                         | 41                    | 2.73      |                    | 9                                             | 60.00 |
| A                                                 | -                  | 15                         | 53                    | 3.53      | $t = 0.754(ns)$    | 10                                            | 66.67 |
| D-96-A                                            | +                  | 16                         | 9                     | 0.56      |                    | 2                                             | 12.50 |
| A                                                 | -                  | 16                         | 19                    | 1.19      | $t = 1.817(ns)$    | 5                                             | 31.25 |
| D-120-A                                           | +                  | 16                         | 8                     | 0.50      |                    | 2                                             | 12.5  |
| A                                                 | -                  | 16                         | 12                    | 0.75      | $t = 0.969(ns)$    | 3                                             | 18.75 |
| Total                                             | +                  | 103                        | 307                   | 2.98      |                    | 54                                            | 52.43 |
|                                                   | -                  | 103                        | 385                   | 3.74      | $F = 0.84(ns)$     | 64                                            | 62.14 |

1/ A = A. plutellae, D = D. eucerothaga and the number indicates the time period between exposures to the two parasites.

2/ Host larvae which did not contain any immature stages of D. eucerothaga upon dissections were excluded from the analysis.

3/ ns = not significant.

Table 9.9 Oviposition of Diadegma eucerothaga Horstm. in relation to the presence(+) and absence(-) of the immature stages of Apanteles plutellae Kurdj. within the host larvae of Plutella xylostella (L.).

| Exposure sequence and interval(hrs) in between 1/ | Condition of hosts | No. of hosts considered 2/ | No. of eggs deposited |           |                    | Hosts superparasitized by <u>D. eucerothaga</u> |       |
|---------------------------------------------------|--------------------|----------------------------|-----------------------|-----------|--------------------|-------------------------------------------------|-------|
|                                                   |                    |                            | Total                 | Mean/host | Mean difference 3/ | (No.)                                           | (%)   |
| A-0-D                                             | +                  | 19                         | 30                    | 1.58      |                    | 10                                              | 52.63 |
| D                                                 | -                  | 19                         | 43                    | 2.26      | t = 1.309(ns)      | 10                                              | 52.63 |
| A-24-D                                            | +                  | 16                         | 28                    | 1.75      |                    | 9                                               | 56.25 |
| D                                                 | -                  | 16                         | 24                    | 1.50      | t = 0.647(ns)      | 7                                               | 43.75 |
| A-48-D                                            | +                  | 20                         | 53                    | 2.65      |                    | 16                                              | 80.00 |
| D                                                 | -                  | 20                         | 50                    | 2.50      | t = 0.419(ns)      | 15                                              | 75.00 |
| A-72-D                                            | +                  | 20                         | 39                    | 1.95      |                    | 13                                              | 65.00 |
| D                                                 | -                  | 20                         | 48                    | 2.40      | t = 1.097(ns)      | 13                                              | 65.00 |
| A-96-D                                            | +                  | 17                         | 17                    | 1.00      |                    | 4                                               | 23.53 |
| D                                                 | -                  | 17                         | 31                    | 1.82      | t = 3.355(**)      | 11                                              | 64.71 |
| A-120-D                                           | +                  | 17                         | 12                    | 0.71      |                    | 2                                               | 11.77 |
| D                                                 | -                  | 17                         | 18                    | 1.06      | t = 1.335(ns)      | 4                                               | 23.53 |
| Total                                             | +                  | 109                        | 179                   | 1.64      | F = 1.88(ns)       | 54                                              | 49.54 |
|                                                   | -                  | 109                        | 214                   | 1.96      |                    | 60                                              | 55.06 |

1/ A = A. plutellae, D = D. eucerothaga and the number indicates the time period between exposures to the two parasites.

2/ Host larvae which did not contain any immature stages of A. plutellae upon dissections were excluded from the analysis.

3/ ns = not significant, \*\* significant at 1% level.

for the former species were 2.98 and 3.74 when immature stages of the other parasite were present and absent, respectively (Table 9.8). For D.eucero-phaga, these were, respectively, 1.64 and 1.96 eggs/host (Table 9.9). When the various treatments of different sequence intervals were analysed separately using the t-test, a similar situation was also obtained. None of the treatments were significantly different with the exception of the treatment A.plutellae-96 hrs-D.eucero-phaga (Tables 9.8 & 9.9). It thus appears that both A.plutellae and D.eucero-phaga do not possess any inter-specific discriminatory ability. This was unexpected, since preliminary studies by Lloyd (1940) suggested that D.eucero-phaga (Angitia cero-phaga) is able to distinguish between unparasitized hosts and those containing the immature stages of A.plutellae, and vice versa. Moreover, it was demonstrated (see above) that A.plutellae does possess some power of discrimination between unparasitized and parasitized hosts. Further analyses with the ANOVA were thus made to compare all the different sequence intervals within the treatment and within the control series. In such analyses for both the species, differences in the mean number of eggs laid were highly significant (F values for A.plutellae treatment = 13.21, A.plutellae control = 12.16, D.eucero-phaga treatment = 7.57, and D.eucero-phaga control = 4.16), indicating that the time interval between first parasitism and subsequent exposure is important in determining the number of eggs that may be deposited.

In general, the number of eggs oviposited showed a tendency to decrease with progressive increase in the time interval between exposures (Tables 9.8 & 9.9). This is probably governed by the advancing age of the host larvae, as indicated by a similar trend in the control series where the age of the hosts was the only variable. For A.plutellae, other studies (see 5.2.2) have also shown this stage preference to be a consistent and strong feature. Although less obvious, a similar trend existed in D.eucero-phaga (Table 9.9), contrasting with Lloyd's (1940) observation that this parasite would 'attack' all stages of DBM with equal facility. Probably, host stage preference has influenced greatly the expression of the discriminatory ability of the parasites. That this is so is suggested by the generally higher egg deposition observed for the respective controls when compared to the corresponding parasitized ones, particularly on hosts of the more advanced age. Another factor is probably the relatively higher parasite: host ratio (1:2) and exposure period used in the present investigations as compared to that of Lloyd (1940). Avoidance of super-parasitism tends to break down in high parasite: host ratio (Venkatraman, 1964) or when the parasite has been deprived of a host for a long period during which a large supply of eggs would have matured. The latter condi-

tion cannot be the cause in the present investigations since only 2-day old parasites were used. Moreover, that high parasite:host ratio was a contributory cause is further suggested by the greater superparasitism obtained when compared to that of the intra-specific discrimination study with A. plutellae where a lower ratio of 1:5 was employed (Tables 9.6 & 9.7). As such, other studies with smaller ratios would seem desirable in order to confirm the conclusions suggested from the present experiments.

#### 9.3.2.4 Inter-specific competition and subsequent survival between A. plutellae and D. eucero-phaga

In multiparasitism invariably only one parasite adult would emerge from a single host, as with superparasitism (see 5.1.2). Dissections made 48 hrs after sequential oviposition by parasites of both or the same species showed that elimination of competitors generally occurs when they are still in the egg or 1st larval stage, and the eventual survivor is the 1st-hatched larva. This was suggested by the rapid deterioration often encountered with either the eggs or the 1st-instar larvae when these were deposited after a previous oviposition. Death of such eggs or larvae were often accompanied by shrinking and distinctive browning. Advanced stages of supernumeraries were almost never obtained. Where this was observed it was isolated and probably was due to some delay in the elimination mechanisms.

It is evident from Table 9.10 (ii) that when D. eucero-phaga had first access to the host the resultant survivors were overwhelmingly D. eucero-phaga, irrespective of the time interval before the subsequent oviposition by A. plutellae. The few adults obtained for the latter species could have emerged from hosts that were initially devoid of D. eucero-phaga since ovipositional 'attack' need not necessarily always result in successful egg deposition (Lloyd, 1940). These data [Table 9.10(ii)] clearly revealed that D. eucero-phaga is intrinsically superior to A. plutellae when the former had first access to the host. Such a condition was still maintained up to the time interval of ca 24 hrs when A. plutellae had first access to the hosts [Table 9.10(i)]. However, after this interval, A. plutellae was observed to be superior as evidenced by its relatively higher level of adult emergence. The few adults obtained of D. eucero-phaga was probably due to hosts initially devoid of A. plutellae (see also 5.5.3).

For sequence intervals of 120 hrs and beyond there was no evidence of the 2nd parasite in the host [Table 9.10 (i & ii)] irrespective of the parasite sequence. Although the explanation for this is not certain it may be reasoned that there is more complete elimination of the 2nd parasite, or there is greater ovipositional restraint exercised by the 2nd parasite adult which lays no egg even when 'stinging' was observed.

#### 9.4 DISCUSSION

Following the initial release and establishment at Tanah Rata both D.eucerothaga and T.collaris were observed to have gradually spread out to colonize new areas. As the pattern of spread is not radial but in a single direction and somewhat linear, dispersal by wind is indicated. This seems all the more probable since direction of the spread coincides with that of the South-West monsoon wind. Under such a strong wind, colonization along the wind path should have been nearly instantaneous rather than in progressive stages from the initial source and over an extended period. However, should wind dispersal be largely responsible, it probably occurred during periods of subdued wind conditions whereby the observed progressive spread can take place. Since evidence of their capability of being air-borne over long distances is not available, this mode of dispersal is a matter of speculation until confirmed, perhaps by aerial trap studies.

The progressive nature of colonization suggests that the parasites may have spread through limited dispersal moving from one farming valley to the next. Although the parasites are reasonably active and fairly strong fliers, it is still difficult to envisage how, by their own flight effort, they could traverse the dense vegetation of primary forest which separates the different agricultural valleys. A possible route would be along man-made openings such as roads and pathways.

The third alternative may be man-assisted by way of commerce through the cabbage heads (see also 6.2.3 & 6.2.4).

In any case, whichever may be the dispersal mechanism, it is envisaged that the parasites will eventually spread further to colonize all the cabbage areas in the Cameron Highlands. Judging by their impressive colonizing capacity, they are likely to become firmly established and constitute a permanent feature in the parasite complex of DBM.

Concerning its relationship with A.plutellae, some form of competition evidently exists since all hosts multi-parasitized by these two species will eventually yield only one adult parasite. Whichever species would finally emerge is largely governed by the relative rate of parasite development within the host. The present experimental evidence and that of Lloyd (1940) show that the species which can attain the larval stage before the eggs of the other have hatched will kill its competitor and emerge as survivor.

Since A.plutellae requires relatively more time to detect a host than D.eucerothaga, under situations where both parasite species enter a host environment simultaneously the latter should emerge functionally more



efficient. Moreover, over a fixed period of time it could detect and parasitize a relatively greater number of hosts, as indicated by the higher  $a'$  and lower  $T_h$  values. Not only is D.eucero-phaga endowed with such adaptive advantage but it has also a shorter (46.4 hrs) incubation period than A.plutellae (54.0 hrs). The difference in incubation has much similarity with the case of multiparasitism in Ephestia by the solitary endo-parasites Nemeritis (Devorgilla) canescens and Diadegma chrysostichus wherein the latter was victor in two thirds of the encounters largely because of the rather longer incubation period of the former (Fisher, 1961). Evidently, all these features are critical in maintaining the superiority of D.eucero-phaga within the A.plutellae-D.eucero-phaga complex, wherein the parasite with higher fecundity and rate of egg laying, and which first attacks the host and hatches earlier would tend to be the eventual victor in the contest competition. As with many hymenopterans, the survivor apparently suppresses the rival(s) physiologically since no sign of physical combat (e.g. injury marks) between supernumerary larvae was observed in the course of dissection.

Although D.eucero-phaga is undoubtedly a more efficient competitor within the confines of the experimental conditions, due caution must be observed in the attempt to apply such laboratory reactions to the natural environment. This is because the measured parameters on foraging behaviour may be modified in the natural environment by a number of factors. Among these, Ulliyett (1943, 1947) has identified for Diadegma sp. the degree of parasitism already present, the host/parasite ratio and non-random search. Central to the latter is the notion of prey 'patch', a term variously interpreted (Wiens, 1976) but can be adequately defined as a spatial unit of the predator's foraging area as perceived by the predator itself (Hassell, 1978). Such a patch could elicit patch specific behaviour causing predator aggregative responses or non-random search, leading to longer time spent in patches of highest encounter with prey. Various arrestant stimuli responsible for this are known and have been thoroughly discussed by Waage (1977) who lists 4 different mechanisms, i.e. fixed number, fixed time, fixed searching time, and fixed rate mechanisms. Among these, the last is likely to be a more efficient mechanism (Hassell, 1978). From optimal foraging model (Cook & Hubbard, 1977), parameters that are crucial in influencing patch-time allocation have been identified as the transit time (between patches) and those of the random predator equation ( $a'$ ,  $T_h$ ,  $T$ ). With increasing transit time when average prey densities are low, stability will also increase arising from a density dependent effect whereby the nett  $a'$  increases with rising prey density (Murdoch & Oaten, 1975; Murdoch, 1977; Hassell, 1978). Under field conditions where prey populations are clumped

(Harcourt, 1960; Chua & Lim, 1977, 1979), the  $a'$  values determined for both A.plutellae and D.eucerothaga under more homogenous conditions of the laboratory will tend to be higher and be of greater significance.

For some of the measured parameters there can be little doubt that the behaviour is identical in laboratory and field (Lloyd, 1940), as for example, the ability to discriminate between parasitized and unparasitized hosts. However, the extent to which this selective faculty determines the incidence of superparasitism and multiparasitism for a given set of field conditions cannot be accurately established. In any case, from the present investigations and that of Lloyd (1940), Ulllyett (1943) and Venkatraman (1964) the following features are now apparent: (i) The ability to discriminate between parasitized and unparasitized hosts by A.plutellae and D.eucerothaga is both intra- and inter-specific. In the former species, the discrimination is only displayed when the parasitized hosts contain the larval stages and is unlike D.eucerothaga which can also avoid parasitized hosts containing eggs (Lloyd, 1940). However, this discrimination is only limited, with the imperfect restraint breaking down at low host density, or at higher parasite: host ratio resulting in superparasitism (Venkatraman, 1964). (ii) Discrimination ability is apparently not simple, but is more complexly related to other biological conditions which may include host: parasite ratio, host age, parasite maturity, etc. The interactions among these, coupled with any inherent imperfection in discrimination or ovipositional restraint, would inadvertently lead to different degree and variable expression of discrimination in the parasites.

A programme for the introduction of entomophagous insects to aid or complement existing pest control is often confronted with problems of multiparasitism. Occurrence of such a phenomenon has resulted in serious disagreements between biological control exponents from different schools. The idea that two parasites competing in the same individual host may result in less destruction of the hosts than by one alone was advanced by Pemberton & Willard (1918) and Turnbull & Chant (1961). Based on studies with the Mediterranean fruit fly Ceratitidis capitata (Wied), Pemberton & Willard concluded that Opius humilis Silv acting alone would have caused greater mortality of the host than the mortality actually occurring from a complex of introduced fruit fly parasites. On the other hand, Smith (1929) analysed the problem of multiparasitism as presented by Pemberton & Willard (1918) and refuted their claims by showing that multiparasitism will never result in a lesser total mortality of the host than would have occurred if one or the other parasitic species had been acting alone. Also, from inductive population models developed from studies of parasite performance in laboratory and field, Hassell & Varley (1969) provided

further support for multiple introduction, as expressed in their 'parasite quest' theory. Examined in more detail recently, May & Hassell (1981) concluded "that the practice of multiple parasitoid introductions, and the use of parasitoids with high searching efficiency and a marked ability to seek out patches of high host density, are sound strategies for maximizing the depression in the host equilibrium populations and for ensuring that they remain locally stable". Although this is borne out by many successful cases (Doutt & DeBach, 1964), it is also recognised that in the great majority of classical biological control (DeBach, 1974) a single or two natural enemy species is usually of overwhelmingly importance (Huffaker & Kennett, 1966). Moreover, additional natural enemy species in some instances can dislocate efficient biological control (Taylor, 1937; Pimentel, 1980). It thus appears that generalised ecological principle concerning natural enemy introduction and performance is likely to face many exceptions. Evidently, each case has to be determined individually. For DBM, the overall parasitism was increased by the introduction of D.eucero-phaga (see 9.3.2.1) and 4.2.2).

Smith (1929) pointed out that the behaviour of competing parasites may differ in two ways; first, intrinsically and second, extrinsically. Parasites which are intrinsically superior survive better in competition within the hosts. Imported species with such superiority would more readily become established, when all other factors are equal. Such parasites would gradually assume a dominant position within the parasite complex, generally maintaining a higher average population level in the new habitat. With D.eucero-phaga, this was apparent in Australia (Venkatraman, 1964; Goodwin, 1979), Indonesia (Vos, 1953) and New Zealand (Robertson, 1939). It is also dominant in some other countries where it exists naturally (Hardy, 1938; Slabospitskiĭ; 1980). Evidently, D.eucero-phaga seems to be extrinsically superior generally.

At present, the spread and establishment of D.eucero-phaga over the Cameron Highlands clearly indicate its adaptability to the habitat. How it will match against the 'endemic' A.plutellae is however still uncertain. Although it is both intrinsically and extrinsically better, no decline of parasitism by A.plutellae was observed in the field. On average, the latter is still higher than that of D.eucero-phaga. Dissections of larvae and records of emergence from parasite cocoons collected in the field have confirmed that A.plutellae still predominates in all the localities. That D.eucero-phaga has not overtaken A.plutellae may possibly be due to an ichneumonid hyperparasite, Diatora lissonata (Viereck) which may cause as much as 38% mortality while averaging 13.6%. Generally,

Table 9.10 Parasitization success and adult emergence of Apanteles plutellae Kurdj. and Diadegma eucero-phaga Horstm. from Plutella xylostella (L.) hosts in relation to different time intervals between exposure sequence.

| Exposure sequence<br>and interval<br>(hrs) in between <sup>1/</sup> | Parasites emerging as adults |        |                        |        |
|---------------------------------------------------------------------|------------------------------|--------|------------------------|--------|
|                                                                     | <u>A. plutellae</u>          |        | <u>D. eucero-phaga</u> |        |
|                                                                     | (No.)                        | (%)    | (No.)                  | (%)    |
| (i) <u>A. PLUTELLAE</u> HAVING FIRST ACCESS TO HOSTS:               |                              |        |                        |        |
| A-0-D                                                               | 6                            | 23.08  | 20                     | 76.92  |
| A-24-D                                                              | 15                           | 78.95  | 4                      | 21.05  |
| A-48-D                                                              | 19                           | 95.00  | 1                      | 5.00   |
| A-72-D                                                              | 18                           | 75.00  | 6                      | 25.00  |
| A-96-D                                                              | 20                           | 74.07  | 7                      | 25.93  |
| A-120-D                                                             | 19                           | 100.00 | 0                      | 0.0    |
| A-144-D                                                             | 22                           | 100.00 | 0                      | 0.0    |
| (ii) <u>D. EUCEROPHAGA</u> HAVING FIRST ACCESS TO HOSTS:            |                              |        |                        |        |
| D-0-A                                                               | 3                            | 10.71  | 25                     | 89.29  |
| D-24-A                                                              | 3                            | 13.64  | 19                     | 86.36  |
| D-48-A                                                              | 6                            | 25.00  | 18                     | 75.00  |
| D-72-A                                                              | 5                            | 18.52  | 22                     | 81.48  |
| D-96-A                                                              | 4                            | 14.29  | 24                     | 85.71  |
| D-120-A                                                             | 0                            | 0.0    | 22                     | 100.00 |
| D-144-A                                                             | 0                            | 0.0    | 23                     | 100.00 |

<sup>1/</sup> A = A. plutellae, D = D. eucero-phaga, and the number indicates the time period between exposures to the two parasites.

where D. eucero-phaga has successfully controlled DBM, there was either no mention of hyperparasites (Vos, 1953), or hyperparasitism was inadequate to limit the parasite (Robertson, 1948; Goodwin, 1979). Besides, the lower level of D. eucero-phaga may be because it is still in the first period of establishment wherein it is increasing only gradually prior to reaching a higher and more stable population in the new habitat. Whether this is so can only be confirmed later through continuing studies.

Thompson (1939) has stated that in a pest's parasite complex, superparasitism is generally more frequent than multiparasitism and this excess is usually attributed to the differential effects of environments on the distributions of parasites. For A. plutellae in the field, a higher level of superparasitism (5.9%) than multiparasitism (0.37%) with D. eucero-phaga was also recorded (Table 9.11). But an inverse situation occurred in the competition studies probably arising from unnatural conditions of the laboratory. However, for D. eucero-phaga superparasitism was 7.7 fold that of multiparasitism (Table 9.4). Generally, the greater superparasitism than multiparasitism indicates that each species tends to inhibit its own

growth more than that of the other species and hence intra-specific effects outweigh inter-specific ones. Theoretically, only this situation allows for possible attainment of a stable equilibrium point and coexistence between the species concerned (Hassell, 1976). However, since superparasitism in both A.plutellae and D.eucero-phaga tends to be greater at lower host densities, inter-specific competition between them would necessary be more prevalent when hosts are more abundant; this gradually giving way as the population declines so that intra-specific competition then assumes greater importance to allow for coexistence.

Table 9.11 Field parasitism of Plutella xylostella (L.) larvae in three localities of the Cameron Highlands.

| Locality                            | Date    | Larvae of <u>P. xylostella</u> dissected | No. of parasitized hosts containing:* |   |   |                      |                                    |     | Others |
|-------------------------------------|---------|------------------------------------------|---------------------------------------|---|---|----------------------|------------------------------------|-----|--------|
|                                     |         |                                          | <u>A.p.</u> alone                     |   |   | <u>D.e.</u> alone    | <u>A.p.</u> & <u>D.e.</u> together |     |        |
|                                     |         |                                          | (No.)                                 |   |   | Parasite No. within: |                                    |     |        |
|                                     |         |                                          | 1                                     | 2 | 3 | 1                    | 1 each                             | 1   |        |
| LPP Station (Brinchang)             | 8.5.80  | 72                                       | 30                                    | 0 | 0 | 17                   | 0                                  | 0   |        |
| MARDI Research Station (Tanah Rata) | 9.5.80  | 148                                      | 56                                    | 6 | 1 | 20                   | 0                                  | 1 ? |        |
| Mensum Valley                       | 10.5.80 | 50                                       | 27                                    | 9 | 0 | 3                    | 1                                  | 0   |        |

\* A.p. = Apanteles plutellae, D.e. = D.eucero-phaga

? = unknown

According to Utida (1957), when several species of parasites attack a common host, the exploitation patterns and abilities of the parasites must be different to allow coexistence. For A.plutellae and D.eucero-phaga, differences exist in their search efficiency, as well as the range and preferred host stages, suggesting them to be not ecological homologues (i.e. having equal exploitation abilities). There is therefore no good reason to believe that the introduced species would displace the other as was feared initially in some quarters prior to introduction. More probably, their activities are complementary; with A.plutellae assisting more effectively at higher host densities because of its high reproductive capacity, and D.eucero-phaga at low host populations because of

its better search ability.

In general, the introduction of D.eucero-phaga has resulted in a higher parasitism compared to that previously effected by A.plutellae alone (Fig. 4.7, Table 9.4). This is probably due to D.eucero-phaga 'interfering' with A.plutellae causing it to seek out more efficiently the remaining unparasitized hosts. According to Hassell (1978), such interference, be it intra- or inter-specific, is potentially a powerful stabilizing mechanism in population interactions. It has the selective advantage of increasing the likelihood of dispersal by the parasites from areas where the prey are already or are likely to become heavily exploited. Also, it increases the chance of the dispersing species to further locate less-exploited areas of prey (Hassell, 1976). This dynamic balance between aggregation and interference acts to leave an optimum number of the two parasite species within a given area (Hassell, 1976). In particular, this will assume especial importance for A.plutellae which, possessing relatively less discriminatory ability, would otherwise tend to be attracted to areas of hosts irrespective of whether or not the hosts are parasitized. From a control viewpoint the optimum number attained by the two parasite species should be at such level whereby the host population can be suppressed and maintained at subeconomic levels. Whether this will be so in the current situation is not yet evident. Only continual monitoring until the new natural equilibrium between the altered parasite complex and the host is attained will the control effect become known. Should the suppressing effect be still insufficient then introductions of additional parasitic species may need to be considered.

10. GENERAL DISCUSSION

The research approach adopted in the present investigations has largely aimed at covering various aspects of the interaction between DBM and its hymenopterous parasites. In this general discussion, no further detailed treatment of each aspect will be attempted, but only to examine their interrelationships and consider how such an understanding may be utilized in pest management of the moth.

Until the recent establishment of D.eucero-phaga and T.collaris, only A.plutellae occurred in significant numbers on DBM infesting brassicas in the Cameron Highlands. Although its suppressive effect over the host is quite considerable, it is unable to maintain consistently the host populations at sub-economic levels. Largely, this is attributable to indiscriminate and widespread employment of chemical insecticides. However, this is not entirely so since in untreated crops the suppressive effect was also not consistently adequate. Although the adverse effects of hyperparasites cannot be completely discounted under such a situation, the intrinsic self-limiting characteristics of the parasite are also partly held responsible. In this regard, the poor discriminatory ability of the parasite for unparasitized hosts amidst parasitized ones is important as this, inevitably, would increase superparasitism which can progressively limit the effects of the parasite as the parasite:host ratio rises beyond certain level. However, the inadequate host suppression under the natural conditions cannot be attributed entirely to superparasitism or any other single factor; rather this is the nett expression of all the parasite's biological characteristics which govern its foraging efficiency as well as adverse influence of extraneous factors. Some important biological determinants will evidently relate to its growth rate, relatively low  $a'$  and high  $Th$ .

Notwithstanding the present inadequacy of the parasite in exerting complete control, from the applied standpoint, it is important to know whether the nett effect of the parasite on the host is density-dependent. Also of significance is whether it can contribute to population stability. In this regard, the positive regression obtained for % parasitism by A.plutellae for host densities less than 6 larvae/plant suggests the relationship to be directly density-dependent. This, however, is undercompensating ( $b = 0.273$ ) at very low host density. At slightly higher density range, it then becomes overcompensating ( $b = 6.62$ ), while with further increase to density of 4-6 larvae/plant an intermediate and more stable condition ( $b = 3.38$ ) is obtained. Beyond this, the regression tends to shift to one that is negative, indicating the parasite's effect to become more limited. The precise reasons for this limitation are not fully

known; however, it is probable that there is an upper limit to the number of attacks that can be made per parasite. Similar functional responses were observed by Miller (1959, 1960) for insect parasites of the spruce budworm, Holling (1959a) for mammalian predators of the European pine sawfly, and Harcourt (1963b) for Diadegma insularis (Cresson) of DBM. This phenomenon has been interpreted by Watt (1959) as a built-in mechanism that prevents natural enemies from annihilating the hosts, their food.

In the Cameron Highlands, a fairly stable host population (ca 4.5 larvae/plant) was observed in unsprayed fields at levels approximating that of the regression shift suggesting this level is at present the natural host equilibrium and probably largely maintained by the parasite. Relating this to the economic threshold of 3.7 larvae/plant for DBM (Jusoh et al, 1981), it is evident that A. plutellae may have only marginally failed to keep the host population at sub-economic levels. However, this marginal difference is necessarily only crudely approximate because of the 'unavoidably-large' limits of error in determining economic injury levels (Way, 1973, 1977b) and the inconstancy inherent in economic thresholds. Notwithstanding this, the close proximity of the natural equilibrium to the threshold has made it likely that on some occasions the host populations may be forced by the normal fluctuations in the equilibrium dynamics to well below the threshold. Occasions such as these have probably accounted for the harvests of several crops with acceptable yields in spite of no insecticidal protection. On the other hand, contrasting situations have often occurred in the cabbage farms where in spite of heavy insecticidal inputs, poor crops due to higher DBM infestations with attendant scarcity of parasites were obtained. Largely, this resulted through selective elimination of the parasite species, especially during periods when the insecticides have been rendered ineffective by insecticide resistance in the host. In general, it is evident that even though A. plutellae is incapable of providing a full control, its beneficial effects are nevertheless sufficiently substantial to merit exploitation and should not be disregarded. Conservation of this parasite is thus desirable.

In conserving natural enemies by environmental manipulations that aim to increase their effectiveness, many possibilities are available (DeBach & Hagen, 1964; van den Bosch & Telford, 1964). However, for A. plutellae in the Cameron Highlands there appear to be limited options. Present information indicates that these are supplementary food for the adult parasites and more judicious use of chemical insecticides. Since the former option of providing adult foods through suitable nectar-bearing plants has been considered in some detail (see 5.7), it suffices here to



state that the scope of maintaining (and perhaps raising) the present overall parasite's effectiveness by this means appears promising. Moreover, other advantages may be envisaged. In particular, ensuring the presence of such plants in the crop's immediate vicinity would encourage the adult parasite to take advantage of them as resting sites and refuges in the process of food searching. This may be important since under normal field conditions the parasites were often observed to rest (besides feeding) on Crotalaria plants which are located some distance (ca 90 m) from the nearest cabbage crop. Evidently, having the plants very close to the crop could detract the parasite from leaving cultivated areas where the host larvae are. On the other hand, parasites may be attracted into the crop from outside. For example, when nectar-bearing plants were grown nearby the cabbage crop in Ukraine (USSR), parasites were attracted there to attack up to 86% of the lepidopterous larvae and increasing the yield by 6-7% (Garnaga, 1975). By encouraging parasites to congregate and take refuge on flowering plants between host searching would also help in sheltering them from undue exposures to pesticide-contaminated crops. Being so, it has the double advantage of maintaining a parasite reservoir within the infested area while keeping this reservoir fairly safe from harmful pesticides that may still be needed. Conditions such as these could be significant in restraining the initial multiplication of the pest as was recorded in the Moscow region (Kopvillem, 1960) where 70-90% of DBM were destroyed by its parasites (chiefly D.fenestralis) on cabbages close to extensive patches of flowering herbs and bushes. Where fields were devoid of flowering plants or having none of the latter in their immediate neighbourhood, the controlling influence was greatly delayed. The close proximity of flowering plants will also make available possible food sources for rapid access by newly emerging parasites. This could prove critical in determining their subsequent period of survival as was found with A.plutellae (see 5.7.1). However, all the advantages mentioned can only be expected if the source plants themselves are not sprayed with chemicals. Otherwise, direct toxicity or hazards which may occur from intake of the contaminated food (Croft, 1977a) may nullify the potential of such food-refuge plants, unless the beneficial species themselves are highly resistant to chemicals which is evidently not so with A.plutellae. In this regard, C.striata has proved highly suitable being a non-economic crop and needing no chemical protection. It flowers regularly, is hardy, fast-growing and does not harbour any potential pests of cabbage. The only limitation is that it cannot fully enhance the parasite's potential longevity (see 5.7.2) and fecundity (see 5.7.3).

In the natural environment, there probably are other plant species that may serve better than C.striata. Efforts should thus be made to determine these. On the other hand economic crops might prove more desirable practically. Such possibilities with economic plants are suggested by the frequent visits of A.plutellae and several other hymenopterous species (including D.eucerothaga) to flowering peas and beans whenever these are cultivated near the cabbage crops. That arthropod species associated with these plants were not parasitized by A.plutellae or D.eucerothaga would suggest that their presence is largely due to reasons other than host searching. Since highest number of parasites are usually observed during peak flowering, food finding is strongly indicated. However, unlike plants like C.striata, the use of economic species cannot always assure safety to parasites as such crops often warrant chemical treatment. Moreover, in seeking the use of multiple cropping system to increase the impact of beneficial insects van Emden (1976) has cautioned that "with the advent of hand-held ultra-low-volume application equipment used with special formulations for the tropics, the envisaged benefits may not be realized if spraying is escalated, leaving no entomological reason for retaining multiple cropping". Often, such a system of cultivating more than one crop will be based largely on economic criteria wherein the development is such as to balance certain components against others through the process of optimization. Otherwise, where inclusion of a crop is aimed mainly to provide appropriate flowers attractive to the parasites, then it is likely to limit the choice of crops to an extent that is uneconomic within the overall strategy of multiple cropping (van Emden, 1976). But many factors can influence a farmer's choice of crops and cropping pattern, and where a serious pest is regularly abundant (as in the case of DBM) with mixed culture regarded as a potentially valuable control measure, then opportunities clearly exist for some emphasis on such an approach (Perrin, 1977).

At present, A.plutellae is abundant and common in the Cameron Highlands in spite of heavy application of insecticides. That substantial development of insecticide resistance was not found in the parasite would suggest its predominance being maintained through other means. Also, the apparent absence of good alternative hosts discounts the possibility of replenishment from reservoirs of such hosts, which in many instances (van den Bosch & Telford, 1964) are important in favouring greater parasitism. On the other hand, since applications of insecticides by farmers are not entirely satisfactory, it seems likely that some parasites have been spared in unkilld hosts. Besides, protection within the cabbage

heads at later stages also affords survival advantage. Furthermore, substantial survival may also be envisaged from adult parasites moving between a cabbage field and the surrounding unsprayed vegetation in search of hosts and food. General observations confirming that the parasite devotes much of its time outside the crop suggest this to be of especial importance. Though some may survive among those which move between cabbage plots that have different spray timings, this is likely to be limited because of the close spraying schedule. Moreover, with achievement of better pesticide coverage through improved spray technology, the chance for parasite survival will be reduced even further should the present trend of intensive spraying continue. Under such a condition, food-refuge plants that are free of pesticides will constitute a major parasite reservoir, particularly when hosts are also present. Besides, such manipulation to conserve nearby parasite reservoirs have the added advantage that they permit the use of otherwise relatively non-selective toxicants when less disruptive materials are not available (Bartlett, 1964), a condition that is not uncommon in the Cameron Highlands. In any case, such an approach is seen to be quite promising according to Hagen (1976) who concluded that "...methods of manipulating insects through their food relationships are worth pursuing, for they are more selective and less ecologically disruptive to agriculture, garden and forest ecosystem than many of the methods we employ today".

Although the above considerations relate essentially to A. plutellae, they are also applicable to other parasites where the adults require nectar feeding. This applies to D. eucero-phaga whose requirement for food has been confirmed by laboratory investigations (Ooi, 1980) and is further suggested by frequent visits to flowering plants observed in the present studies. Evidently, the benefits that may be derived by suitable food-refuge plants are likely to extend well beyond that for A. plutellae alone.

At present, other than food-refuge plants, the judicious use of chemical pesticides would constitute an important strategy in parasite conservation under conditions in the Cameron Highlands. In such consideration, due regard needs to be given to exploiting the intrinsic selectivity and specificity of the various chemicals in relation to their manner of field usage, and also the spatial distribution of both the host and parasite. However, intrinsic selectivity seems rather limited whereas a more realistic aim lies in learning how to use relatively broad spectrum insecticides in ways which make them selective (Way, 1977b).

Firstly, it needs to be appreciated that most of the available insecticides are ineffective as ovicides and pupicides of DBM. Also, as insecticidal effect on adults was not investigated and is little understood, only the larval stage may be considered. Under condition in the Cameron Highlands, the close overlapping of DBM stages dictates the need of chem-

icals that are effective against the different life stages in order to assure satisfactory control. Otherwise, repeated and frequent applications would be needed. However, insecticides with such wide range of activity are generally few. Besides, for conservation of the parasite such a chemical must further satisfy safety of the beneficial species. In the case of A. plutellae this is made particularly difficult by the parasite cocoons being located in positions which are only partially isolated from the main stages of DBM. Evidently, chemicals needing to satisfy all these requirements will be difficult to find. From the present investigations, only fenvalerate (out of 48 insecticides evaluated) is able to satisfy these needs. Another promising candidate is the recently discovered SIR 8514 which is 2-chloro-N-[[[4-(trifluoromethoxy) phenyl]amino]carbonyl] benzamide with the suggested common name, triflumuron (Hammann & Sirrenberg, 1980). This chemical differs essentially from classical insecticides by its specific mechanism of action, i.e. interfering with chitin synthesis. Although such chitin synthesis inhibitors are gaining significance in pest control, not all can provide satisfactory protection of the crop as with diflubenzuron against DBM. SIR 8514, however, has exceptional toxicological properties. Selective activity which favourably spares beneficial insects is also evident (Hammann & Sirrenberg, 1980). It acts mainly as a stomach poison and is not systemic. However, it displays long-lasting residual activity even under increased light intensity and rainfall. Besides, it shows a positive temperature coefficient and features very good plant tolerance. To date, SIR 8514 has provided effective control against DBM in the laboratory (Hammann & Sirrenberg, 1980) and field (Schmidt & Dörntlein, 1980). Moreover, it is also able to control most other major lepidopterous pests of brassicas, and as such, could well reduce the use of mixed chemical treatment in the Cameron Highlands thereby allowing for more precise management of the situation there. Undoubtedly, the availability of this material is potentially of tremendous value. However, in spite of the difficulty of finding such a chemical, there is still the constraint of resistance development. For example in Taiwan, most field strains of DBM had developed resistance to the 4 major synthetic pyrethroids: permethrin, cypermethrin, decamethrin, and fenvalerate (Liu et al, 1981). The latter was used for only 4 years, whereas the others were introduced only recently. Resistance to these compounds was high in general, ranging from ca 80 - 700 fold (Liu et al, 1981). In the Cameron Highlands, signs of resistance build-up to fenvalerate (RR = 4.5) are already evident in less than 2 years (Sudderuddin & Kok, 1978). Evidently, control strategy with limited

objectives to a chemical pesticide is not only unrealistic but impractical, as it is most unlikely to sustain over time. Alternative or complementary strategies that could ensure longer-term stability would clearly be desirable.

Since the eggs and pupae of DBM are now known to be largely unaffected by most insecticides, possible exploits with available biological agents could be attempted instead; for the pupae an introduced parasite (T.collaris) has recently become established. By adopting this kind of strategy, based on complementary controls, the scope of chemicals could be more effectively exploited. In particular, more attention could be devoted to safeguarding the two larval parasites that are already contributing important mortality. However, in doing so, minimising the adverse effects on the parasites of the pupa (and egg parasites when established) by the applied larvicides would have to be given due consideration. To some extent this may be overcome for egg parasites if the chemicals can be carefully directed onto the undersurface of the young leaves (& shoots) and moderately old leaves only. By this means, considerable protection can also be afforded to A.plutellae cocoons which are predominantly present on the old and moderately old leaves. Because of the rather similar distribution (spatially) of both the larvae and pupae of DBM over the plant, safeguarding any pupa parasite by differential placement of insecticides will be more difficult. However, some safety may be afforded if the host pupae can provide adequate protection to the developing parasites within, or if physiologically selective larvicides (e.g. chitin inhibitors, B.t.) are used. Whichever may be the case these will need further investigation, particularly if the pupal parasites are found to be important.

Besides the judicious use of larvicides as given above, other possibilities of ecological selectivity as outlined by Bartlett (1964) as a means of natural enemy protection need also be considered. Although many of these have been observed to aid natural enemies substantially for other pests and on other crops, such as, 'skip', 'spot' or 'strip' treatments (Dowden, 1952; DeBach & Landi, 1959; Bartlett, 1964), reduced dosage (Michelbacher, 1954; Stern et al, 1959), and the selective timing of treatments (Steiner, 1938; DeBach, 1947; Michelbacher & Middlekauff, 1950; Bartlett & Ortega, 1952) particularly with short persistent materials (Ulyett, 1947; Allen, 1958), their effectiveness against DBM in the Cameron Highlands has yet to be investigated. Such studies need also be extended to cover the relative safety to parasites of various pesticide formulations and different types of application. At this time when several parasite species are already in existence there (and perhaps more when

others are later introduced) it becomes imperative for these aspects to be looked at. Moreover, these features are also emphasised here in order to stimulate more exact and discriminating investigations on chemical insecticides which are still much needed.

An important larvicide with good promise in relation to the above criteria is B.t. Although there are hazards to A.plutellae through host starvation its overall advantages, on balance, are believed to outweigh the limitations, as with most other pathogens (Bailey, 1971). In particular, the chief advantages are its relatively high degree of specificity with each strain of B.t. (Burgerjon & Martouret, 1971) thereby affording little danger to many non-target beneficial insects (Bailey, 1971), man and other vertebrates (Heimpel, 1971); its easy application, similar to conventional pesticides (Hall, 1964); its compatibility with many chemical insecticides (Benz, 1971) and other insect pathogens (Krieg, 1971) to the degree that they may be used concurrently and, in some instances, synergistically (Benz, 1971; Krieg, 1971; Creighton & McFadden, 1974, 1975); the lack of indisputable records of resistance (Burges, 1971); and its competitive cost with chemical insecticides to users under many situations (Falcon, 1971). Largely due to these desirable features, B.t. has been extensively used on a wide range of vegetable and field crops, orchards, forest, shade and ornamental plants, as well as experimentally investigated against insects of stored products and of medical importance (Burges & Hussey, 1971). Emerging from these have been many successes, leading Falcon (1971) to conclude in his appraisal that "B.t. is one of the few available 'broad spectrum', yet selective and ecologically safe, insect control agents". As such, it thus seems that greater efforts should be concentrated on exploiting and incorporating B.t. as an integral component in DBM control, particularly since the moth is highly susceptible to it.

The field use of other pathogens associated with DBM (Sawyer, 1931; Ulliyett & Schonken, 1940; Kelsey, 1966; Asayama & Osaki, 1970; Vail et al., 1972) cannot at present be suggested mainly due to insufficient information. However, since it is "....anticipated that microbial control will play a useful — and extremely safe — part in integrated control, ....." (Burges & Hussey, 1971), investigations into these agents need to be pursued, particularly on environmental effects. In particular, E. sphaerosperma and the granulosis virus warrant consideration.

Much of the above account has centred on the parasite A.plutellae. However, since both D.eucerothaga and T.collaris are now permanently part of the parasite complex they cannot be disregarded. More detailed studies will thus be needed to identify their relative roles in the newly-established parasite complex so that they can be properly exploited in practical

management of DBM. This would also apply to any other parasites that may be introduced.

At present the impacts of D.eucerothaga and T.collaris on DBM are still not adequately known. However, they are expected to become more abundant. In general, they seem to be useful especially when gauged by experiences where these species, among a few others, have usually been found to dominate the parasite complex of DBM and are generally considered of importance in the control of the moth (Kanervo, 1936; Hardy, 1938; Robertson, 1939; Ulliyett, 1947; Todd, 1959; Kopvillem, 1960; Goodwin, 1979). For the specific situation in the Cameron Highlands, the impact of T.collaris, if significant, should not interfere with existing control since no other pupal parasites occur there while insecticides are generally ineffective against the pupae. Similarly, with D.eucerothaga it is likely to complement the contributions of A.plutellae. Therefore, it is anticipated that the eventual outcome of the establishment of these two species can only be favourable although the extent of the benefit cannot be predicted. Should the overall effects of the natural enemies prove successful in maintaining the DBM population at sub-economic levels, then, many of the existing problems associated with the widespread use of insecticides can be expected to decline rapidly. Otherwise, introductions of other parasite species would appear desirable besides continuing with efforts to conserve the existing ones.

In considering the possible utilization of other parasites, many species have been recorded on DBM to date. Forty-eight species were catalogued by Thompson (1946) while Goodwin (1979) stated that there are more than 90. However, not all the natural enemies are effective. Frequently, only a few predominate. Even among these, most appear to be unable to exert full control over their host individually under natural conditions, besides differing in their degree of control. Thus, their potentials as biological control agents vary, often depending not only on their direct relationships with their host(s) but also on the interrelationships among themselves and the environment. In view of these, it is often difficult to assess accurately the potential of each individual agent. Nevertheless, some approximation of the potential of the agents and to what extent they may be exploited, if at all, is essential for a control programme aiming at the optimum utilization of such agents. Appendix 4 provides the details in such an attempt to identify and delimit the potential for those DBM parasites commonly reported, based on an extensive review of the relevant literature. Such a basis in parasite assessment is however made with some reservation since parasite that is scarce in one country may be good if introduced to another, perhaps because of less hyperparasites or it fits

better into a niche in the new country. Notwithstanding this limitation, a useful assessment can still be obtained on the relative potentials of the different parasite species.

From the review, it is evident that most of the recorded parasite species are of limited or of no potential use in the control of DBM. These include numerous species which are only rarely recorded, as well as species which, although widespread, can never rise to dominate the parasite complex and whose abundance is consistently low (Appendix 4).

In general, the egg parasites seem to contribute little, with species being restricted to the genera Trichogramma and Trichogrammatoidea (Appendix 4). Since chemical ovicides are largely unavailable, these egg parasites may however be exploited to increase the overall host mortality accumulated over the different developmental stages.

Larval parasites have the greatest control potential. Among these, the major ones in order of decreasing importance, belong largely to the genera Diadegma, Apanteles and Microplitis. Although more detailed assessments of these species and how they might be employed are given in Appendix 4, it seems that, except for D.eucerocephala and possibly D.fenestralis none appears capable of exerting full control by itself. Utilization of even the more promising ones [Apanteles halfordii Ulliyett, Apanteles ippeus Nixon, A.plutellae, A.ruficrus, Apanteles sicarius Marsh, Diadegma armillata Grav., D.insularis, Diadegma neocerocephala Horstm., and Microplitis plutellae (Meus)] would thus be restricted to exploiting only their contributions in combination with others. This is similar for the more important pupal parasites which, although effecting only moderate levels of parasitism, are nevertheless considered beneficial and desirable. Among these however, only the following would appear to be potentially useful: Diadromus plutellae (Ashmead), Diadromus subtilicornis Grav., Tetrastichus sokolowskii Kurdj. and T.collaris (Appendix 4).

From the above considerations it is evident that much scope still exists for increasing the overall parasitic activity in the Cameron Highlands through further introductions, because a number of potentially useful species are today still not present there. Also, the scope for depressing further the DBM infestation to sub-economic levels through these agents appears hopeful, particularly since the mean host density is at present only marginally above the economic threshold.

At present, in spite of the enormous demand for insecticides against DBM as a key pest there, abysmally little is known about how to use such chemicals sensibly in the context of the local peasant farmer economics (Norton, 1975). Customarily, field recommendations for control include a margin of overdosage as noted from



farmer surveys (Ooi & Sudderuddin, 1978). In view of this, as a first step towards reducing production costs and decreasing insecticide inputs the current practices of prophylactic treatment with chemical insecticides 2-3 times per week (Ooi & Sudderuddin, 1978) could be changed to once in 7-10 days as this has been found to be optimal and is more, or as effective (Jusoh *et al.*, 1981). By modifying spray frequency alone, the number of applications per crop can be greatly reduced and the quantity reduced by more than half. A second improvement is to apply sprays only at the young leaves (& shoots) of the cabbage plants. Although this does not provide a maximum crop output, it is however still superior to present farmer practices (see 8.2.5). Such a step would undoubtedly reduce overall chemical inputs further. Following substantial insecticidal reduction through both these means it can be envisaged that the existing levels of parasitism under farmers' conditions should rise, since it has been demonstrated (see 4.2.2 & 4.2.3) that such parasitic activities can be severely suppressed by certain chemicals. With resultant increased control by the biological agents the indiscriminate reliance of chemicals should gradually diminish thereby further encouraging contributions from natural enemies.

It should be well-recognized that even though the above elements for reducing the use of insecticides against the DBM have become available, they may still not be immediately adopted. Numerous constraints can contribute to this, in particular the farmers' perceptions, beliefs and their reliance for advice on the chemical industry which has long dominated pest control in the Cameron Highlands where the pesticide salesman have practically replaced the traditional farmers' dependence on government advisory extension (Lim *et al.*, 1981). Much of these constraints are linked to the fact that the method of pest control is essentially farm-centred wherein the dynamic impact of control strategies on the pest population which extend beyond the farm do not have a significant influence in decision-making (Southwood & Norton, 1973). More often, the high revenue returned from pest control inputs may not be due to yield increase, but to increase in 'quality' and so price. As in many other cases (Southwood & Norton, 1973), these quality effects are no more than 'cosmetic' effects and because of the uncertainties associated with the population dynamics of the pest, chemical controls are often applied as an insurance premium.

As mentioned earlier, field use of insecticides is often excessive, and as such, will adversely affect parasites. Eventual determination of lower dosages that could still effect the desired kill could provide another improvement. Such relatively simple dosage adjustments could further reduce the adverse effects of insecticidal treatment by either preserving parasite reservoirs, or by permitting earlier parasite re-entry

after extermination.

In further integrated developments towards a less chemical approach, microbial agents should be introduced in parallel, particularly B.t. which has advantages of selectivity. Cultural methods should also be considered, in particular, making available appropriate food/shelter plants for parasites. Specifically, this may entail having C.striata or a suitable system of multiple cropping (van Emden, 1976). Also, where normal crop staggering prevails it should be maintained; otherwise staggering needs to be instituted.

Ultimately, when DBM is mostly controlled biologically and farmers made appreciative of the usefulness of parasites as well as the undesirability of calendar treatment, the implementation of 'spraying only when needed' (with emphasis on safeguarding the parasites) could be instituted through a surveillance system. Developing better methods of outbreak prediction coupled with an 'early warning system' that could eliminate insurance spraying will certainly help much in overcoming unnecessary chemical applications (Southwood & Norton, 1973). Also, additional research will be needed to identify pest-yield and control cost-revenue relationships, from which can be provided a rational basis for developing strategies of IPC and could eliminate the application of control measures for populations that are within the range where the crops can compensate while still below the pest-tolerance level of the market (Southwood & Norton, 1973). Although such relationships are already available to some extent (Jusoh et al., 1981), the present threshold is still inadequate as parasites have not been taken into account. Refinement of this would be necessary as improvements to the moth's management programme are being incorporated. By such step-by-step improvement a full programme towards IPC may hopefully be developed.

Although the steps above are outlined specifically for the Cameron Highlands, the strategies involved are generally applicable elsewhere where somewhat similar problems exist. Most relevant are situations in other Southeast Asian countries, the Carribeans and perhaps the South Americas.\* Except for South Africa (Wahl, 1916; Gunn, 1917; Ulliyett, 1943, 1947), many countries in Africa may also be applicable although the situations are not so fully known because of scanty and limited published information, e.g. Egypt (Hassanein, 1958), Ghana (Gupta, 1971), Kenya (Anderson, 1922; Chesquière, 1939; van Emden, 1942; de Pury, 1968), Malawi (Smee, 1942), Tanzania (Morstatt, 1913a, b, 1914; Ritchie, 1932;

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\*Situations in South America appear so largely from impressions gained in discussion with Dr. M. Becker who is currently working on DBM in Brazil.

Harris, 1934; de Pury, 1968; Eberhard, 1978), Uganda (Hargreaves, 1924; de Pury, 1968), Zimbabwe (Jack, 1936, 1942) and Zaire (Ghesquière, 1939). When closely compared most of these areas which are continuously plagued with difficult DBM problems have some common features. In particular, associated parasitic species are absent or scarce (Table 10.1). Furthermore, the total level of parasitism is generally low, usually not exceeding 36%. However, as total parasitism rises the mean host density tends to be further depressed, finally becoming negligible under situations of complete biological control when parasitism rates of more than 70% are normal while levels exceeding 80% are not uncommon (Table 10.1). In parallel, there is an increase in species diversity; situations with higher total parasitism frequently having a greater number of parasite species (Table 10.1). In view of this and also because many of the parasites by themselves are limited in ability to check the host population, biological control objectives and effort against DBM should concentrate and aim at combining their effects to attain a high overall parasitism. However, this should be viewed with some reservation since it is not relevant and applicable to all parasites of DBM but likely to be only meaningful in practice for the crucially important ones as will be made clearer later in the discussion. Except within each parasite's limit potential (which unfortunately is still not known for many) the attempt to achieve very high parasitism by any one particular species should not be looked upon as feasible. Great abundance of various parasites at the same time is unnecessary as each is eventually limited by its own capacity for host finding. Moreover, a great diversity of natural enemy complex is not necessarily desirable in pest management (Way, 1977a) and in some instances can be harmful (Taylor, 1937; Varley, 1959; Turnbull & Chant, 1961; Watt, 1968; Zwolfer, 1963; Way, 1976; Pimentel, 1980; May *et al.*, 1981).

For practical management, various parasite species may be encouraged to act concurrently or in sequence; the latter, however, is considered more effective since high parasitism of the different species usually occurs at different times over the crop and at different stages of the pest. A good knowledge on the sequence or pattern of parasite succession is thus essential. Efforts should therefore be devoted to this, especially to identify the period of natural enemy 'vacuum' or scarcity, and where possible to introduce or encourage appropriate parasites to fill or supplement the 'vacuum'.

Although Table 10.1 shows that DBM abundance is generally less when its parasite diversity is higher, the few exceptional situations have notable implications. Specifically, in Leeward Islands (Lesser Antilles) five parasite species were unable to provide any significant DBM suppression

TABLE 10.1 Infestation status of *Plutella xylostella* (L.) in relation to its insect parasite complex.

| Status of <i>P. xylostella</i>                                                                 | Normal mean host density                                                                                       | Locality                                                   | No. of species                                                                                      | Dominant species                                                                                | Insect parasite complex | Total parasitism                                                                                                              | Information Source                    |             |
|------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------|-------------------------|-------------------------------------------------------------------------------------------------------------------------------|---------------------------------------|-------------|
| CATEGORY I:                                                                                    |                                                                                                                |                                                            |                                                                                                     |                                                                                                 |                         |                                                                                                                               |                                       |             |
| (a) Rarely a problem; predominantly under control.                                             | Very low & almost entirely absent.                                                                             | Ile de Thanet (UK)                                         | 6                                                                                                   | <i>Diadegma eucerocephala</i> & <i>Diadegma fenestralis</i>                                     |                         | More than 80% (1935) )                                                                                                        | Bardy, 1938                           |             |
|                                                                                                |                                                                                                                | N & S of England (UK)                                      | 6                                                                                                   | <i>D. eucerocephala</i> & <i>D. fenestralis</i>                                                 |                         | More than 90% (1935) )                                                                                                        |                                       |             |
|                                                                                                | ca 11.6 larvae/plant                                                                                           | Transvaal (S. Africa)                                      | a/                                                                                                  | <i>Diadegma</i> spp.                                                                            |                         | Parasites responsible for ca 70% of host mortality (1936-39)                                                                  | Ulyett & Schoonen, 1940; Ulyett, 1947 |             |
|                                                                                                | 13.3 larvae/plant                                                                                              | Transvaal (S. Africa)                                      | a/                                                                                                  | <i>Diadegma</i> spp.                                                                            |                         | More than 58.3%.                                                                                                              |                                       |             |
|                                                                                                | 6.2 larvae/plant                                                                                               | Pretoria (S. Africa)                                       | 17                                                                                                  | <i>Diadegma</i> spp.                                                                            |                         | Mean parasitism-34%, increasing to more than 50% at later stage & sometimes attaining as high as 72%.                         | Ulyett, 1947                          |             |
|                                                                                                | Mean larvae + pupae/plant = 1.6 -12.8, averaging 5.3/ plant.                                                   | Patjet (Indonesia)                                         | 1                                                                                                   | <i>D. eucerocephala</i>                                                                         |                         | 77.6% )                                                                                                                       | Voa, 1953                             |             |
|                                                                                                |                                                                                                                | Segunung-Panjawajan & Cunung Putri (Indonesia)             | 1                                                                                                   | <i>D. eucerocephala</i>                                                                         |                         | 80-96% (ave. 86% 1952 end) )                                                                                                  |                                       |             |
|                                                                                                |                                                                                                                | Cunung Putri (Indonesia)                                   | 1                                                                                                   | <i>D. eucerocephala</i>                                                                         |                         | 84-96% (ave. 89%, 1952end) )                                                                                                  |                                       |             |
|                                                                                                |                                                                                                                | Middle Java                                                | 1                                                                                                   | <i>D. eucerocephala</i>                                                                         |                         | 40-60% )                                                                                                                      |                                       |             |
|                                                                                                | Very low & almost entirely absent.                                                                             | Moscow Region (USSR)                                       | 8                                                                                                   | <i>D. fenestralis</i> & <i>Diadromus subtilicornis</i>                                          |                         | More than 80%.                                                                                                                | Kopylov, 1960                         |             |
|                                                                                                | Abundance of <i>P. xylostella</i> markedly reduced to insignificant level following introduction of parasites. | Many parts of Australia                                    | 7                                                                                                   | <i>D. eucerocephala</i> , <i>Thyraella collaris</i> & <i>Apanteles plutellae</i> .              |                         | Heavy parasitism                                                                                                              | Wilson, 1960                          |             |
|                                                                                                | Less than 1.5; 4.0 larvae/plant.                                                                               | S. Ukraine (USSR)                                          | >4                                                                                                  | <i>Diadegma</i> spp. (mainly <i>D. fenestralis</i> ). These caused more than 50% host mortality |                         | 14.2-97.3% (1960-65) )<br>66.4-78.1% (1963-65) )                                                                              | Adashkevich, 1966                     |             |
|                                                                                                |                                                                                                                |                                                            |                                                                                                     | Remainder caused largely by <i>D. subtilicornis</i> & <i>Apanteles</i> spp.                     |                         | )                                                                                                                             |                                       |             |
|                                                                                                | Never reached economic levels (normally 1-5 per 20 plants).                                                    | Columbia (USA)                                             | 3                                                                                                   | <i>Diadegma plutellae</i> , <i>Tetrastichus sokolovskii</i> & <i>Microplitis plutellae</i> .    |                         | High parasitism rates.                                                                                                        | Parker, 1971                          |             |
|                                                                                                | 1.4 larvae + pupae/plant.                                                                                      | West Java (Indonesia)                                      | 1                                                                                                   | <i>D. eucerocephala</i>                                                                         |                         | Up to 73% (1973)                                                                                                              | van den Oever, 1973                   |             |
|                                                                                                | 0.3 larvae + pupae/plant (1972-73)                                                                             | Victoria (Australia)                                       | 9                                                                                                   | <i>D. eucerocephala</i> , <i>T. collaris</i> & <i>Diadegma rasi</i> .                           |                         | 49% (1972-74)                                                                                                                 | Goodwin, 1979                         |             |
|                                                                                                | 1.0 larvae + pupae/plant (1973)                                                                                |                                                            |                                                                                                     |                                                                                                 |                         |                                                                                                                               |                                       |             |
|                                                                                                | 1.5 larvae + pupae/plant (1973-74)                                                                             |                                                            |                                                                                                     |                                                                                                 |                         |                                                                                                                               |                                       |             |
|                                                                                                | 3.1 larvae + pupae/plant (1974)                                                                                |                                                            |                                                                                                     |                                                                                                 |                         |                                                                                                                               |                                       |             |
| Low & generally well controlled naturally.                                                     | (Krasnodar (USSR) (1960-63) )<br>(Byelorussia (USSR) (1964-70) )<br>(Maritime Region (USSR) (1973-76) )        | a/                                                         | <i>D. fenestralis</i> & <i>Apanteles ruficrus</i><br><i>D. eucerocephala</i> & <i>Diadromus</i> sp. |                                                                                                 | 49-66%<br>Up to 90%     | Moiseeva, 1975<br>Slabospitskiĭ, 1980                                                                                         |                                       |             |
| (b) Occasionally a problem when natural control is disrupted (essentially by abiotic factors). | Incidence generally low                                                                                        | Main crucifer-growing areas of North Island (New Zealand). | 2                                                                                                   | <i>D. eucerocephala</i> & <i>T. collaris</i>                                                    |                         | 48.6% (100% on many instances). At high host density periods control is aided largely by <i>Entomophthora sphaceliperma</i> . | Todd, 1959                            |             |
|                                                                                                | Population usually low                                                                                         | Hawkesbury Valley (Australia)                              | 6                                                                                                   | <i>D. eucerocephala</i> , <i>T. collaris</i> & <i>Apanteles ippeus</i>                          |                         | 73% (1971-74)                                                                                                                 | Hamilton, 1978a, b.                   |             |
|                                                                                                | However build-ups to economic importance occur when there are unusually warm & dry conditions.                 |                                                            |                                                                                                     |                                                                                                 |                         |                                                                                                                               |                                       |             |
|                                                                                                | 0.6 larvae + pupae/plant (1971-72)                                                                             |                                                            |                                                                                                     |                                                                                                 |                         |                                                                                                                               |                                       |             |
|                                                                                                | 2.4 larvae + pupae/plant (1972-73)                                                                             |                                                            |                                                                                                     |                                                                                                 |                         |                                                                                                                               |                                       |             |
|                                                                                                | 1.1 larvae + pupae/plant (1973-74)                                                                             |                                                            |                                                                                                     |                                                                                                 |                         |                                                                                                                               |                                       |             |
|                                                                                                | CATEGORY II:                                                                                                   |                                                            |                                                                                                     |                                                                                                 |                         |                                                                                                                               |                                       |             |
|                                                                                                | Natural control partial; sporadic build-ups requiring control by limited supplement of chemical insecticides.  | DM occurring only in fair numbers yearly.                  | Lutjebroek (Holland)                                                                                | 4                                                                                               | <i>D. eucerocephala</i> |                                                                                                                               | More than 55%                         | Lloyd, 1940 |

TABLE 10.1 (Continued 1).

| Status of <i>P. xylostella</i>                                                                                       | Normal mean host density                                                                                                                                       | Locality                                                                   | No. of species | Insect parasite complex                                                            |                                                                     | Information Source         |
|----------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------|----------------|------------------------------------------------------------------------------------|---------------------------------------------------------------------|----------------------------|
|                                                                                                                      |                                                                                                                                                                |                                                                            |                | Dominant species                                                                   | Total parasitism                                                    |                            |
|                                                                                                                      | Normally held at relatively low levels with sporadic build-ups.                                                                                                | Marivale (Canada)                                                          | 12             | <i>Diadegma insularis</i> & <i>Diadromus pluteus</i>                               | ca 52%                                                              | Harcourt, 1960, 1963a,b.   |
|                                                                                                                      | Attaining economic levels occasionally.                                                                                                                        | New York (USA)                                                             | >2             | <i>Diadegma</i> spp.                                                               | 40% (1957)<br>35% (1958)                                            | Pimental, 1961             |
|                                                                                                                      | 6.6 larvae/plant (1960)                                                                                                                                        | Aylmer (Canada)                                                            | b/             | -                                                                                  | -                                                                   | Cass, 1963                 |
|                                                                                                                      | 1.5 larvae/plant (1961)                                                                                                                                        |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 1.6-3.6 per plant, averaging 2.4                                                                                                                               | S. California (USA)                                                        | 5              | <i>D. insularis</i> & <i>Diadegma pluteus</i>                                      | 29.5% (in cooler 1st half year)<br>40.4% (in warmer last half year) | Oatman & Platner, 1969     |
|                                                                                                                      | 1.18 larvae + pupae/plant (1963, test 1)                                                                                                                       | Charleston, S.C. (USA)                                                     | b/             | -                                                                                  | -                                                                   | Creighton et al., 1970     |
|                                                                                                                      | 1.16 larvae + pupae/plant (1963, test 2)                                                                                                                       |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.11 larvae + pupae/plant (1966, test 1)                                                                                                                       |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.09 larvae + pupae/plant (1966, test 2)                                                                                                                       |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.14 larvae + pupae/plant (1967, test 1)                                                                                                                       |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.25 larvae + pupae/plant (1967, test 2)                                                                                                                       |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.04 larvae + pupae/plant (1967, test 3)                                                                                                                       |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.68 larvae + pupae/plant (1968)                                                                                                                               |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | Infestations built up to moderate levels occasionally.                                                                                                         | S.E. Queensland (Aust.)                                                    | 5              | <i>D. eucerocephala</i>                                                            | ca 32%                                                              | Yarrow, 1970               |
|                                                                                                                      | 0.32 larvae+pupae/plant (Spring 1969)                                                                                                                          | Clemson Univ. Truck                                                        | b/             | -                                                                                  | -                                                                   | Creighton et al., 1972     |
|                                                                                                                      | Expt. 1.)                                                                                                                                                      | Expt. Stn. (USA)                                                           |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.76 larvae+pupae/plant (Spring 1970)                                                                                                                          |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | Expt. 3.)                                                                                                                                                      |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.32 larvae+pupae/plant (Fall 1970)                                                                                                                            |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | Expt. 4.)                                                                                                                                                      |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.03 larvae+pupae/plant (Spring, Test 1)                                                                                                                       | Clemson Univ. Truck                                                        | b/             | -                                                                                  | -                                                                   | Creighton et al., 1973     |
|                                                                                                                      | Expt. Stn. (USA)                                                                                                                                               |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.12 larvae+pupae/plant (Spring, Test 2)                                                                                                                       |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | Infestations built up to moderate levels occasionally.                                                                                                         | Saskatchewan (Canada)                                                      | 2              | ( <i>D. insularis</i> (in 2nd host gen.)<br>( <i>M. pluteus</i> (in 1st host gen.) | (68% (in 1st host gen.) )<br>(41% (in 2nd host gen.) )              | Putnam, 1973               |
|                                                                                                                      | NA                                                                                                                                                             | St. Paul, Minnesota (USA)                                                  |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.59 larvae/plant                                                                                                                                              |                                                                            | 2              | <i>Diadegma pluteus</i>                                                            | 43.2% (1968)                                                        | Weires & Chiang, 1973      |
|                                                                                                                      | 0.60 larvae/plant                                                                                                                                              |                                                                            |                |                                                                                    | 12.9% (1969)                                                        |                            |
|                                                                                                                      |                                                                                                                                                                |                                                                            |                |                                                                                    | 4.6% (1970)                                                         |                            |
|                                                                                                                      | NA                                                                                                                                                             | Rosemount, Minnesota                                                       |                |                                                                                    | 57.6% (1968)                                                        |                            |
|                                                                                                                      | 0.47 larvae/plant                                                                                                                                              | (USA)                                                                      |                |                                                                                    | 16.7% (1969)                                                        |                            |
|                                                                                                                      | 0.44 larvae/plant                                                                                                                                              |                                                                            |                |                                                                                    | 9.4% (1970)                                                         |                            |
|                                                                                                                      | 0.22 larvae+pupae (Spring 1969)                                                                                                                                | Clemson Univ. Truck                                                        | b/             | -                                                                                  | -                                                                   | Creighton, et al., 1974    |
|                                                                                                                      | 0.57 larvae+pupae (Spring 1970)                                                                                                                                | Expt. Stn. (USA)                                                           |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.19 larvae+pupae (Fall 1970)                                                                                                                                  |                                                                            |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | 0.29 larvae+pupae (Spring 1973, Test 1)                                                                                                                        | Clemson Univ. Truck                                                        | b/             | -                                                                                  | -                                                                   | Creighton & McFadden, 1975 |
|                                                                                                                      | 0.37 larvae+pupae (Spring 1973, Test 2)                                                                                                                        | Expt. Stn. (USA)                                                           |                |                                                                                    |                                                                     |                            |
|                                                                                                                      | Less than 1.4 larvae+pupae/plant.                                                                                                                              | Hastings (USA)                                                             | 2              | <i>D. insularis</i> & <i>T. sokolowskii</i>                                        | 42%                                                                 | Ru & Workman, 1979         |
| CATEGORY III                                                                                                         |                                                                                                                                                                |                                                                            |                |                                                                                    |                                                                     |                            |
| (a) Continuously a problem requiring regular and heavy insecticidal control in spite of the presence of parasite(s). | Heavy infestations with severe attacks, especially in the drier parts. In many cases it almost completely destroyed the foliage with consequent loss of crops. | In many localities of New Zealand, especially Canterbury & Northern Otago. | 1              | <i>Diadegma</i> sp. (near <i>Diadegma lateralis</i> )                              | 7%                                                                  | Muggeridge, 1930           |

TABLE 10.1 (Continued 2).

| Status of <i>P. xylostella</i>                                                                                                                                                  | Normal mean host density | Locality                                                                                                                                                                                                                                  | No. of species                                          | Insect parasite complex                                                                                                                                                                                                                                  |  | Total parasitism                                                                                                                                                                                                                                                           | Information source                                                                                    |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------|
|                                                                                                                                                                                 |                          |                                                                                                                                                                                                                                           |                                                         | Dominant species                                                                                                                                                                                                                                         |  |                                                                                                                                                                                                                                                                            |                                                                                                       |
| Prior to introductions of <i>D. eucerothaga</i> , <i>T. collaris</i> & <i>A. plutealis</i> there were often large numbers of DM. Also, the crops were often severely destroyed. |                          | Localities in New Zealand )<br>Manawatu (1935-36) )<br>(1935-37) )<br>Hawke's Bay (1936-37) )<br>(1936-37) )<br>Hawke's Bay & Manawatu (1936) )<br>Canterbury (1937) )<br>(1937) )<br>Taranaki (1936) )<br>Weirarapa (1935) )<br>(1935) ) | 2                                                       | <i>Diadegma</i> sp. (near <i>Diadegma lateralis</i> )                                                                                                                                                                                                    |  | 4.5% (on host larvae) )<br>0.5% (on host pupae) )<br>0.6% (on host larvae) )<br>9.3% (on host pupae) )<br>0.42% (on host pupae) )<br>26.9% (on host larvae) )<br>22.0% (on host pupae) )<br>0.65% (on host pupae) )<br>1.48% (on host larvae) )<br>0.79% (on host pupae) ) | Robertson, 1939                                                                                       |
| Infestations common                                                                                                                                                             |                          | West Bengal                                                                                                                                                                                                                               | 3                                                       | <i>Macromalon orientalis</i> & <i>T. collaris</i>                                                                                                                                                                                                        |  | 15.5%                                                                                                                                                                                                                                                                      | Phalak, 1970                                                                                          |
| High infestations with extensive damage common                                                                                                                                  |                          | Saravak (Malaysia)                                                                                                                                                                                                                        | 1                                                       | <i>A. plutealis</i>                                                                                                                                                                                                                                      |  | Very low (often 0%)<br>at beginning of outbreak but may reach 82.7% 6-7 weeks later                                                                                                                                                                                        | Man, 1970                                                                                             |
| Infestations often capable of completely destroying the crops.                                                                                                                  |                          | ( Areas in Lesser Antilles:<br>( Antigua<br>( Barbados<br>( Dominica<br>( Leeward Islands<br>( Montserrat<br>( Nevis<br>( St. Kitts<br>( St. Lucia<br>( Windward Islands                                                                  | 3<br>2:1<br>2:1<br>1:5<br>3:1<br>2:1<br>3:2<br>3:3<br>2 | ( All species negligible<br>( All species negligible<br>( All species negligible<br>( All species negligible<br>( All species negligible<br>( All species negligible<br>( All species negligible<br>( All species negligible<br>( All species negligible |  | Negligible<br>Negligible; 40-60%<br>Negligible; )<br>Negligible; )<br>Negligible; )<br>Negligible; )<br>Negligible; )<br>Negligible; )<br>Negligible; )<br>Negligible; )                                                                                                   | Bennett & Yaseen, 1972<br>Bennett & Yaseen, 1972; Kymat, 1974<br>Bennett & Yaseen, 1972; Yaseen, 1974 |
| 6.65 larvae/plant                                                                                                                                                               |                          | Central Expt. Stn., UPCA (Philippines)                                                                                                                                                                                                    | 1                                                       | <i>Diadegma plutealis</i>                                                                                                                                                                                                                                |  | Negligible                                                                                                                                                                                                                                                                 | Yaseen, 1974<br>Cadapan & Gabriel, 1973;<br>Magallona, 1978                                           |
| 2.5 larvae+pupae/plant. Normally, damage is considerable and unacceptable without extensive chemical protection.                                                                |                          | Sembawang Field Expt. Stn. (Singapore)                                                                                                                                                                                                    | 1                                                       | <i>Apanteles</i> sp.                                                                                                                                                                                                                                     |  | low                                                                                                                                                                                                                                                                        | Chuo, 1973, 1975                                                                                      |
| Infestations high if unprotected with chemicals.                                                                                                                                |                          | Taiwan                                                                                                                                                                                                                                    | 1                                                       | <i>A. plutealis</i>                                                                                                                                                                                                                                      |  | 27%                                                                                                                                                                                                                                                                        | Chin, 1974                                                                                            |
| 187.8 individuals/man-hr (1970-71)<br>83.6 individuals/man-hr (1971-72)                                                                                                         |                          | Trinidad                                                                                                                                                                                                                                  | 2                                                       | <i>Spilochalcis hirtifemora</i>                                                                                                                                                                                                                          |  | 6.61%                                                                                                                                                                                                                                                                      | Yaseen, 1974                                                                                          |
| NA                                                                                                                                                                              |                          | Cameron Highlands (Malaysia)                                                                                                                                                                                                              | 1                                                       | <i>A. plutealis</i>                                                                                                                                                                                                                                      |  | 35.8%                                                                                                                                                                                                                                                                      | Lin & Ko, 1975                                                                                        |
| 14.4 larvae+pupae/plant.                                                                                                                                                        |                          | Cameron Highlands (Malaysia)                                                                                                                                                                                                              | 2                                                       | <i>A. plutealis</i>                                                                                                                                                                                                                                      |  | 35.9%                                                                                                                                                                                                                                                                      | Ooi & Kelderman, 1977                                                                                 |
|                                                                                                                                                                                 |                          | In various localities of the Cameron Highlands )<br>Malaysia (1978): )<br>Kampung Raja )<br>Kuala Terla )<br>Tringkap )<br>Kea Farm/Greencow )<br>Mensum Valley )<br>Ringlet )                                                            | 1                                                       | <i>A. plutealis</i>                                                                                                                                                                                                                                      |  | 23.1% )<br>44.5% )<br>29.2% )<br>42.4% )<br>52.9% )<br>36.0% )                                                                                                                                                                                                             | Ooi & Sudderuddin, 1978                                                                               |

TABLE 10.1 (Continued 3).

| Status of <i>P. xylostella</i>                                                                             | Normal mean host density                                                                                                                                 | Locality                                                  | No. of species | Insect Parasite complex |                  | Information Source     |
|------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------|----------------|-------------------------|------------------|------------------------|
|                                                                                                            |                                                                                                                                                          |                                                           |                | Dominant species        | Total parasitism |                        |
|                                                                                                            |                                                                                                                                                          | In various localities of the Cameron Highlands, Malaysia. |                |                         |                  |                        |
|                                                                                                            | 4.6 larvae+pupae/plant (1973-74)                                                                                                                         | Kampong Raja                                              | 1              | <i>A. pluteellae</i>    | 36.5% )          | Present studies        |
|                                                                                                            | 27.7 larvae+pupae/plant (1979)                                                                                                                           | Kampong Raja                                              |                |                         | 19.0% )          |                        |
|                                                                                                            | 5.0 larvae+pupae/plant (1973-74)                                                                                                                         | Kuala Terla                                               |                |                         | 48.6% )          |                        |
|                                                                                                            | 16.1 larvae+pupae/plant (1979)                                                                                                                           | Kuala Terla                                               |                |                         | 20.9% )          |                        |
|                                                                                                            | 3.8 larvae+pupae/plant (1973-74)                                                                                                                         | Tringkep                                                  |                |                         | 34.0% )          |                        |
|                                                                                                            | 10.4 larvae+pupae/plant (1973-74)                                                                                                                        | Mensum Valley                                             |                |                         | 18.1% )          |                        |
|                                                                                                            | 6.9 larvae+pupae/plant (1973-74)                                                                                                                         | Bertam Valley                                             |                |                         | 30.1% )          |                        |
|                                                                                                            | 3.2 larvae+pupae/plant (1973-74)                                                                                                                         | Kampong Taman Sedia                                       |                |                         | 12.7% )          |                        |
|                                                                                                            | 1.3 larvae+pupae/plant (1979)                                                                                                                            | Brinchang Town                                            |                |                         | 39.5% )          |                        |
|                                                                                                            | 2.8 larvae+pupae/plant (1979)                                                                                                                            | 7th Mile Brinchang                                        |                |                         | 42.4% )          |                        |
|                                                                                                            | 3.6 larvae+pupae/plant (1979)                                                                                                                            | 45th Mile Brinchang                                       |                |                         | 31.9% )          |                        |
| CATEGORY III:                                                                                              | 4.4 larvae/plant (1950)                                                                                                                                  | Patjet (Indonesia)                                        | 0              | -                       | -                | Ankersmit, 1953        |
| (b) Continuously a problem requiring regular and heavy insecticidal control. No parasite reported present. | 16.2 larvae/plant (1951-52)                                                                                                                              | Lembang (Indonesia)                                       |                |                         |                  |                        |
|                                                                                                            | 21.1 larvae/plant.                                                                                                                                       | Cameron Highlands (Malaysia)                              | 0              | -                       | -                | Henderson, 1957        |
|                                                                                                            | 17.1 larvae/plant (Expt. 1)                                                                                                                              | ( Cameron Highlands (Malaysia) )                          | 0              | -                       | -                | Ho, 1965               |
|                                                                                                            | 14.8 larvae/plant (Expt. 2)                                                                                                                              | ( )                                                       |                |                         |                  |                        |
|                                                                                                            | 23.8-612.0 larvae/plant (ave. 280.95 larvae/plant)                                                                                                       | Baguio (Philippines)                                      | 0              | -                       | -                | Sanchez et al., 1968   |
|                                                                                                            | 20.1 larvae/plant (Expt. 1)                                                                                                                              | Cameron Highlands (Malaysia)                              | 0              | -                       | -                | Bo & Ng, 1970          |
|                                                                                                            | High populations throughout the year in the low-lying plains. Impossible to produce cabbage without strict chemical control measures during hot seasons. | Jamaica                                                   | 0              | -                       | -                | Suah & Ellis, 1974     |
|                                                                                                            | Population levels high and causing severe crop damage if unprotected with chemical applications (approx. 2-3 times/week).                                | West Sumatra (Indonesia)                                  | 0              | -                       | -                | Sudarwadi et al., 1974 |
|                                                                                                            | 0.36 larvae/plant (Trans. Mar 76)                                                                                                                        | AVRDC (Taiwan)                                            | 0              | -                       | -                | AVRDC (1976)           |
|                                                                                                            | 3.7 larvae/plant (Trans. Apr 76)                                                                                                                         |                                                           |                |                         |                  |                        |
|                                                                                                            | 91.0 larvae/plant (Trans. Dec 75)                                                                                                                        |                                                           |                |                         |                  |                        |
|                                                                                                            | 3.7 larvae/plant (Trans. Feb 76)                                                                                                                         |                                                           |                |                         |                  |                        |
|                                                                                                            | 68.2 larvae/plant (Trans. Jan 76)                                                                                                                        |                                                           |                |                         |                  |                        |
|                                                                                                            | 80.8 larvae/plant (Trans. Jan 76)                                                                                                                        |                                                           |                |                         |                  |                        |

a/ Complex of several species suggested.

b/ Exact numbers not indicated but several species reported from other ecological studies

NA - Not available.

(Bennett & Yaseen, 1972; Yaseen, 1974) while full control was achieved in Java (Indonesia) by D.eucero-phaga alone (Vos, 1953). Evidently, such a situation does not bear out the dogma that increasing diversity increases stability and in general lessens pest outbreaks/damage (Elton, 1958; Pimentel, 1961; Rudd, 1964; Odum, 1971); a dogma which was seriously queried in mid 1960s (Way, 1966) and wherein was subsequently pointed out that diversity and stability may not necessarily be causally related (van Emden & Williams, 1974; Murdoch, 1975). Also, in practice increasing diversity can sometimes increase rather than decrease pest problems (Southwood & Way, 1970; Way, 1977a). With DBM the increase is unlikely to be due largely to this reason but rather the absence of some crucially important parasite species. This is suggested by the consistent involvement, together or separately, of the same few species (specifically D.eucero-phaga and D.fenestralis) in all but one of the cases where full biological control is achieved (Table 10.1). With the exception in Columbia (USA) where the moth is held in check by Diadegma plutellae, M.plutellae and T.sokolowskii (Parker, 1971), DBM still poses some problems where D.eucero-phaga or D.fenestralis is absent. The situation is however most serious, with the pest continuously requiring regular and heavy insecticidal control, when other Diadegma spp. (except D. sp. (near lateralis) and perhaps Diadegma plutellae) are also absent. Otherwise, partial control may still be obtainable, with limited supplements of chemical insecticides (Table 10.1). From such evidence, it thus appears that effective control of DBM by parasites needs only depend on a few important agents. This parallels most successes in biological control (DeBach, 1974) where a single or only very few natural enemy species have usually proved to be overwhelmingly important (Huffaker & Kennett, 1966). The essence, as summed up by Way (1976) is: "success in biological control is not associated with simple increase in diversity but it depends primarily on a few crucially important functional links". It is the quality of diversity and not the amount that really matters (Way, 1979), the right kind being fundamental to insect pest control (Way, 1976). For some pests, however, very small amounts of the right diversity may be adequate (Way, 1966). The failure to recognize this is perhaps largely responsible for most of the unsuccessful control of DBM where attempts at introductions have been only with relatively less important parasites and have not included the crucial species (largely Diadegma spp., particularly D.eucero-phaga and D.fenestralis) (Wilson, 1960; Bennett & Yaseen, 1972; Yaseen, 1974, 1978; Nagarkatti, 1975). In some instances, the poor parasite choice is also unfortunately governed by mere convenience (Nagarkatti, 1975; Ooi, 1979a) which, relative to the quality of parasite species, should not have taken priority. In particular, recognizing and



ensuring the involvement of these key species is crucial, for failing to do so could lead to much effort and expense being devoted to other biological agents that inherently are unable to effect satisfactory control.

That parasites play a dominant role in the population dynamics of DBM is evident from the present studies as well as in most other accounts of DBM. However, Harcourt (1963b), on the basis of his life tables from studies at Merivale (Canada), suggested that "the value of the biological control method for P.xylostella must seriously be questioned". His conclusion that parasites are relatively unimportant is inevitable since the parasite complex involved in his studies in Canada did not include the seemingly more important species. Although D.insularis was present, by itself it cannot effect full control except when consistently in combination with other appropriate species. D.eucerotheca or D.fenestralis if present, could have resulted in conclusion contrary to what he derived from his life table analysis. Moreover, in support of his contention that parasites are in general unimportant, Harcourt (1963b) also cited that the biological control approach for DBM has not eliminated the need for chemical control in New Zealand (Robertson, 1948) and Australia (Wilson, 1960). Evidently, too high expectation of the parasites' role is unrealistic, as upsets (both biotic and abiotic) needing insecticidal supplements could occasionally occur, as in situations where the moth is predominantly under natural control (Category I, Table 10.1). Furthermore, although attainment of full biological suppression is the prime objective, effecting a substantial decline of pest level from partial biological control such that programme of IPC with attendant reduction of chemical usage can be initiated has often been also considered important (Ooi, 1979a). From these considerations, Harcourt's (1963b) contention would appear untenable; more so when the limited examples on which he based his conclusion are further re-examined and compared with a wider and more comprehensive range of situations as in Table 10.1.

To date, many areas are still continuously plagued by DBM and emerging out of the present studies is strong evidence that this is due to the lack of crucially important parasites. Unless the relevant key species are made a part of the host-parasite complex these problems are likely to persist, largely because such species constitute the few key-links that are usually present in the food-web interactions of a pest (Way, 1976). Learning how to exploit fully these key-links in ways which are compatible with local farm practice (Way, 1966) evidently holds the key to containing the DBM problem. In this regard the current experimental studies with A.plutellae have provided much of the required information for some of these links. For the other parasites, the links for a few species have

been made clearer from the overview which also provides the basis for much of the suggestions on how best these could be exploited. Nevertheless, additional information is still needed to help define more precise methods of exploitation. In general, much of this would aim towards maximizing by any means possible the effects of biological control which has been considered of fundamental importance (Simmonds & Bennett, 1976).

To date, some other important key-links that have been established are adult food sources through flowers (Kopvillem, 1960; Garnaga, 1975), and crop continuity (staggering) and cruciferous host weeds to maintain host-parasite equilibrium (Ulllyett, 1947). Those which are potentially promising have included appropriate multiple cropping systems, in which the right choice and sequence of crops is particularly crucial (van Emden, 1976). Beyond these, except for a few materials, the links with the wide array of microbial agents and conventional chemical insecticides are still less clearly defined, largely because of inadequate investigations on the former (Burges & Hussey, 1971) and conflicting reports on the latter (Ulllyett, 1947; Vos, 1953; Todd, 1959; Kopvillem, 1960; Adashkevich, 1966; Bennett, 1974; Kumar, 1974; Yaseen, 1974; Sudarwohadi *et al.*, 1974; Hamilton & Attia, 1977; Hamilton, 1978a, b; Ooi & Sudderuddin, 1978; Present studies). However, since chemical insecticides are in general detrimental to parasitic arthropods, their exploitation needs only be considered when absolutely necessary, essentially adding on well-thought-out sparing use of chemicals to obtain the degree of control required (Simmonds & Bennett, 1976).

In conclusion, it must be highlighted that the biological control effects of parasites on DBM can be enormous. Those which potentially can provide full control, however, are probably restricted to a few crucially important species. Having them as the basic control component is imperative for it is only through such a basis that an improved and more rational programme of DBM management can be developed; and wherein brassicas everywhere could be grown with either no or far fewer applications of insecticides, this being largely achieved through the combined contributions of parasites, cultural practices, microbial agents and perhaps only to a limited extent the judicious use of chemical insecticides. Although inclusion of the key parasite species may not guarantee complete biological control, marked improvements in overall pest situations can invariably be expected, as exemplified by the examples given in Table 10.1. On the other hand, in most known situations, abandoning these crucial parasites will make brassica cultivation continue to be drenched in ever-increasing amounts of chemicals; and probably when such materials run out economically, the cultivation would then cease in many areas. These conclusions seem inevitable as all

known cases of successful DBM control have been obtained only when the basic control component constitutes either parasites or chemical insecticides. All other potentially useful approaches have yet to be demonstrated as being practically effective under large-area farm situations.

## S U M M A R Y

The status of Diamond-Back Moth (DBM), Plutella xylostella (L.) was reviewed, and wherein it was noted to be widely distributed and a serious pest in many countries. In some countries, it is however effectively suppressed by parasites. In the Cameron Highlands in West Malaysia, it is a key pest of cabbages with chemical insecticides constituting the only control measure, largely because of the firm and widespread adherence in the unquestioned beliefs that (1) no parasites/biological control can exist there because of intensive use of chemicals and (2) cabbages in the Cameron Highlands cannot be grown without insecticidal protection. Consequently, numerous problems have resulted, viz:

(1) development of insecticide resistance in the pest, (2) increase in incidence of chemical poisoning of farmers, (3) presence of chemical residues on marketed produce, (4) hazards to wildlife and (5) rapid rise in cost of crop production. These have led to the need and rationale for examining its biological control.

Since no parasite of DBM in the Cameron Highlands had been reported previously, a parasite search was initiated there, leading to the discovery of an endo-larval parasite, Apanteles plutellae Kurdj. Further surveys showed it to be widespread and abundant, averaging 29.6 - 35.8%. In the lowlands only 12.1% was obtained. Hyperparasites (chiefly Hemiteles sp.) were important in the highlands, causing about 21% parasite mortality. In general, the surveys suggest that A. plutellae is the only important parasite of DBM there and is probably contributing substantially to DBM suppression.

Three experimental studies were conducted to assess its impact on DBM. Basically, these were based on comparison of host population development and survival both in the presence and absence of the parasite. The studies included (1) a laboratory experiment, (2) a field assessment comparing DBM infestation and its parasitism by A. plutellae prior to and after the parasite's access into the Cameron Highlands, and (3) a chemical exclusion method. Emerging out of these investigations are the following findings:

- (1) The parasite can delay a similar host build-up by a generation.
- (2) The parasite can cause significant host suppression; the k-values for generation I, II & III being respectively, 0.47, 0.57 and 0.62.
- (3) Host suppression by the parasite is only partial and not consistently adequate.
- (4) The impact of the parasite is substantial and can cause significant yield increase.

- (5) Insecticides against DBM need not always result in crop improvement.
- (6) Upsurge of DBM in the Cameron Highlands is partly because of the indiscriminate use of chemical insecticides.
- (7) Chemical protection is not always necessary to obtain satisfactory crop yields.
- (8) Although A. plutellae is unable to effect full biological control of DBM, its beneficial effect is nevertheless important and merits exploitation.
- (9) Most important, both the unquestioned beliefs have been shattered.

Upon establishment of the parasite's importance detailed investigations were made on its basic biology and ecology in relation to the host; these aimed to provide insights on how the parasite might be made more effective. The major findings obtained are:

- (1) The parasite has 3 larval instars, the 1st of caudate-mandibulate form, the 2nd vesiculate and the 3rd hymenopteriform. Irrespective of the number of eggs deposited, only 1 larva will emerge from each parasitized host. Just prior to host pupation the 3rd-instar larva will emerge to spin a white cocoon from which the adult emerges by cutting an opening at one end. Developmental periods of the parasite are: egg = 1-2 days, larva = 6-7 days, cocoon (pupa) = 4-5 days, and total life cycle = 13 days.
- (2) In studies on host stage preference, 3 methods were used. The 1st method involved exposing separately different host instars for 15 mins each, while in the 2nd method equal numbers of each host instar were exposed together. For the 3rd method, it involved exposing for 24 hrs two larval instars at a time. The findings clearly showed the parasite's preference to be: 2nd > 3rd > 1st > 4th larval instar.
- (3) Irrespective of host larval instars which the parasite initially 'attacked', the developmental period of the parasite was relatively constant, being approximately 9 days. However, as initial oviposition with respect to the host stage became later, the developmental period of the host was progressively lengthened. Also, there was increased host mortality.
- (4) On parasite development under different temperature and RH conditions duration of the egg, larval and pupal stages were observed to shorten progressively with each additional increment in temperature. For the different stages the temperature threshold ( $t$ ) and thermal constant ( $K$ ) are: egg ( $t_e = 11.2^{\circ}\text{C}$ ,  $K = 41.67 \text{ day}^{-\circ}\text{C}$ ), larva ( $t_l = 15.5^{\circ}\text{C}$ ,  $K = 58.82 \text{ day}^{-\circ}\text{C}$ ), pupa ( $t_p = 15.5^{\circ}\text{C}$ ,  $K = 63.16 \text{ day}^{-\circ}\text{C}$ ) and from oviposition to adult emergence ( $t_T = 13.8^{\circ}\text{C}$ ,  $K = 178.57 \text{ day}^{-\circ}\text{C}$ ). With RH, the range of 70-80% seems most favourable, resulting in greatest parasite survival (93.33%) as well as a higher number of female parasites.

- (5) Concerning parasite oviposition, only 1 egg was usually deposited per ovipositor insertion. Dead hosts were, however, never oviposited upon. When multiparasitism occurred, excessive 'stings' may kill the host. This effect increased rapidly for higher number of ovipositions with a 100% host mortality occurring for 10 ovipositions and beyond.
- (6) Reproduction in the parasite is arrhenotokous with a 1:1 sex ratio normally present in the field. Under laboratory conditions, more males were obtained when (a) the host stage initially parasitized was later, (b) the number of 'ovipositional attack' per host was increased, and (c) when the parasite was reared under extreme climatic conditions.
- (7) The parasite is also synovigenic, with mean longevity increased from 3 days to 14 days and mean fecundity from 193 eggs to 494 eggs when female parasites were prevented and given access to honey (30%). Even an initial starvation of only 12 hrs could adversely affect its longevity and survival.
- (8) The possibility of flowering plants serving as food sources was also investigated. Of 16 flowering species commonly found in the farming area, many were capable of increasing the parasite's longevity. With Crotalaria striata L., the mean fecundity was also increased significantly ( $P < 0.01$ ) to 180.1 eggs when compared to the 'water' control (71.8 eggs). Other extrafloral nectaries capable of increasing the parasite's longevity were those of the leaves and flower stalk's axils. Survey of insects visiting C. striata further confirmed the usefulness of this flowering plant to A. plutellae.
- (9) In laboratory studies involving different lepidopterous species only Crocidolomia binotalis Zell and Hellula undalis F. seemed able to serve as possible alternative hosts. However, in the field, except for DBM a wide range of lepidopterous larvae collected from cabbages and other plants in the vicinity did not yield any A. plutellae, suggesting the parasite to be host specific.

From the above considerations, A. plutellae is observed to have a number of desirable attributes viz: (1) host specificity, (2) great reproductive potential (short generation time, high fecundity), (3) good internal synchronization with host development, (4) well-adapted to fairly wide range of conditions occupied by host and (5) is density responsive to changes in host population.

The spatial distribution of both DBM and A. plutellae on the cabbage plant at different ages was also investigated with the view to help in guiding insecticidal applications. In general, more eggs (65.6%)

of DBM were laid on the abaxial leaf surface and on the young and moderately old leaves. For the larvae and pupae, although more occurred on the under-surface there were still substantial numbers on the abaxial side. Cocoons of A. plutellae, however, predominate in the adaxial surface while there was little difference in the distribution on the different categories of leaves.

Both DBM and its parasites (including the recently introduced species Diadegma eucero-phaga Horstm.) were also found to occur within the cabbage heads. Many emerged alive in spite of the tight overlapping of the leaves; this usually occurred within 14 days after harvest. Such occurrence, evidently, has relevance to the moth's dispersal ecology and its effective control by chemical insecticides.

Studies on the field abundance of DBM over 32 overlapping and unsprayed cabbage crops revealed that its population fluctuations are not related to plant age but seasonal factors. Among the main climatic parameters (rainfall, temperature & RH), only rainfall had significant correlation with high DBM infestations occurring during the drier period. In a partial key factor analysis, mortality from parasites ( $k_p$ ) was observed to increase gradually following the introduction of D. eucero-phaga while that due to diseases ( $k_d$ ) declined, indicating that parasites may soon assume greater importance. The total parasitism of 1.8 - 12.7% for the first 5 crops increased to about 70.3% by the 32nd crop.

Since control of DBM in the Cameron Highlands was exclusively dependent on chemical insecticides, it was considered necessary to investigate further into this aspect particularly to obtain relevant information that could help in their judicious employment. From laboratory screening of 48 insecticides, most were found ineffective as ovicides and pupicides of DBM. As such, possible exploitation with biological control agents against the eggs and pupae need to be attempted. With the larvae, most of the chemicals were effective. However, only fenvalerate was able to also satisfy the safety requirements for A. plutellae. In general intrinsic selectivity seemed rather limited and a more realistic aim would be to use relatively broad spectrum insecticides in ways which make them selective. In this regard, by directing the chemicals onto the undersurface of young leaves (& shoots) would afford considerable protection to A. plutellae cocoons which predominate on the old and moderately old leaves. Such treatment could also increase yield over that of the farmers' practice as well as more easily adopted at the farm level.

Among biological insecticides, Bacillus thuringiensis Berlinger (B.t.) was found effective and showed good promise for integration with other control tactics of DBM. Although there are hazards to A. plutellae

through host starvation, on balance, its overall advantages outweigh the limitations. Under field conditions, more parasites are spared and yield significantly increased. Other microbial agents which also showed possible utilization and warrant consideration are Entomophthora sphaerosperma (Fres.) and the granulosis virus.

Four insecticides were evaluated for possible resistance development to A.plutellae. Resistance ratios of 2.4, 2.7, 0.99 and 3.9 were respectively obtained for lindane, fenvalerate, malathion and methamidophos. In general, development of insecticide resistance by the parasite is very limited, suggesting that abundance of A.plutellae in the Cameron Highlands is largely maintained through other means. Survival in flowering plants outside the crops is considered a likely possibility.

An appraisal was also made of the current status of the imported parasites [D.eucerothaga and Thyraeella collaris (Grav.)] that were recently established in West Malaysia, particularly the role of D.eucerothaga relative to that of A.plutellae. In survey of their presence in the Cameron Highlands, both were found to have gradually spread out from the establishment site to several localities.

On competition between A.plutellae and D.eucerothaga, the latter was superior. It can locate hosts faster and parasitize more over a fixed period, and has a higher  $a'$  ( $1.887 \text{ day}^{-1}$ ) and lower  $Th$  (0.0092 days) than A.plutellae ( $a' = 0.813 \text{ day}^{-1}$ ,  $Th = 0.0115 \text{ days}$ ). In both, the functional response is of Holling's 'type II'.

The ability to discriminate between parasitized and unparasitized hosts by A.plutellae and D.eucerothaga is both intra- and inter-specific. Discrimination in the former was displayed only when the parasitized hosts contained parasite larvae and is unlike D.eucerothaga which could also avoid parasitized hosts containing eggs. In both, discrimination was however limited, with the imperfect restraint breaking down at low host density or at higher parasite: host ratio, resulting in superparasitism.

Generally, the species which can attain the larval stage before the eggs of the other have hatched would kill its competitor and emerge the survivor. However, as superparasitism usually exceeded multiparasitism each species will tend to inhibit its own growth more than that of the other, thus allowing for co-existence. Also, since D.eucerothaga can complement the activity of A.plutellae its introduction is likely to prove favourable. Should host suppression be still inadequate, introductions of other parasites would be desirable besides continuing with efforts to conserve the existing ones.

In considering possible utilization of other parasites, numerous species are noted to exist on DBM. However, from an extensive review, not



all are found to be effective. On the contrary, the key ones are restricted to only a few species. These belong largely to the genera Diadegma, Apanteles and Microplitis for the larval parasites. Except for D.eucero-phaga and possibly Diadegma fenestralis, none appears capable of exerting full control by itself.

To date, many countries are still continuously plagued by DBM and there is strong evidence from the present studies that this is due to the lack of crucially important parasites. Unless the relevant key species are made a part of the host-parasite complex these problems are likely to persist. Having the key species as the basic control component is imperative for it is only through such a basis that an improved and more rational programme of DBM management can be developed; and wherein brassicas could be grown with either no or fewer applications of insecticides, this being largely achieved through the combined contributions of parasites, cultural practices, microbial agents and perhaps only to a limited extent the judicious use of chemical insecticides. Although inclusion of the key parasite species may not guarantee complete biological control, marked improvements in overall pest situations can invariably be expected. Abandoning these crucial parasites will make brassica cultivation continue to be drenched in ever-increasing amounts of chemicals. These conclusions seem inevitable as all known cases of successful DBM control have been obtained only when the basic control component constitutes either parasites or chemical insecticides.

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Appendix 1. Cultural practices in relation to insecticide resistance of farmers in the Cameron Highlands. (These practices do not include the insecticidal usage which may vary from one locality to another, being largely governed by developments of insecticide resistance).

SEEDS: Treated with Captan<sup>R</sup> fungicide before sowing.

NURSERY: Total number of cabbage seedlings = 13,000 - 15,000.

Fertilizers = 1.36 kg (3 lbs) Triple Super Phosphate (TSP),  
and 4.08 kg (9 lbs) NPK (Nitrophoska Blue<sup>R</sup>).

Protection against Clubroot disease = Calome<sup>R</sup> at 4.5 gm/gall.  
or 0.1% solution.

TRANSPLANTED FIELDS: Size of raised bed = 0.91 m x 12.19 m (3 ft x 40 ft).

No. of plants/bed = 27 (including 2 guard row plants  
at the ends).

Planting distance = 0.46 m (1.5 ft) apart.

Liming of beds = 1.81 kg (4 lbs)/bed.

Fertilizers: In transplanting hole, 14.18 gm ( $\frac{1}{2}$  oz)  
ground magnesium limestone (GML),  
14.18 gm ( $\frac{1}{2}$  oz) TSP and 56.70 gm (2 oz)  
poultry manure. At 3 weeks after  
transplanting, each plant was further  
provided with inorganic (0.1-0.3 kg  
NPK blue) fertilizers or organic manure  
(1.5 kg, Malameal<sup>R</sup> + GML).

Appendix 2. Procedures for the rearing and maintenance of the DBM,  
Plutella xylostella (L.), and its parasites, Apanteles  
plutellae Kurdj. and Diadegma eucerothaga Horstn.

a) DIAMOND-BACK MOTH: In the mass breeding of the DBM, a series of 'larval developmental cages' (Plate 2.2) was used. The first in the series was designated for oviposition, wherein, as many as 15-25 pairs of adult P. xylostella of various ages were maintained with water and 17% honey solution. Everyday, a bunch of 5-6 fresh leaves of B. rapa was enclosed for 24 hrs within the cage for oviposition, following which, each bunch was removed to another cage to await larval emergence. Upon eclosions of the eggs, excess supply of leaves to the developing larvae was ensured through regular replenishment every 2 days. This was continued until pupation had occurred, whereupon all the pupae obtained from each cage were transferred to a 'host pupation jar' to await emergence of the adults. The rearing cycle was then repeated, beginning with some of the resultant adults obtained.

From the above rearing method, as many as 3,000 larvae may be readily obtained per cage with more than 18,000 larvae from each rearing series which may involve 7-9 batches of ovipositional exposure. Moreover,

laid eggs, the age for any brood of eggs, larvae, pupae and adults that were obtained can be approximately known.

b) A. PLUTELLAE: Like the DBM, a serial transfer technique was used for the rearing of A. plutellae. In this instant, a series of 'breeding jars' (Plate 1.1) was used instead, with the first being designated for oviposition. Daily, about 200 2nd-instar host larvae were exposed to 10 mated female parasites for 24 hrs. The parasitized larvae, following exposure, were then removed to another 'breeding jar' and reared to parasite cocooning on B. rapa leaves. Whatever parasite cocoons spun each day were collected and kept together in a 'parasite cocoon emergence jar', and whereupon any adults that emerged were again separated out daily. From some of these adults the rearing cycle was again repeated to obtain the subsequent parasite generation.

On average, this method of rearing would yield about 1,000 adult parasites (male:female ratio = 1.2) from each rearing series which would involve 6-8 sets of ovipositional exposure. Whenever more parasites were needed, parallel rearing series were run to increase the production accordingly.

c) D. EUCEROPHAGA: This was similarly carried out as for A. plutellae, except that only 6 mated females were enclosed in the 'ovipositional jar' instead. Under the conditions set up, about 700 adult parasites (male:female ratio = 1.6) may be obtained from each rearing series which would encompass 6-8 sets of ovipositional exposure.

Appendix 3 Insecticides evaluated against *Plutella xylostella* (L.) and its parasite, *Apanteles plutellae* Kurdj.

| Group            | Common Name <sup>1/</sup>                   | Chemical Name<br>(CAS nomenclature) <sup>2/</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     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| Organophosphates | cyanofenphos<br>(BSI; ISO)                  | O-(4-cyanophenyl) O-ethyl<br>phenyl phosphorothioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  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|                  | chlorfenvinphos<br>(BSI; ISO)               | 2-chloro-1-(2,4-dichloro-<br>phenyl)-vinyl diethyl phosphate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          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|                  | chlorpyrifos<br>(ANSI; BSI; ISO)            | O,O-diethyl O-(3,5,6-trichloro-<br>2-pyridinyl) phosphorothioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      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|                  | chlorpyrifos-<br>methyl<br>(BSI; ISO; ANSI) | O,O-dimethyl O-3,5,6-trichloro-<br>2-pyridyl phosphorothioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         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|                  | diazinon<br>(BSI; ESA; ISO)                 | O,O-diethyl O-(6-methyl-2-<br>(1-methylethyl)-4-pyrimidinyl)<br>phosphorothioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      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|                  | dichlorvos<br>(BSI; ISO; ESA)               | 2,2-dichloroethenyl dimethyl<br>phosphate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             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|                  | dicrotophos<br>(BSI; ISO)                   | 3-(dimethylamino)-1-methyl-3-<br>oxo-1-propenyl dimethyl<br>phosphate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 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|                  | disulfoteate<br>(BSI; ESA; ISO)             | O,O-dimethyl S-(2-(methylamino)-<br>2-oxoethyl)phosphorodithioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     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|                  | dimethyl vinphos*                           | 2-chloro-1-(2,4-dichlorophenyl)*<br>Rangado 50 WP vinyl dimethyl phos-<br>phate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       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|                  | fenitrothion<br>(BSI; ISO)                  | O,O-dimethyl O-(3-methyl-4-<br>(methylthio)phenyl)phosphorothioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    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|                  | isofenphos<br>(BSI; ISO)                    | 1-methylethyl 2-(2-ethoxy-(1-<br>methylethyl)-amino)phosphino-<br>thioyl/oxo/benzoate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 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|                  | malathion<br>(BSI; CSA; ESA; ISO)           | diethyl (dimethoxyphosphinothioyl)-<br>thio/ butanedioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             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|                  | methamidophos<br>(BSI; ISO)                 | O,S-dimethyl phosphoramid-<br>oathioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               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|                  | methidathion<br>(BSI; ISO)                  | S-(5-methoxy-2-oxo-1,3,4-<br>thiodiazol-3(2H)-yl)methyl<br>O,O-dimethyl phosphorodi-<br>thioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       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|                  | monocrotophos<br>(BSI; ISO)                 | (E)-dimethyl 1-methyl-3-<br>(methyl-amino)-3-oxo-1-<br>propenyl phosphate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             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|                  | phenothate<br>(BSI; ISO)                    | ethyl S-(dimethoxyphos-<br>phinothioyl)thio/benzenes-<br>catate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       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|                  | phosmet<br>(BSI; ESA; ISO)                  | S-(1,3-dihydro-1,3-dioxo-<br>2H-isindol-3-yl)methyl O,O-<br>dimethyl phosphorodithioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               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|                  | phosphamidon<br>(BSI; ISO)                  | 2-chloro-3-(dimethylamino)-<br>1-methyl-3-oxo-1-propenyl<br>dimethyl phosphate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        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|                  | profenophos<br>(BSI)                        | O-(4-bromo-2-chlorophenyl)<br>O-ethyl S-propyl<br>phosphorothioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    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|                  | quinalphos<br>(BSI; ISO)                    | O,O-diethyl O-2-quinazolinyl<br>phosphorothioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      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|                  | tetrachlorovin-<br>phos (BSI; ISO)          | 2-chloro-1-(2,4,5-trichloro-<br>phenyl) ethenyl dimethyl<br>phosphate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 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|                  | triasophos<br>(BSI; ISO)                    | O,O-diethyl O-(1-phenyl-4-<br>1,2,4-triazol-3-yl)<br>phosphorothioate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 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|                  | trichlorfon<br>(ISO)                        | dimethyl (2,2,2-trichloro-1-<br>hydroxyethyl)phosphonate                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              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| Organochlorines  | dieldrin<br>(BSI; ESA;<br>ISO)              | 1,1,1,2,2,2,3,3,3,4,4,4,5,5,5-<br>pentafluoro-2,2,4,4,6,6,6-<br>heptafluoro-1,1,2,2,3,3,4,4,5,5,5-<br>undecafluoro-7,7,8,8,9,9,10,10,10-<br>nonafluoro-1,2,3,4,5,6,7,8,9,10,11,12-<br>dodecafluoro-13,13,14,14,15,15,16,16,17,17,18,18,19,19,20,20,21,21,22,22,23,23,24,24,25,25,26,26,27,27,28,28,29,29,30,30,31,31,32,32,33,33,34,34,35,35,36,36,37,37,38,38,39,39,40,40,41,41,42,42,43,43,44,44,45,45,46,46,47,47,48,48,49,49,50,50,51,51,52,52,53,53,54,54,55,55,56,56,57,57,58,58,59,59,60,60,61,61,62,62,63,63,64,64,65,65,66,66,67,67,68,68,69,69,70,70,71,71,72,72,73,73,74,74,75,75,76,76,77,77,78,78,79,79,80,80,81,81,82,82,83,83,84,84,85,85,86,86,87,87,88,88,89,89,90,90,91,91,92,92,93,93,94,94,95,95,96,96,97,97,98,98,99,99,100,100,101,101,102,102,103,103,104,104,105,105,106,106,107,107,108,108,109,109,110,110,111,111,112,112,113,113,114,114,115,115,116,116,117,117,118,118,119,119,120,120,121,121,122,122,123,123,124,124,125,125,126,126,127,127,128,128,129,129,130,130,131,131,132,132,133,133,134,134,135,135,136,136,137,137,138,138,139,139,140,140,141,141,142,142,143,143,144,144,145,145,146,146,147,147,148,148,149,149,150,150,151,151,152,152,153,153,154,154,155,155,156,156,157,157,158,158,159,159,160,160,161,161,162,162,163,163,164,164,165,165,166,166,167,167,168,168,169,169,170,170,171,171,172,172,173,173,174,174,175,175,176,176,177,177,178,178,179,179,180,180,181,181,182,182,183,183,184,184,185,185,186,186,187,187,188,188,189,189,190,190,191,191,192,192,193,193,194,194,195,195,196,196,197,197,198,198,199,199,200,200,201,201,202,202,203,203,204,204,205,205,206,206,207,207,208,208,209,209,210,210,211,211,212,212,213,213,214,214,215,215,216,216,217,217,218,218,219,219,220,220,221,221,222,222,223,223,224,224,225,225,226,226,227,227,228,228,229,229,230,230,231,231,232,232,233,233,234,234,235,235,236,236,237,237,238,238,239,239,240,240,241,241,242,242,243,243,244,244,245,245,246,246,247,247,248,248,249,249,250,250,251,251,252,252,253,253,254,254,255,255,256,256,257,257,258,258,259,259,260,260,261,261,262,262,263,263,264,264,265,265,266,266,267,267,268,268,269,269,270,270,271,271,272,272,273,273,274,274,275,275,276,276,277,277,278,278,279,279,280,280,281,281,282,282,283,283,284,284,285,285,286,286,287,287,288,288,289,289,290,290,291,291,292,292,293,293,294,294,295,295,296,296,297,297,298,298,299,299,300,300,301,301,302,302,303,303,304,304,305,305,306,306,307,307,308,308,309,309,310,310,311,311,312,312,313,313,314,314,315,315,316,316,317,317,318,318,319,319,320,320,321,321,322,322,323,323,324,324,325,325,326,326,327,327,328,328,329,329,330,330,331,331,332,332,333,333,334,334,335,335,336,336,337,337,338,338,339,339,340,340,341,341,342,342,343,343,344,344,345,345,346,346,347,347,348,348,349,349,350,350,351,351,352,352,353,353,354,354,355,355,356,356,357,357,358,358,359,359,360,360,361,361,362,362,363,363,364,364,365,365,366,366,367,367,368,368,369,369,370,370,371,371,372,372,373,373,374,374,375,375,376,376,377,377,378,378,379,379,380,380,381,381,382,382,383,383,384,384,385,385,386,386,387,387,388,388,389,389,390,390,391,391,392,392,393,393,394,394,395,395,396,396,397,397,398,398,399,399,400,400,401,401,402,402,403,403,404,404,405,405,406,406,407,407,408,408,409,409,410,410,411,411,412,412,413,413,414,414,415,415,416,416,417,417,418,418,419,419,420,420,421,421,422,422,423,423,424,424,425,425,426,426,427,427,428,428,429,429,430,430,431,431,432,432,433,433,434,434,435,435,436,436,437,437,438,438,439,439,440,440,441,441,442,442,443,443,444,444,445,445,446,446,447,447,448,448,449,449,450,450,451,451,452,452,453,453,454,454,455,455,456,456,457,457,458,458,459,459,460,460,461,461,462,462,463,463,464,464,465,465,466,466,467,467,468,468,469,469,470,470,471,471,472,472,473,473,474,474,475,475,476,476,477,477,478,478,479,479,480,480,481,481,482,482,483,483,484,484,485,485,486,486,487,487,488,488,489,489,490,490,491,491,492,492,493,493,494,494,495,495,496,496,497,497,498,498,499,499,500,500,501,501,502,502,503,503,504,504,505,505,506,506,507,507,508,508,509,509,510,510,511,511,512,512,513,513,514,514,515,515,516,516,517,517,518,518,519,519,520,520,521,521,522,522,523,523,524,524,525,525,526,526,527,527,528,528,529,529,530,530,531,531,532,532,533,533,534,534,535,535,536,536,537,537,538,538,539,539,540,540,541,541,542,542,543,543,544,544,545,545,546,546,547,547,548,548,549,549,550,550,551,551,552,552,553,553,554,554,555,555,556,556,557,557,558,558,559,559,560,560,561,561,562,562,563,563,564,564,565,565,566,566,567,567,568,568,569,569,570,570,571,571,572,572,573,573,574,574,575,575,576,576,577,577,578,578,579,579,580,580,581,581,582,582,583,583,584,584,585,585,586,586,587,587,588,588,589,589,590,590,591,591,592,592,593,593,594,594,595,595,596,596,597,597,598,598,599,599,600,600,601,601,602,602,603,603,604,604,605,605,606,606,607,607,608,608,609,609,610,610,611,611,612,612,613,613,614,614,615,615,616,616,617,617,618,618,619,619,620,620,621,621,622,622,623,623,624,624,625,625,626,626,627,627,628,628,629,629,630,630,631,631,632,632,633,633,634,634,635,635,636,636,637,637,638,638,639,639,640,640,641,641,642,642,643,643,644,644,645,645,646,646,647,647,648,648,649,649,650,650,651,651,652,652,653,653,654,654,655,655,656,656,657,657,658,658,659,659,660,660,661,661,662,662,663,663,664,664,665,665,666,666,667,667,668,668,669,669,670,670,671,671,672,672,673,673,674,674,675,675,676,676,677,677,678,678,679,679,680,680,681,681,682,682,683,683,684,684,685,685,686,686,687,687,688,688,689,689,690,690,691,691,692,692,693,693,694,694,695,695,696,696,697,697,698,698,699,699,700,700,701,701,702,702,703,703,704,704,705,705,706,706,707,707,708,708,709,709,710,710,711,711,712,712,713,713,714,714,715,715,716,716,717,717,718,718,719,719,720,720,721,721,722,722,723,723,724,724,725,725,726,726,727,727,728,728,729,729,730,730,731,731,732,732,733,733,734,734,735,735,736,736,737,737,738,738,739,739,740,740,741,741,742,742,743,743,744,744,745,745,746,746,747,747,748,748,749,749,750,750,751,751,752,752,753,753,754,754,755,755,756,756,757,757,758,758,759,759,760,760,761,761,762,762,763,763,764,764,765,765,766,766,767,767,768,768,769,769,770,770,771,771,772,772,773,773,774,774,775,775,776,776,777,777,778,778,779,779,780,780,781,781,782,782,783,783,784,784,785,785,786,786,787,787,788,788,789,789,790,790,791,791,792,792,793,793,794,794,795,795,796,796,797,797,798,798,799,799,800,800,801,801,802,802,803,803,804,804,805,805,806,806,807,807,808,808,809,809,810,810,811,811,812,812,813,813,814,814,815,815,816,816,817,817,818,818,819,819,820,820,821,821,822,822,823,823,824,824,825,825,826,826,827,827,828,828,829,829,830,830,831,831,832,832,833,833,834,834,835,835,836,836,837,837,838,838,839,839,840,840,841,841,842,842,843,843,844,844,845,845,846,846,847,847,848,848,849,849,850,850,851,851,852,852,853,853,854,854,855,855,856,856,857,857,858,858,859,859,860,860,861,861,862,862,863,863,864,864,865,865,866,866,867,867,868,868,869,869,870,870,871,871,872,872,873,873,874,874,875,875,876,876,877,877,878,878,879,879,880,880,881,881,882,882,883,883,884,884,885,885,886,886,887,887,888,888,889,889,890,890,891,891,892,892,893,893,894,894,895,895,896,896,897,897,898,898,899,899,900,900,901,901,902,902,903,903,904,904,905,905,906,906,907,907,908,908,909,909,910,910,911,911,912,912,913,913,914,914,915,915,916,916,917,917,918,918,919,919,920,920,921,921,922,922,923,923,924,924,925,925,926,926,927,927,928,928,929,929,930,930,931,931,932,932,933,933,934,934,935,935,936,936,937,937,938,938,939,939,940,940,941,941,942,942,943,943,944,944,945,945,946,946,947,947,948,948,949,949,950,950,951,951,952,952,953,953,954,954,955,955,956,956,957,957,958,958,959,959,960,960,961,961,962,962,963,963,964,964,965,965,966,966,967,967,968,968,969,969,970,970,971,971,972,972,973,973,974,974,975,975,976,976,977,977,978,978,979,979,980,980,981,981,982,982,983,983,984,984,985,985,986,986,987,987,988,988,989,989,990,990,991,991,992,992,993,993,994,994,995,995,996,996,997,997,998,998,999,999,1000,1000,1001,1001,1002,1002,1003,1003,1004,1004,1005,1005,1006,1006,1007,1007,1008,1008,1009,1009,1010,1010,1011,1011,1012,1012,1013,1013,1014,1014,1015,1015,1016,1016,1017,1017,1018,1018,1019,1019,1020,1020,1021,1021,1022,1022,1023,1023,1024,1024,1025,1025,1026,1026,1027,1027,1028,1028,1029,1029,1030,1030,1031,1031,1032,1032,1033,1033,1034,1034,1035,1035,1036,1036,1037,1037,1038,1038,1039,1039,1040,1040,1041,1041,1042,1042,1043,1043,1044,1044,1045,1045,1046,1046,1047,1047,1048,1048,1049,1049,1050,1050,1051,1051,1052,1052,1053,1053,1054,1054,1055,1055,1056,1056,1057,1057,1058,1058,1059,1059,1060,1060,1061,1061,1062,1062,1063,1063,1064,1064,1065,1065,1066,1066,1067,1067,1068,1068,1069,1069,1070,1070,1071,1071,1072,1072,1073,1073,1074,1074,1075,1075,1076,1076,1077,1077,1078,1078,1079,1079,1 |                                           |                                                               |                                                             |

Appendix 3 (Continued 1).

| Group              | Common Name <sup>1/</sup>         | Chemical Name<br>(CAS nomenclature) <sup>2/</sup>                                    | Trade Name &<br>Formulation <sup>3/</sup>        | Stage of <i>P.</i><br><i>xylostella</i> tested <sup>4/</sup> | Stage of <i>A.</i><br><i>plutellae</i> tested <sup>5/</sup> |
|--------------------|-----------------------------------|--------------------------------------------------------------------------------------|--------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------|
| Carbamates         | aminocarb<br>(BSI; ISO)           | 4-(dimethylamino)-3-methyl-phenyl methylcarbamate                                    | Metacil 75% WP                                   | E                                                            |                                                             |
|                    | BPMC<br>(JNAF)                    | 2-(1-methylpropyl)phenyl methylcarbamate                                             | Baycarb 50EC                                     | E                                                            |                                                             |
|                    | carbaryl<br>(BSI; ISO)            | 1-naphthalenyl methylcarbamate                                                       | Savin 85 WP<br>Sevinol-3 EC                      | E                                                            | L P C                                                       |
|                    | cartap<br>(BSI; ISO)              | S,S'-1,2-bis-(dimethylamino)-1,3-propanediyl dicarbomethioate                        | Pedan 50% SP                                     | E                                                            | L P C                                                       |
|                    | methiocarb                        | 3,5-dimethyl-4-(methylthio)-phenyl methylcarbamate                                   | Meural 50WP                                      | E                                                            | L F C                                                       |
|                    | methomyl<br>(BSI; CSA; EZA; KAFJ) | methyl N-[[methylamino]carbonyl]oxyethanimidothioate                                 | Lannate SP                                       | E                                                            | L P C                                                       |
|                    | pirimicarb<br>(BSI; ISO)          | 2-(dimethylamino)-5,6-dimethyl-4-pyrimidinyl dimethylcarbamate                       | Pirimor EC                                       |                                                              | L                                                           |
| Pyrethroids        | decamethrin*                      | (S)-α-cyano-α-phenoxymethyl-2,2-dimethyl-3-(2,2-dimethyl-3-cyclopropene carboxylate) | Decis 2.5 EC                                     | E                                                            | L P C                                                       |
|                    | fenvalerate*                      | α-cyano-β-phenoxymethyl α-isopropyl-4'-chlorophenylacetate                           | Sumicidin 30aC                                   | E                                                            | L P C                                                       |
|                    | permethrin<br>(BSI; ISC)          | (3-phenoxymethylmethyl-3-(2,2-dichloroethyl)-2,2-dimethyl-cyclopropene-carboxylate   | Neabush 10% EC                                   | E                                                            | L P C                                                       |
|                    | resmethrin<br>(BSI; ISO)          | dimethyl-3-(2-methyl-1-propenyl)-cyclopropanecarboxylate                             | Bioresmethrin 5 EC                               | E                                                            | L C                                                         |
|                    |                                   |                                                                                      | Sayuron 20 EC                                    |                                                              | F                                                           |
| Biological agents  | Bacillus thuringiensis            | -                                                                                    | Dipel BT WP<br>Bactospeine 500<br>TUK/mg         |                                                              | L P C                                                       |
|                    | Granulosis virus                  | -                                                                                    |                                                  | E                                                            | L P C                                                       |
| Growth<br>regulant | diflubenzuron*                    | N-[[4-(4-chlorophenyl)amino]-carbonyl]-2,6-difluorobenzamide                         | Dimilin 25 WP                                    | E                                                            | L P C                                                       |
| Mixtures           | carbaryl<br>(BSI; ISO)            | 1-naphthalenyl methylcarbamate                                                       | Sevithion 50EC                                   | E                                                            | L P C                                                       |
|                    | malathion<br>(BSI; CSA; EZA; ISO) | diethyl [(dimethoxyphosphinothioyl)-thio]butanedioate                                |                                                  |                                                              |                                                             |
|                    | dichlorvos<br>(BSI; ISO)          | 2,2-dichloroethyl dimethyl phosphate                                                 | Elsan Forte 50%EC                                | E                                                            | L P C                                                       |
|                    | phenothoate<br>(BSI; ISO)         | ethyl α-[(dimethoxyphosphinothioyl)-thio]benzenecarboxylate                          |                                                  |                                                              |                                                             |
|                    | carbaryl<br>(BSI; ISO)            | 1-naphthalenyl methylcarbamate                                                       | Davidol (616) WP                                 | E                                                            |                                                             |
| Organo-tins        | lindane<br>(ESA)                  | (1α,2α,3β,4α,5α,1β)-1,2,3,4,5,6 hexachlorocyclohexane                                |                                                  |                                                              |                                                             |
|                    | cyhexatin<br>(BSI; ISO)           | tricyclohexylhydroxystannate                                                         | Plictran WP                                      |                                                              | L                                                           |
| Formamidines       | amitraz<br>(BSI; ISO)             | N'-[(2,4-dimethylphenyl)-N-[(2,4-dimethylphenyl)imino]-methyl]-N-methylmethanimide   | Amitraz 20 EC                                    | E                                                            | L P C                                                       |
|                    | chlordimeform<br>(BSI; ISO)       | N'-(4-chloro-2-methylphenyl)-N',N'-dimethylmethanimidamide                           | Galecron 50EC<br>Prethylene 35EC<br>Spanone 50EC | E                                                            | C                                                           |

<sup>1/</sup> BSI = British Standards Institution; ANSI = American National Standards Institute; CSA = Canadian Standards Association; ESA = Entomological Society of America; EZA = Japanese Society of Applied Entomology and Zoology; ISO = International Standards Organisation; JNAF = Ministry of Agriculture & Forestry, Japan. <sup>2/</sup> From: (i) Wauveker, W.J. 1976. *Pesticide Index*. (Fifth Edition). Entomological Society of America, College Park, Maryland, (ii) Martin, H. & Worthing, C.R. 1977. *Pesticide Manual* (Fifth Edition). British Crop Protection Council, England. <sup>3/</sup> CAS = Chemical Abstracts Service. <sup>4/</sup> From: (i) Wauveker, W.J. 1976, (ii) Martin, H. & Worthing, C.R. 1977. <sup>5/</sup> EC = Emulsifiable concentrate; SCV = Soluble concentrate in water (= Aqueous concentrate); SP = Soluble powder, WP = Wettable powder. <sup>6/</sup> E = Egg; L = Larva; P = pupa. <sup>7/</sup> C = Cocoons of *A. pluteella*, and \* = From manufacturers' technical bulletins.

Appendix 4 Field performance, potentials and suggested manner of exploiting the parasites of the Diamond-Back Moth, Plutella  
xylostella (L.).

| Parasite species                             | Field parasitism                                                                                                                                                                                                                                                                                                                                     | Limitations/Advantages                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Potential / suggested manner of employment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|----------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>EGG PARASITES:</b>                        |                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <u>Trichogramma brassicae</u> (Asha.)        | Negligible in Lesser Antilles (St. Kitts & St. Lucia) (Yaseen, 1978).                                                                                                                                                                                                                                                                                | In general, still very little is known on the egg parasites of DBM.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | To date, only a few egg parasite species of DBM are recorded and their field performance noted to be generally poor (Oatman & Platner, 1969; Bennett & Yaseen, 1972; Yaseen, 1974, 1978).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <u>Trichogramma minutum</u> Riley            | In Queensland (Australia), it was recorded to parasitize eggs of DBM only in the laboratory (Wilson, 1960; Yarrow, 1970).                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | In view of their inability to exert full control over the host, attempt to utilize them as a sole controlling agent should never be encouraged. However, they may be exploited only to the extent of effecting some host reduction which may be important in increasing the overall host mortality when cumulated over the different developmental stages. In general, the egg parasites cannot be expected to provide satisfactory contribution to DBM suppression.                                                                                                                                                                                                                                                                                        |
| <u>Trichogramma pretiosum</u> Riley          | 3% during 1964 in Southern California, USA (Oatman & Platner, 1969).                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | In the case of <u>T. minutum</u> & <u>T. pretiosum</u> evaluation of their field performance should however be further considered.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| <u>Trichogramma</u> sp.                      | Negligible in Lesser Antilles (St. Kitts & St. Lucia) (Bennett & Yaseen, 1972; Yaseen, 1974). The species is probably <u>T. brassicae</u> .                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <u>Trichogrammatoides arviragra</u> Nagaraja | In India this species was found capable of parasitizing DBM under laboratory conditions (Manjunath, 1972):                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <b>LARVAL PARASITES:</b>                     |                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
| <u>Antrocephalus</u> sp.                     | Rare in Victoria, Australia.                                                                                                                                                                                                                                                                                                                         | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Of minor importance (Goodwin, 1979).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <u>Apanteles aciculatus</u> (Asha.)          | Negligible in Lesser Antilles.                                                                                                                                                                                                                                                                                                                       | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | " " " (Yaseen, 1978).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| <u>Apanteles albipennis</u> Nees             | Rare in Moscow Region, USSR.                                                                                                                                                                                                                                                                                                                         | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | " " " (Kopwille, 1959, 1960).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| <u>Apanteles fuliginosus</u> Wata.           | Rare in Moscow Region, USSR.                                                                                                                                                                                                                                                                                                                         | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | " " " "                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <u>Apanteles halfordii</u> Ulyett            | Comparatively small numbers but occurring throughout the year in Pretoria, S. Africa.                                                                                                                                                                                                                                                                | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Of some importance but never assumes a major place in the parasite complex (Ulyett, 1974). Unsuitable as a sole biological control agent and to be encouraged only as a supplementing component.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| <u>Apanteles</u> <u>ipsum</u> Nixon          | 10% during 1971-74 in Hawkesbury Valley, Aust. (Hamilton, 1978b). Negligible in S.E. Queensland, Aust. (Yarrow, 1970).                                                                                                                                                                                                                               | Unable to exert full control in unusually warm & dry conditions during late Spring & Autumn (Hamilton, 1978b).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | It constitutes one of the major species alongside <u>Diadegma eucrotophaga</u> & <u>Thyreoxenus collaris</u> which together effected an average of 73% parasitism (Hamilton, 1978b). However, it is unsuitable as a sole biological control agent & is to be encouraged only as a supplementing component.                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| <u>Apanteles laevigatus</u> group.           | 2.3% together with other <u>Apanteles</u> spp. during 1972-74 in Victoria, Aust.                                                                                                                                                                                                                                                                     | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Of some benefit only very occasionally when it rises in numbers (Goodwin, 1979). Generally unimportant & cannot be exploited as a sole controlling agent.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <u>Apanteles lisibatus</u> Marsh             | Rare in Moscow Region, USSR.                                                                                                                                                                                                                                                                                                                         | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Of insignificant importance (Kopwille, 1959, 1960).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
| <u>Apanteles plutealis</u> Kurdj.            | 6.9% in Lutjebrook, Holland (Lloyd, 1940). 10.8-18.3% in Verrellia District, Tuscany (Delucchi et al., 1974). Negligible in many parts of Australia (Wilson, 1960). Total parasitism of 58.8% along with <u>D. eucrotophaga</u> & <u>Diadegma neocrotophaga</u> in Silwood Park, UK (Sallinas, 1972). Negligible in Lesser Antilles (Antigua, 1978). | Distribution widespread. Mean rate of parasitism is inversely related to higher host density (approx. > 6 larvae/plant) (Present studies). Its maximum mean superparasitism rarely exceeds 50%, largely checked by self-limiting characteristics, such as, relatively lower searching efficiency & poor discriminating ability that results in superparasitism. Can co-exist with <u>D. eucrotophaga</u> though itself may be checked substantially. Ulyett (1943, 1947) has pointed out that the occurrence of <u>Diadegma</u> & <u>Apanteles</u> is negatively correlated with the latter increasing only if <u>Diadegma</u> declines, although | Though self-limited, role played is of significance (Present studies) & is generally considered to be of moderate importance (Lloyd, 1940; Delucchi et al., 1974; Chin, 1974; Kumar, 1974; Jila & Ko, 1975; Ooi & Kelderman, 1977; Yaseen, 1978; Ooi & Suddaruddin, 1978; Present studies). Among the different <u>Apanteles</u> spp. present, <u>A. plutealis</u> usually predominates. However, unable to exert full control by itself (Kumar, 1974; Jila & Ko, 1975; Ooi & Suddaruddin, 1978; Yaseen, 1978; Ooi, 1979a; Present studies). Thus, utilizing it as a sole controlling agent should not be encouraged. Instead, should strive for 45-50% parasitism only; further control to be supplemented by others (biological agents, chemicals, etc.). |

## Appendix 4 (Continued 1).

| Parasite species/                | Field parasitism                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Limitations/Advantages <sup>2/</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Potential & suggested manner of employment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                  | <p>Barbados, Dominica, Montserrat, Nevis &amp; St. Lucia (Bennett &amp; Yasen, 1972; Yasen, 1974, 1978). 27% in Taiwan (Chin, 1974). 40-60% during 1972 in Barbados (Kumar, 1974). 35.8% during 1973 in the Cameron Highlands, Malaysia (Lia &amp; Ko, 1975). 36.3%, 48.6%, 34.0%, 18.1%, 30.1%, 21.2% during 1973-74 in Kampong Raja, Kuala Terla, Tringkap, Nensum Valley, Barta Valley &amp; Kampong Tamas Sedia respectively in the Cameron Highlands, Malaysia (Present studies). 35.3% during 1976 in the Cameron Highlands, Malaysia (Goi &amp; Kaldersan, 1977). Increasing from 5.1% (July 1976) to 55.9% (June 1977), &amp; from 3.6% to 26.6% during 1977 in Aranguez, Trinidad (Yasen, 1978). 23.1%, 44.3%, 29.2%, 42.4%, 52.9% &amp; 36.0% during 1978 in Kampong Raja, Kuala Terla, Tringkap, Kea Para/Greenoov, Nensum Valley &amp; Ringlet respectively in the Cameron Highlands, Malaysia (Goi &amp; Sunderuddin, 1978). 19.0%, 20.9%, 39.3%, 42.4% &amp; 31.9% during 1979 in Kampong Raja, Kuala Terla, Brinchang Town, 7th mile Brinchang &amp; 45th mile Brinchang respectively in the Cameron Highlands, Malaysia (Present studies).</p> | <p>occasionally <i>Apanteles</i> can increase without the usual decrease of <i>Diadegma</i> when <i>Tetrastichus</i> spp. are also notably present. In any case, the overall parasitism attained is normally much higher than when either anyone of them occurring alone (Lloyd, 1940; Present studies). It is generally the next important larval parasite to <i>Diadegma</i> spp. (Delucchi et al, 1954) &amp; could rapidly increase in numbers to supplement the activity of <i>P. superophaga</i> when the latter declines (Lloyd, 1940; Ulyett, 1943, 1947). Often occurs commonly among <i>P. superophaga</i> &amp; <i>T. gollaryi</i> to provide substantial &amp; significant DBM control. Although <i>A. plutellae</i> can tolerate rather wide range of climatic conditions, temperatures between 18-28°C are noted to particularly favour its activity (Chin, 1974; Present studies). Contributions, however, may be partially offset by hyperparasites, many species of which have been recorded (Delucchi et al, 1954; Yasen, 1978; Goi, 1979a; Present studies).</p> | <p>For supplementation by biological agents, priority consideration should be given to <i>P. superophaga</i> as they can co-exist as well as their activities are often complementary (Lloyd, 1940; Present studies). However, in view of the negative correlation relationship between <i>Diadegma</i> &amp; <i>Apanteles</i> with the former constituting the main determining component (Ulyett, 1943, 1947), priority consideration should be given to <i>P. superophaga</i> over <i>A. plutellae</i> when they occur together. That this should be so is also clearly evident from the fact that unlike <i>A. plutellae</i> (Kumar, 1974; Lia &amp; Ko, 1975; Goi &amp; Sunderuddin, 1978; Yasen, 1978; Goi, 1979a; Present studies), <i>P. superophaga</i> can possibly exert full biological control by itself (Hardy, 1938; Ulyett, 1947; Yee, 1953). In cases where other parasites are already providing substantial but inadequate control, <i>A. plutellae</i> could be introduced to help further supplement their activities. This could prove critical as it is often noted to be responsible for a substantial portion of the overall parasitism (Delucchi et al, 1954; Wilson, 1960). In Australia, such combined &amp; heavy overall parasitism had led to marked reduction in abundance of DBM following the parasite introductions (Wilson, 1960). As a consequence, in recent years cabbages &amp; cauliflowers in S. Australia can be grown without insecticides while only very restricted use of chemicals are needed in some other areas (Wilson, 1960). Since <i>A. plutellae</i> is less efficient at temperatures outside the range of 18-28°C (Chin, 1974; Present studies), utilization of this parasite in areas with such conditions should not be given major emphasis. In particular, it is unlikely to appear favourable in the temperate regions &amp; the hot tropical lowlands. This should be recognised since general climatic limits are usually pervasive &amp; override many other subsidiary influences (e.g. food sources, etc.) within a locality. On the other hand, in areas within the limits of these favourable temperatures special consideration should be given to exploit fully the potential contribution of this species. Of some importance but never assumes a major place in the parasite complex (Ulyett, 1947). Unsuitable as a sole biological control agent &amp; to be encouraged only as a supplementing component. As suggested by Hardy (1938), its potential should be explored in the Tropics where its parasitic activity may rise much higher with the continuous availability of DBM. Of minor importance (Kopville, 1959, 1960).</p> |
| <i>Apanteles ruficornis</i> Hal. | Comparatively small numbers but occurring throughout the year in Pretoria, S. Africa.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <i>Apanteles siogarii</i> Marsh  | 0.6% in N & S England (Hardy, 1938).                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Highly specific with no alternative hosts (Hardy, 1938). Because of this feature, Hardy (1938) considered it to have good potential in areas with continuous availability of hosts.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| <i>Apanteles vestalis</i> Hal.   | Rare in Moscow Region, USSR.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |

Appendix 4 (Continued 2).

| Parasite species <sup>1</sup>           | Field parasitism                                                                                                                                                                                                                 | Limitation/Advantages <sup>2</sup> | Potential & suggested manner of employment                                                                                 |
|-----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|----------------------------------------------------------------------------------------------------------------------------|
| <u>Apanteles</u> sp. (ster group)       | Negligible in Lesser Antilles (Leeward & Windward Islands) (Yaseen, 1974).                                                                                                                                                       | NA                                 | Of minor importance (Yaseen, 1974).                                                                                        |
| <u>Apanteles</u> sp. (glomeratus group) | Negligible in Lesser Antilles (Yaseen, 1978).                                                                                                                                                                                    | NA                                 | " " " (Yaseen, 1978)                                                                                                       |
| <u>Apanteles</u> sp.                    | Negligible numbers which eventually disappeared within few months of <u>Diadegma eucrotophaga</u> introduction into Patjet area, Indonesia (Vos, 1953).                                                                          | NA                                 | " " " (Vos, 1953).                                                                                                         |
| <u>Apanteles</u> spp.                   | Total parasitism effected together with <u>Diadegma</u> spp. (predominantly <u>Diadegma fenestralis</u> ) & <u>Diadegma subtilicornis</u> - 16.2-97.2% (1960-65) & 66.4-78.1% (1961-65) in S. Ukraine, USSR (Adashkevich, 1966). | NA                                 | Only of moderate importance as most of the parasitism activity is caused by <u>Diadegma</u> spp. (Adashkevich 1966).       |
| <u>Apanteles</u> spp.                   | Negligible in all the areas of Lesser Antilles (Bennett & Yaseen, 1972; Yaseen, 1974).                                                                                                                                           | NA                                 | Of minor importance (Bennett & Yaseen, 1972; Yaseen, 1974).                                                                |
| <u>Apanteles</u> spp.                   | Invariably uncommon (0.08%) in Trinidad (Bennett & Yaseen, 1972; Yaseen, 1974).                                                                                                                                                  | NA                                 | " " "                                                                                                                      |
| <u>Brachymeria rhyta</u> (Walk.)        | Negligible in Australia (Hawkesbury Valley & S.E. Queensland) (Yarrow, 1970; Hamilton, 1978a).                                                                                                                                   | NA                                 | Of minor importance (Yarrow, 1970; Hamilton, 1978a).                                                                       |
| <u>Brachymeria eidsiae</u> Hlg.         |                                                                                                                                                                                                                                  | NA                                 | " " "                                                                                                                      |
| <u>Brachymeria</u> spp.                 | Rare in Victoria, Australia (Goodwin, 1979).                                                                                                                                                                                     | NA                                 | Of minor importance (Goodwin, 1979).                                                                                       |
| <u>Campoplex</u> sp.                    | Rare in Merivale, Canada (Harcourt, 1960).                                                                                                                                                                                       | NA                                 | Of minor importance (Harcourt, 1960).                                                                                      |
| Chalcid sp.                             | Rare in Hawkesbury Valley, Australia (Hamilton, 1978a).                                                                                                                                                                          | NA                                 | Of minor importance (Hamilton, 1978a).                                                                                     |
| <u>Chelonus ritchiei</u> Wilcox.        | Only occasionally found in Pretoria, S. Africa (Ulyett, 1947).                                                                                                                                                                   | NA                                 | Of minor importance (Ulyett, 1947).                                                                                        |
| <u>Diadegma areolata</u> Grew.          | Together with <u>D. fenestralis</u> effected 88% parasitism in the Moscow Region, USSR (Kopvillem, 1959, 1960). Of the two species, <u>D. fenestralis</u> was dominant.                                                          | NA                                 | Only of moderate importance as most of the parasitism activity is caused by <u>D. fenestralis</u> (Kopvillem, 1959, 1960). |

Diadegma eucrotophaga Morata. Largely together with P. fenestralis effected 80% & more than 90% respectively in the Isle of Thanet & N. ss. England, UK during 1935 (Hardy, 1938). Effected 74.6% together with P. fenestralis in Lut.-brook, Holland (Lloyd, 1940). Of the two species, P. eucrotophaga was more common.

Distribution widespread & normally occurring in high abundance when present (Hardy, 1978; Robertson, 1948; Vos, 1953; Delucchi et al. 1954). It usually dominates in a parasite complex, being highly competitive against others while able to co-exist with them (Lloyd, 1940; Present studies). Being active for most parts of the year as well as capable of attacking all larval stages quite efficiently P. superparasitica is thus able to effect high host mortality. This is also enhanced by its relatively good searching efficiency & the ability to seek out unparasitized hosts (Lloyd, 1940; Ooi, 1980; Present studies), especially at higher host density (Goodwin, 1979).

That Diadegma spp. are commonly associated with DBM in many parts of the world has suggested that the Plutella-Diadegma complex is of prime importance to the Diadegma parasites (Hardy, 1938). This appears so since in no other host-parasite complex are they able to raise their populations to such high level. In the case of P. sucroborana the parasite was considered (Voe, 1953) to be highly 'specialised' on P. xylosteella on which it is able to reach very high population level in spite of the presence of many other alternative hosts (Hardy, 1938; Voe, 1953). Besides even though numerous hyperparasites

In view of the numerous advantageous features found associated with *D. sucrotophaga*, the parasite is generally considered to be potentially a highly effective parasite of BEM, and under actual field conditions has been widely found to contribute substantially towards its suppression (Hardy, 1936; Lloyd, 1940; Robertson, 1948; Vos, 1953; Delucchi et al., 1954; Todd, 1959; Wilson, 1960; Venkatraman, 1964; Yarrow, 1970; Salinas, 1972; van den Oever, 1973; Hamilton, 1978b; Goodwin 1979). On some occasions, it predominates among several other parasite species to exert complete biological control (Hardy, 1936; Ulliyett, 1947; Wilson, 1960). By itself alone, it is also capable of achieving full control (Vos, 1955). As such, unlike most other parasites of *P. xylostella* it may be utilised as a sole controlling agent, particularly in areas with equable climatic condition (e.g. Tropics), and wherein its ability to attack all larval stages of the host can be maximally exploited in relation to the continuous presence & overlapping generations of the host. Particularly in the absence of other adverse features (e.g. hyperparasites, extensive insecticide applications, etc.), such conditions may possibly account for the attainment of

Appendix 4 (Continued 3).

| Parasite species <sup>1/</sup>       | Field parasitism                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | Limitations/Advantages <sup>2/</sup>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Potential & suggested manner of employment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
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|                                      | <p>Responsible for a major portion of the overall heavy parasitism by several parasite species in many parts of Australia (Wilson, 1960).</p> <p>Mean parasitism rising from 9 % during Nov. 1952 to almost 90% during March 1953 in Goulburn, Australia (Venkatesan, 1964).</p> <p>Mean parasitism 29% during 1966-67 in S.E. Queensland, Australia. In 1967, parasitism is consistently above 50% (Tarrow, 1970).</p> <p>Attaining parasitism of up to 73% in West Java, Indonesia (van den Oever, 1973).</p> <p>64% during 1971-74 in Hawkesbury Valley, Australia (Hamilton, 1978b).</p> <p>Total parasitism of 58.8% with <i>D. eucerothra</i> as an important component in Silwood Park, UK (Salinas, 1972).</p> <p>17.4%, 49.8%, 30.8% &amp; 39.9% respectively during 1972-73, 1973, 1973-74 &amp; 1974 in Victoria, Australia (Goodwin, 1979).</p> | <p>Are recorded, these are observed to have no significant adverse effect on it (Hardy, 1938; Robertson, 1948; Vos, 1953; Delucchi et al., 1954; Todd, 1959; Yarrow, 1970; Goodwin, 1979).</p> <p>Another advantageous feature of <i>D. eucerothra</i> is that its population development is generally well-synchronized with that of the host (Goodwin, 1979). Moreover, it is also better able to avoid multiple parasitism than other species within the parasite complex, such as, <i>A. pluteus</i> &amp; <i>T. collaris</i> (Lloyd, 1940), &amp; <i>Diadegma rufi</i> (Venkatesan, 1964).</p> <p>Among the limitations is the slight lag in population development in relation to that of the host during winter in Australia (Goodwin, 1979). Also, during unusually warm &amp; dry conditions in late Spring &amp; Autumn, it is unable to exert full host control (Hamilton, 1978b). Under such situations where extreme high host density may occur, aids from other parasite species (esp. <i>T. collaris</i>) Wilson, 1960; Tarrow, 1970; Salinas, 1972; Hamilton, 1978b; Goodwin, 1979) &amp; the microbial agent <i>Entomophthora sphaceliperma</i> are considered desirable (Todd, 1959).</p> | <p>Full biological control within 2 years of its introduction in Indonesia (Vos, 1953).</p> <p>Based largely upon its general good performance over a wide area as well as the highly desirable feature of a closely-knit <i>Plutella-Diadegma</i> complex pointed out by Hardy (1938), <i>D. eucerothra</i> (and/or other <i>Diadegma</i> spp., particularly <i>D. fenestralis</i>) should be given serious consideration for introduction into areas where other existing parasites are not providing adequate control. Some such localities would include the Carribeana, East and Southeast Asia where the present dominant parasite species in existence consists largely of <i>Apanteles</i> spp. which, by themselves, will not be able to exert full control. Further supplement by <i>D. eucerothra</i> would clearly be desirable as parasite complex involving these species together with <i>T. collaris</i> have provided quite satisfactory control in many instances (Hardy, 1938; Robertson, 1948; Delucchi et al., 1954; Todd, 1959; Wilson, 1960; Tarrow, 1970; Salinas, 1972; Hamilton, 1978b; Goodwin, 1979).</p> <p>Such situations also clearly demonstrate that having a greater number of appropriate parasite species would tend to have added advantage. In Australia, such combined heavy parasitism following introductions has led to marked reduction in host abundance; for many areas in the south, cabbages &amp; cauliflowers can now be cultivated without any insecticides against <i>P. rhyssalis</i> while in some localities the chemicals used are very restricted (Wilson, 1960).</p> <p>Although full biological control can normally be achieved, it should be realized that the control may sometimes only be partial under extreme climatic conditions, especially during unusually warm &amp; dry conditions (Hamilton, 1978b; Goodwin, 1979). Under such situations the supplemental control measures employed should avoid increasing further any hazards to the parasite complex. Use of appropriate chemical insecticides selectively or microbial agents such as <i>B.t.</i> or <i>S. sphaceliperma</i> would thus appear preferable so as to encourage restoration to full biological control as soon as possible.</p> <p>In maintaining &amp; conserving whatever biological control that may exist, the provision of adult food sources &amp; shelters by way of appropriate flowering plants in the immediate vicinity of the crop is also to be encouraged.</p> |
| <i>Diadegma fenestralis</i> Holmgrén | <p>Largely together with <i>D. eucerothra</i> effected 80% &amp; more than 90% respectively in the Isle of Thanet &amp; N. &amp; S. England, UK during 1935 (Hardy, 1938).</p> <p>Effected 74.6% together with <i>D. eucerothra</i> in Lutjebroek, Holland (Lloyd, 1940). Of the two species, <i>D. eucerothra</i> was more common.</p> <p>Total parasitism about 80% with <i>D. fenestralis</i> dominating in the Moscow Region, USSR (Kopvillen, 1960).</p>                                                                                                                                                                                                                                                                                                                                                                                               | <p>Although information pertaining to this species are relatively much less than that of <i>D. eucerothra</i>, its field performance is observed comparable to that of the latter. Probably such of the features noted for the latter species would also appear applicable to <i>D. fenestralis</i> in general. It thus suffice therefore to emphasize that <i>D. fenestralis</i> could be exploited as a sole controlling agent and its manner of utilization very much parallels that of <i>D. eucerothra</i>.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

## Appendix 4 (Continued 4).

| Parasite species                                  | Field parasitism                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Limitations/Advantages                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Potential & suggested manner of employment                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
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| <i>Diadegma insularis</i> (Cresson)               | <p>Together with <i>D. armillata</i> effected 80% parasitism in the Moscow Region, USSR (Kopvillas, 1959, 1960). Of the two species, <i>D. fenestralis</i> was dominant.</p> <p>Total parasitism effected together with <i>D. subtilicornis</i>, <i>Apanteles</i> spp. and other <i>Diadegma</i> spp. - 14.2-77.3% (1960-65) and 66.4-78.1% (1963-65) in S. Ukraine, USSR (Adashkevich, 1966). Among the species, <i>D. fenestralis</i> was dominant.</p> <p>19.8% during 1960 in Nagpur, India (Tikar &amp; Thakare, 1961).</p> <p>Together with <i>Diadromus pluteus</i> effected about 52% parasitism (Harcourt, 1960) while itself averaging 33% (Harcourt, 1963a, b) in Merivale, Canada.</p> <p>17% &amp; 23% seen parasitism in 1961-70 for the 1st &amp; 2nd generation of host larvae respectively in Saskatchewan, Canada (Putnam, 1973).</p> <p>Together with other species such as <i>Diadegma pluteus</i>, <i>Diadromus erythronotus</i> &amp; <i>Microplitis pluteus</i> the following total seen parasitism rates were obtained in Southern California, USA - 35.2% (1963-65), 60.3% (July-Sept. 1963-65), 28.0% (Jan-Mar. 1963-65), 30.9% (April-June, 1963-65) &amp; 33.6% (Oct-Dec, 1963-65) (Cattam &amp; Flatner, 1969).</p> <p>32% during 1974-75 in Hastings, USA (Ru &amp; Workman, 1979).</p> | <p>It constitutes the principal species in the parasite complex normally found in Canada and the USA (Harcourt, 1960, 1963a, b; Putnam, 1968, 1973; Cattam &amp; Flatner, 1969; Ru &amp; Workman, 1979). Although generally regarded to be important &amp; having close synchronisation of parasite-host relationship with only a little lag occasionally (Cattam &amp; Flatner, 1969), it is still unable to exert satisfactory control by itself. However, it can co-exist well with others, particularly with <i>M. pluteus</i> and with each supplementing the activity of the other, thereby increasing the parasitic activity considerably to provide substantial control (Putnam, 1968). Nevertheless, chemical supplementation is sometimes still needed (Ru &amp; Workman, 1979).</p> <p>Parasites incapable of appreciable increase under conditions (abiotic) favourable to DBM, e.g. following a hot summer. The reverse is however found true suggesting poor synchrony (Robertson, 1939).</p> | <p>Since the parasite is unable to exert adequate host suppression, avoid using it as a sole biological control agent. Rather, it should be used in conjunction with others. When employed together with <i>M. pluteus</i> it has been noted that one of each species operating among the same lot of larval hosts would produce more total progeny than two of the same species (Putnam, 1968). Moreover, additional individual of the same species tends to reduce the total parasitism indicating self-limitation. Evidently, with such parasites a better strategy would be to encourage mixture of the species rather than attempting to boost a single species with total effort.</p> |
| <i>Diadegma</i> sp. (near <i>lateralis</i> Grav.) | <p>7% in New Zealand (Muggeridge, 1930).</p> <p>Combined parasitism with <i>Diadromus</i> sp. in various parts of New Zealand (Robertson, 1939):</p> <p>Wairarapa: 1.3% (1935) on host larvae.</p> <p>0.8% (1935) on host pupae.</p> <p>Manawatu: 4.3% (1935-36) on host larvae.</p> <p>0.3% (1935-37) on host pupae.</p> <p>Taranaki: 0.7% (1936) on host pupae.</p> <p>Hawke's Bay &amp; Manawatu: 0.4% (1936) on host pupae.</p> <p>Hawke's Bay: 0.6% (1936-37) on host larvae.</p> <p>9.3% (1936-37) on host pupae.</p> <p>Canterbury: 26.9% (1937) on host larvae.</p> <p>22.0% (1937) on host pupae.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <p>NA</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Of minor importance.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <i>Diadegma neocerophaga</i> Horvath.             | <p>Total parasitism of 58.8% effected together with <i>D. eucerothaga</i> &amp; <i>A. pluteus</i> (Salinas, 1972).</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | NA                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Of moderate importance.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| <i>Diadegma pluteus</i> Viereck.                  | <p>For details on total parasitism rates in Southern California, USA see "<i>D. insularis</i> (Cattam &amp; Flatner, 1969)".</p> <p>Combined parasitism with <i>Diadromus pluteus</i> in two localities of Minnesota, USA inconclusive (Weires &amp; Chiang, 1973). Between the two species, <i>Diadegma pluteus</i> was dominant. At St. Paul, respectively 43.2%, 12.9% &amp; 4.6% during 1968, 1969</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <p>Unable to effect consistent rate of attack (Weires &amp; Chiang, 1973). Although Cattam &amp; Flatner (1969) considered it to be well-synchronised with the host, the reverse was found by Weires &amp; Chiang (1973) who concluded that it is unable to afford maximum protection.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <p>Since the findings are conflicting (Cattam &amp; Flatner, 1969; Weires &amp; Chiang, 1973) as well as the relevant information inadequate, the real potential of the parasite cannot be accurately assessed. At this juncture, therefore little suggestion can be made as to its manner of utilization.</p>                                                                                                                                                                                                                                                                                                                                                                              |



## Appendix 4 (Continued 5).

| Parasite species <sup>1/</sup>                              | Field parasitism                                                                                                                                                                                                                                                                                                                                                                                                             | Limitations/Advantages <sup>2/</sup>                                                                                                                                                                                                                                                                                                                            | Potential & suggested manner of employment                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                             | & 1970. At Rosemount, respectively 57.6%, 16.7% & 9.4% during 1968, 1969 & 1970.                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                 | except to urge for more intensive investigations on it, especially the assessment of its potential.                                                                                                                                                                                                                                                                                       |
| <u>Diadegma rufi</u> (Cassbridge)                           | In the presence (introduction) of <u>D. eucerotheca</u> it declined from about 24% (1952) to negligible numbers (1953) in Goulburn, N.S.W. (Venkatraman, 1964). This also occurred in Victoria: 21.1%, 1.2%, 2.1% & 0.0% respectively in 1972/73, 1973, 1973/74 & 1974 (Goodwin, 1979).                                                                                                                                      | Little ability to avoid multiple parasitism (Lloyd, 1940).                                                                                                                                                                                                                                                                                                      | Though able to increase the overall parasitism in a parasite complex, the contribution is generally minor (Lloyd, 1940; Goodwin, 1979).                                                                                                                                                                                                                                                   |
| <u>Diadegma varuna</u> Gupta                                | 1.3% in Kaliapong, W. Bengal (Phalak, 1970).                                                                                                                                                                                                                                                                                                                                                                                 | NA                                                                                                                                                                                                                                                                                                                                                              | It is only an occasional parasite of DBM and is of no importance (Phalak, 1970).                                                                                                                                                                                                                                                                                                          |
| <u>Diadegma</u> spp.                                        | Mean parasitism = 58.3% (range = 9-68%) in Transvaal, S. Africa (Ulliyett, 1947).<br>Mean parasitism generally between 34% & 50% though sometimes attaining as high as 72% in Pretoria, S. Africa (Ulliyett, 1947).<br>36% & 52% respectively during 1957 & 1958 in N. York, USA (Pimentel, 1961).<br>For details on total parasitism rates in Southern California, USA see " <u>D. insularis</u> (Oatman & Platner, 1969)". | NA                                                                                                                                                                                                                                                                                                                                                              | Of considerable importance and dominating in the parasite complex (Pimentel, 1961).                                                                                                                                                                                                                                                                                                       |
| <u>Diadromus erythrotoeus</u> (Casseron)                    |                                                                                                                                                                                                                                                                                                                                                                                                                              | NA                                                                                                                                                                                                                                                                                                                                                              | Not a dominating species in the parasite complex and is probably of little importance (Oatman & Platner, 1969).                                                                                                                                                                                                                                                                           |
| <u>Diapriid</u> sp.                                         | Rare in the Moscow Region, USSR (Kopvillem, 1960).                                                                                                                                                                                                                                                                                                                                                                           | NA                                                                                                                                                                                                                                                                                                                                                              | Of minor importance (Kopvillem, 1960).                                                                                                                                                                                                                                                                                                                                                    |
| <u>Diapriid</u> sp.                                         | Rare in Pretoria, S. Africa (Ulliyett, 1947).                                                                                                                                                                                                                                                                                                                                                                                | NA                                                                                                                                                                                                                                                                                                                                                              | Of minor importance (Ulliyett, 1947).                                                                                                                                                                                                                                                                                                                                                     |
| <u>Macrobracon hebetor</u> Say.                             | Not more than 5-6% in Pretoria, S. Africa (Ulliyett, 1947).                                                                                                                                                                                                                                                                                                                                                                  | Not usually a parasite of DBM, but essentially that on stored insects. It normally attacks larvae within restricted spaces between folded leaves of the 'heart' forming stage (Ulliyett, 1947).                                                                                                                                                                 | Of limited use against DBM (Ulliyett, 1947).                                                                                                                                                                                                                                                                                                                                              |
| <u>Macromalon orientale</u> Kerrich                         | Together with <u>D. varuna</u> & <u>T. collaris</u> effected a total parasitism of 15.3% in Kaliapong, W. Bengal (Phalak, 1970).                                                                                                                                                                                                                                                                                             | In some parasite complex, this species tends to predominate. However, the total parasitism attained is still low (Phalak, 1970), perhaps largely because of superparasitism which is common in <u>Macromalon</u> spp. (Chacko, 1968).<br>Can co-exist well with <u>D. insularis</u> to effect a substantial and higher overall parasitism (Putnam, 1968, 1973). | May be utilized to a limited extent to supplement the activities of other parasite species.                                                                                                                                                                                                                                                                                               |
| <u>Microplitis plutellae</u> (Mew.)                         | 1.3%, 4.3% & 2.1% respectively during 1954, 1955 & 1956 in Merivale, Canada (Harcourt, 1960).<br>Averaging 10% in Merivale, Canada (Harcourt, 1963a, b).<br>51% & 16% respectively on the 1st & 2nd generation host larvae during 1961-70 in Saskatchewan, Canada (Putnam, 1973).<br>For detailed total parasitism rates in Southern California, USA see " <u>D. insularis</u> (Oatman & Platner, 1969)".                    |                                                                                                                                                                                                                                                                                                                                                                 | It is considered of some importance in Canada (Harcourt, 1960, 1963a, b; Putnam, 1968, 1973) but of no significance in USA (Oatman & Platner, 1969). Unable to provide effective control by itself and should not be used as a sole controlling agent. Its potential has to be exploited in combination with other species with which it can co-exist, particularly <u>D. insularis</u> . |
| <u>Spilochalcis hirtifemora</u> (Ashmead)                   | Negligible in Lesser Antilles (Leeward Islands) (Bennett & Yaseen, 1972; Yaseen, 1974).<br>Total parasitism of 0.08% and 6.5% together with <u>Anatolus</u> spp. from host larvae and pupae respectively in Trinidad (Yaseen, 1974).<br>Negligible in Lesser Antilles (Yaseen, 1978).                                                                                                                                        | Parasitism level low, inconsistent, and may be totally absent for certain periods. It sometimes also acts as hyperparasite (Bennett & Yaseen, 1972; Yaseen, 1978).                                                                                                                                                                                              | Of limited value for the control of DBM.                                                                                                                                                                                                                                                                                                                                                  |
| <u>Spinolia</u> sp.                                         | Rare in Victoria, Australia (Goodwin, 1979).                                                                                                                                                                                                                                                                                                                                                                                 | NA                                                                                                                                                                                                                                                                                                                                                              | Of minor importance (Goodwin, 1979).                                                                                                                                                                                                                                                                                                                                                      |
| <u>Stictoplatys</u> sp.                                     |                                                                                                                                                                                                                                                                                                                                                                                                                              | NA                                                                                                                                                                                                                                                                                                                                                              |                                                                                                                                                                                                                                                                                                                                                                                           |
| Tachinid sp. (probably <u>Cadurcia pluvialis</u> van Emden) | Rare in Pretoria, S. Africa (Ulliyett, 1947).                                                                                                                                                                                                                                                                                                                                                                                | NA                                                                                                                                                                                                                                                                                                                                                              | Of minor importance (van Emden 1942; Ulliyett, 1947).                                                                                                                                                                                                                                                                                                                                     |

## Appendix 4 (Continued 6).

| Parasite species <sup>1/</sup>                     | Field parasitism                                                                                                                                                                                                                                                                                                                                                                               | Limitations/Advantages <sup>2/</sup>                                                                                                                                   | Potential & suggested manner of employment                                                                                                                                                                                                                                                                                                                                      |
|----------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>Tetrastichus</i> sp.                            | Population level very low but constantly present (Uilyett, 1947).                                                                                                                                                                                                                                                                                                                              | For reasons still unknown, its presence is able to increase the level of <i>Apanteles</i> without the decline usually associated with <i>Diadegma</i> (Uilyett, 1947). | Apparently of little importance although its potential role with respect to <i>Apanteles</i> increase is yet to be investigated.                                                                                                                                                                                                                                                |
| <b>PUPAL PARASITES:</b>                            |                                                                                                                                                                                                                                                                                                                                                                                                |                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                 |
| <i>Diadegma plutellae</i> (Ashmead)                | Recorded at mean levels of 16.2% (Harcourt, 1960) and 21% (Harcourt, 1963a, b) in Merivale, Canada. Generally low. For details on total parasitism rates in: Southern California, USA see "D. insularis" (Oatman & Platner, 1969).                                                                                                                                                             | Shown good ability to avoid hosts already parasitized by <i>D. insularis</i> (Harcourt, 1960).                                                                         | Considered a principal pupal parasite (Harcourt, 1960) to be used as supplement to others, particularly <i>D. insularis</i> .                                                                                                                                                                                                                                                   |
| <i>Diadegma subtilicornis</i> Grav.                | Abundance low to moderate (Koprilova, 1959) and could readily cause 30-60% mortality of the host under laboratory conditions (Koprilova, 1960). Total parasitism effected together with <i>Diadegma</i> spp. and <i>Apanteles</i> spp. = 14.2-97.3% (1960-65) and 66.4-78.1% (1963-65) in S. Ukraine, USSR (Adashkevich, 1966).                                                                | Found capable of avoiding <i>T. collaris</i> and its presence would not adversely affect the latter species (Lloyd, 1942).                                             | Considered to be fairly important (Koprilova, 1960; Adashkevich, 1966). Though not a dominant species, its contribution was substantial. Since it does not adversely affect <i>T. collaris</i> (Lloyd, 1942) it could be introduced to supplement the latter when desirable. This would include areas having no pupal mortality or when other parasitic activity is negligible. |
| <i>Diadegma</i> sp.                                | Generally low. For details on combined parasitism in various parts of New Zealand, see " <i>Diadegma</i> sp. (near <i>lateralis</i> Grav.)" (Robertson, 1939).                                                                                                                                                                                                                                 | Incapable of appreciable increase under conditions (abiotic) favourable to DBM.                                                                                        | Of minor importance (Robertson, 1939).                                                                                                                                                                                                                                                                                                                                          |
| <i>Dibrachys caryus</i> (Vikr.)                    | Rare in Merivale, Canada (Harcourt, 1960).                                                                                                                                                                                                                                                                                                                                                     | NA                                                                                                                                                                     | Of minor importance (Harcourt, 1960).                                                                                                                                                                                                                                                                                                                                           |
| <i>Eupicrostus viridescens</i> (Wahle)             | "                                                                                                                                                                                                                                                                                                                                                                                              | NA                                                                                                                                                                     | "                                                                                                                                                                                                                                                                                                                                                                               |
| <i>Celis tenellus</i> (Say.)                       | Rare in Merivale, Canada (Harcourt, 1960).                                                                                                                                                                                                                                                                                                                                                     | Although it parasitizes DBM, it also acts as a hyperparasite to <i>D. insularis</i> (Harcourt, 1960).                                                                  | Of minor importance (Harcourt, 1960) and because it is also a hyperparasite its introduction should be avoided.                                                                                                                                                                                                                                                                 |
| <i>Habrocytus</i> sp. (near <i>phycidis</i> Ashm.) | Rare in Merivale, Canada (Harcourt, 1960).                                                                                                                                                                                                                                                                                                                                                     | NA                                                                                                                                                                     | Of minor importance (Harcourt, 1960).                                                                                                                                                                                                                                                                                                                                           |
| <i>Itoplectis maculator</i> Fab.                   | Less than 0.1% in England, UK (Hardy, 1938).                                                                                                                                                                                                                                                                                                                                                   | NA                                                                                                                                                                     | Of minor importance (Hardy, 1938).                                                                                                                                                                                                                                                                                                                                              |
| <i>Phaenogenes</i> sp.                             | "                                                                                                                                                                                                                                                                                                                                                                                              | NA                                                                                                                                                                     | "                                                                                                                                                                                                                                                                                                                                                                               |
| <i>Spilochalcis albifrons</i> (Wahle)              | Rare in Merivale, Canada (Harcourt, 1960).                                                                                                                                                                                                                                                                                                                                                     | NA                                                                                                                                                                     | Of minor importance (Harcourt, 1960).                                                                                                                                                                                                                                                                                                                                           |
| <i>Stenomacrus</i> sp.                             | Negligible in Pretoria, S. Africa (Uilyett, 1947).                                                                                                                                                                                                                                                                                                                                             | NA                                                                                                                                                                     | Of minor importance (Uilyett, 1947).                                                                                                                                                                                                                                                                                                                                            |
| <i>Tetrastichus arvari</i> Rohw.                   | 1.3% in the Cameron Highlands, Malaysia and not recorded on DBM in the field elsewhere (Cherian & Subramanian, 1940; Ooi & Kelderman, 1977).                                                                                                                                                                                                                                                   | Believed to be an incidental parasite of DBM.                                                                                                                          | Of minor importance (Ooi & Kelderman, 1977).                                                                                                                                                                                                                                                                                                                                    |
| <i>Tetrastichus sokolowskii</i> Kurdj.             | 18.2-68.3% (ave. 45.3%) in India (Cherian & Basheer, 1939). Rare in Merivale, Canada (Harcourt, 1960). Generally low in Lesser Antilles (Antigua, Leeward Islands, Montserrat, Nevis & St. Kitts) (Bennett & Yaseen, 1972; Yaseen, 1974) though sometimes abundant and causing more than 80% mortality of DBM pupae (Bennett, 1974). 10% during 1974-75 in Hastings, USA (Ru & Workman, 1979). | NA                                                                                                                                                                     | To be utilized only in combination with other species. In such a manner, substantial control may be more readily obtained as was recently noted in Zambia (Yaseen, 1978) where a combination of the newly-established <i>A. plutellae</i> & <i>T. collaris</i> , along with the endemic <i>T. sokolowskii</i> , provided an 80% reduction in damage.                            |
| <i>Thrasella collaris</i> Grav.                    | Less than 0.1% in England, UK (Hardy, 1938). 13.6% in Lurjebroek, Holland (Lloyd, 1940). Less than 2% in Versilia District, Tuscany (Delucchi et al., 1954). 1.1% in the main crucifer-growing areas of North Island, New Zealand (Todd, 1959).                                                                                                                                                | Can co-exist with another pupal parasite <i>D. subtilicornis</i> and is not adversely affected by it (Lloyd, 1942).                                                    | Although occurring at relatively low levels in general, it is considered an important parasite largely because of its constant involvement in parasite complexes that have provided effective suppression of DBM (Lloyd, 1940; Delucchi et al., 1954; Todd, 1959; Wilson, 1960). Its ability to co-exist with most of the                                                       |

Appendix 4 (Continued 7).

| Parasite species <sup>1/</sup> | Field parasitism                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Limitations/Advantages <sup>2/</sup> | Potential & suggested manner of employment                                                                                                                                                                                                                                                                                     |
|--------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                | Effect heavy overall parasitism together with <u>D.eucerothaga</u> & <u>A.plutellae</u> in many parts of Australia (Wilson, 1960).<br>Together with <u>M.orientale</u> & <u>D.varuna</u> effected 15.5% total parasitism in Kalimpong, W.Bengal (Phalak, 1970).<br>24% during 1971-74 in Hawkesbury Valley, Australia (Hamilton, 1978b).<br>7.63%, 4.41%, 3.82% and 5.61% respectively during 1972-73, 1973, 1973-74 and 1974 in Victoria, Australia (Goodwin, 1979). |                                      | species in such parasite complexes (Lloyd, 1940, 1942) has perhaps enabled it to provide the effective supplementation. Utilization of the species should thus aim to exploit fully this supplementary feature, in particular to enhance the pupal mortality. Attempt to use it as a sole controlling agent should be avoided. |
| <u>Thyraeella</u> sp.          | Negligible in Pretoria, S.Africa (Ulliyett, 1947).                                                                                                                                                                                                                                                                                                                                                                                                                    | NA                                   | Of minor importance (Ulliyett, 1947).                                                                                                                                                                                                                                                                                          |

OTHER MISCELLANEOUS : These include numerous species that are only incidentally recorded as parasites of DBM. The identification of some are doubtful, requiring further examination and clarification, while others are suspected to be hyperparasites. Moreover, the host species in some instances are unconfirmed. In general, the parasitism rates are usually low and the reported cases few and isolated, with little information available. As regard their potentials and suggested manner of utilization, little can be said at present except to note that further detailed studies are required before any recommendations can be made.

<sup>1/</sup> Names recognized by the Commonwealth Institute of Entomology (C.I.E.), London as on 17.12.81 unless otherwise qualified; names marked with an asterisk are not in the record of C.I.E. and could have been invalid or misidentified species, while the following were still maintained by C.I.E. although recently (July) revised (Mason, 1981) in "Memoire de la Société entomologique du Canada [C.I.E. Ref: BNA 2a]": A.aciculatus to Rhygoplitis aciculatus Mason, A.laevigatus to Dolichogenidea laevigatus Mason, A.plutellae to Cotesia plutellae Mason and A.sicarius to Dolichogenidea sicarius Mason.

<sup>2/</sup> NA = Information not available.