

Effects of the Soil Environment on Oviposition and Egg  
development of the Desert Locust, Schistocerca gregaria (Forsk).

A Thesis submitted for the Degree of Doctor of Philosophy in the  
Faculty of Science, London University.

by

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### Abstract

Field observations were carried out on the oviposition behaviour of the desert locust swarms in relation to soil moisture.

Laboratory experiments are described on the effect of soil environments on the selection of oviposition sites. The factors examined were soil compaction, temperature, type and particles size.

Investigations on the following are also described:-

1. The effect of soil moisture on egg development and hatching of larvae from gregaria egg-pods at two temperatures.
2. Egg development and the quality of the hatchlings from solitaria egg-pods in relation to soil moisture.
3. Soil salinity on egg development and hatching of larvae from gregaria egg-pods.
4. The weight, water contents, colour and survival capacity of the hatchlings in all the above experiments.
5. Moisture Kinetics of the eggs in hypotonic, isotonic and hypertonic solutions of sea water and glucose.
6. The osmotic pressure of the egg contents as determined by the depression of the freezing point method.

The mechanism of water absorption by the eggs is discussed and also the role of environmental conditions in phase transformation and the nature of phases.

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## Table of Contents.

|                                                                                                                           | <u>Page</u> |
|---------------------------------------------------------------------------------------------------------------------------|-------------|
| I Part one: OVIPOSITION BEHAVIOUR.                                                                                        |             |
| 1. Field Observation on Oviposition Behaviour .....                                                                       | 1           |
| i Introduction .....                                                                                                      | 1           |
| ii Description and survey of oviposition sites .....                                                                      | 2           |
| iii Discussion of results .....                                                                                           | 20          |
| 2. Laboratory Experiments on the Selection of<br>Oviposition Sites in the Desert Locust .....                             | 24          |
| i Introduction .....                                                                                                      | 24          |
| ii Materials and Methods .....                                                                                            | 25          |
| a) Means of acceptability .....                                                                                           | 26          |
| b) Experimental soil types .....                                                                                          | 27          |
| iii The ability of the Desert Locust to lay in Sand<br>and Gravel .....                                                   | 28          |
| iv Experiments on significance of Soil moisture<br>in choice of oviposition sites .....                                   | 31          |
| v Experiments on significance of Soil compaction<br>in choice of oviposition sites .....                                  | 37          |
| vi Effect of Soil temperature on the selection<br>of oviposition sites .....                                              | 45          |
| II Part two: EFFECT OF SOIL MOISTURE AND SALINITY ON<br>THE DEVELOPMENT OF THE DESERT LOCUST EGGS AND<br>HATCHING LARVAE. |             |
| 1. Introduction .....                                                                                                     | 53          |
| 2. Definition and Discription of Terms .....                                                                              | 55          |
| i Soil Moisture .....                                                                                                     | 55          |
| ii The site of absorption of water by the egg .....                                                                       | 56          |
| iii RESULTS .....                                                                                                         | 107         |

Field Observations on Oviposition Behaviour.

Introduction:

Uvarov (1954), stated that, although S. gregaria is closely connected with semi-arid and arid regions, its physiological requirements do not suggest a high degree of adaptation to what is understood as desert conditions. Thus, as S. gregaria is not a stationary insect, it can make use of temporarily favourable ecological islands in the desert.

It has been reported (Uvarov 1928, 1932; Waloff 1950) that S. gregaria like other locusts and grasshoppers has a restricted choice of oviposition sites. An initial investigation was carried out in the desert of Saudi Arabia during 1961, 1962, in order to study its oviposition sites in the field and to collect more information on the selection of sites, particularly in relation to the water content of the soil. Field observations were made at four sites from the time of oviposition till hatching. The soil water content was determined periodically at the four sites.

A series of laboratory experiments was then undertaken at Imperial College to test and elucidate some of the conclusions drawn in the field, particularly regarding soil temperature, soil moisture, soil compaction, type of soil and the ability of the desert locust to lay eggs in a gravel soil.

The field work was done before the candidate was registered as a higher degree student at London University, but it is

included in the thesis because it provides the field records which are a basis for the analytical laboratory studies undertaken for the Ph. D.

Description and survey of oviposition sites:

Site I: The first of four oviposition sites was approximately 18km<sup>2</sup>, (location, the Jeddah - Medina Highway at Mastura valley, long. 38, lat. 23.0). This site was divided into two areas, the first of which (A), consisted of sandy-clay soil, cultivated with Zea mais and water melon. The plants were in rows  $\frac{1}{2}$  - 1 metre apart. The Zea mais was about 50 - 70 cm. in height, and the water melon was nearly ripe. The second area (B), consisted of sandy dunes, was surrounded by cultivation and was largely bare with some sparse vegetation. The predominant species were Heliotropium diptrygium, Eleusine compressa and a few Acacia spp. The site was bounded in the north by open desert, in the west by the road and in the south and east by large patches of land cultivated with crops as above.

The swarm arrived at the site on April 2 nd. 1961, and observations were started the next morning. As the major part of oviposition had taken place earlier in the previous day, observations on egg-laying behaviour relate only to its less intense phase. At sunrise nearly 40% of the population was copulating and about 10% of the females had started probing and laying. Half an hour later, the individual locusts which were roosting on the top of the Zea mais started to fly from one plant

to the other and began feeding. The pairs were crawling and tended to aggregate in the furrows between plants and on the eastern slopes of the sand dunes. Four hours later, almost all the females were probing and laying in groups of two to over one hundred pairs. The site was revisited the following morning when a few individuals remained scattered over the area.

Survey of the site: In view of the shortage of staff and time, it was decided to get only a rough idea of the distribution of egg-pods at areas A and B, previously described. 30 x 30 metre plots were marked out for study in each area. In area (A), nine one metre sub-plots were selected systematically as shown in Fig. 1. Each of the square metres was scraped, the surface of the soil cleared and the exposed frothplugs of the egg-pods marked with match sticks (Popov 1958). 53, 67 and 111 egg-pods were found in the sub-plots 1, 4 and 6 respectively. No egg-pods were found in the other sub-plots. The distribution pattern of egg-pods is plotted in Fig. 1.

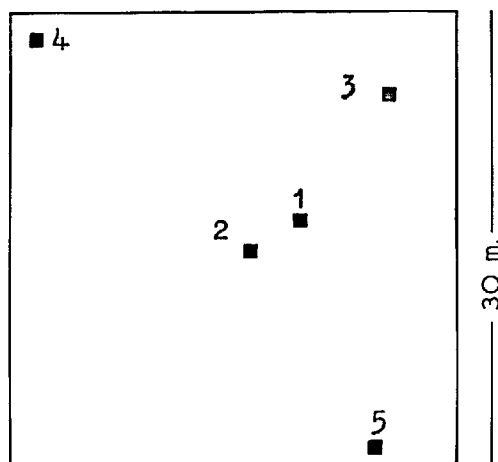
Five one square metre sub-plots were selected at random in area (B). 43, 36 and 27 egg-pods were found in sub-plots B<sub>1</sub>, B<sub>3</sub> and B<sub>5</sub> respectively and Fig. 2, shows the distribution pattern of the egg-pods in these sub-plots. No egg-pods were found in the other sub-plots.

Number of eggs per pod: Seven egg-pods were collected from the site. The numbers of eggs per pod were 57, 57, 61, 64, 65, 91 and 98, the mean being  $70.4 \pm 15.6$ .

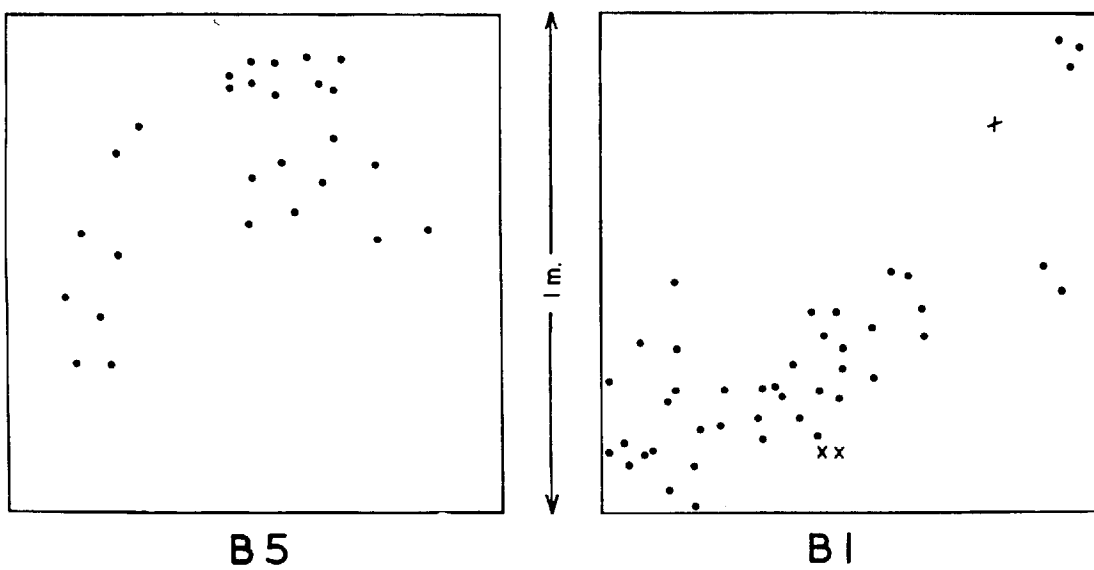
Figure 1 consists of four square plots arranged in a 2x2 grid. Each plot is labeled below it: AREA-A, A6, A1, and A4. Each plot has a vertical scale bar on the left and a horizontal scale bar on the right, both labeled '30m'. AREA-A shows a regular grid of 9 points, numbered 1 through 9. A6, A1, and A4 show random distributions of points. The points in A6 are more densely clustered in the center than in A1 and A4.

. indicates position of egg-pods.

FIG. 2



AREA - B



B5

B1

Distribution pattern of egg-pods in Site I Area B .

Temperature: The maximum and minimum air temperatures at the site were recorded every 24 hours during the incubation period. This was done using a maximum and minimum thermometer hung in a shady position at a height of one metre from the surface of the soil on an ~~an~~ Acacia spp. bush. Fig. 3 shows the temperature fluctuations during the incubation period.

Soil water content: The soil water content of the two areas was measured at intervals from the time of egg-laying until the time of hatching. Moisture was determined in gms. water / 100 gms. soil by means of a moisture tester, in which a weighed sample of soil was shaken with the contents of a standard calcium carbide ampoule, the pressure of the released methane indicating the water content of the soil. The soil samples were taken between 10 - 12 cm. below the surface. The averages of 2 - 3 samples from different places in each area are given in Fig. 3.

Rainfall: There was a short spell of rain on April 1 st. 1961. Not far from the site ( 2 km. south) a river bed was in flood for three days.

Time of Hatching: Hatching continued for four days from April 15 th. The incubation period was therefore 13 - 17 days.

Site II, III and IV: These observations were made from 29th. of December 1961 till 21 st. of January 1962. The oviposition area was near Rabej (long. 38.5 latit. 22.7) on the Red Sea coast of Saudi Arabia. The size of the area occupied by the swarm was about 15 km<sup>2</sup>. Topographically the landscape was heterogeneous and

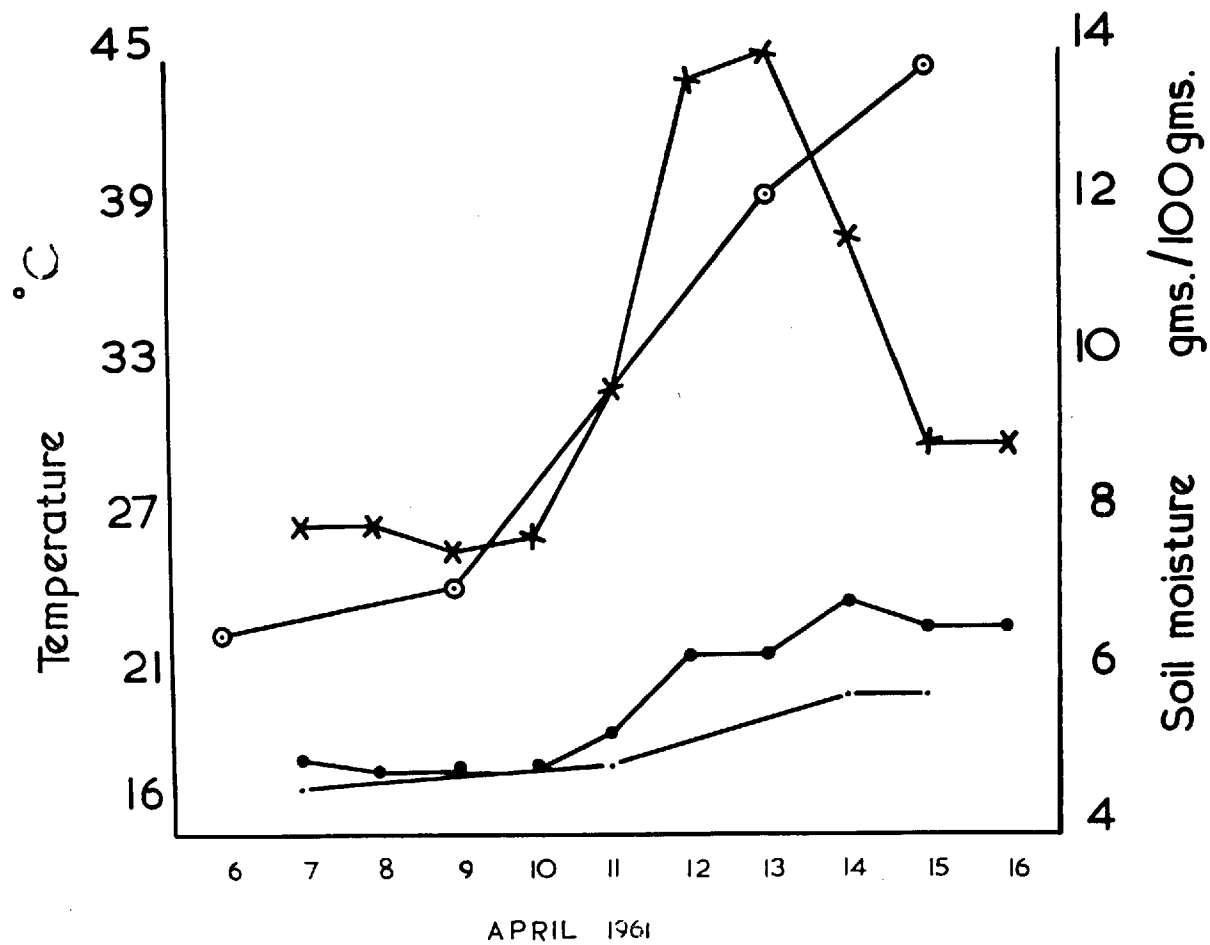


FIG. 3 Soil moisture and temperature records at Site I Area A&B.

consisted of a flat plain of sand, stony slopes and sand dunes. The area was crossed by numerous water channels which flow from time to time during the rainy season. Three sites II, III and IV, one km. apart were examined.

Temperature: These were recorded daily at mid-day and 8 p.m., during the incubation period by means of a dry bulb thermometer hung in a shady place at a height of one meter from the surface of the soil (Fig. 4).

Soil moisture: The soil water content was estimated at 4 and 12 cm. as previously described.

Soil Structure: Five equal samples were taken at random from each site at a depth of 3 - 12 cm. Those from each site were mixed and analysed mechanically (Table 1).

Table 1: Mechanical analysis of soils from sites II, III and IV.

| %s of different constituents |       |       |                   |              |                |                   |                |                 |
|------------------------------|-------|-------|-------------------|--------------|----------------|-------------------|----------------|-----------------|
| Site                         | Clay  | Silt  | Clay<br>+<br>Silt | Fine<br>Sand | Coarse<br>Sand | CaCO <sub>3</sub> | Total<br>Salts | Type of<br>Soil |
| II                           | 29.50 | 18.50 | 48.0              | 29.06        | 18.26          | 3.98              | 0.70           | Clay            |
| IIIa                         | 7.00  | 7.0   | 14.0              | 66.38        | 19.40          | 0.16              | 0.06           | Loam            |
| IIIb                         | 10.00 | 6.0   | 16.0              | 40.59        | 42.57          | 0.76              | 0.08           | Loam            |
| IV                           | 4.00  | 3.50  | 7.50              | 34.79        | 56.60          | 1.06              | 0.05           | Sandy           |

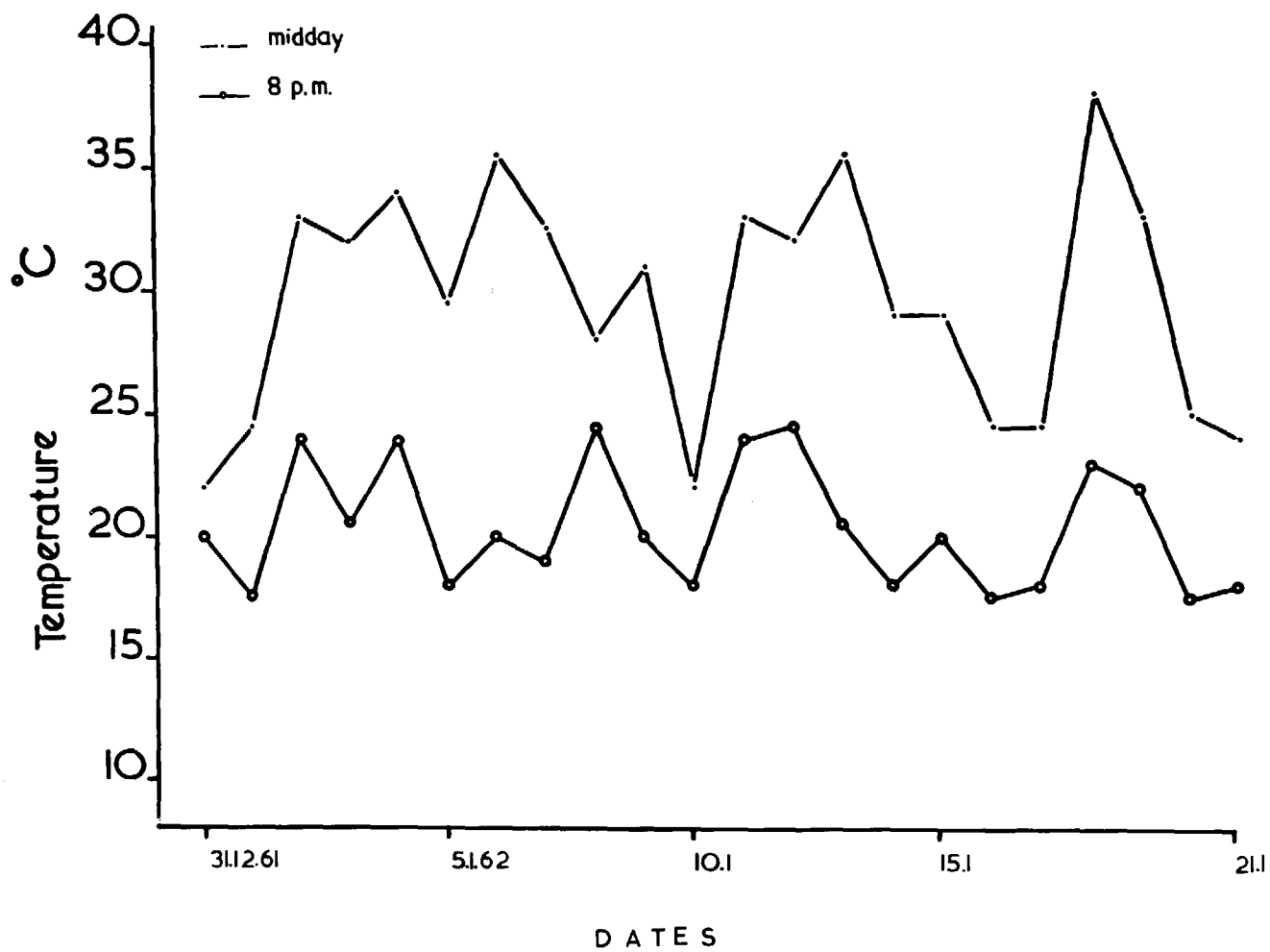


FIG.4

Temperature fluctuations during the incubation period in the region of Sites II, III and IV .

Site II on slopes at a depth of 3 - 12 cm.

Site IIIa at a depth of 3 - 10 cm.

Site IIIb at a depth of 10 - 15 cm.

Site IV at a depth of 3 - 12 cm.

Egg laying at all sites continued for 3 days from 28th. of December 1961.

Site II: Fig. 5 and 6, illustrate the topography of the site which consists of slopes extending from north to south, covered with gravel of variable size. The soil between the slopes was sandy with scattered *Acacia* spp. Observations were started on the 29 th. of December two hours before sunset. Most of the locusts (about 70%) were crawling about in copulation on the west side of the slopes facing the sunset. Most of the females were probing and laying in small groups and individually. Although, the west facing slopes were covered with locusts, the latter did not tend to aggregate and form dense groups for egg-laying. A few were scattered over the sandy plains between the slopes probing and laying individually, especially round the bushes. At this time, the soil surface temperature averaged 32°C on the west slopes and 28°C on the plains.

Survey of egg-laying: Three one square metre sub-plots were selected on each of two slopes and on the intervening sandy soil. The sub-plots in each group of three were one meter apart. The surface of the soil was scraped over to expose the egg-pods, but this was very difficult on the slopes because the soil was hard and



Figs. 5 & 6: General view illustrating the gravelly surface  
and topography of Site II.

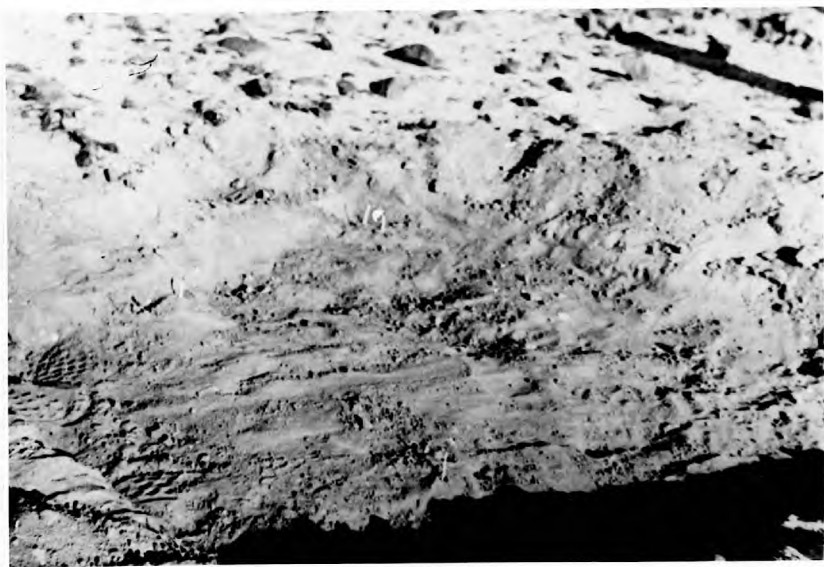
gravel was scattered in it. Match sticks were used to indicate the position of the egg-pods. The numbers of egg-pods in each sub-plot on the first slope were 14, 15 and nil. On the second slope five egg-pods were found in one of the sub-plots and none in the others. No egg-pods were found between the slopes. Fig. 7 and 8 indicate the distribution of the egg-pods in two sub-plots on the slopes. Numbers of eggs per pod in four pods were 58, 59, 64 and 72, (Mean  $63.2 \pm 5.5$ ).

Temperature: Fig. 4 shows the temperature fluctuation during the incubation period.

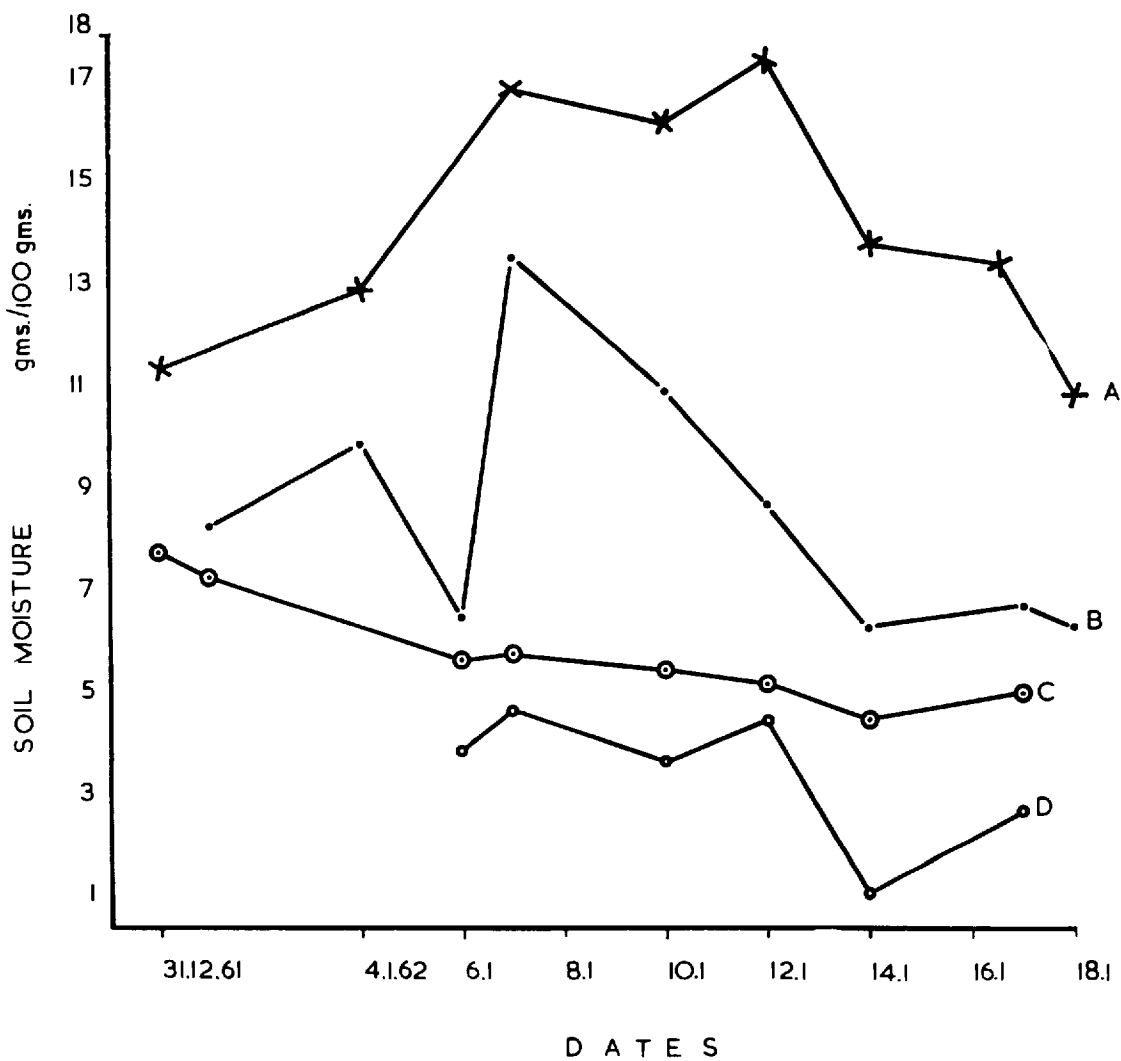
Soil moisture: Soil water content was estimated at intervals in and between the slopes at depth of 4 and 12 cm. (Fig. 9).

Hatching: This occurred on 21.1 and continued for 2 days.

Site III: Site III was about one km. to the north of site II. The area studied (Fig. 10, 11 and 12) was about 100 x 100 metres, more or less level with scattered *Acacia* spp. bushes. The soil was loamy and loose. Egg-pods survey started on 31 st. of December 1961, after the swarm had already emigrated. Four one square metre sub-plots were examined for egg-pods. Each was 25 metres apart and forming with each other a square at the centre of the selected area. Thirty eight and 132 egg-pods were found in two of the square metres (Figures 11 and 12) and none in the others. The distribution of the egg-pods indicates that the locust formed dense groups for laying. The numbers of eggs per pod were 62, 62, 63, 69, 73, 90 and 93, the mean being  $73.1 \pm 12.2$ .



Figs. 7 & 8: Showing the distribution pattern of egg-pods at Site II. (Marked with matchsticks.)



**FIG.9** Soil water content at Site II .  
 A: On slopes at 12 cm. depth .  
 B: " " " 4 cm. "  
 C: Between slopes at 12 cm. depth .  
 D: " " " 4 cm. depth .



Fig. 10: Above: General view for Site III.

Fig. 11: Below: Illustrates the distribution pattern of egg-pods at Site III as well as the moisture tester.

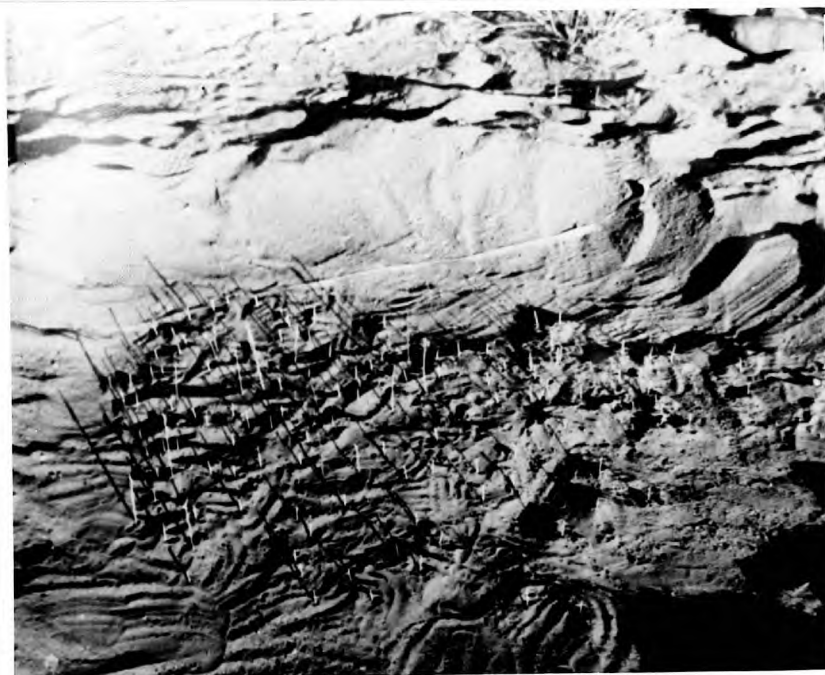


Fig. 12: Showing the density of egg-laying groups at Site III.

Temperature: Fig. 4 shows the temperature fluctuations during the incubation period.

Soil moisture: Fig. 13 , shows the soil water content during the incubation period.

Time of Hatching: Hatching occurred on 21.1 and continued for 2 days.

Site IV: The site was situated 1 km., to the south of site II. The area was flat and sandy. The characteristic pattern of vegetation was many *Acacia* spp., and some other plant spp. The same procedure as in site III was adopted to give some idea of the egg-pods distribution and density. The number of egg-pods were 43, 58 and 62 in three of the sub-plots and none in the fourth.

Temperature: Fig. 4 shows the temperature fluctuations during the incubation period.

Soil moisture: Fig. 14 shows the soil water content during the incubation period.

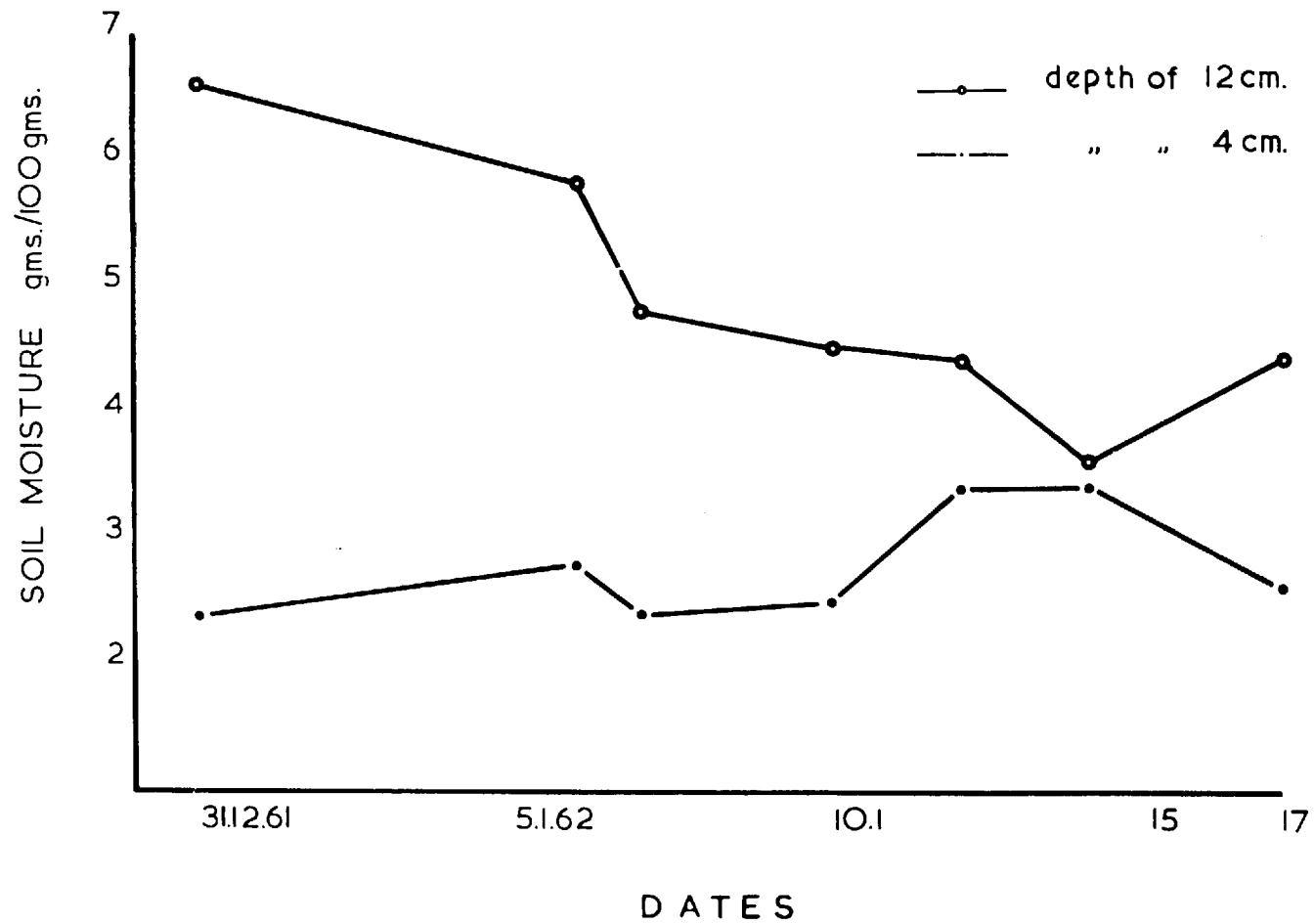


FIG.13

Soil water content at Site III .

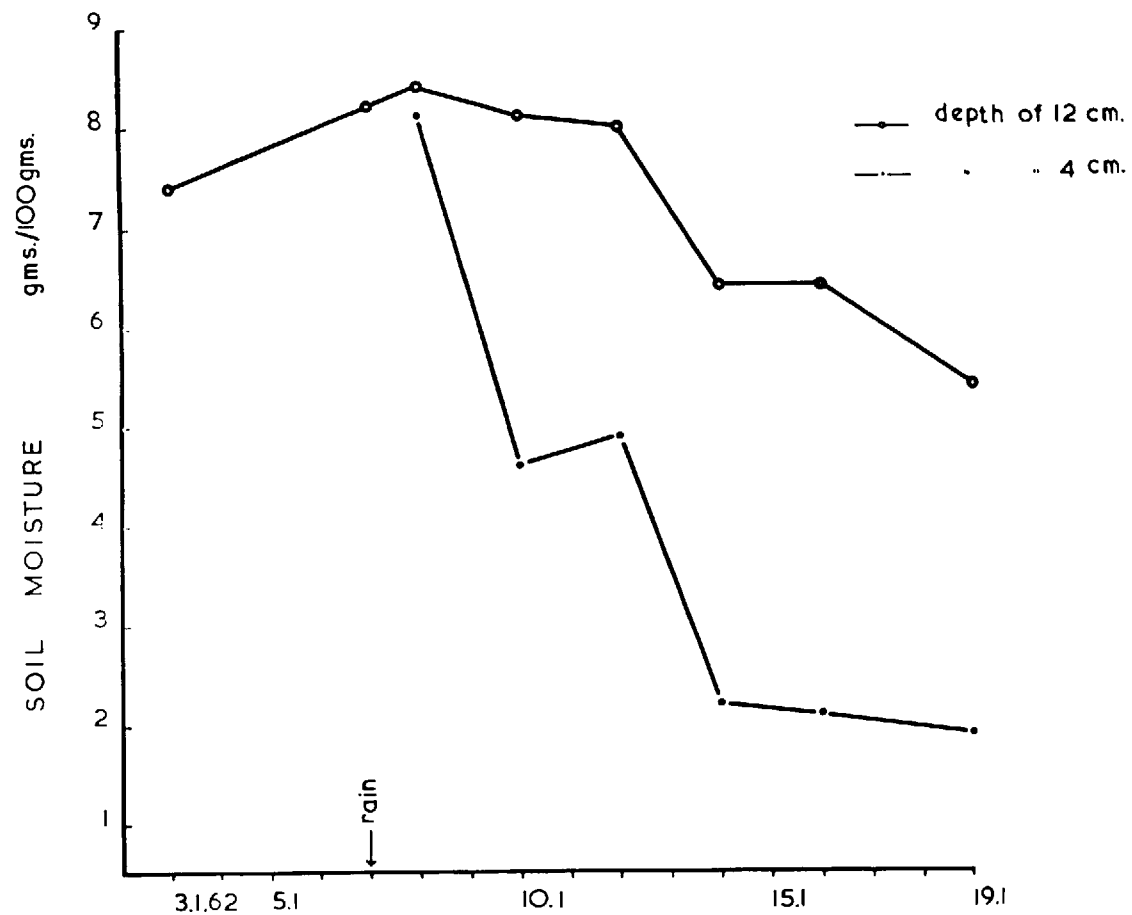


FIG.14 Soil water content at Site IV .

### Discussion of Results.

The literature contains numerous reports on the oviposition habits of species of Acrididae. Several field workers have observed that most spp. of locusts and grasshoppers have restricted oviposition sites. The selection of oviposition sites is most marked in the locusts, (Uvarov 1911, 1928, 1932; Bodenheimer 1944; Waloff 1950; Popov 1958; Stower et al. 1958; Ashall and Ellis 1962.). However, no serious attempt has been made to study the water content of the oviposition sites and whether it plays an important part in the mechanism of oviposition. Observations on locusts in the field suggest that oviposition occurs only after rainfall (Johnston 1924, on Anacridium moestum melanorhodum Walker; Coterell 1931, on Locusta migratoria migratorioides Reiche and Ramachandra Roa 1934, and Maxwell-Darling (1934, 1936) on Schistocerca gregaria Forsk. Kennedy (1949), found that for Locusta m.m., the completion of digging occurs most frequently when the soil is moist, while egg-laying requires soil moistened with water. Stower et al (1958) stated, " it would seem that the combined effect of environmental factors influences the choice of oviposition sites, particularly the vegetational cover, soil compaction and temperature".

Each kind of soil has its water holding capacity or field capacity which differs according to the particle size and the presence of the organic matter in the soil. Veihmeyer and Hendrickson (1931), have defined the field capacity as the amount of water held in the soil after the excess gravitational water has drained away

and after the rate of downward movement of water was materially decreased. This value has also been defined in the literature as the field carrying capacity, the normal moisture capacity and the capillary capacity and usually determined one to five days after a fall of rain or an application of irrigation water. Capillary movement of moisture can take place against gravity in certain cases, as when the water table or ground level where the soil is completely saturated rises or when the capillary movement takes place from wet soil to drier soil.

In site I, the amount of water at area A was initially 6.6 gms./100 gms. soil as shown in Fig. 3. The increase during the incubation period was due to flooding which occurred in the river bed 2 km. from the site; the ground water level rose and subsequently increased the soil water content at the site. Meanwhile, in area B which was sandy, the soil water content rose more gradually than in area A. There was a significant difference between the soil water content at areas A and B ( $t: 2.6316; n: 8; P < 0.05$ ) and the number of egg-pods/square metre at area A was more than that at Area B.  $\parallel \parallel$  .). Area A had a greater vegetational cover than B which was sandy and more open. The density of ovipositing females and hence the number of eggs laid therefore appears to be governed more by the moisture available at a particular site than by its topography or vegetational cover (at any rate within these ranges of soil moisture). Hatching occurred on the same day in both areas A and B which indicates

that soil water content has no effect on the time required for development and hatching.

Fig. 9, shows that in site II, the soil water content of the clayey soil on slopes was much more than that of the sandy soil between them (  $t = 3.5129$  ;  $n:14$  ;  $P(0.01)$  ) and was initially 11.4 gms/100 gms. soil. The increase shown in Fig. 9 was due to light rain which fell on January 7th. At the end of the incubation period, the soil water content had decreased to nearly its initial value and it would seem that this level represented the field capacity of this soil. Mechanical analysis showed that the soil structure on the slopes was clayey which explains its high content of water. At a depth of 4 cm., the sharp increase and equally sharp decline in the water content were mainly due to evaporation. Although the area between slopes had a water content like that of site IB, the locusts did not lay egg-pods and preferred laying on the slopes where the soil was more compact and was covered with gravel of variable size. The soil surface temperature at the time of observation was 32°C on the slopes and 28°C between them. It would thus seem that the combined effects of soil temperature and moisture determined selection of sites. The locusts at sites II and III were from the same swarm, for, they arrived on the oviposition area on one occasion and at the same time. Yet the oviposition behaviour was completely different at the two sites. At site III the locusts showed a high degree of gregariousness (Fig. 11), while dense grouping was avoided at site II and mostly isolated

egg-pods were laid. At site III, where the soil was loamy and flat, the water content of soil was much less than site II. Thus, it seems in this case that the presence of gravel of variable size on the soil surface and subsequently the absence of visual stimuli were the principle causes for avoiding dense grouping.

Incubation periods were 13 - 17 days in site I

21 - 23 " " " II and III

23 - 25 " " " IV.

Although the moisture contents of soil in the three last named sites were different, this seemingly had no effect on time required for egg-development and hatch, although it is known that high moisture content may decrease its temperature (Popov 1958).

Unfortunately a maximum and a minimum thermometer was not available at the time when the swarm arrived in sites II, III and IV.

Readings were obtained at 8 p.m. and at midday by means of a dry bulb thermometer (Fig. 4). Temperature at midday may be close to the hottest period of the day. The highest and lowest readings recorded were 38°C and 17°C. At site IV, the slight difference in the incubation period must be due to changes in the microclimate especially because of the vegetational cover at the site. In site I, it seems reasonable that the high peak in the temperature curve (Fig. 3) was the principle cause of such quick hatching.

Laboratory experiments on the selection of oviposition  
sites in the desert locust.

Introduction:-

It has been suggested that oviposition may occur in any kind of soil, but most frequently in moist sand (Popov 1958). Uvarov (1928), mentioned that the selection of a habitat by Acrididae is influenced by the kind and conditions of vegetation. A particular habitat is selected by an insect not merely because it contains a preferred food-plant or offers optimum conditions of temperature and humidity, but because the selected habitat provides a suitable combination of all these favourable factors and also offers protection from natural enemies. According to Popov (1954) the settling of locust swarms is induced by weather conditions, or fatigue or by a visual attraction of vegetation but is not directly connected with the discovery of suitable sites for egg-laying. According to the same author (1958), soon after settling down, the mature female locusts begin to explore the area in search of suitable sites for egg-laying. Stower et al (1958) stated that the character of the vegetation cover and the size of patches of bare soil have much influence in the choice of oviposition sites. Some preliminary experiments on the influence of the structure, temperature and moisture of the soil on oviposition in S. gregaria Forsk, were conducted by Husain and Ahmed (1936); Husain and Ahmed and Mather (1941). Popov (1958) carried out laboratory experiments to clarify some of his conclusions in the field such as avoidance of damp sites

during very high moisture conditions. However, while their conclusions were generally in agreement with field observations, the exact role which the soil environment plays in the selection of the oviposition sites, in particular, the soil temperature, compaction and type of soil is not yet clear. The object of this work was to make a more precise study of the factors influencing the selection of the sites and to establish a connection between laboratory observation and field phenomena. Soil temperature, compaction, and type of soil were examined. Some aspects of behaviour in the field such as selection of humid sites irrespective of their superficial topography and the ability of the desert locust to lay in a gravel soil have also been tested.

#### Materials and Methods:

Except when otherwise stated the experimental locusts were obtained from a culture kept at high density and hence of gregarious phase. They were reared in 30" x 30" x 24" breeding cages at a temperature ranging from 28°C at day time and 26°C during the night. All locusts used in these experiments were mature. In some experiments where large numbers of similar mature locusts were needed, batches of 100 newly fledged adults were kept together in a constant temperature room at 32°C in a cage 25 x 30 x 25 cm., until they were needed. They were fed on grass, brussel sprouts and bran mixed with yeast. Experiments were done in a constant temperature room at  $32 \pm 0.5^\circ\text{C}$ , illuminated at day time for 13 hours, and with a controlled ambient relative humidity of  $50 \pm 5\%$ . Numbers of egg-pods laid and abortive

probes were recorded every day. Details of procedures are given in the descriptions of each experiment.

Means of acceptability: Soil factors likely to affect the choice of oviposition site include soil type, soil compaction, soil moisture, temperature and vegetational cover. It is common in deserts to find great variation in soil temperature and water content over a small area. Williams (1927) investigated this variations in the Egyptian desert and showed that when the ground surface temperature was  $56^{\circ}\text{C}$ , it was only  $34^{\circ}\text{C}$ , 10 cm. below the surface. There were also large fluctuations within very few hours in the same place. Edney (1958), showed a great variation in a very small part of the Algerian desert. Thus, the surface temperature was about  $34^{\circ}\text{C}$  when the sun was covered by a cloud, but rose immediately by as much as  $15^{\circ}\text{C}$  in 10 seconds after the cloud had passed. The landscape is always heterogenous and the vegetational cover differs within an area over which a locust swarm settles. According to Bhatia et al (1962) a swarm may initially settle anywhere irrespective of its topography or vegetational cover and meanwhile the mature females start probing and exploring the site before actual egg-laying takes place. From this it is evident that probing is a means of exploring and discovering the acceptability of the oviposition area, and that the number of trial probes does not indicate the suitability of the oviposition site. Suitability is however indicated by the ratio of number of egg-pods to abortive probes. The suitability of an oviposition site may therefore be expressed by the equation:-

$$A.I. = \frac{E}{ExP} \times 100$$

Where A.I. = is the acceptability index of the site, i.e. the percentage of egg-laying to total probes.

E = No. of egg-laying bores.

P = No. of probes resulting in no oviposition.

Theoretically ideal value is when P = 0, i.e. A.I. = 100. Since all the probes lead to egg-laying. A.I. values can be used to compare suitability of different sites, e.g. a value of 70 may be considered better than one of 69.

A measure of suitability or preference can also be obtained by subtracting the actual A.I. from the ideal, thus indicating deviation from the ideal. Such measures of acceptability were found to be very useful in comparing different experimental conditions.

Experimental soil types: Common builder's sand was used in some of the experiments. It was sieved through a very coarse gauze to remove litter and large particles, then washed thoroughly with tap water, dried and sieved through 25 mesh sieve. The sifted sand was then heated at 120°C for 24 hours. A sandy loam soil from a deep pit in the Bagshot beds was used in soil compaction experiments. It was dried, and then sieved through a 40 mesh sieve before use. The mechanical analysis of the sandy loam soil was as follows:-

Coarse sand 22.6

Fine sand 42.8

Silt 17.5

Clay 15.3

Organic Carbon 1.6

Grading into fractions was done by the pipette method and the determination of Organic Carbon by Walkley and Black's titration method (Piper 1947). The particles of gravel in the experiments were  $\frac{1}{2}$  - 1 cm. in diameter.

The ability of the desert locust to lay in a sand and gravel:

In the field site II (page II ), there was typical sandy soil between the slopes, but oviposition occurred mainly on the slopes which had clay soil with gravel (Figs. 5 and 6). It was shown that in this case preference was probably affected by soil moisture and soil surface temperature. An experiment was done to determine how the presence of gravel in the soil affects egg-laying.

Experiment I: Cylindrical celluloid cages 22 cm. in diameter and 21 cm. in height were used. A circular cake tin formed the base and the celluloid fitted closely over it. The lid of the cake tin formed the top of the cage, and for aeration a circle 14 cm. in diameter was cut in the lid and covered with muslin. The floor of the cage was of perforated zinc with a 9 cm. diameter circular hole in the middle in which a plastic flower pot was placed. The top of the pot was flush with the floor. The pot was filled with the required mixture of sand and gravel and replaced by a new one every day. Five copulating pairs of S. gregaria were put in each cage. Treatments were set up as follows:-

- |   |   |   |       |    |       |      |    |     |       |    |        |     |         |
|---|---|---|-------|----|-------|------|----|-----|-------|----|--------|-----|---------|
| A | - | 3 | parts | of | sandy | soil | to | one | part  | of | gravel | (by | volume) |
| B | - | 2 | "     | "  | "     | "    | "  | 2   | Parts | "  | "      | "   | "       |
| C | - | 1 | part  | "  | "     | "    | "  | 3   | "     | "  | "      | "   | "       |

D - Sandy soil covered with gravel for 2 cm. depth.

E - Sandy soil as control.

The gravel was  $\frac{1}{2}$  - 1 cm. in diameter and the soil was the sandy soil as described. Water was added to each pot in the proportion 15 parts of water to 100 parts by volume of the mixture (Hunter-Jones 1961).

Egg-laying was observed during the day time. Females which laid eggs were recorded as well as those failed to lay or laid eggs on the cage floor. The numbers of trial probes were also recorded.

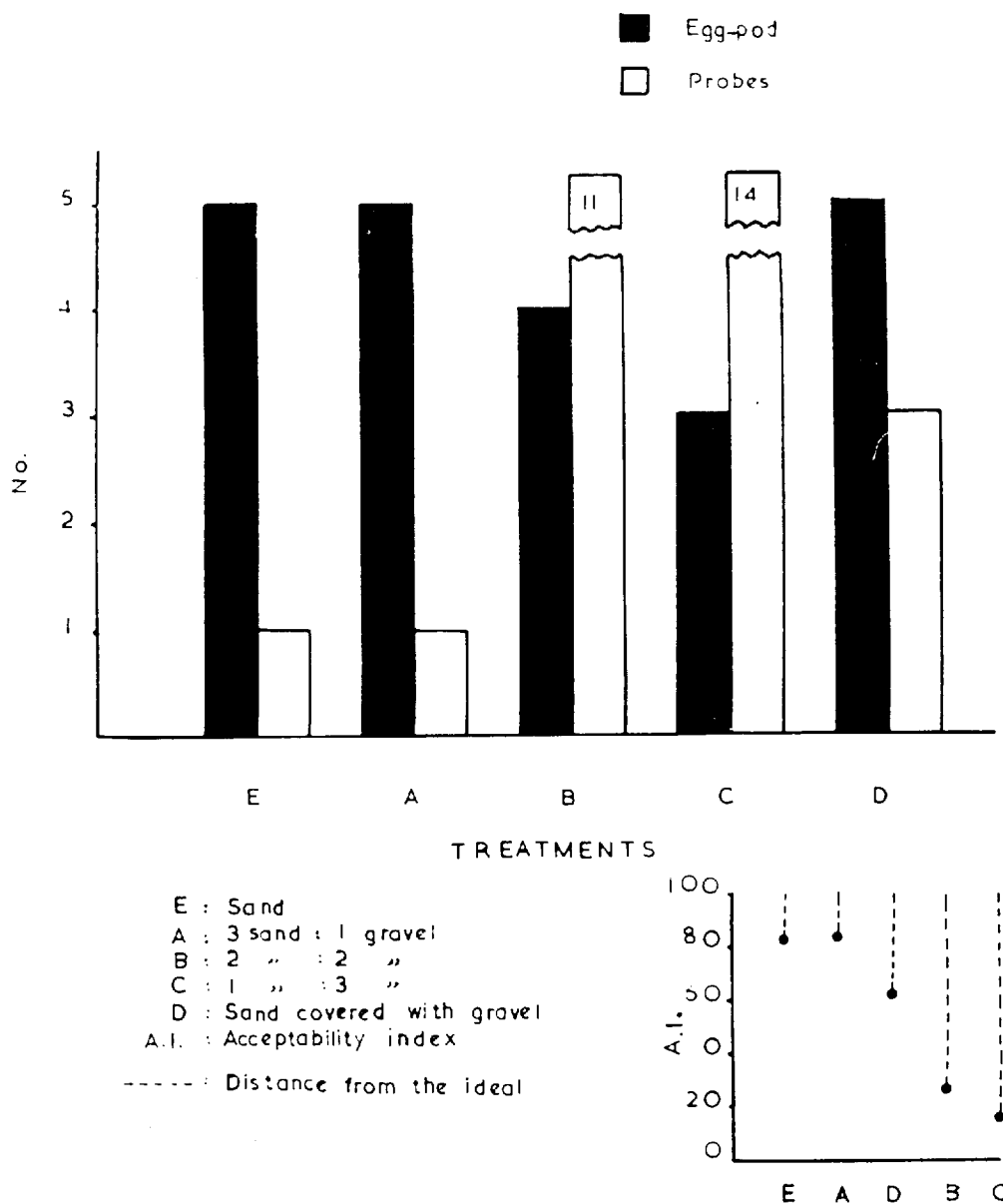
The results with calculated acceptability indices are tabulated in table 2. The numbers of trial bores and egg-pods are graphically represented in Fig. 15. Fig. 15 also shows the A.I. for each treatment as well as the deviation of the different treatments from the theoretical ideal.

Table 2. Numbers of egg-pods, trial bores and calculated acceptability indices. (Experiment I)

| Item              | Soil types                     |                             |                            |                                      |               |
|-------------------|--------------------------------|-----------------------------|----------------------------|--------------------------------------|---------------|
|                   | 3 parts sand:<br>1 part gravel | 2 parts sand:<br>2 " gravel | 1 part sand:<br>3 " gravel | Sandy soil<br>covered<br>with gravel | Sandy<br>soil |
| No. of eggpods    | 5                              | 4                           | 3                          | 5                                    | 5             |
| No. pods on floor | -                              | 1                           | 2                          | -                                    | -             |
| No. trial bores   | 1                              | 11                          | 14                         | 3                                    | 1             |
| A.I.              | 83.3                           | 26.6                        | 17.6                       | 62.2                                 | 83.3          |

The figures show that the desert locust will oviposit even in a mixture of 1 part of sand to 3 parts of gravel by volume. The

FIG. 15



Number of egg-pods and trial probes in mixtures of sand and gravel. The graph below shows the acceptability indices.

acceptability index shows that the sand and the mixture of 3:1 sand and gravel are of equal suitability. Sand overlaid by gravel was also better than 2:2 sand and gravel. Oviposition occurred relatively infrequently, there were many more incomplete trial probes and the females spent much time in egg-laying in the sand and gravel mixed in the proportion 1:3; the time taken for deposition of one of the egg-pods was four hours and Fig. 17 shows this particular egg-pod when it was 10 days old. In contrast Popov (1958) found that the usual time required for laying one pod was  $1\frac{1}{2}$  to 2 hours. Husain (1932) gave 2 hours 20 minutes for the completion of egg-laying. Ballard et al (1932) stated a minimum of one hour and a maximum of 2 hours 47 minutes for 116 females which they observed.

Experiments on significance of soil moisture in choice of oviposition

sites:

In site II, the soil water content of the clay-gravel slopes was greater than that of the intervening sandy soil. This indicates that in the field, the desert locust may prefer the humid sites, even if their topography and soil structure are not suitable.

Experiments were done to study this problem.

Experiment 2: Two cages were used as described in experiment I.

A slight modification was made in the perforated zinc floor to meet the requirement of this experiment. Instead of one hole in the floor, two 6 cm. diameter holes were made in which flat bottomed



Fig. 16: Above: Illustrates the flower pots used in experiment I (sand covered with gravel, matchsticks indicate the position of the egg-pods).

Fig. 17: Below: Abnormal egg-pod laid in gravelly soil.

aluminium tubes 6 cm. in diameter and 12 cm. in height were placed with their tops flush with the cage floor. One of the tubes was filled with a comparatively dry sand (2.3 cc. water/100 gms. of sand = 10% saturation) covered with 2 cm. of dry sand. The other tube was filled with wetter sand (11.3 cc. water/100 gms. sand = 50% saturation), with 2 cm. of gravel above it. A pair of mature locusts was put in each cage and oviposition was observed during the day time. Five replicates were achieved by doing the experiments in successive days. The tubes were checked and replaced by new ones every day. Their positions were interchanged after each daily examination. A fresh pair of mature locusts was introduced to the cage after the old one had deposited an egg-pod.

Results: The data obtained are recorded in table 3 and graphically represented in Fig. 18.

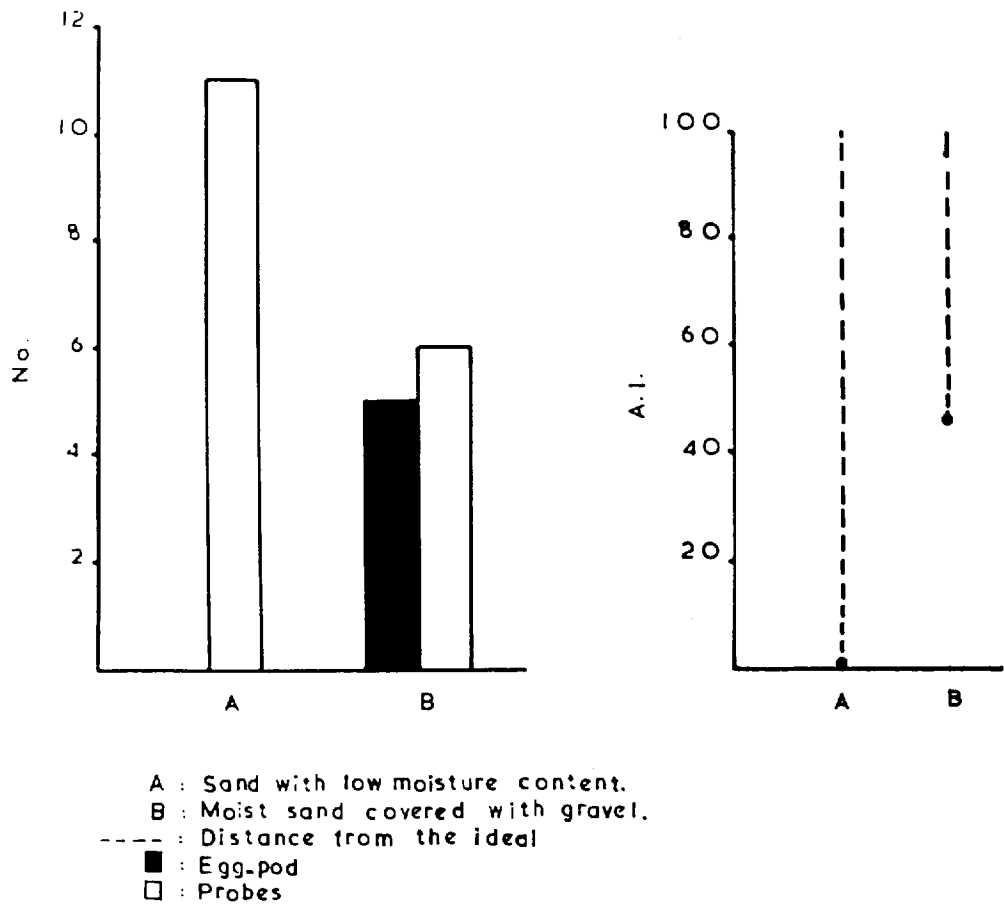
Table 3. Numbers of egg-pods, trial bores as well as the calculated acceptability indices. (Experiment 2)

| Item               | Treatments                      |                                                      |
|--------------------|---------------------------------|------------------------------------------------------|
|                    | Sand with low moisture content. | Sand with high moisture content covered with gravel. |
| No. of eggpods     | 0                               | 5                                                    |
| No. of trial bores | 11                              | 6                                                    |
| A.I.               | 0                               | 45.5                                                 |

Experiment 3: In this experiment two types of soil were offered to the ovipositing locusts:-

- a) Sandy soil with low moisture content, (2.3 cc. water/100 gms. soil = 10 % saturation).

FIG. 18



Number of egg-pods and trial probes as related to soil moisture and structure. The graph on the left shows the acceptability indices.

- b) Sandy loam soil (containing 14.5 cc. water/100 gms. soil = 50% saturation) covered by 2 cm. of gravel.

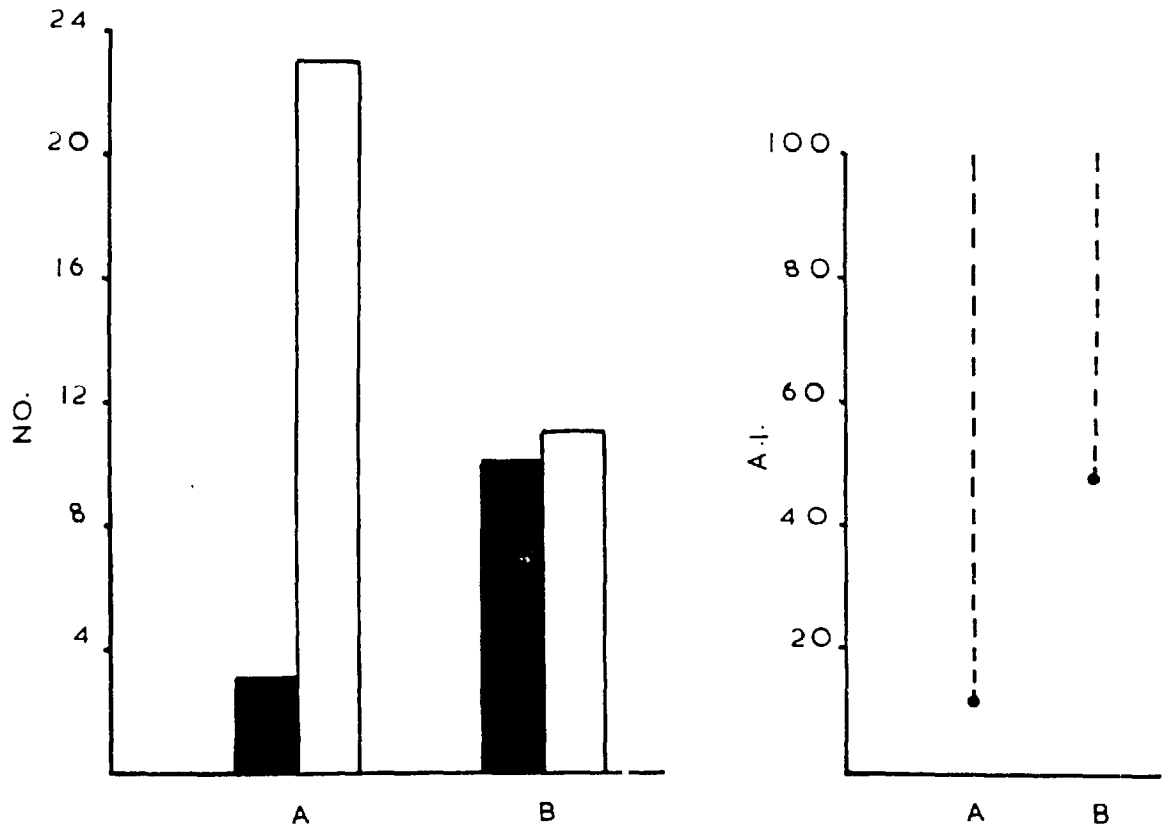
Aluminium tubes 4 cms. in diameter and 10 cms. long were used, and each treatment was replicated 3 times. The tubes were placed at random in a perforated zinc floor of a 25 x 30 x 25 cms. cage and five pairs of mature locusts were put in the cage. Replicates were achieved by doing experiments in three successive days. The total numbers of egg-pods and trial bores are tabulated in table 4, and represented graphically in Fig. 19.

Table 4: Numbers of egg-pods, trial bores and calculated acceptability indices. (Experiment 3)

| Item               | Treatments                            |                                                                   |
|--------------------|---------------------------------------|-------------------------------------------------------------------|
|                    | Sandy soil with low moisture content. | Sandy loam soil with higher moisture content covered with gravel. |
| No. of egg-pods    | 3                                     | 10                                                                |
| No. of trial bores | 23                                    | 11                                                                |
| A.I.               | 11.5                                  | 47.6                                                              |

Tables 3 and 4 <sup>indicate</sup> ~~show~~ that the desert locust preferred ovipositing in media with a high moisture content, even if this was unsuitable superficially and structurally. In experiment 2, no egg-laying occurred in the sand with low moisture content, although relatively more trial bores were recorded, which indicates an absolute preference for moist sites and supports the conclusions of results obtained in the field. The moist site in experiment 3 was unsuitable

FIG.19



A : Sandy soil with low moisture content.  
 B : Moist sandy loam covered with gravel.  
 ■ : Egg-pod  
 □ : Probes

Number of egg-pods and trial probes showing the significance of soil moisture against its texture and structure. The graph on the left shows the acceptability indices.

superficially and in structure and yet the female locust showed a significant preference for it. The acceptability indices proved useful for comparing suitability. In both experiments, A.I. values were higher for moist sites than for drier ones.

Experiments on significance of soil compaction in choice of oviposition sites:

Soil compaction may play a direct and indirect role in the selection of oviposition sites, first because it affects the amount of water available to the egg-pods, and secondly it may mechanically affect the probing process. Popov (1958), studied the behaviour of the desert locust swarms in the field in relation to soil compaction and he showed that the locust rejects compact and hard surfaces. He also found that in a particular site where soil compaction varied (range of compaction from 7 - 122 strokes of a standard penetrometer), the least compact soil was chosen for egg-laying. Choudhuri (1954), also found that the least compact soils were the most attractive for oviposition of several British Acrididae.

Soil compaction can be determined in the field by a soil penetrometer, but in the laboratory, it was found that this was not satisfactory for use in conditions when the treatments were offered to the locust in 4 cms. diameter by 10 cms. long aluminium tubes. The bulk density or weight/volume method was therefore, adopted for laboratory experiments. The bulk density (apparent density) of soil is the mass of soil/unit volume, and the porosity of the soil is

the fraction of soil volume not occupied by soil particles. Increase in bulk density of a particular soil leads to a decrease in its porosity or in the fraction of the soil volume which can be occupied by water or air. Veihmeyer and Hendrickson (1946), stated that plant roots were unable to penetrate <sup>a</sup> ~~the~~ gravelly loam soil when the bulk density exceeded a value of around 1.8 gm/cc., also when the bulk density of medium to fine textured subsoils exceeds 1.7 gm/cc., hydraulic conductivity values will be so low that drainage difficulties can be anticipated. The bulk density method proved satisfactory for preparing soils of different compactnesses. The soils used were the standard sandy soil and <sup>sandy</sup> loam soil.

Experiment 4: The effect of soil compaction on the selected <sup>ion of</sup> oviposition site was determined in this experiment. The standard sandy soil was used. The 4 cm. diameter and 10 cm. long aluminum containers had a volume of 127.7 cc. A lead plunger was used for compressing the sand in the container. The amounts of sand used in loose, pressed and compact treatments were as follows:-

| <u>Treatments</u> | <u>Weight of sand gms.</u> | <u>Bulk density value gm/cc.</u> |
|-------------------|----------------------------|----------------------------------|
| Loose             | 145.1                      | 1.15                             |
| Pressed           | 174.1                      | 1.38                             |
| Compact           | 203.1                      | 1.61                             |

The amounts of air dried sand required, were weighed and 18.8 cc. water/tube was mixed thoroughly with the soil of each replicate. Thus, each replicate contained 15% (v/v) of water. In order to obtain a uniformly compact soil, small volumes of sand were put in turn in the container and pressed with plunger until the container

was filled with the required amount of soil. Nine 4 cms. diameter holes were drilled in the hardboard base of a 56 x 53 x 46 cms. cage of which the roof and the front were of transparent perspex. The other three sides were of perforated zinc. Two opposite sides of the cage were fitted with mirrors. This provided visual stimulation and spatial infinity which made locusts behave as closely as possible to their behaviour in the field. The containers were placed at random with their tops flush with the cage floor. Factors other than soil compaction which may influence the selection of the oviposition site, such as food, light and temperature were eliminated by putting the food in the floor corners; also the cage was placed in an uniformly illuminated constant temperature room at  $32^{\circ}\text{C} \pm 0.5$ .

Result: The results are given in table 5 and Fig. 20.

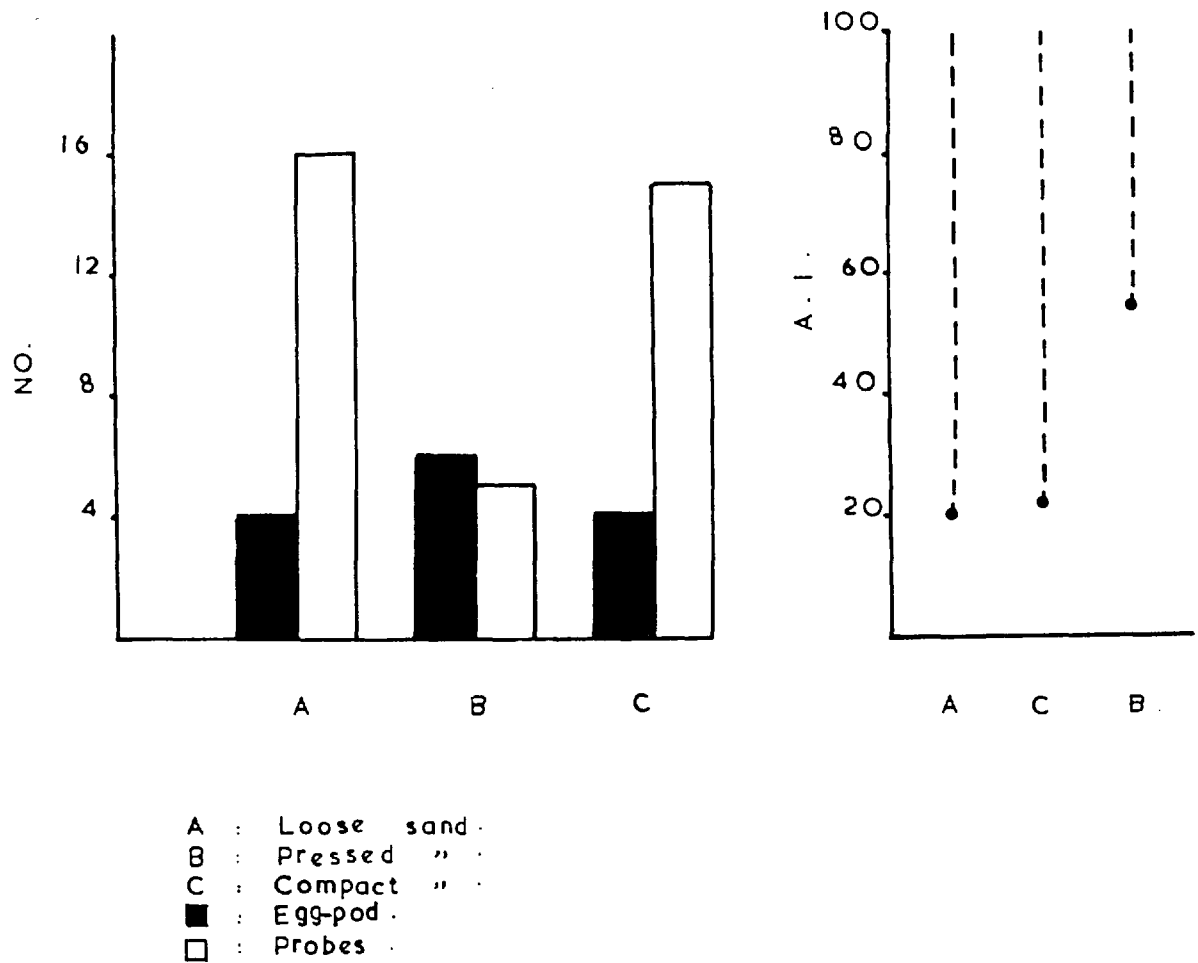
Table 5. Numbers of egg-pods, trial bores and acceptability indices.

(Experiment 4)

| Item            | Treatments |              |              |
|-----------------|------------|--------------|--------------|
|                 | Loose sand | Pressed sand | Compact sand |
| No. of eggpods  | 4          | 6            | 4            |
| No. trial bores | 16         | 5            | 15           |
| A.I.            | 20         | 54.5         | 21           |

These show that the ovipositing desert locust does not respond markedly to the degree of compaction of sandy soil, but, if we consider the number of trial probes in relation to numbers of egg-pods i.e. the acceptability index, a preference for pressed sand is apparent (Table 5). Loose and compact sand seem equally suitable

FIG. 20



Number of egg-pods and trial probes in sandy soil at different compactions. The graph on the left shows the acceptability indices.

for ovipositing i.e. acceptability index of 20 and 21 respectively.

Experiment 5: Sandy loam soil was used in this experiment. The procedure adopted was the same as for experiment 4. Weights of soil used for each treatment and bulk densities were as follows:-

| <u>Treatments</u> | <u>Weights of soil (gms)</u> | <u>Bulk density value gm/cc.</u> |
|-------------------|------------------------------|----------------------------------|
| Loose             | 105.0                        | 0.83                             |
| Pressed           | 146.7                        | 1.16                             |
| Compact           | 188.5                        | 1.49                             |

Result: The data obtained is given in table 6 and Fig. 21.

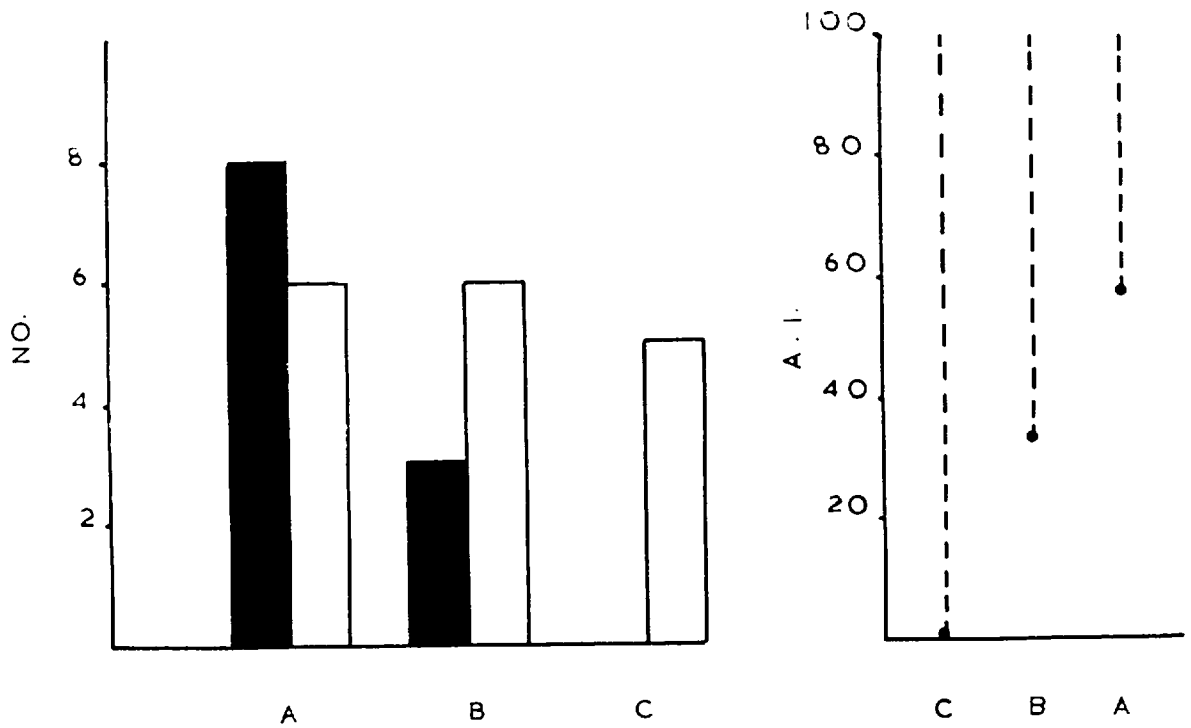
Table 6. The number of egg-pods laid, the number of trial bores by S. gregaria and the acceptability index of different compacted sandy loam soil.

| Item               | Treatments |         |         |
|--------------------|------------|---------|---------|
|                    | Loose      | Pressed | Compact |
| No. of egg-pods    | 8          | 3       | 0       |
| No. of trial bores | 6          | 6       | 5       |
| A.I.               | 57.1       | 33.3    | 0       |

Table 6, <sup>indicates</sup> ~~shows~~ that loose sandy loam soil is more suitable for oviposition than pressed sandy loam soil

Whereas compact soil was most unsuitable and had an A.I. of zero. Many attempts of digging were noticed in compact soil, but this amounted mainly to scratching the soil surface. Records were made only of those occasions when a hole was bored.

FIG. 21



A : Loose sandy loam.  
 B : Pressed " " :  
 C : Compact " " :  
 ■ : Egg-pod .  
 □ : Probes .

Number of egg-pods and trial probes in sandy loam soil at different compactions. The graph on the left shows the acceptability indices.

Experiment 6: Experiment 4 and 5, showed that the locust tends to oviposit in pressed sandy soil and loose sandy loam soil. Experiment 6 was done to find out which of these two situations was preferred. Pressed sandy soil and loose sandy loam were made up as described in experiments 4 and 5. Each treatment was replicated 3 times. The position of the tubes in the cage was assigned at random in a cage similar to that used in experiment 3. Fifteen mature pairs were introduced into the cage and the tubes were changed every morning. Egg-laying and probing were recorded as before.

Results: The results are given in table 7 and Fig. 22.

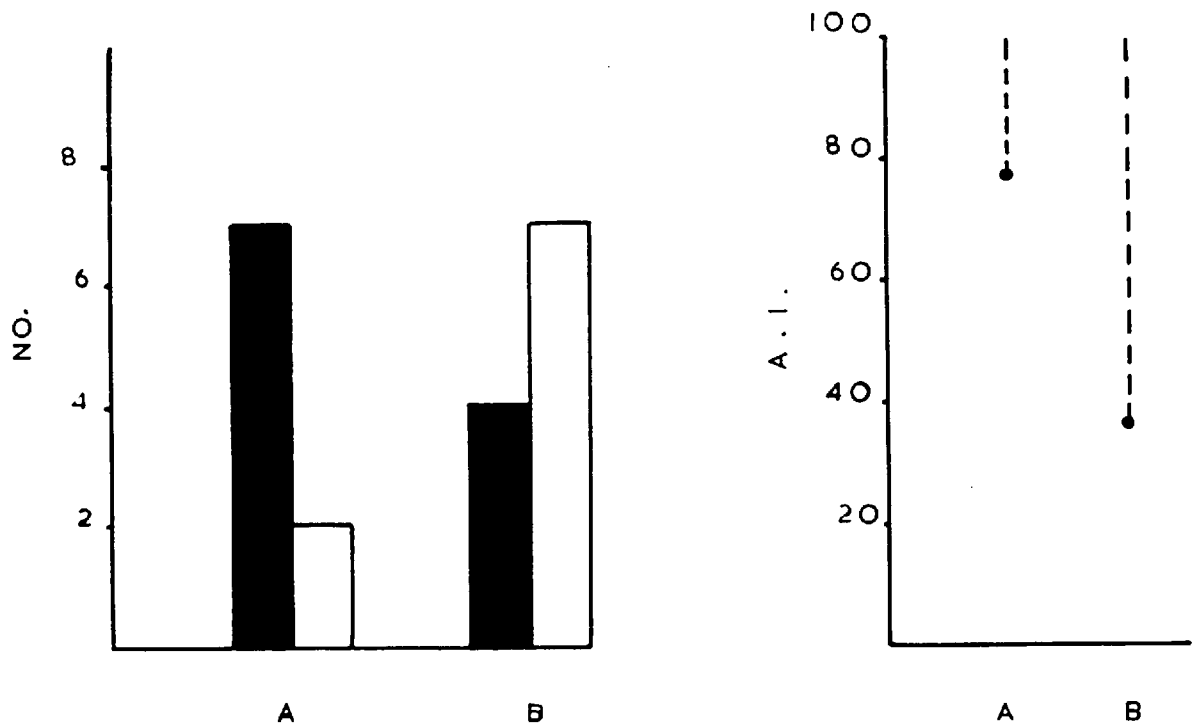
Table 7. The number of egg-pods laid, the number of trial bores and the acceptability index of pressed sandy soil and loose sandy loam.

| Item               | Treatments          |                   |
|--------------------|---------------------|-------------------|
|                    | Pressed sandy soil. | Loose sandy loam. |
| No. of eggpods     | 7                   | 4                 |
| No. of trial bores | 2                   | 7                 |
| A.I.               | 77.7                | 36.4              |

*indicates*  
Table 7 ~~shows~~ that the desert locust preferred the sandy medium

Experiment 7: Experiment 5 shows that the ovipositing desert locust prefers loose sandy loam soil to pressed or compact soil. The bulk density for compact sandy loam soil (in which no eggs were laid) was 1.49 gms/cc. Experiment 7 was done to find out the

FIG. 22



A : Pressed sandy soil.  
 B : Loose „ loam soil.  
 ■ : Egg pod.  
 □ : Probes

Number of eggpods & probes in pressed sandy and loose sandy loam soils. The graph on the left shows the acceptability indices.

ability of the desert locust to lay in compact sandy loam soil as well as to determine the maximum compaction acceptable for egg-laying. Three degrees of compaction were offered simultaneously over a period of 3 days to mature locusts. The laying media in each set was three aluminium tubes filled with sandy loam soil of a known compaction in a cage as described in experiment 3 and the tubes were changed everyday. Treatments were prepared as described on page 38. The amounts of soil compaction were expressed in bulk density and were as follows:-

First set = Bulk density value of 1.49 gm/cc.

Second set = " " " " 1.33 gm/cc.

Third set = " " " " 1.20 gm/cc.

Locusts did not oviposit in the two most compact soils i.e. 1.49 gm/cc and 1.33 gm/cc., and the females laid their eggs on the cage walls. Six egg-pods were recorded in the soil with a bulk density of 1.2 gm/cc. It seems that the upper limit of bulk density for sandy loam soil is therefore about 1.2 gm/cc.

Experiments on the effect of soil temperature on the selection of oviposition site:

Popov (1954), reporting field observations on oviposition behaviour of desert locust swarms, stated that mass oviposition was restricted to times when the temperature ranged from 22.5°C to 33.3°C. Stower et al (1958) mentioned that adults of the desert locust aggregated on east facing slopes in the morning and west facing slopes in the evening, which possibly enabled them to take

advantage of higher soil surface temperature or air temperature close to the ground. Field observations at site II (page 10 ), showed that oviposition occurred mainly on the west facing slopes where the soil surface temperature was higher by 4°C than elsewhere. An experiment was therefore done in the laboratory to find out the range of soil temperature preferred for oviposition.

Experiment 8: A rectangular tray 27" x 18" x 5" high filled with moist sand, was used as the oviposition site (Fig. 23). The base and the two longitudinal sides of the tray were made of wood and the remaining sides of galvanised iron sheet. One metal side was heated and the other cooled. Heat was provided by two heating mats controlled by a Sunvic thermostat and relay. The thermostat was adjusted to cut off the current when the sand temperature adjacent to the heating plate reached 70°C. The cool end consisted of a metal chamber 18" x 2.5" x 5" with outer walls insulated and a drainage tube at the bottom. The chamber was filled with ice which was replenished as required. The sand in the tray was moistened by 15 parts of water to 100 of sand v/v except for the top 2 cm. which was unmoistened sand. The oviposition tray was covered with a 27" x 18" x 18" cage consisting of a wooden frame, Tygan sides and perspex top. The experiment was done in a constant temperature room at 32°C. The apparatus was switched on for three days before the experiment was commenced and soil surface temperatures as well as soil temperatures at a depth of 2" were recorded at  $\frac{1}{2}$  hourly intervals during the day. Temperature measurements were made by

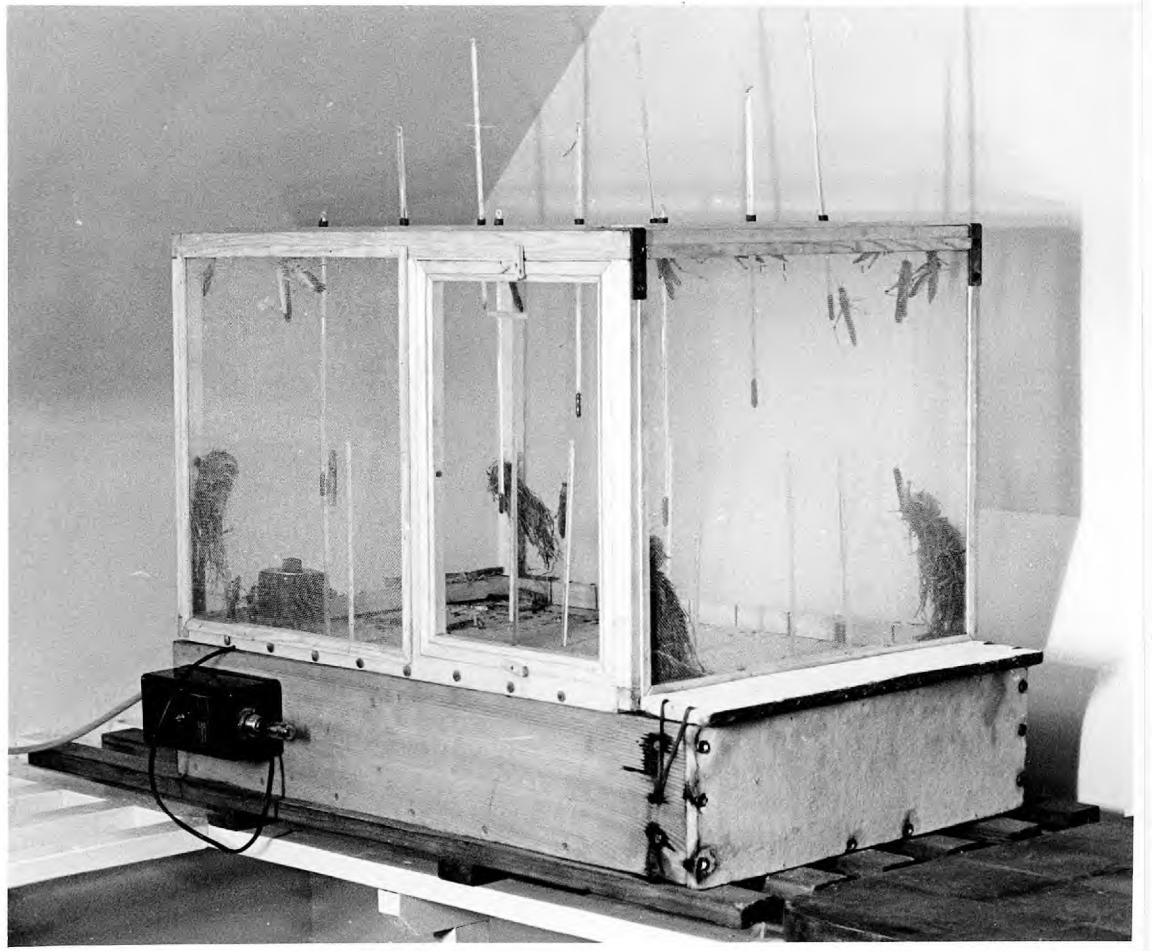


Fig. 23: Cage used in the soil temperature experiment.

means of a thermistor Bridge at the sand surface and by a number of mercury-in-glass thermometers at 2" depth. The mean temperature readings  $\pm$  s.d. for each zone are shown in Fig. 24. It was found that three hours were needed to obtain an equilibrium between sand and room temperature, leading to the stabilisation of various graded isothermal zones in the laying bed. Thirty locusts which were ready to lay were introduced into the cage three hours after switching on the apparatus. Observations were taken during day time after which the apparatus was switched off and the locusts were collected in another cage untill the next morning and so on.

Fig. 25, illustrates the distribution pattern of the egg-pods laid as well as the trial bores made in the tray of a sand. Most egg-pods were laid in zone B ( $42 - 60^{\circ}\text{C}$ ), followed by zone C ( $32 - 42^{\circ}\text{C}$ ) and zone E ( $26 - 28^{\circ}\text{C}$ ). The data obtained was subjected to correlation coefficient analysis which gave a value of  $r$  of 0.96, which is significant at  $P < 0.05$ . The results of this experiment indicate a positive correlation of oviposition with soil temperature. In the field, during the locust season the soil surface temperature is generally higher than soil temperature at different depths during the day time (Williams 1927 and personal observations). The females were attracted to warm sites for basking, which is followed by probing to investigate the suitability of the soil environment for egg-laying, i.e. in terms of temperature, moisture, compaction ... etc. In the present work, it appears that the locust was attracted to the warmer sites for basking and, when probing commenced, they

FIG. 24

Temp. gradient zones at the oviposition bed

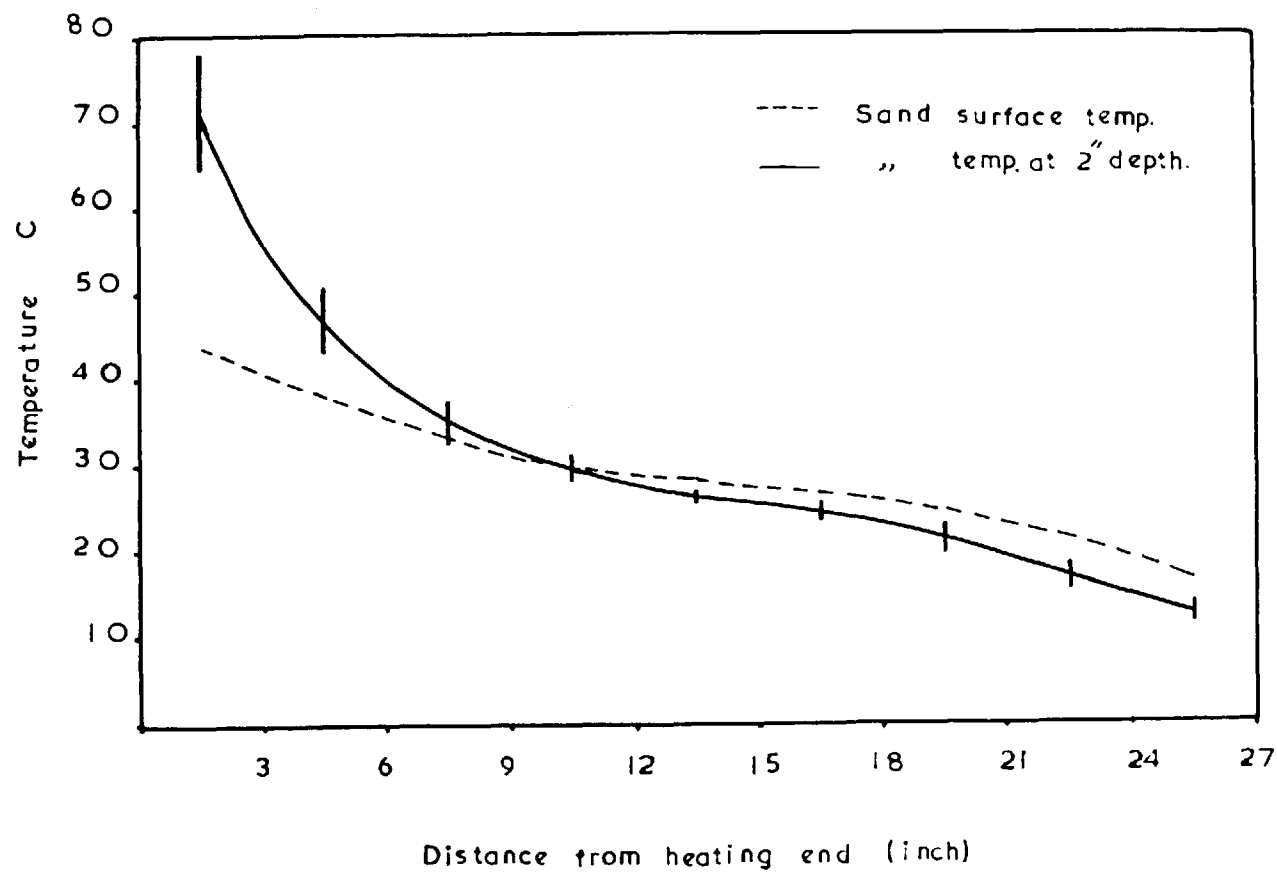
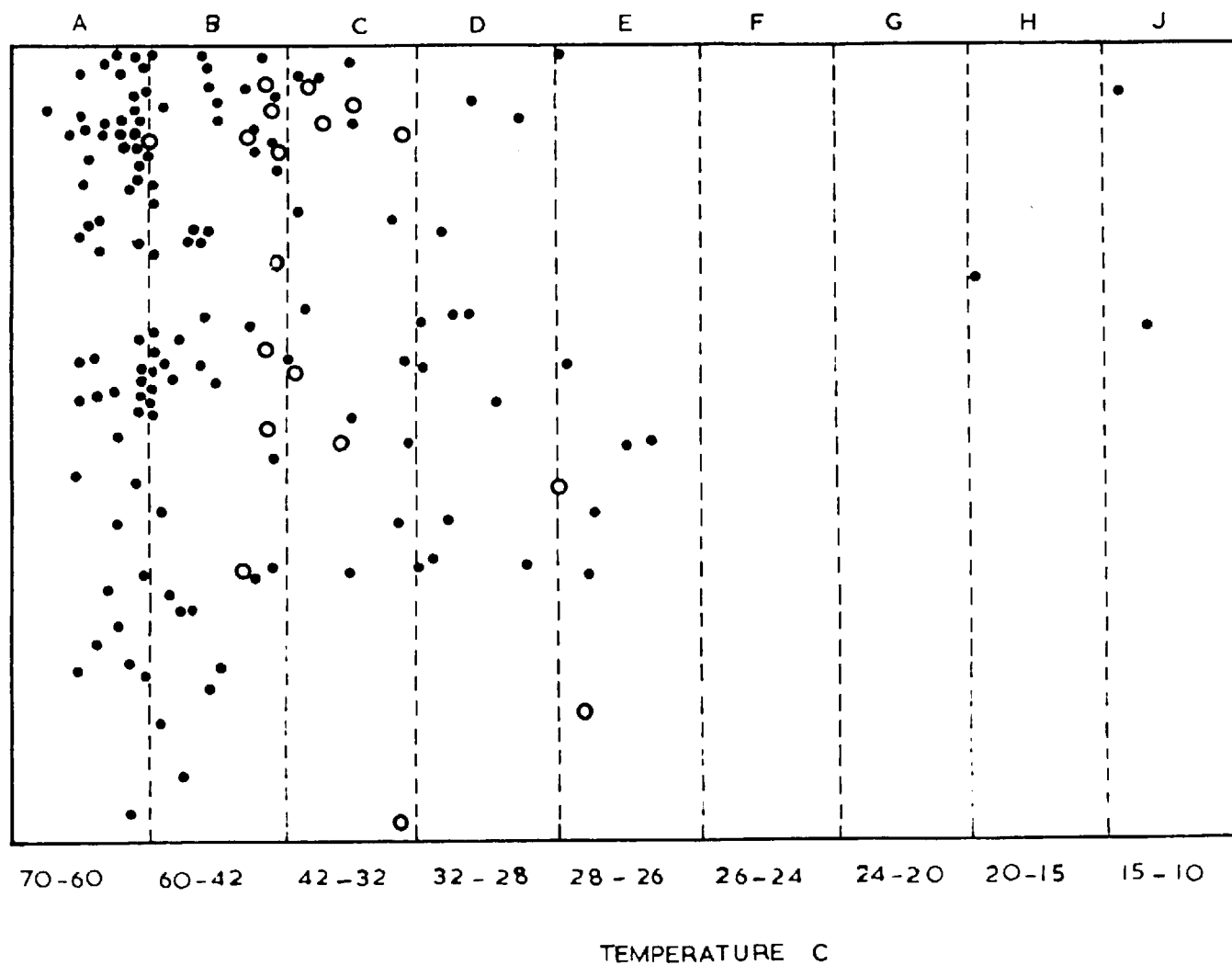


FIG. 25

Distribution pattern of egg-pods & trial probes.

○ egg pods  
● probes



found that the underlaying sand temperature was too high for oviposition (Fig. 24). This may explain the large number of trial bores but no oviposition in zone A (70 - 60°C at 2" depth, and 44°C at the surface). The maximum number of egg-pods was recorded in zone B, (42 - 60°C at 2" depth and 39°C at the surface), but there were also many trial bores indicating that here also the zone was more suitable in its surface temperature than at 2" depth. The distribution pattern of egg-pods in Fig. 25 shows that most egg-pods in zone B, was close to zone C where the average soil temperature is less. The sand temperature at a depth of 2" was recorded in the area adjacent to the egg-pod directly after each egg-pod was observed to be laid. The highest temperature recorded in this was 52.5°C (soil surface temperature was 40°C) which is far above the maximum for embryonic development. The minimum 28°C was in zone E with a soil surface temperature of 29°C. Most of the egg-pods laid in zone B did not hatch, although they were exposed to high temperature for 2 - 5 days and only during the day time.

The acceptability indices calculated from the data, showed that the most acceptable zone for egg-laying was zone C at 32°C - 42°C with a surface temperature around 35°C, followed by zone E (28°C) with a surface temperature of about 29°C, and lastly by zone B (42 - 60°C) with a surface temperature of 39°C. The acceptability index gives a more accurate indication of best temperature for egg-laying and embryonic development. These results indicate that when the ovipositing locust has the choice, the minimum acceptable

soil temperature would be a surface temperature of 29°C and soil temperature of 28°C, although it can lay in soil at a temperature as high as 52.5°C. The optimum for egg-laying is when the surface temperature is around 35°C and the temperature at a depth of 2" is 32 - 42°C. Thus, it appears, that attraction to the oviposition sites is governed by soil surface temperature, but the act of egg-laying depends on the temperature of the soil where the egg-pods will be deposited.

PART TWO

EFFECT OF SOIL MOISTURE AND SALINITY ON THE DEVELOPMENT  
OF THE DESERT LOCUST EGGS AND HATCHING LARVAE.

### Introduction.

Soil moisture plays a vital part in the lives of all animals inhabiting semi-arid and arid zones. This is especially true of insects like grasshoppers and locusts which oviposit in soil. The vegetational cover also varies with increase or decrease of soil moisture. This affects the quality and quantity of available food and shelter, and hence the population density of the locusts.

For example, Ashall and Ellis (1962) found that during seasons of low rainfall, the number of eggs/pod of S. gregaria was significantly reduced. The development of desert locust eggs in relation to humidity was first studied by Bodenheimer in 1929. He found that the egg-pods which has completed approximately one third of their development under normal conditions of temperature and soil moisture gave a reasonable hatch even when removed from soil, providing they were kept in a saturated atmosphere. Since then, several studies have been made on the role of water in the development of locusts and grasshoppers eggs. Salt (1949, 1952) showed that for Melanoplus bivittatus Say., contact water is necessary for egg development. Shulov (1952) and Roonwal (1954) studied the increase in weight of the desert locust egg and both showed that it nearly doubled its weight during development. Blackith (1961) found differences in the percentage moisture content of the two sexes issuing from the same S. gregaria pod; the females contained more water than the males. He considered that the weight difference

of the hatching larvae may be due to moisture conditions of the soil in which incubation takes place. However, Hunter-Jones (1964) concluded that the weight of S. gregaria hatchlings was to some extent related to the amount of water in the soil, but he could not show this to be statistically significant. He mentioned that the coloration of the hatchlings and their subsequent mortality were not related to soil moisture.

Mature desert locust swarms have been reported to settle on the sea beach (Popov 1958 and Waloff 1963). Popov (personal communication) reported several occasions where females were seen ovipositing in soils showing abundant visible salt deposits. However, no quantitative estimate of salinity of egg fields seems to have so far been recorded.

Achillides (1963) in experiments with desert locust eggs, showed that the LD<sub>50</sub> is about 5‰ of sea water in water. Water absorption by S. gregaria eggs during development, particularly the uptake in a saline soil seems to have received little attention.

The present work includes an attempt to investigate the influence of soil moisture on the desert locust eggs and hatching larvae in both gregaria and solitaria phases.

The effects of sub-lethal doses of sea water on egg development and on the quality and quantity of hatchlings have also been studied.

Some experiments were conducted, to ascertain whether the process of water absorption is a purely physical, depending upon the osmotic pressure of the egg yolk and the media in which incubation takes place.

Definition and Description of Terms.

Soil Moisture:

Desert locust eggs need contact with moisture in the soil in which incubation takes place. Thus, a brief discussion of the meaning of soil moisture would be helpful. The character of the soil pore space determines to a considerable extent the disposition of infiltrated water. The retention of soil moisture depends mainly upon the size and number of the capillary spaces. The retention of the water by soil can be conveniently considered in terms of the changes in moisture status that take place, starting from an air dry soil and increasing the moisture content until the soil is completely saturated.

a: Hygroscopic moisture: A soil, dried in air at ordinary temperature still retains some moisture which is held as a thin film of approximately molecular dimension as a result of attractive forces in the surface of the particles.

b: Imbibitional moisture: Most soils contain appreciable amounts of clay and organic matter present as soil colloids. When water is added to air-dry soil, the colloids begin to absorb water of imbibition, swelling in the process.

c: Capillary moisture: With increasing moisture content, water begins to appear as external films on the surfaces of the soil particles, the so called pendular stage. Further increase in moisture leads to the funicular stage in which the film becomes continuous.

d: Gravitational moisture: As the amount of moisture in the soil increases still further, the larger interstices become filled with water. Finally the pore space becomes completely filled to the exclusion of air and the soil is then saturated or in ordinary terms water-logged.

The sites of absorption of water by the egg:

"The egg of S. gregaria is slightly curved more or less cylindrical and tapers towards both ends, which are rounded. According to Imms (1930) definition, the pole of the egg which is cephalad when the egg is in the ovary or in the egg calyx is the anterior pole. This is upper or nearest the mouth of the burrow when the egg is in the soil. It is narrower than the opposite pole, which is slightly flattened. The micropylar apparatus which consists of a complete ring of canals is situated near the posterior pole (Uvarov 1928). Each micropylar canal is an elongated, funnel-shaped, narrow, chitinous tube running longitudinally towards the posterior pole of the egg. The mouth of the funnel appears on the surface of the egg as an oblique, shallow depression. The canals tranverses the vitelline membrane and finally opens into the anterior of the egg by means of an extremely fine opening. The number of micropylar canals varies as does the length of individual canals" (Hussein and Roonwal 1933). Mathur (1944) mentioned that this specialized micropylar area functions as a site of water absorption from almost immediately after the egg is laid. He reported that newly laid eggs embedded in moist soil

except for their posterior tip, began to suffer from moisture deficiency within the first 24 hours.

Materials and Methods.

Locust and Egg-pods:

(a) Gregarious stock: The experimental locusts S. gregaria were kept under crowded conditions and hence were of the gregarious phase. The breeding cages were fitted with 60 W. electric lamps lit for 13 hours/24 hours. The temperature was  $32 \pm 1^{\circ}\text{C}$  during the day and  $28 \pm 1^{\circ}\text{C}$  at night and R.H. was about 50%. Three inch diameter flower pots fitted with moist sand were used for egg-laying. Their tops were flush with the wooden floor of the cages. The pots were replaced by new ones every night and were examined for egg-pods every morning except where otherwise stated. The egg-pods collected in this way were considered as 0 - 14 hours old.

(b) Solitary stock: The culture of the solitary stock was started with 421 larvae hatched from five egg-pods obtained from parents breed in solitary conditions for 50 generations. The egg-pods were kindly provided by Dr. F.O. Albrecht (Laboratoire d'evolution des etres Organises, Paris). Most of the hatchlings (86.4%) was green, and the rest (13.6%) was blackish. The larvae were reared individually in  $\frac{3}{4}$  litre glass jars until just before the final moult when they were each transfered to cylindrical celluloid oviposition cages (capacity 8.4 litres). In the larval stage as well as in the adult stage the locusts were kept completely isolated by surrounding each jar or cage with a white paper so that they could not see

each other. Fifteen days after the last moult, one male was introduced into each cage containing adult female. The male was left for 12 hours for copulation after which it was removed. The solitaria were bred under the same temperature and R.H. conditions as the gregarious stock. The locusts were fed daily on Brussel sprouts Brassica oleracea gemmifera and on bran mixed with yeast. The oviposition cages were fitted with a false perforated zinc floor in which a 3" diameter flower pot of sand was placed. In another set of experiments, aluminium tubes 4 cm. in diameter and 10 cm. in height were used instead of flower pots. The egg-pods were collected immediately after laying and in some occasions in the morning to be considered 12 hours old. The morphometrics of the adults were recorded according to Dirsh (1953), the measurements being confined to the elytron length E, femur length F. The average for the ratio E/F was 1.99 ♂ and 2.09 ♀. All the adults possessed seven eye stripes, indicating a solitary phase.

Soil:

The two kinds of soil (sandy, sandy loam) used in the earlier experiments (part I) were also used in these experiments.

Temperature:

Incubation of the egg-pods was at a constant temperature of 27°C or 32°C in thermostatically controlled cabinets in which the fluctuation in temperature was  $\pm 0.5^\circ\text{C}$ .

Sea water:

Artificial sea water was prepared by dissolving the following

constituents in 100 cc. distilled water:-

| salt                                 | g/100 ml. | gm. Mol/litre (molar) | O/P <u>atms.</u> | <del>cc</del> |
|--------------------------------------|-----------|-----------------------|------------------|---------------|
| Na Cl                                | 2.656     | 0.452                 | 18.204           | 75%           |
| Mg SO <sub>4</sub> 7H <sub>2</sub> O | 0.679     | 0.028                 | 1.921            | 100%          |
| Ca Cl <sub>2</sub> 6H <sub>2</sub> O | 0.221     | 0.010                 | 0.692            | "             |
| Mg Cl <sub>2</sub> 6H <sub>2</sub> O | 0.500     | 0.028                 | 1.729            | "             |
| K Cl                                 | 0.075     | 0.010                 | 0.432            | "             |
| Na H CO <sub>3</sub>                 | 0.019     | 0.002                 | 0.005            | "             |
|                                      |           |                       | <u>22.98</u>     |               |

The osmotic pressure of this artificial sea water is 22.98 atms. at 32°C. Calculations of the osmotic pressure was done by the following equation:-

$$P \times V = n RT$$

$$P = \frac{n}{v} RT$$

$$= (1 + \alpha) \frac{n}{v} RT$$

Where  $\alpha$  = % ionisation of the salt

$n$  = No. of gm./molecules

$v$  = Nos. of litre

$\frac{n}{v}$  = gm. mols/litre

$R$  = constant (0.0821 litre atmosphere

#### Preparation of soils with different water content:

The saturation point (saturation percentage) of the sand and

sandy loam was considered as a standard (100% saturation) for preparing sand with variable amount of water. The following procedure was adopted to determine the saturation point on the amount of water that 100 grammes of soil requires to become saturated (United States salinity laboratory, Agric. Handbook No. 60).

1. A weighed sample of air dried soil was put in a clean dry mortar.
2. Small increments of distilled water were added and meanwhile the soil was thoroughly stirred, smoothed off and kneaded with a spatula.
3. The soil-water mixture was consolidated from time to time during the stirring process by tapping the container on the work bench.

At saturation, the soil paste glistens as it reflects light, flows slightly when the container is tipped, and slides freely and cleanly off the spatula. On smoothing the surface of the soil with a spatula and placing a drop of water on the smoothed surface, it is not immediately absorbed, but instead spreads out and glistens. After mixing, the sample should be allowed to stand for an hour or more, and then the criteria for saturation should be rechecked. Free water should not collect on the surface nor should the paste stiffen markedly or lose its glistening appearance on standing. At this point the soil was completely saturated to the exclusion of air, and all the pore spaces were filled with water. The amount of water required to saturate 100 gms. of sand and sandy loam soil were 23 cc. and 29 cc. respectively. In order to obtain soil

of 50% saturation, half the amount of water was added to 100 gms. of soil and thoroughly mixed with a spatula. By means of this method, soils with variable levels of saturation were prepared starting from 5% saturation up to 100%.

Statistical analysis:

The results of all statistical tests are given in terms of the value of P. A probability of 5% is taken as a division between significance and non-significance, so that when  $P < 0.05$ , the difference between the values compared is significant.

Experiments at  $27 \pm 0.5^{\circ}\text{C}$

Egg-pods of Gregaria.

Experiment I: Effect of Soil Moisture in Sandy Soil on Egg  
Development and Hatchlings.

The egg-pods used were 0 - 14 hours old. They were removed very carefully from the soil in which they had been laid and cleaned from all the adherent particles of sand. Only complete undamaged egg-pods were used. The amount of water required for each treatment was added to the weighed sample of sand and mixed carefully and quickly. Moistured soil was then put in 8 oz. glass jars with plastic lids, leaving 5 cm. between the soil surface and the lid. One previously cleaned egg-pod with its froth-plug was transferred very carefully to a hole made in the sand at the middle of each container, equal to its length. Care was taken in planting the egg-pod in its new surrounding to leave a distance of 2 cm. between the uppermost egg in the egg-pod and the surface of the sand. The container was then closed very firmly and water-proofed by brushing its cover with two layers of shellac dissolved in 95% alcohol. The egg-pods were thus incubated in a sand of known water content until the time of hatching. The containers were labelled and transferred to a constant cabinet at  $27^{\circ} \pm 0.5^{\circ}\text{C}$ . The time required for this procedure was about 10 minutes for each egg-pod.

Treatments: Sandy soils with different saturation levels were

replicated five times. The grades of saturation used and the amount of water added to 100 gms. of soil in each treatment were as follows:-

|                           |     |     |     |     |     |     |     |      |      |      |      |      |      |
|---------------------------|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|
| % Saturation              | 5%  | 6%  | 8%  | 10% | 20% | 30% | 40% | 50%  | 60%  | 70%  | 80%  | 90%  | 100% |
| cc. Water/<br>100gm. Soil | 1.1 | 1.3 | 1.8 | 2.3 | 4.6 | 6.9 | 9.2 | 11.5 | 13.8 | 16.1 | 18.4 | 20.7 | 23   |

### Results:

1. Time from egg-laying until hatching: Hatching was observed daily from 15 days after the beginning of incubation. Hatchlings were collected within 6 - 12 hours of emergence and the times recorded. The containers were closed again after each examination.

Table 8. Length of the egg stage of S. gregaria eggs kept in sand of different moisture contents at 27°C.

| % Saturation<br>of sand | Mean of each Replicate in days |    |     |    |    | Overall mean    |
|-------------------------|--------------------------------|----|-----|----|----|-----------------|
|                         | I                              | II | III | IV | V  |                 |
| 6%                      | 19                             | 17 | 17  | 17 | 18 | 17.6 $\pm$ 0.8  |
| 8%                      | 17                             | 18 | 18  | 19 | 19 | 18.2 $\pm$ 0.7  |
| 10%                     | 18                             | 19 | 20  | 18 | 18 | 18.6 $\pm$ 0.8  |
| 20%                     | 19                             | 19 | 18  | 18 | 19 | 18.6 $\pm$ 0.49 |
| 30%                     | 18                             | 19 | 19  | 19 | 19 | 18.8 $\pm$ 0.4  |
| 40%                     | 18                             | 17 | 18  | 18 | 19 | 18.0 $\pm$ 0.64 |
| 50%                     | 18                             | 19 | 18  | 19 | 19 | 18.6 $\pm$ 0.49 |
| 60%                     | 19                             | 18 | 18  | 18 | 18 | 18.2 $\pm$ 0.4  |
| 70%                     | 17                             | 18 | 19  | 19 | 19 | 18.4 $\pm$ 0.8  |
| 80%                     | 18                             | 18 | 18  | 19 | 18 | 18.2 $\pm$ 0.4  |
| 90%                     | 19                             | 18 | 19  | 19 | 17 | 18.2 $\pm$ 0.8  |

The data was subject to  $\chi^2$  test and the calculated value for  $\chi^2$  is 0.1496, which is not significant. It seems therefore that the soil moisture in sandy soil at 27°C, has no effect on the time required for hatch.

2. Percentage hatch: Calculation of the percentage hatch for individual egg-pods was done by counting the hatching larvae and after seven days when no hatchable eggs remained in the containers they were investigated for those hoppers which had hatched but died without appearing on the surface of the sand. These were included among those which had hatched. The eggs that did not hatch were also counted. Table 9 and Fig. 26, show the percentage hatch from individual egg-pods. Table 9 and Fig. 26, show that the range of soil moisture required for hatching in the sandy soil at 27°C was from 6% to 90% soil saturation. At the lower limit (6% saturation) egg-development occurred without interruption. Below the limit (5% saturation), there was not enough water for development and all the eggs died. In sand at the saturation level, where the soil pore spaces were completely filled with water to the exclusion of air the eggs failed to hatch. At 90% saturation the percentage hatch was very low. It seems that the amount of oxygen present was not enough for the development of all eggs.

There was no correlation between the soil moisture and the percentage hatch in soils containing moisture up to 60% saturation. Above 60% the hatch decreased as water content increased. The correlation coefficient value was 0.3919 which is not significant.

FIG. 26

Percentage hatch of  
gregaria eggpods in sandy soil at  
27C as related to soil moisture.

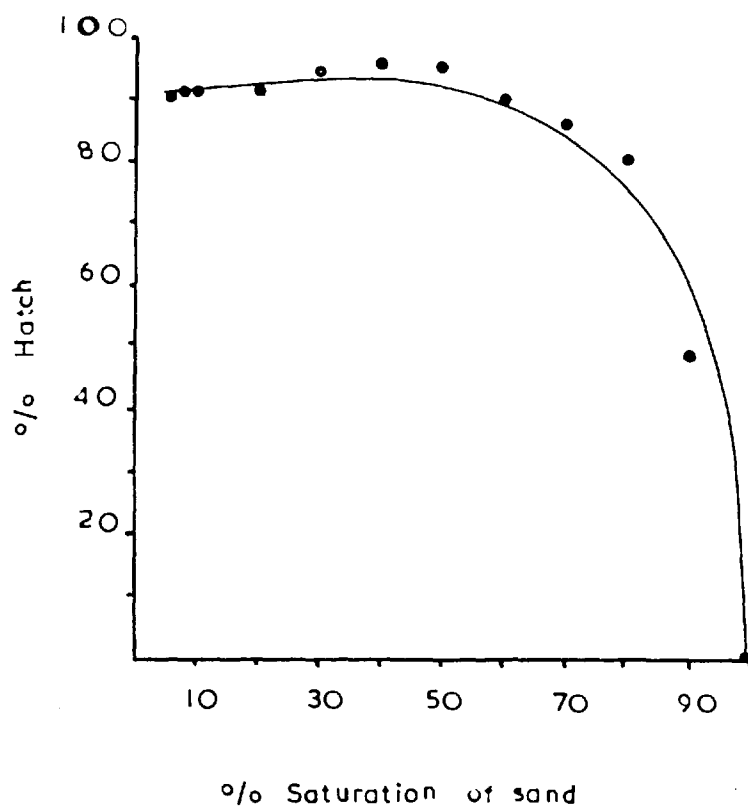


Table 9. Percentage hatch from individual egg-pods at 27°C from sandy soil of different moisture content.

| % Saturation<br>of sand | Replicates |      |      |      |      | Mean |
|-------------------------|------------|------|------|------|------|------|
|                         | I          | II   | III  | IV   | V    |      |
| 5%                      | 0          | 0    | 0    | 0    | 0    | 0    |
| 6%                      | 85.7       | 93.3 | 90.9 | 86.2 | 96.5 | 90.5 |
| 8%                      | 78.6       | 97.8 | 95.3 | 92.8 | 94.1 | 91.7 |
| 10%                     | 87.5       | 90.0 | 96.8 | 91.9 | 92.5 | 91.7 |
| 20%                     | 90.0       | 93.7 | 91.3 | 85.1 | 98.5 | 91.7 |
| 30%                     | 97.1       | 93.5 | 92.8 | 92.0 | 98.0 | 94.6 |
| 40%                     | 96.9       | 92.5 | 95.5 | 94.4 | 100  | 95.9 |
| 50%                     | 95.4       | 91.8 | 100  | 94.8 | 94.7 | 95.3 |
| 60%                     | 96.2       | 95.2 | 92.1 | 87.8 | 82.0 | 90.6 |
| 70%                     | 87.5       | 90.6 | 95.3 | 84.2 | 77.1 | 86.9 |
| 80%                     | 80.3       | 86.6 | 80.2 | 78.7 | 78.4 | 80.8 |
| 90%                     | 44.1       | 36.6 | 64.8 | 60.8 | 41.9 | 49.6 |
| 100%                    | 0          | 0    | 0    | 0    | 0    | 0    |

3. Weight of hatchling: The same levels of soil saturations as used for the incubation period and percentage hatch were used to find out the effect of soil moisture on the hatchling's weight. The hoppers were collected within 6 - 12 hours after issuing from the egg-pods. The cover of each container was removed and it was placed in a covered celluloid cage. As the hoppers left the

container, they were collected individually and put in glass tubes 2.5 cm. in diameter and 7.5 cm. long. They were weighed individually in aluminium pill-boxes using a torsion balance (accuracy  $\pm 50 \mu\text{g.}$ ). The aluminium pill-boxes were stored in an oven at  $110^{\circ}\text{C.}$  When required, they were transferred to a desiccator over phosphorus pentoxide. They were used for weighing the live hoppers after about  $\frac{1}{2}$  hour when their temperature had reached room temperature. The hoppers were then killed by rapid heat-shock and dried for one hour at  $110^{\circ}\text{C.}$  The same weighing procedure was used to obtain the dry body weights. Fifteen larvae were weighed at random from each egg-pod. A total of 45 larvae from three egg-pods represented each treatment.

Tables 10 and 11 show the mean weight of hatchlings  $\pm$  s.d. and the distribution of weights of hatchlings emerging from sandy soils at different moisture levels. For simplicity the percentage frequency of weight of hatchlings was represented graphically in Fig. 27 after categorising the treatments together as follows:-

Category A: including treatments 6%, 8%, 10%, 20% representing light rain.

|   |    |   |   |                    |   |                |
|---|----|---|---|--------------------|---|----------------|
| " | B: | " | " | 30%, 40%, 50%      | " | moderate rain. |
| " | C: | " | " | 60%, 70%, 80%, 90% | " | heavy rain.    |

FIG. 27

Percentage of larvae in different weight categories.

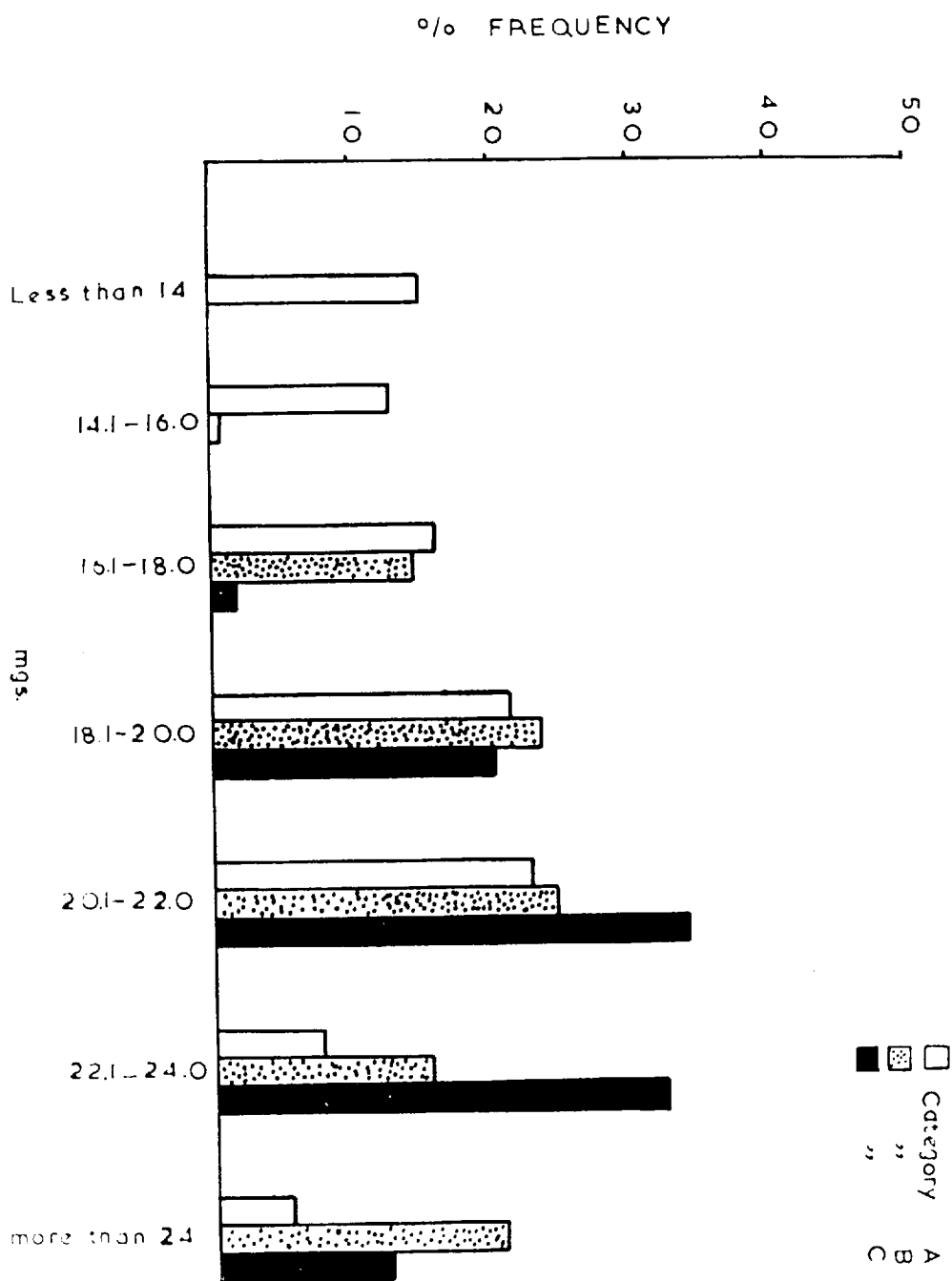


Table 10: Mean weight of hatchlings (mg.)  $\pm$  s.d. from egg-pods incubated at 27°C in sandy soil as related to soil moisture.

|                 | % of Saturation of sandy soil. |       |       |       |       |       |       |       |       |       |       |
|-----------------|--------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
|                 | 6%                             | 8%    | 10%   | 20%   | 30%   | 40%   | 50%   | 60%   | 70%   | 80%   | 90%   |
| Mean $\pm$ s.d. | 13.3                           | 17.4  | 21.3  | 20.5  | 20.6  | 21.5  | 21.4  | 22.1  | 20.9  | 21.9  | 22.3  |
|                 | $\pm$                          | $\pm$ | $\pm$ | $\pm$ | $\pm$ | $\pm$ | $\pm$ | $\pm$ | $\pm$ | $\pm$ | $\pm$ |
|                 | 3.1                            | 2.4   | 2.03  | 1.7   | 3.2   | 2.7   | 2.8   | 1.9   | 1.6   | 2.3   | 1.6   |
| No. of samples. | 45                             | 45    | 45    | 45    | 45    | 45    | 45    | 45    | 45    | 45    | 45    |

Analysis of variance applied to the weights of hatchlings from soils at different moisture levels.

| s.v.       | d.f. | s.s.    | m.s.   | F.       |
|------------|------|---------|--------|----------|
| Treatment  | 10   | 3168.5  | 316.85 | 57.12*** |
| Replicates | 44   | 391.09  | 8.88   | 1.6      |
| Error      | 440  | 2440.97 | 5.55   |          |
| Total      | 494  | 6000.59 |        |          |

Analysis of variance, showed that there was a highly significant difference between the treatments (F: 57.12; n: 10/440;  $P < 0.001$ ).

The correlation coefficient value shows a positive significant correlation between soil moisture and weight of hatchlings

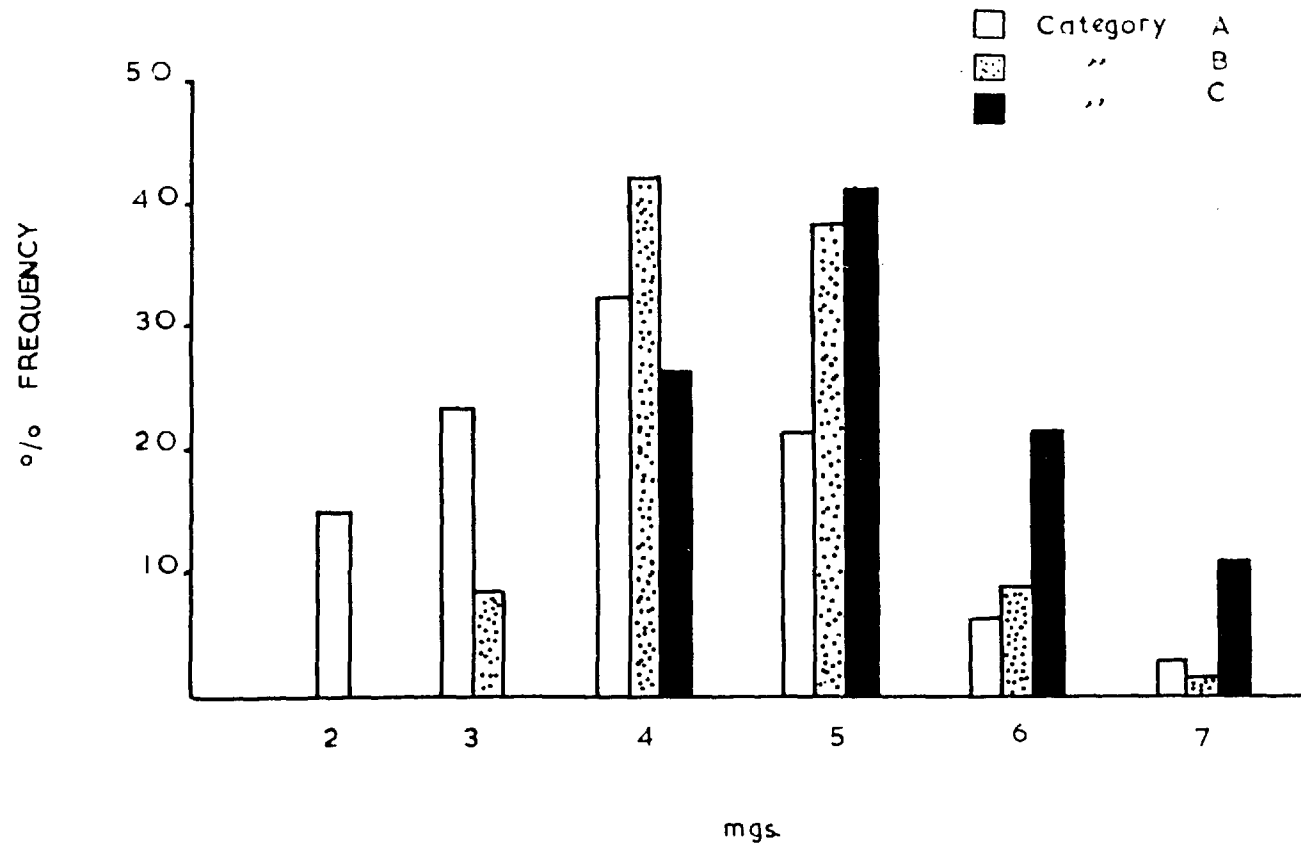
( $r: 0.6510$ ;  $n: 9$ ;  $0.05 < P < 0.02$ ). But it seems that mean weight is significantly decreased only when soil water content is less than 10% of saturation.

Table 11. Showing percentages of larvae in different weight categories.

| 7 satur.<br>of sand | Weights of larvae in mgs. |               |               |               |               |               |                   |
|---------------------|---------------------------|---------------|---------------|---------------|---------------|---------------|-------------------|
|                     | less than<br>14 mg.       | 14.1-<br>16.0 | 16.1-<br>18.0 | 18.1-<br>20.0 | 20.1-<br>22.0 | 22.1-<br>24.0 | more than<br>24.0 |
| 6%                  | 57.8%                     | 15.6%         | 24.4%         | 2.2%          |               |               |                   |
| 8%                  | 2.2                       | 37.8          | 22.2          | 20.0          | 15.6          | 2.2           |                   |
| 10%                 |                           |               | 4.4           | 28.9          | 31.1          | 24.4          | 11.1              |
| 20%                 |                           |               | 11.1          | 33.3          | 44.4          | 2.2           | 8.9               |
| 30%                 |                           |               | 31.1          | 24.4          | 6.7           | 13.3          | 24.4              |
| 40%                 |                           |               | 8.9           | 22.2          | 35.6          | 11.1          | 22.2              |
| 50%                 |                           | 2.2           | 4.4           | 24.4          | 31.1          | 22.2          | 15.6              |
| 60%                 |                           |               | 2.2           | 20.0          | 17.8          | 42.2          | 15.6              |
| 70%                 |                           |               | 2.2           | 37.8          | 35.6          | 20.0          | 4.4               |
| 80%                 |                           |               | 2.2           | 13.3          | 51.1          | 20.0          | 13.3              |
| 90%                 |                           |               |               | 8.9           | 31.1          | 46.7          | 13.3              |

4. Water reserves of hatchlings: Tables 12 and 13 show that the amount of water in mg./mg. dry body weight of the hatchlings as well as water as percentage of total body weight are closely linked with the weight of hatchlings and with soil moisture. The percentage frequency is represented graphically in Fig. 28, after categorizing the treatments as previously described.

FIG. 28



Percentage frequency of water in  $\text{mg/mg}$  dry body weight as related to soil moisture at  $27^{\circ}\text{C}$ .

Table 12. Mean amount of water in mgs./mg. dry body weight as well as water as percentage of total body weight for hatchlings emerging from sandy soil at different moisture levels.

| Item                                                 | % Saturation of sand |      |      |      |      |      |      |      |      |      |      |
|------------------------------------------------------|----------------------|------|------|------|------|------|------|------|------|------|------|
|                                                      | 6%                   | 8%   | 10%  | 20%  | 30%  | 40%  | 50%  | 60%  | 70%  | 80%  | 90%  |
| Mean H <sub>2</sub> O in mg/<br>mg. dry body weight. | 2.9                  | 4.5  | 4.4  | 5.2  | 4.7  | 5.3  | 4.9  | 5.0  | 5.2  | 6.5  | 6.0  |
| Mean H <sub>2</sub> O as % of<br>total body weight.  | 73.8                 | 81.4 | 81.1 | 83.8 | 82.2 | 84.0 | 82.8 | 83.3 | 83.7 | 86.3 | 85.6 |

Analysis of variance applied to the data of water in mgs./mg. dry body weight at 27°C.

| s.v.       | d.f. | s.s.   | m.s.   | F.       |
|------------|------|--------|--------|----------|
| Treatments | 10   | 366.59 | 36.659 | 48.59*** |
| Replicates | 44   | 7.84   | 0.178  | 0.2359   |
| Error      | 440  | 331.96 | 0.7544 |          |
| Total      | 494  | 706.39 |        |          |

Analysis of variance applied to the data of water as percentage of total body weight.

| s.v.       | d.f. | s.s.    | m.s.   | F.       |
|------------|------|---------|--------|----------|
| Treatment  | 10   | 4874.44 | 487.44 | 67.14*** |
| Replicates | 44   | 99.28   | 2.256  | 0.3099   |
| Error      | 440  | 3198.20 | 7.268  |          |
| Total      | 494  | 8171.92 |        |          |

Analysis of variance showed that there was a significant difference between the treatments when water was calculated as amount of water/mg. dry body weight and also as a percentage of total weight (F: 48.59; n: 10/440; p:  $P < 0.001$ ) and (F: 67.14; n: 10/440;  $P < 0.001$ ).

Table 13: Frequency distribution for water in mgs./mg. dry body weight for hatchlings issuing from soils at different moisture levels.

| % saturation of sand. | Water in mgs./mg. dry body weight |      |      |      |      |      |
|-----------------------|-----------------------------------|------|------|------|------|------|
|                       | 2                                 | 3    | 4    | 5    | 6    | 7    |
| 6%                    | 53.3                              | 33.3 | 11.1 | 2.2  |      |      |
| 8%                    | 6.7                               | 20.0 | 44.4 | 20.0 | 6.7  | 2.2  |
| 10%                   |                                   | 37.8 | 37.8 | 17.8 | 4.4  | 2.2  |
| 20%                   |                                   | 2.2  | 35.6 | 44.4 | 13.3 | 4.4  |
| 30%                   |                                   | 17.8 | 44.4 | 35.6 | 2.2  |      |
| 40%                   |                                   |      | 37.8 | 42.2 | 20.0 |      |
| 50%                   |                                   | 8.9  | 44.4 | 37.8 | 4.4  | 4.4  |
| 60%                   |                                   |      | 53.3 | 37.8 | 8.9  |      |
| 70%                   |                                   |      | 35.6 | 55.6 | 8.9  |      |
| 80%                   |                                   |      | 13.3 | 22.2 | 31.1 | 33.3 |
| 90%                   |                                   |      | 2.2  | 48.8 | 37.8 | 11.1 |

5. Colour of the hatchlings: It was noticed that many hatchlings from soil at low moisture levels (6 - 10%) tended to be green. Those from soils at 20 - 90% saturation were black with a very few

green forms. More attention was paid to the hatchling's colour in experiments at 32°C.

Experiment II: Effect of Soil Moisture in sandy loam soil on Egg development.

This experiment was done to find out if the type of soil at different moisture levels influenced development of the eggs. The soil used was loam (chemical analysis p.27 first part), the saturation point being when 29 cc. water was added to 100 gms. of soil. This soil was characterised by turning to a sticky paste at high moisture levels. The same procedure as in experiment I was used to prepare different moisture levels and to determine the incubation period and percentage hatch. The egg-pods were incubated at 27°C. Fewer replicates were achieved than in experiment I because a large stock of standard sandy loam soil was not available.

Treatments: The amounts of water added to 100 gms. of soil for each level of saturation are as below:-

|                            |     |     |     |      |      |      |      |      |      |
|----------------------------|-----|-----|-----|------|------|------|------|------|------|
| 7 soil saturation          | 10  | 20  | 30  | 40   | 50   | 60   | 70   | 80   | 90   |
| ml. water to 100 gms. soil | 2.9 | 5.8 | 8.7 | 11.6 | 14.5 | 17.4 | 20.3 | 23.2 | 26.1 |

Results:

1. Time from egg-laying until hatching: Table 14 shows the times in days from egg-laying until hatching. The data in table 14 was subject to  $X^2$  test and the calculation<sup>ed</sup> value was 0.038 which is not significant. This confirms the conclusion drawn from the first experiment, that the soil moisture has no effect on time required to hatch.

Table 14. Duration of incubation as related to the amount of water in sandy loam soil at 27°C.

| 7 saturation of<br>sandy loam soil | Mean of Replicates in days |      |       |      | Mean        |
|------------------------------------|----------------------------|------|-------|------|-------------|
|                                    | R I                        | R II | R III | R IV |             |
| 10                                 | No hatching occurred       |      |       |      | -           |
| 20                                 | 18                         | 19   | 21    | 20   | 19.5 ± 1.1  |
| 30                                 | 19                         | 18   | 21    | 20   | 19.5 ± 1.1  |
| 40                                 | 21                         | 19   | 19    | 20   | 19.7 ± 0.8  |
| 50                                 | 20                         | 19   | 18    | 20   | 19.2 ± 0.8  |
| 60                                 | 19                         | 19   | 19    | 20   | 19.2 ± 0.4  |
| 70                                 | 18                         | 22   | 22    | 19   | 20.2 ± 1.8  |
| 80                                 | 20                         | 19   | 20    | 20   | 19.7 ± 0.45 |
| 90                                 | No hatching occurred       |      |       |      | -           |
| 100                                | No hatching occurred       |      |       |      | -           |

2. Percentage hatch: Table 15, shows the percentage hatch from individual egg-pods (see also Fig. 29). Table 15 and Fig. 29, show that the range of soil moisture required for egg development and hatching in loam soil at 27°C covers from about 20% soil saturation to about 80%. The curve for percentage hatch (Fig. <sup>29</sup>4) followed the same pattern as for sandy soil. The percentage hatch tended to decrease with increase of soil moisture over 50% saturation level.

FIG.29

Percentage hatch of  
gregaria eggpods in sandy loam  
soil at 27°C.

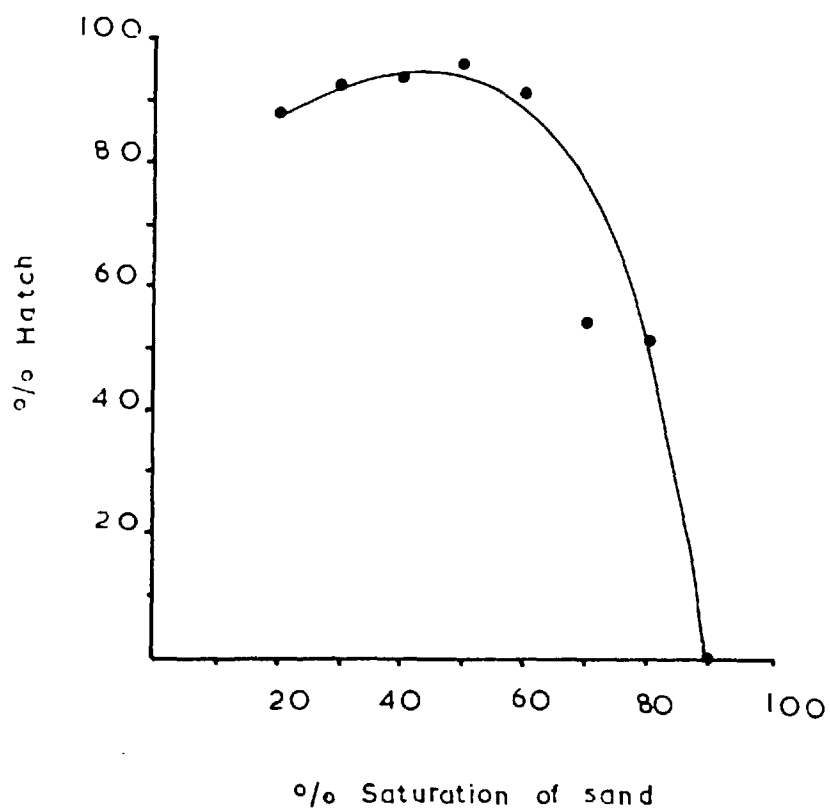


Table 15. Percentage hatch from individual egg-pods kept in loam soil at 27°C.

| 7 saturation of<br>sandy loam soil | Replicates           |      |       |      | Mean       |
|------------------------------------|----------------------|------|-------|------|------------|
|                                    | R I                  | R II | R III | R IV |            |
| 10                                 | No hatching occurred |      |       |      | -          |
| 20                                 | 81.2                 | 90.0 | 92.8  | 91.1 | 88.7 ± 4.5 |
| 30                                 | 93.9                 | 89.6 | 92.0  | 96.4 | 92.9 ± 2.5 |
| 40                                 | 98.3                 | 86.9 | 96.4  | -    | 93.8 ± 4.5 |
| 50                                 | 100                  | 92.0 | 95.3  | -    | 95.8 ± 3.2 |
| 60                                 | 93.5                 | 92.3 | 88.6  | -    | 91.4 ± 2.1 |
| 70                                 | 54.3                 | 54.5 | -     | -    | 54.4 ± 0.1 |
| 80                                 | 55.1                 | 48.2 | -     | -    | 51.6       |
| 90                                 | No hatching occurred |      |       |      | -          |
| 100                                | No hatching occurred |      |       |      | -          |

Experiment III:

This was done to find out if the changes in the weight of hatchlings were due to soil moisture only. Two levels of soil moisture were used, one to represent low moisture namely 10% saturation, and the other optimum humidity for hatching namely 40% saturation. The standard sandy soil was used and the eggs were incubated at 27°C. Four egg-pods 0 - 12 hours old were used. After cleaning each egg-pod, it was split longitudinally into two halves, one of which was placed in each treatment. Thus eliminated differences in results due to differences between egg-pods.

Results:

1. Incubation period: Hatching occurred on the same day in both

halves of the egg-pod. The duration of development in days was 18 days for each treatment.

2. Weight of hatchlings: Larvae were weighed in batches of ten. The mean weights of hatchlings from low and optimum moisture levels were  $17.7 \pm 0.79$  mgs. and  $22.8 \pm 1.6$  mgs. respectively. The difference between the two means is highly significant.

(T: 6.18; n: 8:  $P \leq 0.001$ )

#### Rate of Increase in Weight of the Eggs:

##### Experiment IV:

This was done to follow the changes in weight of S. gregaria eggs under two extreme moisture levels, i.e. 10% and 90% soil saturation. Eggs were obtained from newly laid egg-pods 0 - 14 hours old. They were separated individually and cleaned with a fine brush from the sand particles and the adherent froth material. They were incubated in specimen tubes 2.5 cm. in diameter and 7.5 cm. long at 27°C. For each replicate 9 specimen tubes were filled two thirds with moistened sand for that treatment. Five eggs were weighed and placed in each tube and the tubes corked and waterproofed. As the eggs were liable to damage and loss of weight during weighing, eggs from each tube were used only once for weighing and then discarded i.e. eggs in tube number one were weighed after 24 hours, eggs in tube number two after 3 days, eggs in tube number three after 5 days and so on to a maximum period of 17 days. The average weight of eggs in each tube which were all taken from the same pod,

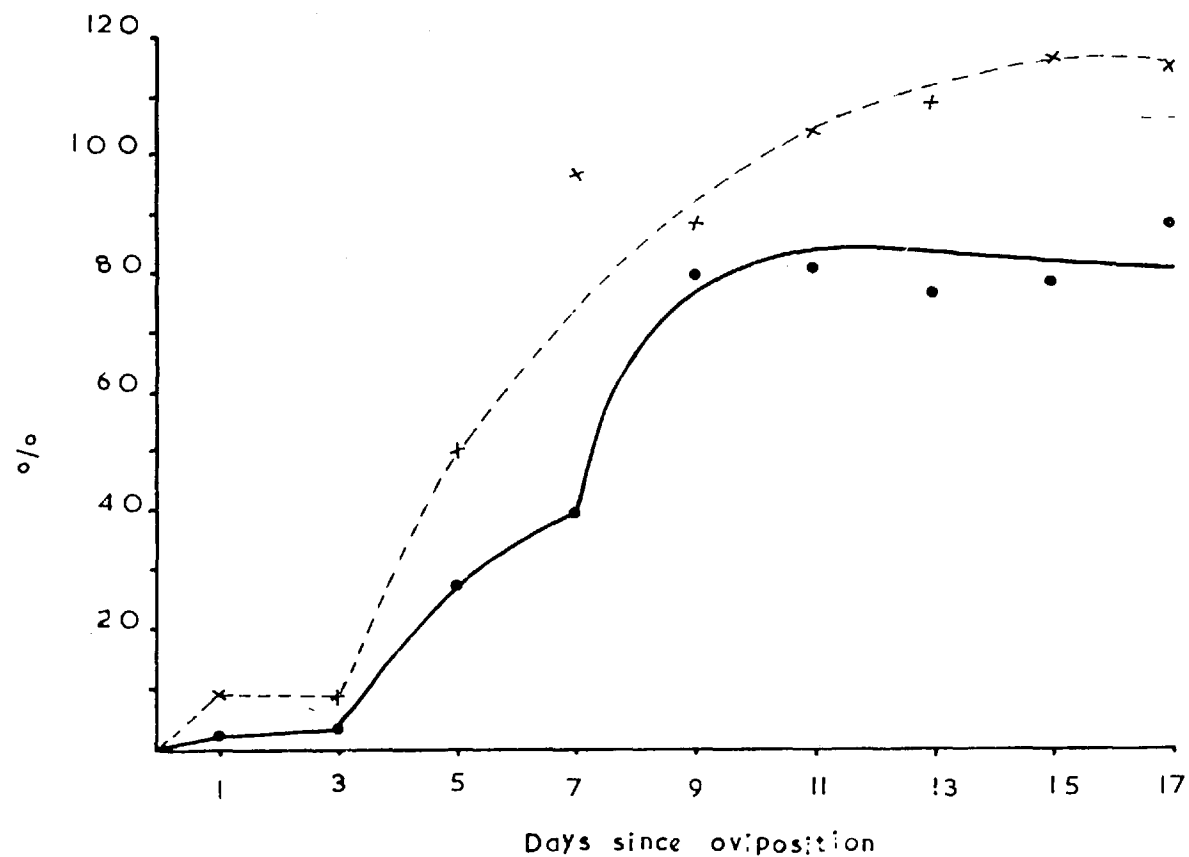
was used to obtain the mean increase in weight up to the time of weighing. Each treatment was replicated 4 - 7 times depending upon the availability of normal undamaged eggs. Fig. 30 shows the percentage increase in weight of the eggs kept at the two extreme conditions of soil moisture. At low moisture the increase in weight in the first 3 days was very small followed by a sudden increase between the 4th. and 9th. day of incubation. This represented 80% increase over the initial weight after which no further increase occurred. In soils with the high moisture content, the increase in the first three days was relatively greater. The increase in weight was sudden after the third day and continued up to the eleventh day beyond which the increase still continued but at a comparatively slower rate. The total increase in weight of the eggs was 116% of the initial weight after 17 days of incubation.

#### Survival capacity:

##### Experiment V:

This was done to find out the survival capacities of starved hatchlings emerging from soils containing extreme moisture conditions. It consisted of two soil moisture levels i.e. sandy soil containing 2.3 cc. water/100 gms. soil = 10% saturation and 20.7 cc. water/100 gms. = 90% saturation. The egg-pods were incubated at 27°C. Two pods were used in each treatment and twenty larvae were collected at random immediately after hatching from each egg-pod. Each treatment consisted of 40 observations. Hatchlings were collected

FIG. 30



Percentage increase in weight of eggs as related to soil moisture.

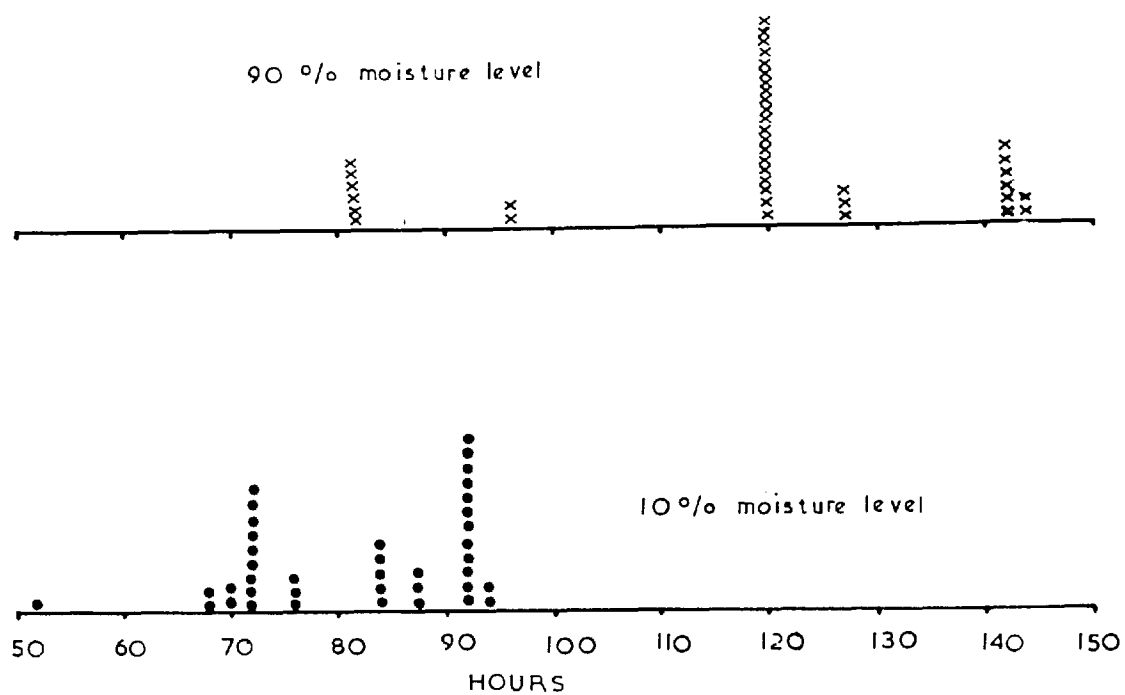
●—● 10 % saturation level.  
 x---x 90 % " " "

separately in specimen tubes 2.5 cm. in diameter and 7.5 cm. long covered with a Tygan screen. The tubes were then put in a constant temperature room at  $27^{\circ}\text{C} \pm 0.5$  and with a controlled R.H. of  $30 \pm 5\%$

Average survival time varied between 52 and 94 hours (mean  $81.45 \pm 10.2$  hours) for hatchlings from soil at 10% saturation and between 82 and 142 hours (mean  $117.5 \pm 18.9$  hours) for those emerging from soil at 90% saturation. The difference between the two means is highly significant ( $t: 10.494$ ;  $n: 80$ ;  $P < 0.001$ ).

Fig. 31, shows frequency distribution of survival times at  $27^{\circ}\text{C}$  and 30% R.H. for hatchlings as related to soil moisture.

FIG. 31



Scatter diagram showing the distribution frequency of survival times in hrs. as related to soil moisture at 27°C.

Experiments at 32 ± 0.5°C.

The Effect of Soil Moisture on Gregaria Egg-pods at 32 ± 0.5°C.

Experiment VI:

The same procedure as adopted in experiments I and II was used to prepare sandy soil at different moisture levels and to determine the incubation period, percentage hatch, weight and water reserves of hatchlings and their colour. The treatments were three levels of soil moisture namely 6%, 40% and 90% saturation. Each treatment was replicated nine times and incubation was at 32°C.

Results:

1. Time from egg-laying until hatching: Table 16, shows the times in days from egg-laying until hatching occurred.

Table 16. Duration of development of the egg stage in days at 32°C under particular conditions of soil moisture.

| Saturation of sand | Replicates |    |     |    |    |    |     |      |    | Mean        |
|--------------------|------------|----|-----|----|----|----|-----|------|----|-------------|
|                    | I          | II | III | IV | V  | VI | VII | VIII | IX |             |
| 6                  | 14         | 14 | 15  | 14 | 14 | 16 | 14  | 14   | 16 | 14.5 ± 0.83 |
| 40                 | 15         | 16 | 15  | 15 | 14 | 14 | 14  | 14   | 15 | 14.6 ± 0.66 |
| 90                 | 16         | 15 | 15  | 14 | 14 | 15 | 15  | 15   | 14 | 14.7 ± 0.63 |

The data in Table 9 was subject to X<sup>2</sup> test and the calculated value for X<sup>2</sup> is 0.9656 which is not significant. Thus it seems that the soil moisture in sandy soil at 32°C has no effect on the time

required for egg development within the limits studied.

2. Percentage hatch: Table 17 shows the percentage hatch of individual egg-pods incubated at 32°C in sandy soil of different moisture levels.

Table 17. Percentage hatch from individual egg-pods at 32°C from sandy soil of different moisture content.

| ✓ satur.<br>of sand | ✓ hatch for each replicate |      |      |      |      |      |      |      |      | Mean        |
|---------------------|----------------------------|------|------|------|------|------|------|------|------|-------------|
|                     | I                          | II   | III  | IV   | V    | VI   | VII  | VIII | IX   |             |
| 6                   | 97.6                       | 96.7 | 95.5 | 91.6 | 100  | 89.7 | 85.7 | 94.1 | 98.5 | 94.4 ± 4.3  |
| 40                  | 66.6                       | 79.0 | 84.3 | 90.4 | 87.0 | 95.0 | 87.8 | 94.9 | 96.0 | 86.8 ± 8.8  |
| 90                  | 70.0                       | 80.5 | 63.6 | 71.0 | 89.1 | 69.7 | 33.3 | 88.2 | 80.3 | 71.7 ± 15.8 |

Percentage hatch seems to decrease with the increase of soil moisture at 32°C.

3. Weight of hatchlings: 80 larvae from four egg-pods (20 larvae each), were weighed from each treatment. The procedure of collecting and weighing was as described on page <sup>68</sup>~~29~~. Tables 18 and 19 show the mean weight of hatchlings ± s.d. and the distribution of weights of hatchlings emerging from sandy soil at different moisture levels.

Table 18. Mean weight of hatchlings (mg.) ± s.d. from egg-pods incubated at 32°C in sandy soil.

| Item                   | Saturation level of sandy soil |            |            |
|------------------------|--------------------------------|------------|------------|
|                        | 6                              | 40         | 90         |
| Mean weight mg. ± s.d. | 17.9 ± 2.1                     | 19.9 ± 1.3 | 22.8 ± 1.6 |
| Number of samples      | 80                             | 80         | 80         |

Table 19. Showing percentages of larvae in different weight categories (Fig. 32).

| Larvae weight<br>in mg.<br>saturation<br>of sand | 14-16 | 16.1-18 | 18.1-20 | 20.1-22 | 22.1-24 | 24.1-26 | No.<br>S. | No.<br>E.P. |
|--------------------------------------------------|-------|---------|---------|---------|---------|---------|-----------|-------------|
| 6                                                | 22.5  | 31.2    | 32.5    | 11.2    | 2.5     | -       | 80        | 4           |
| 40                                               | -     | 7.5     | 42.5    | 48.8    | 1.2     | -       | 80        | 4           |
| 90                                               | -     | -       | 1.2     | 38.7    | 33.7    | 26.2    | 80        | 4           |

No. S. = No. of samples.

No. E.P. = No. of Egg-pods.

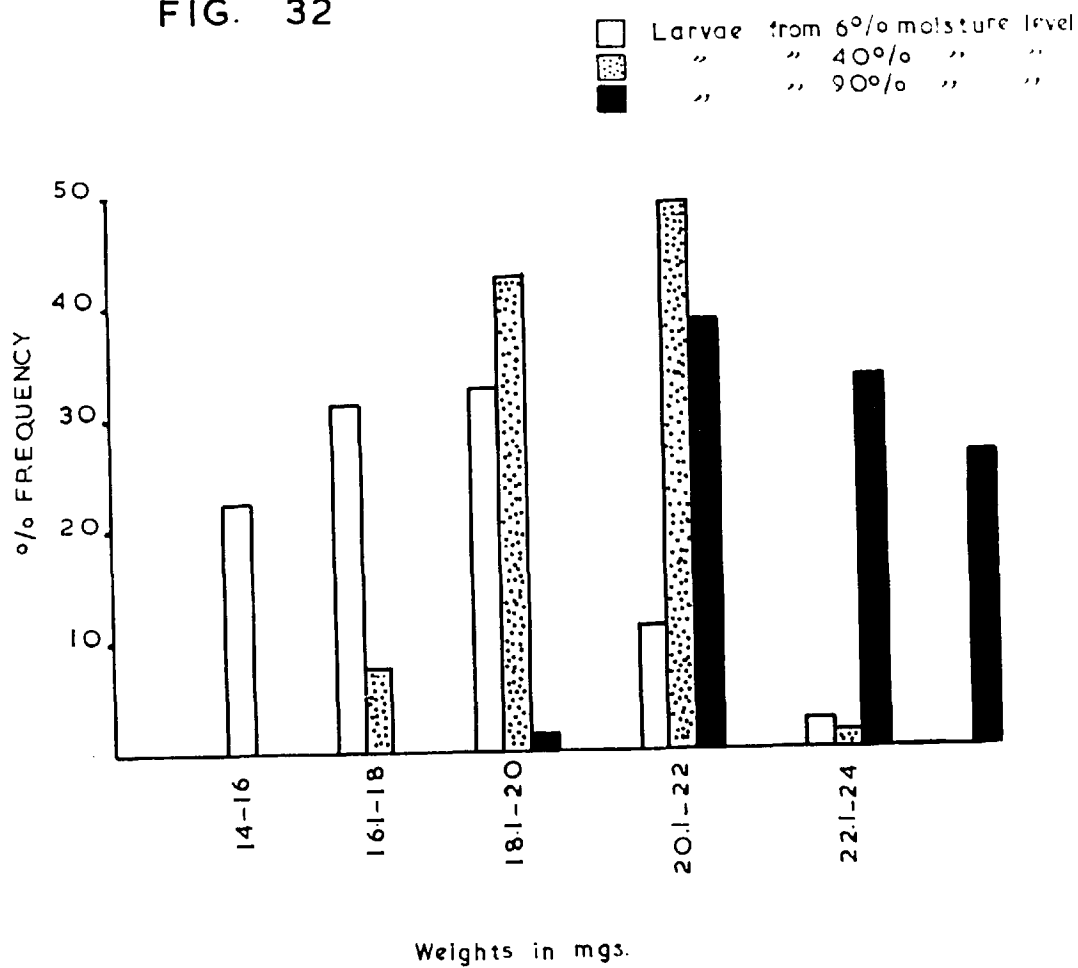
Analysis of variance applied to the weights of hatchlings from sandy soil with different moisture levels at 32°C.

| S.V.       | D.F. | S.S.    | M.S.   | F.         |
|------------|------|---------|--------|------------|
| Treatments | 2    | 948.36  | 474.18 | 154.45***  |
| Replicates | 79   | 229.65  | 2.9    | 0.9436n.s. |
| Error      | 158  | 485.23  | 3.07   |            |
| Total      | 239  | 1663.24 |        |            |

Analysis of variance shows a highly significant difference between the treatments (F: 154.45; n; 2/158;  $P \leq 0.001$ ). The correlation coefficient value shows a positive correlation between soil moisture and weight of hatchlings ( $r$ : 0.99994; n: 3;  $P \leq 0.01$ ).

4. Water reserves of hatchlings: Tables 20 and 21 show that the amount of water in mgs./mg. dry body weight of the hatchlings as well as, water percentage of total body weight are related to soil

FIG. 32



Percentage of larvae in different weight categories.

moisture. The percentage frequency is represented graphically in Fig. 33.

Table 20. Mean amount of water in mgs./mg. dry body weight as well as water as percentage of total body weight for hatchling from sandy soil at 32°C.

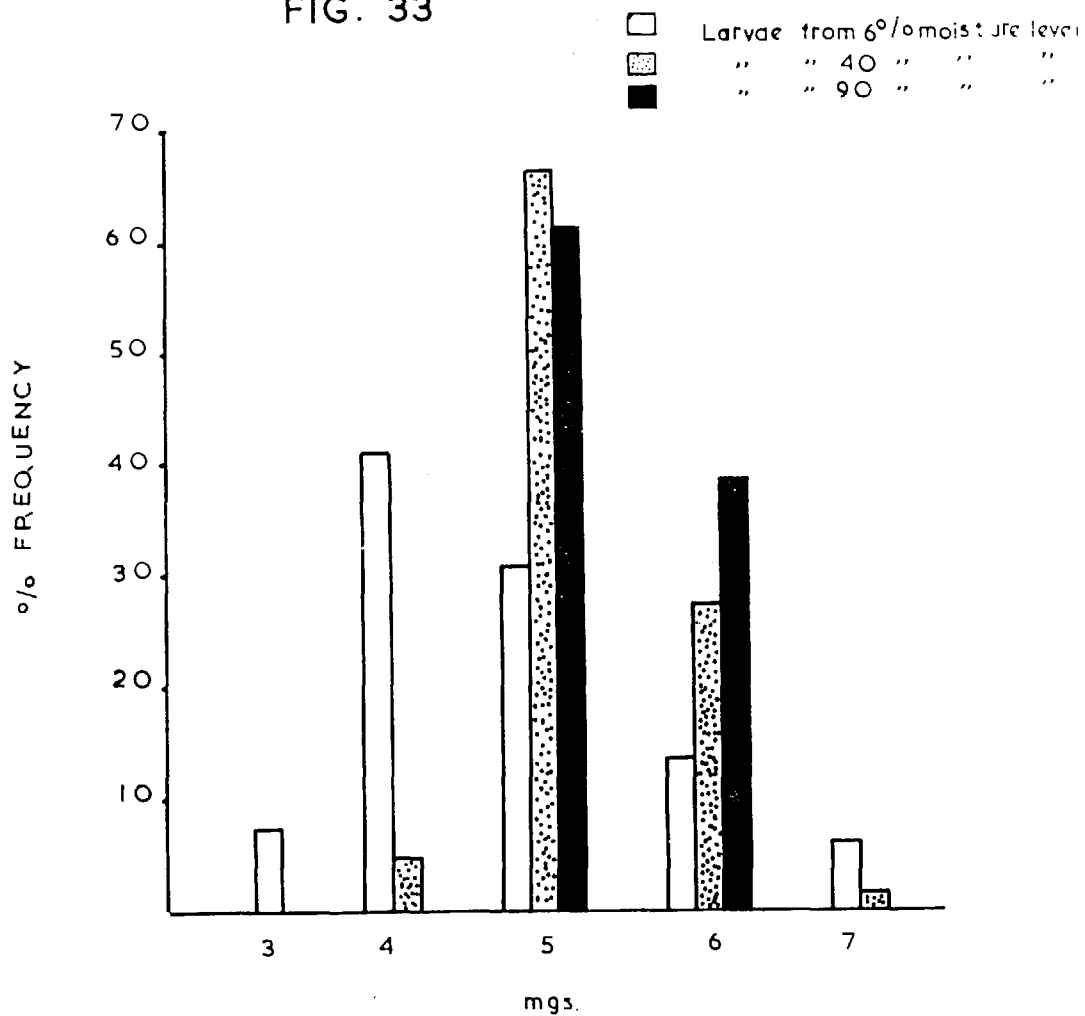
| Item                                              | % Saturation of sand |       |       |
|---------------------------------------------------|----------------------|-------|-------|
|                                                   | 6%                   | 40%   | 90%   |
| Mean H <sub>2</sub> O in mg./mg. dry body weight. | 5.1                  | 5.7   | 5.9   |
| Mean % of total weight.                           | 83.4%                | 85.0% | 85.4% |
| No. of samples.                                   | 80                   | 80    | 80    |

Table 21. Frequency distribution for water in mgs./mg. dry body weight for hatchlings issuing from soils at different moisture levels (Fig. 33).

| H <sub>2</sub> O in mgs./mg dry body weight |     |      |      |      |      | No. of samples | No. of egg-pods |
|---------------------------------------------|-----|------|------|------|------|----------------|-----------------|
| % saturation of soil                        | 3   | 4    | 5    | 6    | 7    |                |                 |
| 6                                           | 7.5 | 41.2 | 31.2 | 13.7 | 6.2  | 80             | 4               |
| 40                                          | -   | 5.0  | 66.2 | 27.5 | 1.25 | 80             | 4               |
| 90                                          | -   | -    | 61.2 | 38.8 | -    | 80             | 4               |

Analysis of variance applied to the data of water in mgs./mg. dry body weight of the hatchlings at 32°C.

FIG. 33



Percentage frequency of water in mgs/mg dry  
body weight as related to soil moisture at 32°C.

| s.v.       | d.f. | s.s.   | m.s.    | F.          |
|------------|------|--------|---------|-------------|
| Treatments | 2    | 23.77  | 11.8850 | 24.0295***  |
| Replicates | 79   | 32.01  | 0.4052  | 0.8192 n.s. |
| Error      | 158  | 78.15  | 0.4946  |             |
| Total      | 239  | 133.93 |         |             |

Analysis of variance applied to the data of water as percentage of total body weight.

| s.v.       | d.f. | s.s.   | m.s.   | F.          |
|------------|------|--------|--------|-------------|
| Treatments | 2    | 185.84 | 92.92  | 28.3759***  |
| Replicates | 79   | 214.80 | 2.7189 | 0.8302 n.s. |
| Error      | 158  | 517.39 | 3.2746 |             |
| Total      | 239  | 918.03 |        |             |

Analysis of variance shows that there is a significant difference between the treatments when water reserves were calculated as water in mgs./mg. dry body weight and also as percentage of total body weight (F: 24.0295; d.f: 2/158;  $P < 0.001$ ) and (F: 28.3759; d.f: 2/158;  $P < 0.001$ ).

5. Hatchling colour: The colour of hatchlings was noted within 6 - 12 hours of their emergence from the soil. Each hopper was examined and classified according to the following pattern:-

- a- Black or dirty black.
- b- Dark grey.
- c- Pale green.
- d- Green.

As the differences between (a) and (b), and (c) and (d) colour patterns were not clearly distinct, they were combined into two major categories i.e. black (a + b) and green (c + d) hatchlings. Table 21 and Fig. 34 show the percentage frequency of colour of the newly hatched larvae in relation to soil moisture.

Table 21. Percentage frequency of colour of hatchling larvae at 32°C as related to soil moisture.

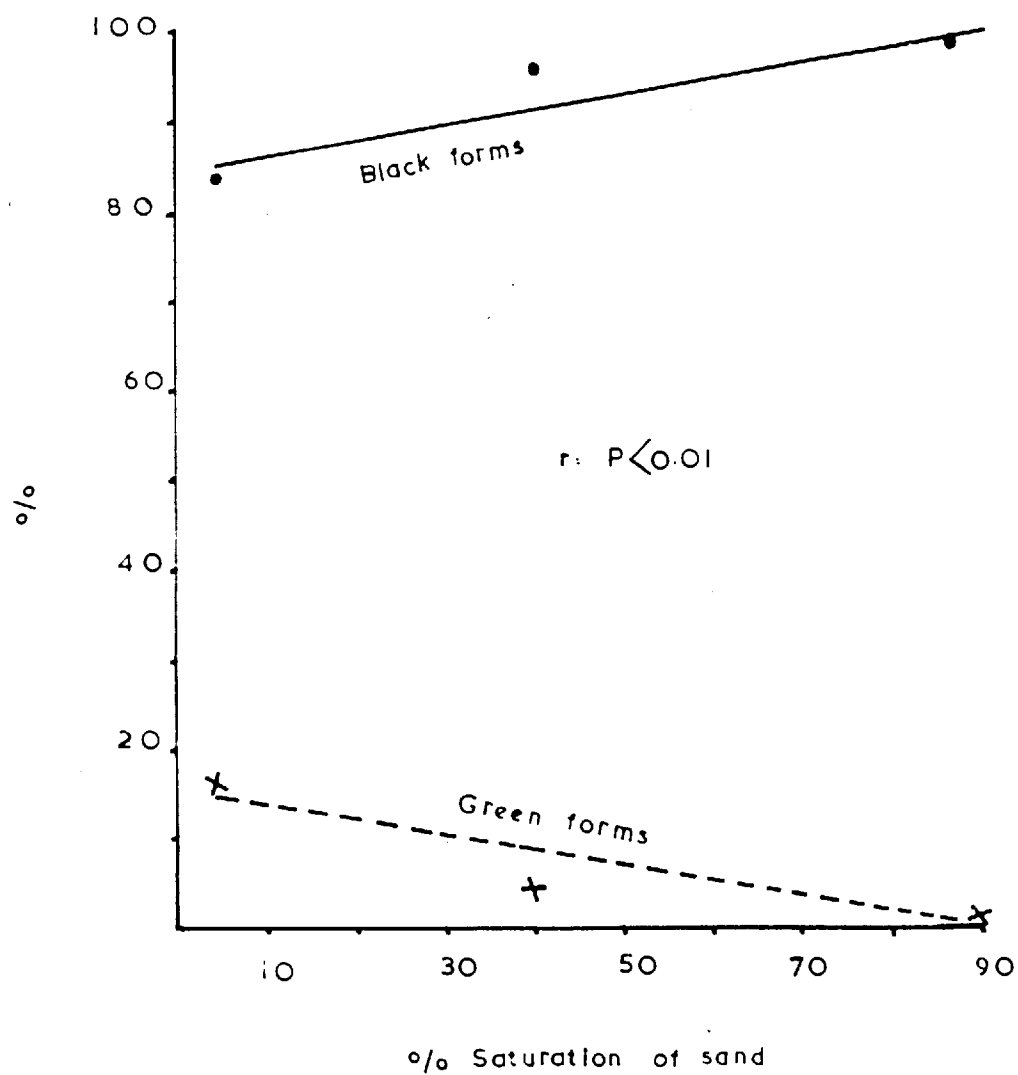
| Colour pattern.<br>% Saturation<br>of sand. | Black | Green | Nos. of hoppers | Nos. of egg-pods |
|---------------------------------------------|-------|-------|-----------------|------------------|
| 6                                           | 83.7  | 16.3  | 425             | 11               |
| 40                                          | 95.9  | 4.1   | 381             | 8                |
| 90                                          | 98.6  | 1.4   | 252             | 8                |

Table 21 and Fig. 34, show that soil moisture influenced the colour of gregaria egg-pod hatchlings. With the increase of soil moisture there is an increase of the black forms and a proportional decrease of the green forms. The correlation is highly significant ( $r = 0.5439$ ;  $n = 26$ ;  $P < 0.01$ ).

Regression analysis was applied to the data of colour of hatchlings in relation to soil moisture.

| <u>s.v.</u>  | <u>s.s.</u>    | <u>d.f.</u> | <u>m.s.</u> | <u>F.</u> |
|--------------|----------------|-------------|-------------|-----------|
| Regression   | 1004.22        | 1           | 1004.22     | 10.89**   |
| Error        | 2397.54        | 26          | 92.21       |           |
| <u>Total</u> | <u>3401.76</u> | <u>27</u>   |             |           |

FIG. 34



Relationship between coloration of gregarina hatchling and soil moisture at 32C.

The regression was highly significant  $P < 0.01$ . The regression equation was  $Y_e = 81.364 + 0.7589 X$  for black forms.

$Y_e = 18.616 - 0.7589 X$  for green forms.

Experiment VII: Effect of soil moisture on the survival capacity of the hatchlings at 32°C.

Freshly emerged hatchlings from eggs kept at the three soil moisture levels were left to starve at two different relative humidities. The soil moisture levels for rearing the eggs were 6%, 40% and 90%. Starvation was at  $32^{\circ}\text{C} \pm 0.5$ . Three egg-pods were used for each treatment and 30 hatchlings were collected at random from each egg-pod. They were further subdivided into two batches of 15 larvae each. Larvae of each batch were put individually in 15 specimen tubes 2.5 cm. in diameter and 7.5 cm. long, covered with Tygan screen and kept under two relative humidities. The first batch was kept at  $50 \pm 5\%$  R.H., and the second at  $0 - 5\%$  R.H., the latter being obtained by putting the specimen tubes in a dessicator over phosphorus pentoxide. Each subdivision consisted of 45 larvae from three egg-pods. The temperature during the experiment was  $32 \pm 0.5^{\circ}\text{C}$ . Tables 22 and 23, show the mean survival times in hours and percentage frequency of survival times respectively.

The effect of soil moisture on the survival potential of the hatchlings is highly significant. Hatchlings emerging from soil containing high moisture level survived more at dry atmosphere as well as at 50% R.H. The survival times for hatchlings from optimum and high moisture levels were significantly more at 50% R.H. than at

dry atmosphere. Those emerging from soils at low moisture level seem to acquire some adaptation to dry atmosphere.

Table 22. Mean survival times in hours at 0 - 5% R.H. and 50 ± 5% R.H. as related to moisture content of soil in which the eggs were incubated (incubation and survival observations were at 32° ± 0.5°C.

| 7 Saturation of sand during egg development.<br>R.H. level. | 6                            | 40                | 90                |
|-------------------------------------------------------------|------------------------------|-------------------|-------------------|
| 0 - 5% R.H.                                                 | 69.6 hrs.<br>(range 48 - 90) | 69.2<br>(48 - 82) | 75.4<br>(60 - 96) |
| 50 ± 5% R.H.                                                | 69.2<br>(48 - 86)            | 73.3<br>(48 - 83) | 80.5<br>(54 - 96) |

Table 23. Percentage frequency of survival times at 0 - 5% R.H. and 50 ± 5% R.H. as related to moisture content of soil in which the eggs were incubated.

| 7 saturation of soil.<br>Time in hours. | 0 - 5% R.H. |      |      | 50 ± 5% R.H. |      |      |
|-----------------------------------------|-------------|------|------|--------------|------|------|
|                                         | 6%          | 40%  | 90%  | 6%           | 40%  | 90%  |
| 48 - 58                                 | 4.4         | 17.8 | -    | 15.5         | 6.7  | 2.2  |
| 59 - 68                                 | 22.2        | 24.4 | 28.9 | 33.3         | 22.2 | 6.7  |
| 69 - 78                                 | 60.0        | 37.8 | 35.5 | 26.6         | 33.3 | 33.3 |
| 79 - 88                                 | 8.9         | 20.0 | 26.6 | 24.4         | 37.8 | 35.5 |
| 89 - 98                                 | 4.4         | -    | 8.9  | -            | -    | 22.2 |

The mean survival time for each batch were subjected to analysis of variance.

Analysis of variance.

| s.v.                  | d.f. | s.s.   | m.s.   | F.          |
|-----------------------|------|--------|--------|-------------|
| Treatments (T)        | 2    | 242.51 | 121.25 | 19.056***   |
| Relative Humidity (H) | 1    | 38.14  | 38.14  | 5.994*      |
| T x H                 | 2    | 26.07  | 13.03  | 2.0477 n.s. |
| Replicates            | 2    | 11.92  | 5.96   | 0.9366 n.s. |
| Error                 | 10   | 63.63  | 6.36   |             |
| Total                 | 17   | 382.27 |        |             |

Experiment VIII: The ability of the Desert Locust Eggs to Withstand Low Moisture.

Egg-pods incubated in the sandy soil at 5% saturation at 27°C did not hatch and dried out. In order to find out if the eggs can resume development if water is available at a later stage, 15 cc. water was added to each container after 30 days of incubation, but no hatching occurred. In the case of sandy loam soil the situation was different. In the 10% treatment (2.9 cc. water/100 gms. soil) when hatching did not occur at the expected time, the containers were opened and the eggs examined. Many eggs showed signs of development and looked healthy. It was decided to find out if the eggs underwent an arrested development when incubated in sandy loam soil at low moisture level. The experiment was done at two temperatures i.e., 27 and 32°C. Five egg-pods were used in each set. The same procedure as adopted in experiment II, was used to prepare sandy loam soil at 10% saturation level and after 30 days

of incubation, the containers were opened and 15 cc. water was added to each. Three egg-pods hatched from each set after 24.6 (range 23 - 27) days at 27°C and after 11.3 (range 11 - 12) days at 32°C. Table 24 shows the numbers of eggs hatched and the time required for egg-development when water was available.

Table 24. Percentage hatch and time required for egg-development when water was available after 30 days of egg-laying in sandy loam soil containing 2.9 cc. water/100 mg. soil.

| Incubation temp. | No. of replicate | No. of eggs/pod | No. of eggs hatched | % hatch | Time required for eggs to hatch when water was available after 30 days of incubation. |
|------------------|------------------|-----------------|---------------------|---------|---------------------------------------------------------------------------------------|
| 27°C             | 1                | 28              | 8                   | 28.5%   | 27                                                                                    |
|                  | 2                | 34              | 12                  | 35.2%   | 23                                                                                    |
|                  | 3                | 52              | 14                  | 26.9%   | 24                                                                                    |
| 32°C             | 1                | 39              | 21                  | 53.8%   | 11                                                                                    |
|                  | 2                | 41              | 26                  | 63.4%   | 11                                                                                    |
|                  | 3                | 44              | 16                  | 36.3    | 12                                                                                    |

Solitaria Egg-pods.

Experiment IX: The Effect of Soil Moisture on Solitaria Egg-pods  
at 32°C.

The egg-pods used in this experiment were taken from the solitaria stock bred at 32°C. In a preliminary experiment, the procedure for obtaining egg-pods and transferring them into sandy soil of known moisture level was the same as in experiments I and II. The soil was sandy soil, the treatments were 6%, 40% and 90% soil saturation and incubation was at 32°C. Only two out of 25 egg-pods hatched. It was thought that solitaria egg-pods were perhaps sensitive to handling and the procedure was changed. Laying tubes 10 cm. in height and 4 cm. in diameter, filled with a mixture of sand and water in the required ratio, were offered to each female. These tubes were changed every morning. Immediately after egg-laying the tube was taken and the top 2 cm. of the sand removed to give space for the hatchling to emerge. The mouth of the tube was then covered firmly with a polythene sheet and tied with rubber bands, to prevent evaporation. Incubation was at  $32 \pm 0.5^\circ\text{C}$ . Thus, the egg-pods were incubated in a sand of known water content throughout the incubation. The numbers of egg-pods used in each treatment varied from 5 - 9 depending upon their availability. When hatching occurred, incubation period, percentage hatch, hatchling colour, weight of hatchlings and their water contents were determined as described for the gregaria.

Results:

1. Time from egg-laying until hatching: Table 25 shows the time in days from egg-laying until hatching.

Table 25. Duration of development of Solitaria egg-pods in days at 32°C as related to soil moisture.

| % saturation<br>of sandy soil | Mean of each replicate in days |    |     |    |    |    |     |      |    | Mean $\pm$ s.d. |
|-------------------------------|--------------------------------|----|-----|----|----|----|-----|------|----|-----------------|
|                               | I                              | II | III | IV | V  | VI | VII | VIII | IX |                 |
| 6                             | 14                             | 14 | 16  | 15 | 15 | -  | -   | -    | -  | 14.8 $\pm$ 0.7  |
| 40                            | 15                             | 15 | 15  | 15 | 15 | 14 | -   | -    | -  | 14.8 $\pm$ 0.3  |
| 90                            | 15                             | 15 | 15  | 15 | 15 | 16 | 14  | 14   | 16 | 15.0 $\pm$ 0.6  |

The data in Table 25 was subjected to  $X^2$  test and the calculated value for  $X^2$  was 0.516 which is not significant.  $X^2$  test was applied to the data of duration of development for gregaria and solitaria egg-pods at 32°C. The value for  $X^2$  was 0.0109 which indicates no significant difference between the two phases at 32°C.

2. Percentage hatch: Table 26 shows the percentage hatch of solitaria eggs at 32°C as related to soil moisture.

Table 26. Percentage hatch of Solitaria eggs at 32°C as related to soil moisture.

| % saturation<br>of sandy soil | Replicates |      |      |      |      |      |      |      | Mean |
|-------------------------------|------------|------|------|------|------|------|------|------|------|
|                               | I          | II   | III  | IV   | V    | VI   | VII  | VIII |      |
| 6                             | 62.1       | 63.8 | 84.3 | 81.1 | 77.3 | -    | -    | -    | 73.7 |
| 40                            | 64.4       | 39.0 | 63.4 | 30.6 | 79.0 | 60.3 | -    | -    | 56.1 |
| 90                            | 82.4       | 90.6 | 39.5 | 41.9 | 75.0 | 68.6 | 44.7 | 66.6 | 63.6 |

It seems that percentage hatch decreases slightly with increase of soil moisture, following to some extent the same pattern as gregaria egg-pods.

3. Weight of hatchling: Sixty larvae from four egg-pods (15 larvae each) represented each treatment. The procedure for collecting the hatchlings and weighing them individually was as described for gregaria egg-pods. Tables 27 and 28 show the mean weight of hatchlings  $\pm$  s.d. and the percentage distribution of weights respectively.

Table 27. Mean weight of solitaria larvae  $\pm$  s.d. as related to soil moisture at 32°C.

| Item                       | Saturation level of sandy soil |                |                |
|----------------------------|--------------------------------|----------------|----------------|
|                            | 6                              | 40             | 90             |
| Mean weight mg. $\pm$ s.d. | 14.2 $\pm$ 2.5                 | 15.8 $\pm$ 2.3 | 17.5 $\pm$ 2.4 |
| No. of samples             | 60                             | 60             | 60             |

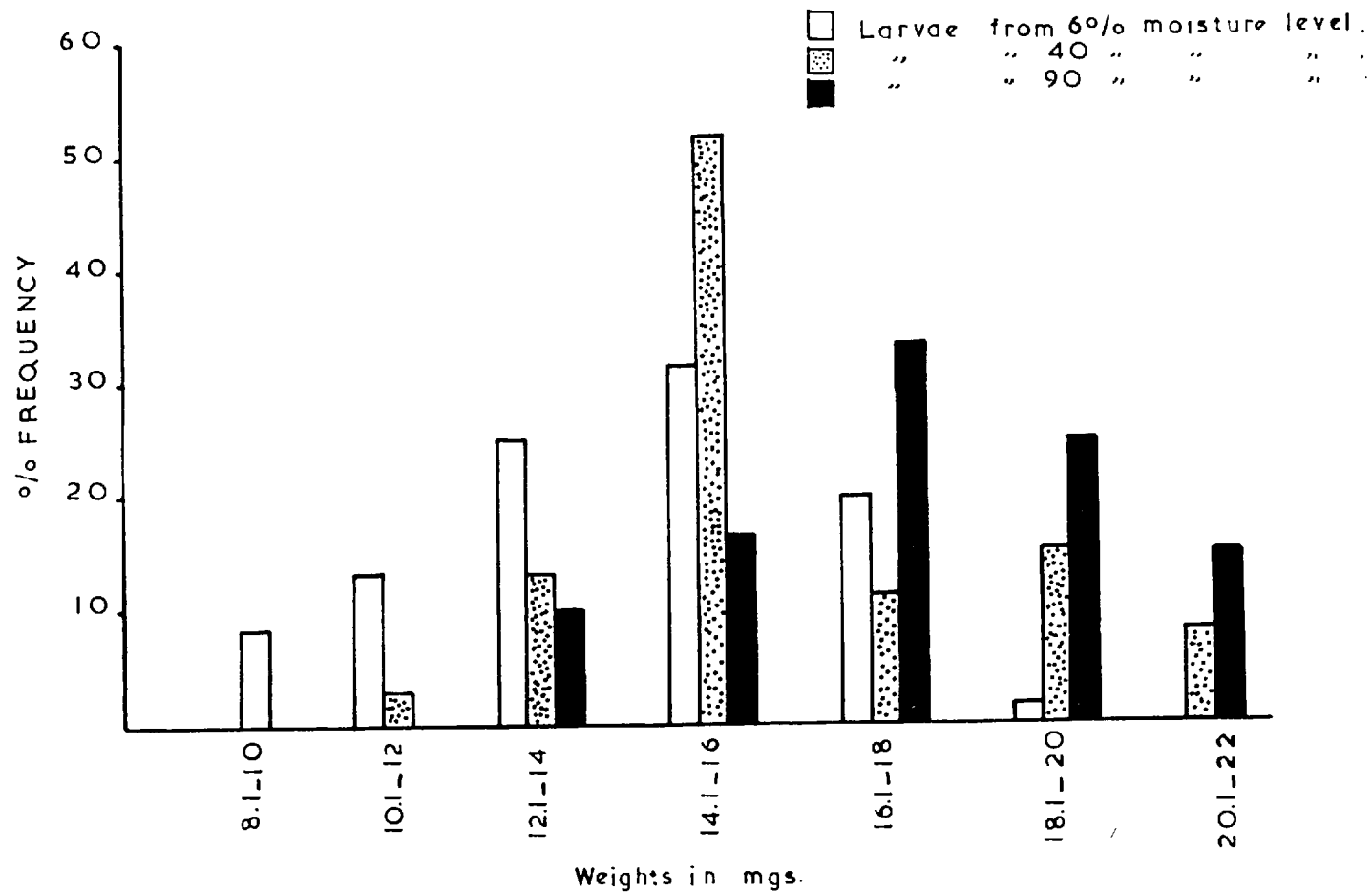
Table 28. showing percentages of larvae in different weight categories.

(Fig. 35.)

| % saturation of sandy soil | Weight categories mg. |         |         |         |         |         |         | L. W. | E. P. |
|----------------------------|-----------------------|---------|---------|---------|---------|---------|---------|-------|-------|
|                            | 8.1-10                | 10.1-12 | 12.1-14 | 14.1-16 | 16.1-18 | 18.1-20 | 20.1-22 |       |       |
| 6                          | 8.3                   | 13.3    | 25.0    | 31.6    | 20.0    | 1.6     | -       | 60    | 4     |
| 40                         | -                     | 3.3     | 13.3    | 51.6    | 11.6    | 15.0    | 8.3     | 60    | 4     |
| 90                         | -                     | -       | 10.0    | 16.6    | 33.3    | 25.0    | 15.0    | 60    | 4     |

L.W. = Number of larvae weighed. E.P. = number of egg-pods.

FIG. 35



Percentage of larvae in different weight categories [Solitaria]

Analysis of variance applied to weights of solitaria hatchlings from sandy soil with different moisture levels at 32°C.

| s.v.       | d.f. | s.s.    | m.s.s. | F.       |
|------------|------|---------|--------|----------|
| Treatments | 2    | 332.03  | 166.01 | 32.11*** |
| Replicates | 59   | 466.72  | 7.91   | 1.5      |
| Error      | 118  | 610.61  | 5.17   |          |
| Total      | 179  | 1409.36 |        |          |

Analysis of variance shows a highly significant difference between the treatments (F: 32.11; d.f: 2/118; P < 0.001).

Comparison between the weight of hatchlings from gregaria parents and those from solitaria was done as follows:-

| Item                                         | Mean weight of hatchlings | No. of samples | t test                   |
|----------------------------------------------|---------------------------|----------------|--------------------------|
| Solitaria hatched from 6% saturation level.  | 14.2                      | 60             | (t:6.7029;n:140;P 0.001) |
| Gregaria hatched from 6% saturation level.   | 17.9                      | 80             |                          |
| Solitaria hatched from 40% saturation level. | 15.8                      | 60             | (t:9.2613;n:140;P 0.001) |
| Gregaria hatched from 40% saturation level.  | 19.9                      | 80             |                          |
| Solitaria hatched from 90% saturation level. | 17.5                      | 60             | (t:10.86;n:140;P 0.001)  |
| Gregaria hatched from 90% saturation level.  | 22.8                      | 80             |                          |
| Solitaria hatched from 90% saturation level. | 17.5                      | 60             | t:0.7312 not significant |
| Gregaria hatched from 6% saturation level.   | 17.9                      | 80             |                          |

This test shows that each phase is confined to its own character and the differences are highly significant between the two phases. However, when the mean weight of solitaria hatchlings from high moisture level was compared with those of gregaria from low moisture level, there was no significant difference.

4. Water reserves: Tables 29 and 30 show the mean amount of water in mgs./mg. dry body weight and its frequency distribution respectively for solitaria hatchlings.

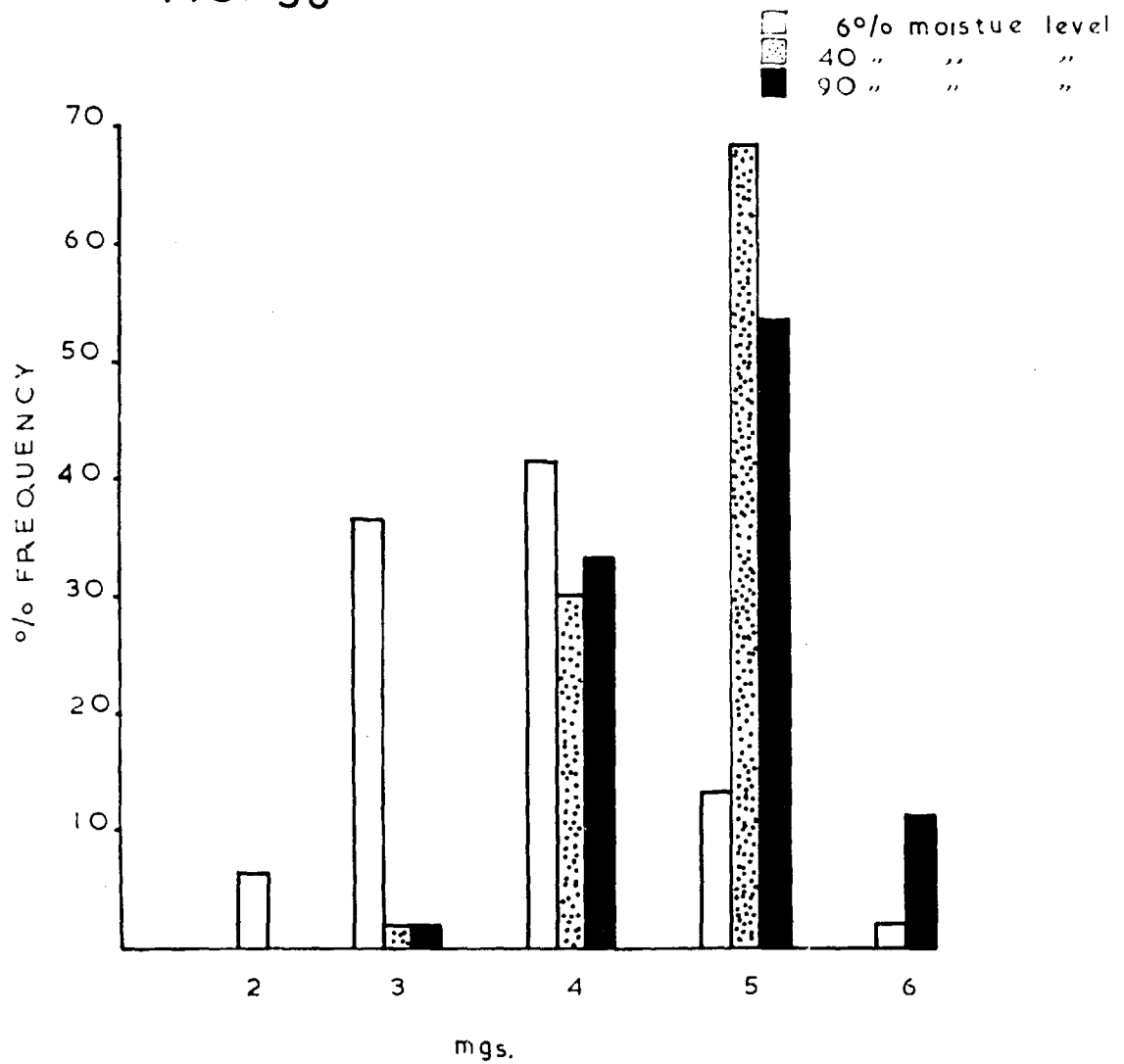
Table 29. Mean amount of water in mgs./mg. dry body weight of solitaria hatchlings.

| Item           | % Saturation of sandy soil |     |     |
|----------------|----------------------------|-----|-----|
|                | 6%                         | 40% | 90% |
| Mean           | 4.1                        | 5.1 | 5.1 |
| No. of samples | 60                         | 60  | 60  |

Table 30. Frequency distribution for water in mgs./mg. dry body weight for solitaria hatchlings at 32°C as related to soil moisture (Fig. 36).

| H <sub>2</sub> O mgs./mg. dry body weight. | 2-2.9 | 3-3.9 | 4-4.9 | 5-5.9 | 6-6.6 | No. of samples | No. of egg pods |
|--------------------------------------------|-------|-------|-------|-------|-------|----------------|-----------------|
| % saturation of sand.                      |       |       |       |       |       |                |                 |
| 6%                                         | 6.6   | 36.7  | 41.6  | 13.3  | 1.6   | 60             | 4               |
| 40%                                        | -     | 1.6   | 30.0  | 68.3  | -     | 60             | 4               |
| 90%                                        | -     | 1.6   | 33.3  | 53.3  | 11.6  | 60             | 4               |

FIG. 36



Percentage frequency of water in mgs / mg dry  
body weight as related to soil moisture.[*Solitaria*]

Analysis of variance applied to the data of water in mgs./mg. dry body weight of solitaria hatchlings at 32°C as related to soil moisture.

| s.v.       | d.f. | s.s.   | m.s.s. |          |
|------------|------|--------|--------|----------|
| Treatments | 2    | 41.48  | 20.74  | 25.55*** |
| Replicates | 59   | 24.67  | 0.4181 |          |
| Error      | 118  | 46.44  | 0.3935 | Residual |
| Total      | 179  | 112.59 |        |          |

Analysis of variance showed that there is a significant difference between the treatments ( $F: 255.55$ ; d.f. 2/177;  $P < 0.001$ ). The correlation coefficient value shows a positive significant correlation between soil moisture and the water reserves of hatchlings ( $r: + 0.6847$ ;  $n: 180$ ;  $P < 0.001$ ).

5. Hatchlings colour: Colour of hatchling was noted within 6 - 12 hours after hatching occurred and classified according to the following colour patterns:-

- a- Blackish or dark grey.
  - b- Pale green
  - c- Green
- } joined together as green hatchlings.

Table 31 and Fig. 38 show the numbers and percentage frequency of coloration in solitaria hatchling as related to soil moisture.

Table 31 Numbers and percentage frequency of solitaria newly hatching larvae colour in relation to soil moisture.

| Colour pattern<br>Item      | Green |      | Pale Green |      | Total Green |      | Blackish |      |                |                 |
|-----------------------------|-------|------|------------|------|-------------|------|----------|------|----------------|-----------------|
| % saturation of sandy soil. | No.   | %    | No.        | %    | No.         | %    | No.      | %    | No. of samples | No. of egg pods |
| 6                           | 205   | 91.1 | 18         | 8.0  | 223         | 99.1 | 2        | 0.9  | 225            | 5               |
| 40                          | 177   | 72.5 | 41         | 16.8 | 218         | 89.4 | 26       | 10.6 | 244            | 6               |
| 90                          | 164   | 58.6 | 61         | 21.7 | 225         | 80.4 | 55       | 19.6 | 280            | 8               |

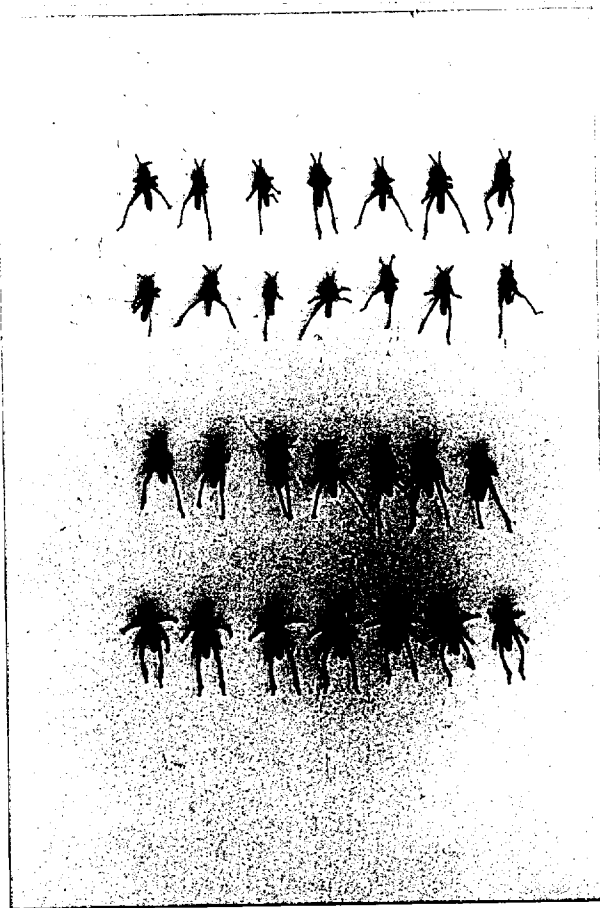


Fig. 37: Showing the effect of soil moisture on size and colour of *Solitaria* hatchlings.

- a) Greenish smaller hoppers from low soil moisture.
- b) Blackish larger hoppers from higher soil moisture.

Effect of Soil Salinity on the Development and Hatchlings  
of Gregaria Desert Locust Eggs.

Experiment X:

The effect of sea water on the mortality of the desert locust eggs was studied by Achillides (1963). He found that the concentration which produced 50% mortality is about 53% by volume of sea water in water. In the present work, concentrations of artificial sea water less than the LD<sub>50</sub> concentration were used to test their effect on egg development and hatchlings.

Procedure: Laying tubes 10 cm. in height and 4 cm. in diameter filled with moistened sand were offered to the locust. The sand was coarse sand, washed thoroughly with tap water and then with distilled water to get rid of any soluble salts. For each replicate the air dried sand was mixed with 18.8 ml. of the required concentration of sea water. It thus contained 15% (v/v) of moisture. These tubes were changed every morning. When egg-laying occurred the tube was removed and the same procedure as in experiment IX was used for incubating the egg-pods at 32°C. The treatments were 10%, 20%, 30%, 40% sea water. Distilled water was used as control. The number of replicates for each treatment was eight. The females were reluctant to lay in sand containing 40% sea water and many egg-pods were scattered over the cage floor. However, eight replicates were achieved for this treatment over a long period. When hatching occurred, incubation period, percentage hatch, hatchling

colour, weight water reserves and dry weights were determined.

Results:

1. Incubation period: Table 32, shows the times in days from egg-laying until hatching.

Table 32. Duration of development of gregaria eggs in days at 32°C as related to soil salinity.

| Treatments      | Mean of each replicate in days |    |     |    |    |    |     |      | Mean $\bar{X}$ |
|-----------------|--------------------------------|----|-----|----|----|----|-----|------|----------------|
|                 | I                              | II | III | IV | V  | VI | VII | VIII |                |
| 10% S.W.        | 14                             | 14 | 15  | 14 | 15 | 15 | 15  | 14   | 14.5           |
| 20%             | 14                             | 14 | 14  | 14 | 15 | 14 | 14  | 14   | 14.1           |
| 30%             | 14                             | 13 | 14  | 15 | 14 | 15 | 15  | 14   | 14.2           |
| 40%             | 14                             | 14 | 14  | 16 | 14 | 14 | 15  | 14   | 14.3           |
| Distilled water | 14                             | 14 | 14  | 14 | 14 | 15 | 14  | 14   | 14.1           |

The data in table 32 was subjected to  $\chi^2$  test and the calculated value for  $\chi^2$  was 0.0084 which is not significant. Thus, it seems that soil salinity under this range does not affect the incubation period of the eggs.

2. Percentage hatch: Table 33, shows the percentage hatch from individual egg-pods as related to soil salinity. Table 33, shows that the percentage hatch tends to decrease with increase of soil salinity. The correlation coefficient value is very close to the 5% level of significance ( $r$ : - 0.3383). Egg-pods incubated in neutral media (distilled water) gave higher percentage hatch than

those incubated in saline soils (t: 2.5878; n: 40; P=0.02).

Table 33. Showing the percentage hatch of gregaria egg-pods at 32°C as related to soil salinity.

| Treatments      | Replicates |      |      |      |      |      |      |      | Mean $\bar{X}$ |
|-----------------|------------|------|------|------|------|------|------|------|----------------|
|                 | I          | II   | III  | IV   | V    | VI   | VII  | VIII |                |
| 10% S.W.        | 76.9       | 66.7 | 89.2 | 69.7 | 85.2 | 95.0 | 81.3 | 87.8 | 81.5           |
| 20% S.W.        | 81.8       | 86.7 | 67.2 | 89.7 | 47.6 | 84.6 | 82.1 | 90.7 | 78.8           |
| 30% S.W.        | 34.8       | 81.8 | 67.3 | 81.2 | 61.1 | 85.5 | 78.3 | 85.1 | 71.9           |
| 40% S.W.        | 25.0       | 78.3 | 75.8 | 75.0 | 77.8 | 80.8 | 62.0 | 71.9 | 68.3           |
| Distilled water | 82.9       | 90.4 | 96.7 | 100  | 92.1 | 93.7 | 90.8 | 86.4 | 91.6           |

3. Weight of hatchlings: Sixty larvae from three egg-pods (20 larvae each) represented each treatment. The procedure for collecting the hatchlings and weighing them individually was as described before. Tables 34 and 35 show the mean weight of hatchlings and the percentage distribution of weights respectively.

Table 34. Mean weight of hatchlings as related to soil salinity.

|                | Treatments  |            |            |            |                       |
|----------------|-------------|------------|------------|------------|-----------------------|
|                | 10% S.W.    | 20% S.W.   | 30% S.W.   | 40% S.W.   | Dist.H <sub>2</sub> O |
| Mean mg.       | 22.09 ± 1.5 | 20.9 ± 2.8 | 19.5 ± 2.4 | 19.8 ± 4.0 | 25.2±2.3              |
| No. of samples | 60          | 60         | 60         | 60         | 60                    |

Table 35. Percentage distribution of larval weights as related to soil salinity.

| Treatments      | Weights of larvae in mgs. |         |         |         |         |         |                  |
|-----------------|---------------------------|---------|---------|---------|---------|---------|------------------|
|                 | less than 14 mgs.         | 14.1-16 | 16.1-18 | 18.1-20 | 20.1-22 | 22.1-24 | more than 24 mg. |
| 10% S.W.        | -                         | 1.67    | -       | 3.3     | 51.7    | 35.0    | 8.3              |
| 20% S.W.        | -                         | -       | 8.3     | 50.0    | 10.0    | 10.0    | 21.6             |
| 30% S.W.        | 3.3                       | 11.6    | 28.3    | 13.3    | 13.3    | 28.3    | 1.67             |
| 40% S.W.        | 3.3                       | 25.0    | 11.6    | 10.0    | 18.3    | 16.7    | 15.0             |
| Distilled water | -                         | -       | -       | -       | 6.7     | 26.7    | 66.6             |

Analysis of variance applied to the data of weight of larvae as related to soil salinity.

| s.v.       | d.f. | s.s.    | m.s.   | F.         |
|------------|------|---------|--------|------------|
| Treatments | 4    | 1284.65 | 321.16 | 35.2149*** |
| Replicates | 59   | 122.47  | 2.0757 | 0.2269     |
| Error      | 239  | 2152.73 | 9.1217 |            |
| Total      | 299  | 3559.85 |        |            |

Analysis of variance shows a highly significant difference between the treatments (F: 35.2149; d.f. 4/239;  $P < 0.001$ ). With the increase of soil salinity there is a decrease in the larvae's weight. This negative correlation is highly significant ( $r: - 0.3033$ ;  $n: 238$ ;  $P < 0.01$ ).

4. Water reserves: Tables 36 and 37, show the mean amount of water in mgs./mg. dry body weight and its frequency distribution

respectively for hatchlings at 32°C as related to soil salinity.

Table 36. Mean amount of water in mgs./mg. dry body weight as related to soil salinity.

|                | Treatments |          |          |          |                 |
|----------------|------------|----------|----------|----------|-----------------|
|                | 10% S.W.   | 20% S.W. | 30% S.W. | 40% S.W. | Distilled water |
| Mean           | 3.7        | 3.3      | 3.6      | 3.1      | 4.9             |
| No. of samples | 60         | 60       | 60       | 60       | 60              |

Table 37. Percentage distribution for amount of water in mgs./mg. dry body weight as related to soil salinity.

| Treatments      | Water in mgs./mg. dry body weight |         |         |         |         |         |
|-----------------|-----------------------------------|---------|---------|---------|---------|---------|
|                 | less than<br>2                    | 2.0-2.9 | 3.0-3.9 | 4.0-4.9 | 5.0-5.9 | 6.0-6.9 |
| 10% S.W.        | -                                 | 6.7     | 73.3    | 15.0    | 5.0     | -       |
| 20% S.W.        | -                                 | 31.7    | 53.3    | 13.3    | 1.7     | -       |
| 30% S.W.        | -                                 | 5.0     | 80.0    | 13.3    | 1.7     | -       |
| 40% S.W.        | 8.3                               | 31.7    | 46.7    | 13.3    | -       | -       |
| Distilled water | -                                 | -       | 5.0     | 50.0    | 40.0    | 5.0     |

Analysis of variance applied to the data of water in mgs./mg. dry body weight as related to soil salinity.

| s.v.       | d.f. | s.s.   | m.s.   | F.         |
|------------|------|--------|--------|------------|
| Treatments | 4    | 114.54 | 28.6   | 65.8076*** |
| Replicates | 59   | 20.84  | 0.3532 | 0.8127     |
| Error      | 236  | 102.57 | 0.4346 |            |
| Total      | 299  | 237.95 |        |            |

Analysis of variance shows a highly significant difference between the treatments ( $F: 65.807$ ; d.f.  $4/236$  ;  $P \approx 0.001$ ). The water reserves of hatching larvae tends to decrease with increase of salinity. This negative correlation is highly significant ( $r: - 0.2329$ ;  $n: 238$ ;  $P \approx 0.02$ ).

5. Dry weight of hatchlings: Tables 38 and 39, show the mean dry weight for hatchlings and its frequency distribution respectively as related to soil salinity.

Table 38. Mean dry body weight of hatching larvae as related to soil salinity.

|                | Treatments |          |          |          |                 |
|----------------|------------|----------|----------|----------|-----------------|
|                | 10% S.W.   | 20% S.W. | 30% S.W. | 40% S.W. | Distilled water |
| Mean           | 4.74       | 4.85     | 4.24     | 4.76     | 4.2             |
| No. of samples | 60         | 60       | 60       | 60       | 60              |

Table 39. Percentage distribution of dry body weights as related to soil salinity.

| Treatments      | Dry body weight in mg. |         |         |         |         |
|-----------------|------------------------|---------|---------|---------|---------|
|                 | 2.0-2.9                | 3.0-3.9 | 4.0-4.9 | 5.0-5.9 | 6.0-6.9 |
| 10% S.W.        | -                      | 8.3     | 60.0    | 26.7    | 5.0     |
| 20% S.W.        | -                      | -       | 43.3    | 53.3    | 3.3     |
| 30% S.W.        | 3.3                    | 33.3    | 38.3    | 25.0    | -       |
| 40% S.W.        | -                      | 3.3     | 61.7    | 31.6    | 3.3     |
| Distilled water | -                      | 11.7    | 85.0    | 3.3     | -       |

Analysis of variance applied to the data of dry weights as related to soil salinity.

| s.v.       | d.f. | s.s.   | m.s.   | F.      |
|------------|------|--------|--------|---------|
| Treatments | 4    | 20.63  | 5.15   | 18.39** |
| Replicates | 59   | 30.00  | 0.5084 | 1.8     |
| Error      | 239  | 67.11  | 0.2807 |         |
| Total      | 299  | 117.74 |        |         |

Analysis of variance shows that there was a significant difference between the treatments (F: 18.39; d.f.: 4/239;  $P < 0.001$ ). The dry body weights of larvae emerging from saline soils are comparatively greater than for those from neutral soils. t - test applied to the means (i.e. mean for those hatching from saline soils and the mean for those from distilled water) proved a highly significant difference (t: 4.807  $n_1/n_2$ : 240/60;  $P < 0.001$ ).

6. Hatchling colour: Colour of hatchlings was noted within 6 - 12 hours after hatching occurred and the colour patterns were the same as in experiment VI.

Table 40 and ~~Fig. 57~~, show that soil salinity influenced the colour of hatchlings. With increase of salinity there is a decrease in the black forms and a proportional increase in the green ones. The correlation is highly significant ( $r$ :  $\pm 0.6221$ ;  $n$ : 30  $P < 0.001$ ).

Table 40. Numbers and percentages of hatchling colour in relation to soil salinity.

| Treatment       | Colour pattern |             |              |           |                   | Total green |      | No. of samples |
|-----------------|----------------|-------------|--------------|-----------|-------------------|-------------|------|----------------|
|                 | Black No.      | D. grey No. | P. green No. | Green No. | Total black No. % |             |      |                |
| 10% S.W.        | 190            | 45          | 7            | -         | 235 97.1          | 7           | 2.9  | 242            |
| 20% S.W.        | 150            | 51          | 21           | 17        | 201 84.1          | 38          | 15.9 | 239            |
| 30% S.W.        | 178            | 117         | 35           | 83        | 295 71.4          | 118         | 28.6 | 413            |
| 40% S.W.        | 52             | 86          | 47           | 18        | 138 67.9          | 65          | 32.1 | 203            |
| Distilled water | 338            | 39          | 13           | 2         | 377 96.2          | 15          | 3.8  | 392            |
|                 | Total          |             |              |           |                   |             |      | 1489           |

Ionic Penetration of Egg Membranes:

Experiment X, showed that hatchlings emerging in saline soils possessed greater dry body weight than those hatched in soils moistened with distilled water. It was thought that with saline soils, some ions might be capable of penetrating the egg shell, thus increasing the dry weight of the hatching larvae. The most likely ions in sea water to penetrate the egg shell are sodium and potassium, owing to their higher hydration energy. Therefore, estimations were made of sodium (Na) and potassium (K) in the hatching larvae.

Procedure:

Na and K, were estimated in the dry bodies of larvae hatching in neutral soils (distilled water), and soil containing 20% S.W. and 30% S.W. Five larvae were used in each estimation. They were

dried in an oven running at 110°C for one hour, and the total dry weight was obtained. They were then ashed in a platinum crucible in an oven at 400°C for 24 hours. The contents of the crucible were dissolved in 50 ml. ultra-distilled water, and estimation of Na and K was made using a calibrated flame photometer. Table 41, shows the amounts of Na and K in  $\mu\text{g}/\text{mg}$ . dry body weight.

Table 41. Sodium and potassium in  $\mu\text{g}/\text{mg}$ . dry body weight of hatchlings as related to soil salinity.

| Ion | Treatments      | Replicates |       |        | Mean  |
|-----|-----------------|------------|-------|--------|-------|
|     |                 | I          | II    | III    |       |
| Na  | Distilled water | 5.54       | 2.25  | 3.06   | 3.61  |
|     | 20% Sea water   | 8.07       | 2.12  | -      | 5.1   |
|     | 30% Sea water   | 7.14       | 2.64  | 4.55   | 4.78  |
| K   | Distilled water | 11.92      | 6.62  | 9.32   | 9.27  |
|     | 20% Sea water   | 14.58      | 9.198 | -      | 11.89 |
|     | 30% Sea water   | 12.72      | 8.17  | 10.817 | 10.57 |

Table 41 shows that hatchlings from saline soils contain more (Na) and (K) than those from neutral soil. This increase in ions may account for the greater dry weight shown by larvae from saline soils.

Moisture Kinetics of the eggs in a saline medium:

The purpose of these experiments was to study water movement in the desert locust eggs in saline medium. 48 hours and six days old eggs were used. It was thought that active and alive eggs

might undergo chemical changes in their contents to regulate their osmotic pressure, in which larger molecules may break down into smaller ones and the molecular concentration and osmotic pressure of egg contents are thereby increased. Therefore two series of experiments were done, 1. on alive eggs, 2. on freshly killed eggs. Killing the eggs was done by exposing them to ammonia vapour for 10 minutes in a closed vessel (Mattheé 1951).

Procedure: The egg-pods were laid by gregaria parents in a neutral sand moistened with distilled water and were kept at 32°C until required. Eggs of the required age were taken from one egg-pod. They were cleaned with fine brush and distilled water under a binocular microscope and left to dry for 5 minutes over a filter paper. When experiments were conducted with live eggs they were weighed individually after drying, while with freshly killed eggs, weighing was done after poisoning. Treatments were done by putting the eggs for 48 hours over a cotton wool pad covered with a filter paper and impregnated with 25 ml. of the required concentration of sea water, in a petri dish. Incubation was at 32°C. After 48 hours the eggs were washed with distilled water, dried and weighed. The differences between the original and the second weight represented the gain or loss of water from the eggs. The concentration of S.W. at which absorption or loss of water ceased was considered to be an isotonic concentration. Many preliminary trials were made in order to establish broadly the range of salinity to be used in these experiments.

Experiment XI: Effect of salinity on water gain or loss in live eggs 48 hours old.

The concentrations of sea water used in this experiment were 46%, 48%, 50%, 52%, 54%, 56%, 58%, 60%, 62% and 64%. Table 42 and Fig. 38, show the percentage gain or loss in weight per hour for 48 hours old live eggs.

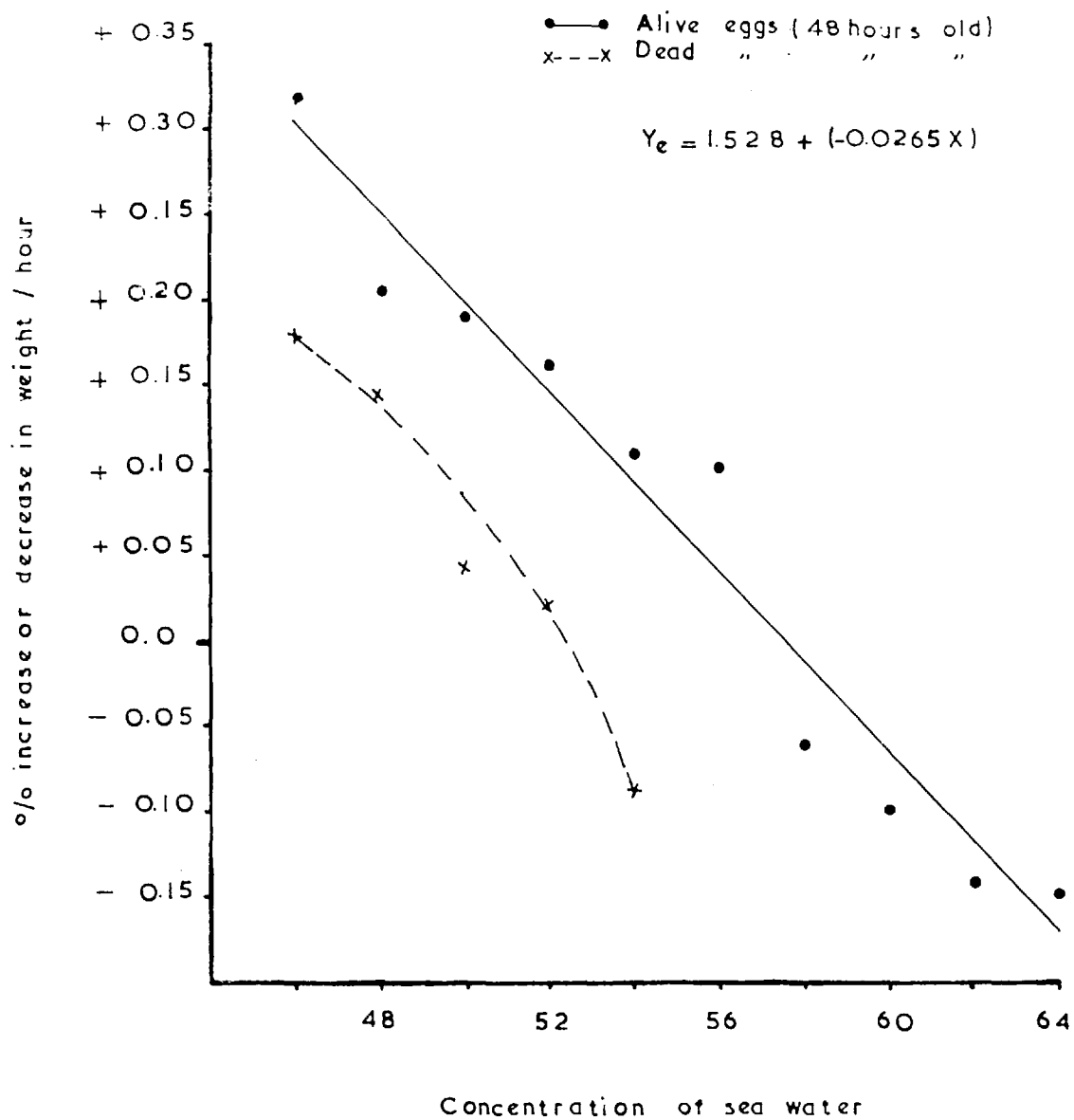
Table 42. Percentage decrease or increase in weight per hour of live eggs 48 hours old, kept in water of different salinities.

| Item            | Repl. | % Sea water in water |        |        |        |        |        |
|-----------------|-------|----------------------|--------|--------|--------|--------|--------|
|                 |       | 46                   | 48     | 50     | 52     | 54     | 56     |
| Percentage dec. | 1     | 0.2558               | 0.1687 | 0.2141 | 0.2604 | 0.0938 | 0.092  |
| or inc. in      | 2     | 0.2923               | 0.2439 | 0.1749 | 0.2233 | 0.1687 | 0.092  |
| weight/hrs.     | 3     | 0.4385               | 0.2063 | 0.1943 | 0.0125 | 0.0938 | 0.1289 |
| Mean            |       | 0.3288               | 0.2063 | 0.1944 | 0.1654 | 0.1187 | 0.1043 |
|                 |       | 58                   | 60     | 62     | 64     |        |        |
| Percentage dec. |       | -0.1024              | -0.108 | -0.179 | -0.106 |        |        |
| or inc. in      |       | 0                    | -0.114 | -0.073 | -0.141 |        |        |
| weight/hrs.     |       | -0.106               | -0.077 | -0.174 | -0.146 |        |        |
| Mean            |       | -0.069               | -0.099 | -0.142 | -0.131 |        |        |

A regression analysis was applied and found to be highly significant at  $P < 0.001$ . The regression equation is  $Y_e = 1.528 + (-0.0265 X)$ .

Fig 38, shows that the isotonic concentration is about 57.5% S.W. = 13.24 atms.

FIG. 38



% increase or decrease in weight / hr. of 48 hrs. old eggs in relation to soil salinity.

Analysis of variance.

| s.v.                                  | s.s.    | d.f. | m.s.    | F.         |
|---------------------------------------|---------|------|---------|------------|
| Regression                            | 0.23287 | 1    | 0.23287 | 130.094*** |
| Error or deviation<br>from regression | 0.01434 | 8    | 0.00179 |            |
| Total                                 | 0.24721 | 9    |         |            |

Experiment XII: Effect of salinity on water gain or loss in 48 hours  
freshly killed eggs.

The concentrations of sea water used were 46‰, 48‰, 50‰, 52‰, 54‰ and distilled water. Table 43 and Fig. 38 show the percentage gain or loss in weight per hour.

Table 43. Percentage decrease or increase in weight/hour of freshly killed eggs (48 hours old). Kept in water of different salinities.

| Item                                         | Repl. | ‰ Sea water in water |        |        |        |        | Distilled water |
|----------------------------------------------|-------|----------------------|--------|--------|--------|--------|-----------------|
|                                              |       | 46                   | 48     | 50     | 52     | 54     |                 |
| Percentage dec.<br>or inc. in<br>weight/hrs. | 1     | +0.417               | +0.285 | 0      | -0.023 | -0.045 | All             |
|                                              | 2     | +0.135               | +0.109 | +0.179 | +0.115 | -0.090 | eggs            |
|                                              | 3     | +0.090               | +0.109 | 0      | -0.069 | -0.069 | burst           |
|                                              | 4     | +0.090               | +0.197 | +0.044 | +0.115 | -0.023 |                 |
|                                              | 5     | +0.180               | +0.023 | 0      | -0.023 | -      |                 |
| Mean                                         |       | 0.182                | 0.145  | 0.045  | 0.023  | -0.057 |                 |

Table 43 and Fig. 38 show that there is a sudden decrease in weight of the eggs at 54‰ S.W. It seems that the isotonic solution is about 53‰ = 12.2 atms.

Experiment XIII: Effect of salinity on water loss or gain in live eggs 6 days old.

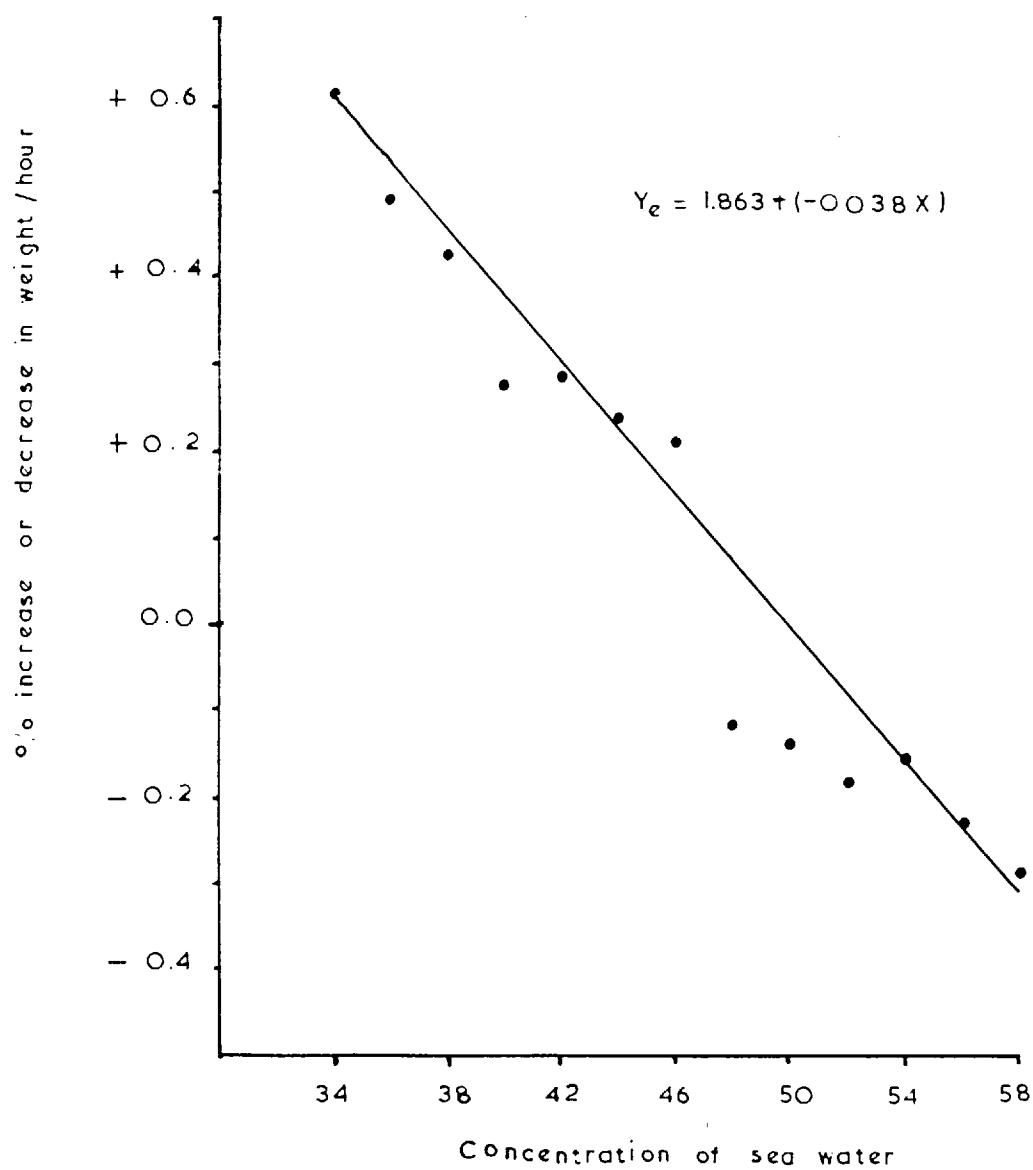
The concentrations of sea water used were 34%, 36%, 38%, 40%, 42%, 44%, 46%, 48%, 50%, 52%, 54%, 56%, 58%, and distilled water. Table 44 and Fig. 39 show the percentage gain or loss in weight/hour.

Table 44. Percentage increase or decrease in weight/hour of 6 days old live eggs.

| Item            | Repl. | % sea water in water |        |        |        |        |                 |       |        |
|-----------------|-------|----------------------|--------|--------|--------|--------|-----------------|-------|--------|
|                 |       | 34                   | 36     | 38     | 40     | 42     | 44              | 46    | 48     |
| Percentage dec. | 1     | 0.545                | 0.547  | 0.399  | 0.265  | 0.278  | 0.175           | 0.128 | -0.117 |
| or inc. in      | 2     | 0.635                | 0.568  | 0.399  | 0.285  | 0.278  | 0.285           | 0.257 | -0.124 |
| weight/hrs.     | 3     | 0.679                | 0.378  | 0.505  | 0.285  | 0.322  | 0.263           | 0.257 | -0.111 |
| Mean            |       | 0.619                | 0.497  | 0.434  | 0.278  | 0.292  | 0.241           | 0.214 | -0.117 |
|                 |       | 50                   | 52     | 54     | 56     | 58     | Distilled water |       |        |
| Percentage dec. | 1     | -0.143               | -0.148 | -0.082 | -0.139 | -0.167 | +0.615          |       |        |
| or inc. in      | 2     | -0.160               | -0.167 | -0.092 | -0.293 | -0.279 | +0.895          |       |        |
| weight/hrs.     | 3     | -0.110               | -0.202 | -0.288 | -0.237 | -0.366 | +0.787          |       |        |
| Mean            |       | -0.137               | -0.172 | -0.154 | -0.223 | -0.271 | +0.765          |       |        |

A regression analysis was applied and found to be highly significant at  $P < 0.01$ . The regression equation is  $Y_e = 1.863 + (-0.038 X)$ . Fig. 39 shows that the apparent isotonic concentration is 50% S.W.  $\equiv$  11.51 atms.

FIG. 39



% increase or decrease in weight / hr of 6 days old olive eggs in relation to soil salinity.

Analysis of variance.

| s.v.                                   | s.s.    | d.f. | m.s.    | F.       |
|----------------------------------------|---------|------|---------|----------|
| Regression                             | 1.05519 | 1    | 1.05579 | 17.752** |
| Error or deviation<br>from regression. | 0.06538 | 11   | 0.05944 |          |
| Total                                  | 1.12057 | 12   |         |          |

Experiment XIV: Effect of salinity on water gain or loss in 6 days  
old freshly killed eggs.

The concentrations of sea water used were 30, 32, 34, 36, 38 and 40%. Table 45 shows the percentage gain or loss in weight per hour.

Table 45. Percentage decrease or increase in weight of freshly killed eggs (6 days old). Kept in water of different salinities.

| Item                                         | Repl. | % of sea water in water |         |         |         |         |         |
|----------------------------------------------|-------|-------------------------|---------|---------|---------|---------|---------|
|                                              |       | 30                      | 32      | 34      | 36      | 38      | 40      |
| Percentage dec.<br>or inc. in<br>weight/hrs. | 1     | 0.106                   | 0.074   | 0.1255  | 0.0915  | -0.0083 | -0.6663 |
|                                              | 2     | 0.0081                  | 0.008   | -0.0585 | -0.0499 | -0.0332 | -0.8181 |
|                                              | 3     | 0.057                   | 0.074   | -0.0418 | -0.0166 | +0.0332 | -0.7001 |
|                                              | 4     | 0.089                   | -0.0415 | 0.0418  | -0.0665 | 0.0166  | -0.7169 |
|                                              | 5     | 0.057                   | 0       | 0.0083  | +0.0665 | -0.0332 | -0.8350 |
| Mean                                         |       | 0.0634                  | 0.023   | 0.015   | 0.005   | -0.0116 | -0.747  |

Table 45, shows that there is a sudden decrease in weight at 40% S.W. It seems probable that in these circumstances the isotonic solution is about 37% = 8.52 atms.

Moisture Kinetics of the eggs in glucose solutions.

The behaviour of living and freshly killed eggs in glucose solutions was studied in order to study the role of osmotic pressure in water loss or uptake by eggs. Unlike salts in the sea water, the glucose molecules are comparatively large; not being ionised in water they are very unlikely to penetrate the egg-membranes. The procedure used for these experiments was the same as with saline medium. The glucose concentrations were as follows:-

| <u>Osmotic pressure atms.</u> | <u>Molar</u> | <u>Glucose gms./100 ml. D.W.</u> |
|-------------------------------|--------------|----------------------------------|
| 3                             | 0.1199       | 2.160                            |
| 4                             | 0.1598       | 2.8789                           |
| 5                             | 0.1998       | 3.5990                           |
| 6                             | 0.2397       | 4.3184                           |
| 7                             | 0.2797       | 5.039                            |
| 8                             | 0.3196       | 5.757                            |
| 9                             | 0.3596       | 6.478                            |
| 10                            | 0.3995       | 7.197                            |
| 11                            | 0.4395       | 7.918                            |
| 12                            | 0.4790       | 8.630                            |
| 13                            | 0.5194       | 9.358                            |
| 14                            | 0.5594       | 10.078                           |

Calculations: Example: The concentration of a glucose solution equal in its osmotic pressure to 8 atms at 32°C is:-

1. The osmotic pressure corresponds with a pressure at 0°C of

$$\frac{8 \times 273}{305} = 7.16$$

2. ∴ The molar concentration to give this pressure is

$$\frac{1 \times 7.16}{22.4} = 0.3196$$

3. ∴ The concentration =  $0.3196 \times 180.16 \text{ (M.W.)} = 57.579 \text{ gr./1000ml.}$

Experiment XV: Behaviour of 48 hours old live eggs in glucose solutions.

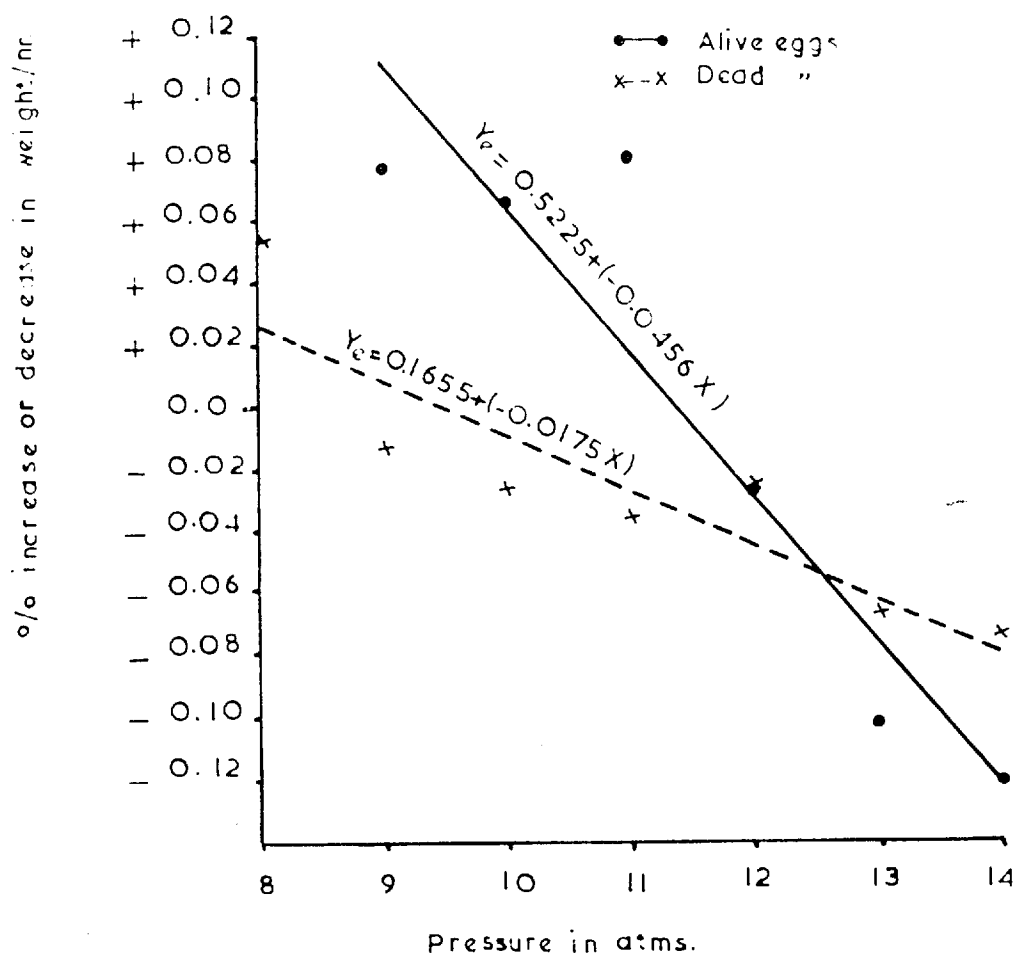
The glucose solutions used had an osmotic pressure equal to 9, 10, 11, 12, 13 and 14 atms. Table 46 and Fig. 40 show the percentage decrease or increase in weight per hour at 32°C.

Table 46. Percentage decrease or increase in weight/hour of 48 hours old live eggs kept at different concentrations of glucose.

| Item            | Repl. | Treatment (in atmospheres) |        |        |         |         |         |
|-----------------|-------|----------------------------|--------|--------|---------|---------|---------|
|                 |       | 9                          | 10     | 11     | 12      | 13      | 14      |
| Percentage inc. | 1     | 0.1156                     | 0.0408 | 0.0802 | 0       | -0.0816 | -0.0802 |
| or dec. in      | 2     | 0.0400                     | 0.0785 | 0.0801 | -0.0785 | -0.1487 | -0.1179 |
| weight/hr.      | 3     | 0.0785                     | 0.0816 | 0.0801 | 0       | -0.0785 | -0.1633 |
| Mean            |       | 0.078                      | 0.066  | 0.080  | -0.026  | -0.103  | 0.120   |

A regression analysis was applied and found to be highly significant at ( $P < 0.01$ ). The regression equation is  $Y_e = 0.52254 + (-0.0456 X)$ . Fig. 40 shows that equilibrium occurred at a pressure of about 11.4 atms.

FIG. 40



% increase or decrease in weight / hr.  
of 48 hrs. eggs kept in different concentrations  
of glucose.

Analysis of variance.

| s.v.       | s.s.    | d.f. | m.s.    | F.      |
|------------|---------|------|---------|---------|
| Regression | 0.03675 | 1    | 0.03675 | 25.17** |
| Error      | 0.00585 | 4    | 0.00146 |         |
| Total      | 0.04260 | 5    |         |         |

Experiment XVI: Behaviour of 48 hours old freshly killed eggs in glucose solutions.

The glucose solutions used had an osmotic pressure equal to 8, 9, 10, 11, 12, 13 and 14 atms. Table 47 and Fig. 40, show the percentage decrease or increase in weight per hour at 32°C.

Table 47. Percentage decrease or increase in weight/hours of freshly killed 48 hours old eggs in different concentrations of glucose.

| Item         | Repl. | Treatment (in atmospheres) |         |         |         |         |         |         |
|--------------|-------|----------------------------|---------|---------|---------|---------|---------|---------|
|              |       | 8                          | 9       | 10      | 11      | 12      | 13      | 14      |
| Percentage   | 1     | 0.0417                     | 0       | 0       | -0.0373 | 0       | -0.758  | -0.1436 |
| inc. or dec. | 2     | 0.0385                     | -0.0771 | -0.0400 | -0.0731 | -0.0373 | -0.0850 | -0.0379 |
| / hour.      | 3     | 0.0802                     | +0.0400 | -0.0385 | 0       | -0.0417 | -0.0425 | -0.0379 |
| Mean         |       | 0.0535                     | -0.0124 | -0.0262 | -0.0368 | -0.0263 | -0.0678 | -0.0731 |

A regression analysis was applied and found to be highly significant at  $P < 0.01$ . The regression equation is  $Y_e = 0.1655 + (-0.0175 X)$ . Fig. 40 shows that equilibrium occurred at a pressure of about 9.5 atms.

analysis of variance.

| s.v.       | s.s.    | d.f. | m.s.     | F.        |
|------------|---------|------|----------|-----------|
| Regression | 0.00859 | 1    | 0.00859  | 21.5829** |
| Error      | 0.00199 | 5    | 0.000398 |           |
| Total      | 0.01058 | 6    |          |           |

Experiment XVII: Behaviour of 6 days old live eggs in glucose solutions.

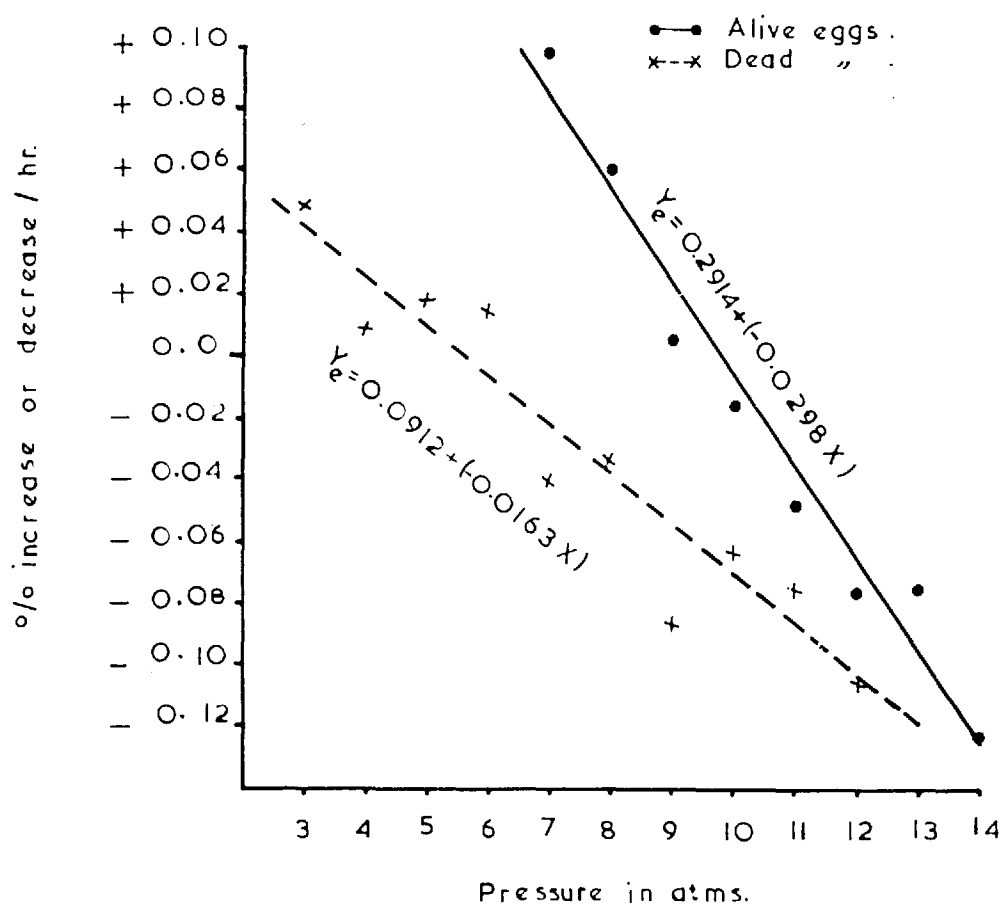
The glucose solutions used had an osmotic pressure equal to 7, 8, 9, 10, 11, 12, 13 and 14 atms. Table 48 and Fig. 41 show the percentage decrease or increase in weight per hour at 32°C.

Table 48. Percentage increase or decrease in weight /hour of 6 days old live eggs kept in different concentrations of glucose.

| Item    | Repl. | Treatment (in atmospheres) |        |        |         |         |         |         |         |
|---------|-------|----------------------------|--------|--------|---------|---------|---------|---------|---------|
|         |       | 7                          | 8      | 9      | 10      | 11      | 12      | 13      | 14      |
| % inc.  | 1     | 0.0677                     | 0.0718 | 0      | -0.0164 | -0.0333 | -0.1225 | -0.0840 | -0.1279 |
| or dec. | 2     | 0.1176                     | 0.0529 | 0      | -0.0164 | -0.0771 | -0.0385 | -0.0688 | -0.1246 |
| /hour   | 3     | 0.1121                     | 0.0568 | 0.0166 | -0.0161 | -0.0338 | -0.0656 | -0.0706 | -0.1176 |
| Mean    |       | 0.099                      | 0.061  | 0.0055 | -0.0163 | -0.048  | -0.0755 | -0.0745 | -0.1233 |

A regression analysis was found to be highly significant at  $P < 0.01$ . The regression equation is  $Y_e = 0.2914 + (-0.0298 X)$ . Fig. 41 shows that equilibrium occurred at a pressure of about 9.75 atms.

FIG. 41



% increase or decrease in weight / hr. of six days old eggs kept in different concentrations of glucose.

Analysis of variance.

| s.v.       | s.s.    | d.f. | m.s.    | F.       |
|------------|---------|------|---------|----------|
| Regression | 0.03738 | 1    | 0.03738 | 14.213** |
| Error      | 0.00158 | 6    | 0.00263 |          |
| Total      | 0.03896 | 7    |         |          |

Experiment XVIII: Behaviour of 6 days old freshly killed eggs in glucose solution.

The glucose solutions used had an osmotic pressure equal to 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 atms. Table 49 and Fig. 41 show the percentage decrease or increase in weight per hour at 32°C. Table 49. Percentage increase or decrease in weight/hour of 6 days old freshly killed eggs kept in different concentrations of glucose.

| Item    | Repl. | Treatment (in atmospheres) |        |        |        |         |         |         |
|---------|-------|----------------------------|--------|--------|--------|---------|---------|---------|
|         |       | 3                          | 4      | 5      | 6      | 7       | 8       | 9       |
| % inc.  | 1     | 0.0449                     | 0.0143 | 0.0141 | 0.0149 | 0.0344  | -0.0365 | -0.0875 |
| or dec. | 2     | 0.0617                     | 0      | 0.0283 | 0.0315 | 0.0368  | -0.0512 | -0.0875 |
| /hour   | 3     | 0.0431                     | 0.0144 | 0.0155 | 0      | -0.0516 | -0.0167 | -0.0845 |
| Mean    |       | 0.0499                     | 0.0096 | 0.0193 | 0.0153 | -0.04   | -0.034  | -0.086  |

|         | 10      | 11      | 12      |
|---------|---------|---------|---------|
| % inc.  | -0.0504 | -0.0860 | -0.0883 |
| or dec. | -0.0712 | -0.0875 | -0.1236 |
| /hour   | -0.0689 | -0.0525 | -0.1059 |
| Mean    | -0.064  | -0.075  | -0.106  |

A regression analysis was found to be significant at  $\alpha = 0.05$  and very close to the 1% level. The regression equation is  $Y_e = 0.09117 + (-0.01633 X)$ . Fig. 41 shows that equilibrium occurred at a pressure of about 5.7 atms.

Summary for the osmotic experiments results:

Table 50 shows the osmotic pressures at which equilibrium was attained.

Table 50.

| Age of eggs  | Sea water  |                | Glucose solutions |                |
|--------------|------------|----------------|-------------------|----------------|
|              | Alive eggs | Freshly killed | Alive             | Freshly killed |
| 48 hours old | 13.24      | 12.2           | 11.4              | 9.5            |
| 6 days old   | 11.51      | 8.52           | 9.75              | 5.7 atms.      |

The osmotic pressure of the contents of living eggs:

It has been shown in Table <sup>50</sup>~~44~~ that 48 hours old eggs were in osmotic equilibrium with a concentration of sea water of an osmotic pressure of about 13.4 atms, while six days old eggs were in equilibrium with a concentration equal to about 11.5 atms. Lower osmotic pressure values of about 11.4 and 9.75 atms. respectively were, however, obtained using glucose solutions.

The isotonic solutions are supposed to produce the same tension or pressure in the eggs as the egg contents or in other words are isosmotic with the yolk. Owing to, the differences at which equilibrium occurred when using sea water and glucose solutions, it was thought that further light might be thrown on the problem

of water absorption from saline soils by comparing the osmotic pressure of the egg contents with that of the sea water and glucose at which equilibrium was attained. The osmotic pressure of the contents of eggs 48 hours and six days old was measured by using the cryoscopic or the depression of freezing point method.

Depression of the freezing point: The depression of the freezing point was measured by using a calibrated thermocouple reading from  $-5^{\circ}\text{C}$  to  $0^{\circ}\text{C}$ . One end of the thermocouple was put in melting ice giving a constant temperature of  $0^{\circ}$ . The other end was introduced inside the posterior end of one egg. The egg was then put in a hole 2 mm. in diameter and one cm. deep, drilled in the middle of 2.5 x 2.5 x 2.5 cm. perspex block. Liquid nitrogen was then splashed on the block to freeze the egg. Readings were taken at 10 seconds intervals. The measurements were made for each age. Table 51, shows the depression of the freezing point and the corresponding osmotic pressure.

Table 51. Depression of the freezing point and the corresponding osmotic pressure of the contents of 48 hours and 6 days old eggs.

| Eggs 48 hours old |                                 |         |                     | Eggs 6 days old                 |        |                     |
|-------------------|---------------------------------|---------|---------------------|---------------------------------|--------|---------------------|
| Repl.             | Depression of<br>freezing point | Mean    | Osmotic<br>pressure | Depression of<br>freezing point | Mean   | Osmotic<br>pressure |
| 1                 | -0.90                           |         |                     | -0.74                           |        |                     |
| 2                 | -0.933                          | -0.9330 | 11.233<br>atms.     | -0.60                           | 0.6467 | 7.786<br>atms.      |
| 3                 | -0.966                          |         |                     | -0.60                           |        |                     |

Calculation of the osmotic pressure from the depression of the freezing point was done according to 1. the law of Blagden which states that for a given solute the depression of the freezing point is proportional to the concentration of the solute and 2. the law of Raoult which states that for one and the same solvent equi-molecular amounts of different solutes depress the freezing point to the same extent. A deci-molar solution freezes at  $-0.186^{\circ}\text{C}$  and since such a solution would have been an osmotic pressure equal to 2.24 atms., a depression of  $0.100^{\circ}\text{C}$  would correspond with an osmotic pressure of 1.204 atms. Thus, a depression of  $-0.993$  corresponds to  $\frac{1.204 \times 0.993}{0.1} = 11.233$  atms., or, alternatively the following straight forward equation was used

$$P = 12.04 \Delta - 0.02 \Delta^2$$

where  $P$  = osmotic pressure

and  $\Delta$  = depression of the freezing point.

General Discussion.

Oviposition behaviour:

Field observers have reported that oviposition occurs only after rain has fallen (Rao 1934; Maxwell-Darling 1934-36). Hamilton (1936) found that moisture is necessary for hatching and he stressed the need to distinguish between 100% relative humidity of the atmosphere and the direct contact of eggs with water. The locust lives in areas where the moisture content of the soil may vary from zero to saturation, which influences the distribution of the species in these areas. Thus, Ashall and Ellis (1962) found that during the season of low rainfall and poor growth of vegetation, the number of eggs per pod was significantly reduced. Popov (1958) stated that the desert locust may reject very moist as well as completely dry soils. Soil moisture, thus, very much influences the selection of a site for oviposition. Some observations on the role of soil moisture in field oviposition have been mentioned in Part I of this thesis. Thus, the females selected the more humid sites for egg laying inspite of their structural unsuitability (hard surface with gravel). Possibly the avoidance of wet surfaces referred to by Popov (1958) is due to the resultant lower surface temperature compared with drier surfaces. The experimental results incages on the significance of soil moisture as a factor determining the selection of oviposition sites showed that the females prefer moist to dry sand. The moisture

preference was still pronounced when there was a choice between moist sandy loam soil with a gravelly top and a sandy soil containing less moisture. This indicates that soil moisture plays an important part in the selection of the sites and is more significant than soil structure and texture. Moreover, the presence of moisture in soil, not only provides the eggs with a suitable media for development but it also assists in the probing process in clayey and loam soils (Norris, personal communication). Thus, it seems that the desert locust in a particular area would select the more humid sites (under the range of soil moisture investigated), in preference to the less humid ones. The female prefers to lay eggs in sand, but this must be wet sand. In the desert, great variations in soil moisture may occur in a small area (field observations - Part I). In day periods, the desert locust depends for its multiplication on the existence of favourable ecological islands in its vast desert habitat (Uvarov, 1962). The migration of the desert locust must be one of the important adaptations for escaping from severe unfavourable environments in the desert. The locust will avoid these unfavourable places and emigrate to areas where food and soil moisture is available for a successful egg development, which is a sort of built in safety device for the maintenance of the species. Waloff and Rainey (1951), Waloff (1953) and Rainey (1964) studied the desert locust migrations in relation to the weather factors and they put a well documented hypothesis, that the major swarm movements take place towards zones of convergence of air masses which are always followed by precipitation. The result is that

locusts and rain are likely to arrive in an area together.

Soil compaction is also one of the important factors that determine the suitability of oviposition sites. In the field, the locust swarms were reported to prefer laying in the less compact soils (Popov, 1958), although oviposition may occur in clayey soil with a hard surface (Part I site II), if there is more soil moisture than elsewhere. Soil selection experiments showed that S. gregaria females, prefer "pressed" sandy soil more than the "loose" sandy soil and "loose" sandy loam soil more than "pressed" sandy loam for egg-laying. When given a choice they preferred to oviposit in "pressed" sandy soil rather than "loose" sandy loam. With sandy loam soil, the females did not succeed in laying in compact soil exceeding a bulk density value of 1.2 gm./cc. Many attempted probings were noticed, but these did not go beyond the scratching of the soil and it was very seldom that successful bores were recorded. According to Agrawala (1952) who studied the structure of the ovipositors in Acrididae, S. gregaria prefers sandy and moderately loose soils.

For all poikilothermic animals including locusts, temperature plays an important and vital part in their activity and behaviour. It is characteristic of locusts in the field that they form basking groups in sunlit places, and as the day gets hotter and the temperature rises, the locusts start to regulate their temperature by sheltering under shady places and bushes. Frankel (1930), stated that the desert locust is in state of cold stupor below 17°C., and begins to

move about between 17 and 20°C. When the air temperature rose to this level, the locust form dense groups on slopes facing east and on the eastern sides of bushes. Basking lasts until air temperature rises to about 28°C and then the locusts start to migrate. Popov (1958), mentioned that basking ceases when the ground temperature began to rise steeply to about 23°C - 25°C, and sheltering starts when the soil surface temperature rises above about 43°C. Basking is a general phenomena in all active stages of the desert locust. Hussein (1937) working on Locusta, Schistocerca and Nomadacris found positive thermokinesis. Popov (1954), mentioned that mass oviposition by S. gregaria swarms was observed at a temperature range of 22.5 - 33.3°C. Husain et al (1936), in their laboratory experiments found that S. gregaria females could bore into the soil when the surface temperature was 42°C and the soil temperature at a depth of 3" 43°C. The lower limit of soil temperature for oviposition recorded by them was 20°C. Popov (1958) mentioned that oviposition occurred frequently at the site which was initially selected by the swarm for basking. He also, reported one occasion in which the formation of egg-laying groups was due to the warmer surface of the sand in relation to the surrounding terrain.

In the present work, the highest soil temperature recorded for egg-laying was 52.5°C at 2" depth (soil surface temp. 40°C), the minimum was 28°C (soil surface temp. 29°C), and the most acceptable zone for egg-laying was between 32 - 42°C (soil surface temp. around 35°C). The situation resulting from the interaction

of basking, egg-laying, soil surface temperature, and soil temperature at 2" depth is highly complex; for example, is the attraction to warmer sites for the purpose of basking or/and for egg-laying? And, what is the factor determining oviposition in a particular temperature zone? Is it soil surface temperature or is it the soil temperature at the depth where the egg-pods are deposited? In the field, the soil surface temperature is generally higher in day time than at 2" depth, and the commencement of probing and egg-laying appears to be connected with a suitable soil surface temperature for the process. On the contrary, in the present work, soil surface temperature in the hot side of the oviposition site was less than that at a depth of 2". It would thus, seem that the locusts were attracted to the warmer sites for either basking or egg-laying and the most suitable soil surface temperature for these purposes appears to be from 35 - 44°C. But, when probing commenced the females withdraw their abdomen quickly, although many attempts continued to be made presumably in an attempt to find suitable subsoil temperature for egg-laying. The present work suggests that it is possible that attraction to warmer sites is governed by soil surface temperature, but it seems likely that the act of egg-laying depends on the temperature of the soil where the egg-pods will be deposited. Slifer (1951) mentioned, the existence of thermoreceptors in Locusta m. m. at the antennal crescents. Such thermoreceptors have not yet been discovered in the desert locust.

Effect of soil moisture on the development of desert locust eggs:

It has been recorded that the incubation period may vary from 9 - 106 days in the field according to the month of the year and temperature records (Ballard et al, 1932). In the present work, soil moisture proved not to affect the time required for the duration of egg-development of gregaria and solitaria eggs. But, the role of temperature on the incubation period appears to be important. Hamilton (1950), mentioned that as the temperature increases the incubation period of S. gregaria decreased up to 43.3°C, thereafter a complete failure of hatching occurred.

King (1921) suggested the possibility of an arrested development of S. gregaria eggs, laid in dry soil and provided with moisture after periods of time. Ballard et al (1932) as well as Husain et al (1941) stated that the arrested development may occur in natural conditions. Shulov and Penner (1963) found that S. gregaria eggs pre-incubated in moist sand for 5 days and then transferred to an atmosphere of 100% R.H. can remain in a state of arrested development for as long as 98 days and hatching can occur after return to wet sand, where 2.3% of the eggs hatched. Popov (1959) was able to keep an egg-pod of Locusta m.m. 30 days old in which none of the eggs had reached katatrepsis, in a viable state up to 86 days after oviposition by adding from time to time a drop or two of water which prevented dessication.

Some insect eggs have a remarkable ability to withstand lack of moisture for a long period. Davis (1948), showed that the eggs of

the blowfly Lucilia sericata developed satisfactorily at 37°C and 50% R.H., and in dry air these eggs lose water at the rate of 0.5 mg./cm<sup>2</sup>./hr., which is low compared with many adult insects. Leclercq (1948) found that eggs of the beetle Melasma populi all developed in humidities down to 17% and a few could survive in dry air. Davidson (1932), found that the activity and abundance of collembola are associated with the moisture of their environment. Sminthurus viridis occurred in large numbers in certain areas of South Australia during the rainy season, but the number rapidly decreases when the dry season sets in, although certain eggs remain dormant in the soil throughout the dry season. According to Way's definition (1962) diapause is unlike quiescence because the diapausing insect is not reactivated by favourable climate until it has completed a definite temperature controlled phase of physiological diapause development. Thus, all these conditions are not due to a definite diapause, but to an enforced quiescence from lack of moisture.

In the present work, with gregaria egg-pods incubated in sandy soil containing moisture below the limit for full egg development did not hatch when water was provided 30 days after oviposition. However, eggs incubated in sandy loam soil containing inadequate water for development (e.g. 2.9 cc. water/100 grms. soil = 10% saturation) were healthier after 30 days and when water was provided some resumed growth and hatched. The mean time required for hatching at 27°C, when water was available was 24.6 days which

is more than that required for development under normal conditions of moisture at the same temperature (19.5 days). This may be explained by faults in experimental technique namely, the handling of the containers at room temperature and the addition of tap water which was cold (15°C). Eggs kept for 30 days at 32°C in sandy loam soil with inadequate moisture, hatched after a mean of 11.3 days when water was added. On this occasion, care was taken to add water warmed to 32°C. The time for development at 32°C in adequate water conditions was 14.6 days. Thus, it would seem that at 32°C in the absence of adequate water, the eggs undergo development equal to about  $\frac{1}{4}$  of the time for full development. As the containers were waterproofed and fully sealed, the R.H. was at or near saturation. Therefore dessication could not have occurred.

The experimental results showed that soil moisture in different kinds of soils (sandy and sandy loam) and at different temperatures 27 and 32°C) decreases percentage hatch when increased over the level of 50% of soil saturation. When soil was completely saturated, the eggs sometimes burst or sometimes the yolk coagulated. At low moisture levels i.e. below the 50% level and above the critical minimum, a high percentage of eggs hatched.

The range of soil moisture required for egg development differs from soil to soil depending upon the soil texture. Loam soil may contain the same percentage of moisture as sandy soil, but may differ in the availability of this moisture to the egg-pods. For example; if the sandy and sandy loam soils which have been used in

these experiments are saturated at 10% level, the sandy soil will be more visibly moist with perhaps 4% of free moisture available for the eggs. The sandy loam will barely look moist and have no moisture available for the use of the eggs. This may explain why the critical minimum for egg development was at 6% and 20% soil saturation in sandy and sandy loam soils respectively.

It is characteristic of locusts that when the parents are crowded their progeny tend to be mostly black and conversely, hatchlings from isolated parents are mostly green. In the present work, it has been found that to some extent the soil moisture also influenced the colour of hatchlings. When eggs from gregaria parents were incubated in very moist soil, the proportion of green hatchlings was much reduced, whereas hatchlings from rather dry soil had an appreciable proportion of green forms. The effect on hatchling colour was similarly pronounced in hatchlings from eggs laid by solitaria parents. At high moisture levels a higher proportion of black forms was obtained than at low moisture level when the larvae tended to be green. This degree of influence exercised by soil moisture on the colour of the larvae was more pronounced at an incubation temperature of 32°C than at 27°C.

The relationship between the weight of hatchlings from gregaria as well as solitaria parents and the soil moisture provided an interesting study. At the incubation temperature of 27 and 32°C, the weights of both gregaria and solitaria hatchlings tended to decrease when soil moisture was at low levels and increased with the

increase of moisture. This was associated with the amount of water in the hatchlings which fluctuated similarly with the increase or decrease of weight which in turn was determined by the amount of water available in the soil. Blackith (1961) found that the percentage moisture content in a S. gregaria hatchling depended upon total weight at eclosion. He showed that the percentage of water increased steadily as the initial weight increased. If for example a S. gregaria hatchling contained on an average 79% water, the smallest would contain some 74% and the largest 84%. He also stated that in a Catantopinae, the larger larvae within any egg-pod have a moisture content which is higher both absolutely and relatively than the smaller ones in the same pod. He also mentioned that about 2% of additional water was found to correspond to 1 mg. extra weight. In the present work, the smallest larvae from rather dry soil contained 61.9% of water, and the largest one from very moist soil contained 86.7% of water. Thus, the large larvae have more disposable water than the small ones.

It is known that the young instars are more sensitive to loss of water than the adult S. gregaria which is able to tolerate a reduction to 36% of water (Millot and Fontaine, 1937). Bodenheimer (1929); Langford (1930); Ludwig (1937) and Smith (1960) have related the survival capacity of 1 st. instar larvae to ambient temperature in a wide range of species. Albrecht (1962) has related the survival capacity of the hatchlings to weight at birth. Working on the survival capacity of the hatchlings for the two phases of the desert

locust, he found that the small larvae of solitaria origin were relatively short lived when deprived of food, while larvae produced by gregaria parents survived longer. Field mortality in British grasshoppers too, has been shown to be highest during the early instars (Richards and Waloff, 1954). In a study of Doclostarus maroccanus Thumb, over three generations, Dempster (1957) also found that in each successive generation a very large percentage (59%, 26%, and 57% respectively) of the hatchlings died in the first instar. These observations emphasise the importance of the appropriate timing of the locust emergence in an ever changing habitat. This is further substantiated by the present studies. Starved hatchlings from very wet soils at 27°C survived longer than those from soil containing less moisture. Similarly at 32°C, hatchlings from very moist soil survived longer at 50% and 0 - 5% R.H. than those hatching from low moisture.

Since Uvarov (1921) propounded his classical theory of locust phases, many attempts have been made to elucidate the transformation from one phase to the other. Phases in the desert locust seems to be the result of the interactions of population density with various physical and non-physical factors, vis., moisture, temperature, vegetation, fecundity, photoperiod, parasites, predators ... etc. All these factors individually or collectively play a critical role in the phase dynamics. Of all these factors, the role of soil moisture in phase biology appears to be of great importance. In fact, the very concept of S. gregaria habitat is intimately linked

with the moisture level of the soil as well as the atmosphere. Both the adults as well as the hoppers are endowed with a unique and facultative dynamism which enable them to escape from the stresses of an unfavourable habitat to one that is favourable. However, this is not so with eggs, which lie embedded in the soil and under conditions from which they can not escape. The physical characteristics of the static habitat where the egg has to spent from 9 - 106 days, must have a profound effect on the quality of the emergent stage. This emphasises the role as well as the importance of soil moisture as a vital factor in the life cycle of the species. The effect of soil moisture on gregaria as well as solitaria eggs at 32°C can be summarised in the following table.

| Effect of soil moisture on ... | Gregaria Origin                                       |                                                      | Solitaria Origin                                       |                                                      |
|--------------------------------|-------------------------------------------------------|------------------------------------------------------|--------------------------------------------------------|------------------------------------------------------|
|                                | High moisture<br>20.7cc. H <sub>2</sub> O/<br>100gms. | Low moisture<br>1.3cc. H <sub>2</sub> O/<br>100 gms. | High moisture<br>20.7cc. H <sub>2</sub> O/<br>100 gms. | Low moisture<br>1.3cc. H <sub>2</sub> O/<br>100 gms. |
| Weight of hatchlings           | Heavy                                                 | Light                                                | Light                                                  | very light                                           |
| % of black hatchlings          | 98.6                                                  | 83.7<br>decreased                                    | 19.6<br>increased                                      | 0.9                                                  |
| Survival capacity              | High                                                  | Low                                                  | High<br>(Albrecht 1961)                                | Low<br>(Albrecht 1961)                               |
| Percentage hatch               | 71.7<br>reduced                                       | 94.4<br>high                                         | 63.6<br>reduced                                        | 73.7<br>high                                         |
| Incubation period              | No effect                                             |                                                      | No effect                                              |                                                      |

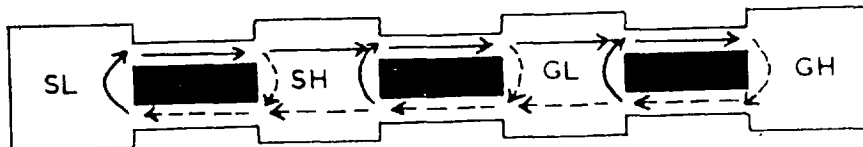
The position summarised in the above table illustrates the relationship between soil moisture and quality and quantity of the hatchlings which as <sup>well</sup> ~~will~~ implies their phase status. A gregaria hatchling from eggs incubated in rather dry soil will tend to acquire some of the characteristics of phase solitaria. The response is manifested in decreased larval weight, appearance of lighter coloured hoppers and the decrease of survival capacity, corresponding to similar characters of solitaria larvae emerging from very moist soil. The level of soil moisture available to eggs, thus, appears to influence both quantitative as well as the qualitative characteristics of the progeny. The pattern of the relationship between soil moisture and phase movements can be likened to a system of two lane but one way traffic where a change of lane is possible only at specified intermediate stations or at the termini. Fig. 42, shows the influence of soil moisture in which the eggs were incubated, on the phase status of the progeny. The unbroken lines show the direction of movements towards gregaria characters in relation to the increase of moisture level, while the broken lines signify the opposite trend when soil moisture levels tend to fall.

It therefore, appears that selection of relatively very moist soil for oviposition (i.e. above the level for optimum egg hatch) is connected to some extent, with a preference mechanism which is more concerned with the long term survival prospects of the progeny than with the short term advantage of potentially high percentage of egg hatch. The capability of the desert locust to oviposit successfully

in a wide range of soil moisture is a sort of double acting mechanism. Because, first, it ensures the survival potential of the progeny, as well as seeks to prevent or retard the process of solitarization of the population. Secondly, in case the inevitable happens and the population is faced with lower soil moisture conditions, it is yet capable of oviposition with greater percentage hatch, thereby, spreading more evenly the hazard of an oncoming unfavourable environment. However, although in the field the conditions of high moisture or drought may not alone be sufficient for the shift from one phase to the other, it would certainly be sufficient in conjunction with some other factors.

FIG. 42

Diagram illustrating the relationship between soil moisture and quality of the hatchlings.

[illegible]

Effect of soil salinity on the hatchlings and the mechanism  
of water absorption by the eggs:

Achilides (1963), showed that artificial sea water has a harmful effect on egg development of the desert locust. Mortality of the eggs increased with increased concentration, the median lethal dose being around 53% of sea water in water. To the authors knowledge, it seems that there are no records of the salinity of egg-fields in nature. The desert locust breeds in a vast area in Africa and Asia, in habitats ranging from river beds to sandy plains of the sea shore.

The present work shows that concentrations of artificial sea water less than LD<sub>50</sub> concentration affect the quality of the hatchlings. Their fresh weights are less than those of controls, while their dry weights are greater. Thus, their water reserves are decreased.

The mechanism by which eggs control the intake and out-put of water, together with the expenditure of energy necessary to maintain a water balance is still a matter of controversy. Birch and Andrewartha (1942) concluded that uptake of water by the eggs of Austroicetes cruciata could be explained in terms of physical laws. Thompson and Bodine (1936) in their work on diapausing eggs of M. differentialis, found that these remain relatively constant in weight and are very resistant to water loss. It may be concluded from their work that water uptake is related to metabolic activity. They recorded a sudden increase in oxygen consumption when dehydration of post-diapause eggs exceeded the limit of 2.5 to 3 mg. per egg.

However, these eggs were presumably dead, for they did not hatch. Thus, it seems possible that this increase in oxygen consumption is due to post-mortem changes. Mathee (1951) stated that a sharp increase in oxygen consumption very often follows immediately after death. According to Schipper's findings (1938), the loss of water is attributable entirely to the physiological state of the eggs.

M. differentialis eggs are most susceptible to hypertonic solutions e.g. during active differentiation when the embryo is being formed.

In the present work, eggs were put in contact with hypotonic, isotonic and hypertonic solutions. The rate of water uptake increased with hypotonicity of the solution while water loss increase with hypertonicity. Thus, at equilibrium, we are dealing with an isotonic solution. If the egg-membranes are impermeable to the dissolved substances, isotonic solutions will also be isosmotic. The osmotic pressure of the isotonic solutions will differ according to the age of the egg, whether they are alive or poisoned, and whether the dissolved substances are ionized salts (sea water) or unionized molecules (glucose). The data in table 50 shows interesting results. The osmotic pressure obtained for 48 hours old eggs is always higher than that obtained for six days old eggs. It also indicates that poisoned eggs reach equilibrium at lower concentrations than the alive eggs. Data in table 50 shows that the osmotic pressure of sea water concentrations required to maintain equilibrium with 48 hours and six days old eggs are higher than for glucose. It is interesting that eggs of Anisophia austriacata are able to extract

water from 4% Na Cl, 2% K N O<sub>3</sub> and 2% Ba Cl<sub>2</sub> (Kerenski, 1930). It is not likely that S. gregaria eggs are able to remove water from a hypertonic solution, since equilibrium has been attained at lower concentrations of glucose. Thus, it seems that the penetration of (Na) and (K) ions increases the ionic concentration of the egg contents resulting in a rise in its osmotic pressure. Also, the increase of dry weight of the hatchlings may be attributed partly to this ionic penetration.

Since, egg membranes are not permeable to glucose molecules, it is more likely that the osmotic pressure of the egg contents is the same as that of the glucose solutions at which equilibrium occurs rather than that of the sea water. The results obtained by the depression of the freezing point method agree roughly with this conclusion. Since they indicated that the osmotic pressure of the egg contents was slightly lower than that of the isotonic glucose solution. It thus appears that when eggs are placed in a hypertonic solution there is some kind of osmo-regulation, perhaps by breaking down of large molecules. The limit of osmo-regulation is around 0.2 and 1.8 atmospheres in 48 hours and 6 days old eggs respectively.

Poisoned eggs attained equilibrium at lower concentrations of sea water and glucose than did unpoisoned eggs. Eggs were poisoned by ammonia vapour. It is likely that ammonia reacts with the amino acids in the egg leading to the formation of ammonium proteinates, which would have a lower osmotic pressure than amino acids.

From the foregoing, the water absorption by S. gregaria eggs

may be explained in terms of a physical osmo-regulatory mechanism. Proteins need water to be hydrolized to amino acids. When the eggs are laid the yolk/embryo ratio is very high. Proteins in the yolk start utilizing the water in the egg, thus, producing free amino acids. Utilization of water would increase the ionic concentration in the eggs, thus, increasing its osmotic pressure. Moreover, the osmotic pressure will be further increased by the formation of free amino acids in the egg. The role which proteins play in regulating the movements of water in living organisms has been emphasized by Jordan (1933). Colombo et al (1962), stated that a sharp increase of total free amino acids is observed on the third day of embryonic development. This coincides with the sudden increase in water uptake by the eggs. The absorption of water leads to stretching in the egg membranes and this depends on the elasticity and plasticity of the membranes. Matthee (1951) found that the average elastic yield point of egg membranes of L. pardalina was 3.8 atmospheres. An internal pressure of 3.8 atmospheres would therefore be sufficient to stretch the egg membranes. In the later stages of embryonic development the yolk/embryo ratio is very small. It appears that at this stage with the reduction of yolk volume, the effect of its osmotic pressure is no longer great enough to stretch the egg membranes by drawing water into the egg. It may be presumed at this stage that there is equilibrium between the osmotic pressure of the egg contents and the internal mechanical pressure of egg membranes. This state of equilibrium is a physical osmo regulatory mechanism which prevents the egg from rupturing.

Environmental conditions and their implications on phase dynamics:

Uvarov's (1921, 1928) famous phase theory was put forward not only to explain polymorphism in locusts, but also outbreaks. The essence of the theory is that locusts exist in two forms, one of which is the solitaria phase, leads a sedentary life. In favourable conditions there is increase in number of individuals in a given habitat, this increase, if maintained for long enough results in the production of the gregaria or swarming phase.

Since the phase theory was propounded many attempts have been made to investigate and clarify the role of crowding or isolation on phase transformation (Hunter-Jones, 1958; Gunn & Hunter-Jones, 1952; Ellis, 1959; Albrecht, 1959a). Kennedy (1956), reviewed most of the work done in this respect. He also discussed the case against the phase theory put by Key (1950). The main points considered by Key are (1) that the phase theory contains various mistaken assumptions in its own favour, and (2) that phase change could not, in principle, be the fundamental cause of the coming and going of locust plagues. Key (1950) stated that "phase transformation must be regarded as a secondary concomitant in the development of locust outbreaks, or at the most a minor contributing factor in which only certain aspects of the transformation are significant .... The whole field of locust ecology and epidemiology can be studied without reference to phases". Key considers that the fundamental cause of outbreaks is primarily due to changes in the population level in the outbreak areas. However, multiplication in

itself is the manifestation of phase transformation and Kennedy (1956) concluded that population changes and phase changes are highly interdependant and cannot be separated. Solitaria in a given habitat would indicate a low density population, while gregaria indicate a highly mobile and dense population. Uvarov (1928) when he mentioned the word "phase" in locusts did not only mean the difference in morphometrics, but also, their behavioural and physiological differences. Roonwal (1944) put forward a hypothesis that in a sufficiently large sample of a solitaria population, if the proportion of six eye striped individuals rises above about 80% and tends towards 100% the population is rapidly on its way towards swarming. Conversely, if in a gregaria population the proportion of 6 - striped individuals falls below 100% and tends towards 80% or lower, the population is on its way towards the acquisition of solitaria or non-swarmling status.

Kennedy (1956) suggested as a working hypothesis that the solitary phase is somewhat juvenile or neotenic compared with the gregaria phase which is more adult, as a result of a difference in the hormone balance during development. He based his hypothesis on Joly's (1953, 54) work, who found that implantation of corpora allata into gregarious nymphs biased the facies of the ensuing adults in the same direction, towards solitaria.

The present work on the effect of some environmental factors on egg development of the desert locust, brought again to the light, the importance of these factors on phase transformations and

population dynamics. It is well known, that dispersion or isolation of gregaria individuals results in the production of solitaria individuals. This can happen in natural habitat by factors such as strong wind, predators, tall vegetations and control methods. Also, experiments showed that locusts could be transferred in the direction of gregaria by crowding. Norris (1950), found that solitaria females of L.M.Migratorioides are more fecund than the crowded gregaria, and when the locust were fed on poor quality grass the figure for gregaria was reduced, while that for solitaria remained as it is. She concluded that, it is clear that under all circumstances, solitaria tend to be superior to gregaria, both in the number of eggs which they lay and in the rate at which they lay them. Also, that their reproductive performance is much less susceptible to adverse environmental factors such as inferior food and crowding during adult life. Hunter-Jones 1958, found that crowded S. gregaria laid fewer eggs/pod than strictly isolated females. Hamilton (1955) found that solitaria females of S. gregaria can multiply parthenogenically for several generations and he discussed its effect on the maintenance of the species.

In the present work, soil moisture proved to have a significant effect on phase status. The progeny of gregaria egg-pods laid in very moist soil would be expected to emerge in an area with abundant vegetation. Thus, they will have a double chance of survival; firstly, because of plenty of food and secondly, because of their heavy weight and high water contents which provide them with a

longer survival potential. Conversely, with eggs laid in rather dry soil, a high proportion of the emerging progeny will find poor vegetation. They will have some of the solitaria characters, i.e. colour, weight and perhaps behaviour. It is significant that solitaria egg-pods laid in very moist soil produce heavier and more pigmented larvae, while at low moisture the progeny are true solitaria.

Saline soils harmed the desert locust eggs (Achillides 1963). Thus, saline soils are considered to be an unfavourable habitat for egg development. Gregaria egg-pods produced lighter larvae with a high proportion of green forms from saline soils, i.e. with characteristics of solitaria hatchlings.

The foregoing evidence provides the starting point for a hypothesis concerning the nature of phases. It can be suggested from field phenomena and laboratory observations that phase gregaria is a competitive phase, while phase solitaria is a protective phase. In a given habitat of the desert locust breeding areas, gregaria locusts aggregate and struggle for food, egg-laying and basking, although there may be abundance of food and space for everyone. The high fertility, green colour and solitary behaviour of solitaria provide them with a great advantage against predators. Also, they spread over a large area where they can feed without competition. Thus, it may be stated that when gregaria face unfavourable environmental conditions at the time of oviposition, the resulting progeny acquire some solitaria characters, as a safety mechanism for the maintenance of the species. In contrast, the combined effect

of favourable environmental factors should produce a gregaria population from solitaria.

The quality and quantity of the hatching larvae are essential for the determination of the phase of the resulting population. Soil moisture and salinity affected the quality and quantity of the hatchlings, thus, in turn influencing the phase status of the progeny. This phase transformation would need more than one generation of favourable or unfavourable conditions for it to be completed.

In order to add more support to the above statement the following studies should be done on the solitaria phase.

1. Oviposition behaviour in regard to soil moisture, temperature, type of soil and salinity.
2. The minimum moisture requirements for egg development and the possibility of arrested development in the egg stage at low moisture levels. (e.g. Matthee (1951), found that the percentage of the diapause eggs of L. pardalina rises with the age of the mother and is highest in the solitaria forms).
3. Tolerance of the eggs to adverse conditions compared with that of gregaria eggs.
4. Temperature requirements for egg development (max., min., optimum).
5. Effect of population density per square metre on the shift from one phase to another.

Summary

Observations on ovipositing swarms were carried out on the Red Sea Coast. The moisture content of the egg-fields was determined throughout the incubation period. It was found that the desert locust swarms would select the more humid sites for egg-laying, irrespective of whether its structure or texture were suitable.

Oviposition behaviour was studied in the laboratory in relation to soil structure, texture, compaction and temperature. Preliminary data suggested that the females preferred laying in "pressed" sandy soil rather than in "loose" or "compact" sandy soils and in "loose" sandy loam rather than in "pressed" or "compact" sandy loam soils. They also seemed to prefer to oviposit in "pressed" sandy soil rather than in "loose" sandy loam .

The females were attracted to the warmer sites for basking and egg-laying. The most acceptable range for egg-laying was when soil temperature was between  $32 - 42^{\circ}\text{C}$  at 2" depth ( soil surface temperature being around  $35^{\circ}\text{C}$ ).

The effect of soil moisture on egg development and the hatchlings of gregaria as well as solitaria egg-pods was studied. It was found that soil moisture ( between the limits of 6% - 90% saturation for sandy soil and between 20%-80% for sandy loam soil) had no effect on the incubation period except in sandy loam soil when inadequate moisture arrested development.

The quality and quantity of hatchlings in both phases were affected by soil moisture. Gregaria hatchlings from eggs incubated under low moisture tended to acquire some of the characteristics

of phase solitaria. The response was manifested in decreased larval weight, appearance of lighter coloured hoppers, and the decrease of survival capacity, corresponding to similar characters of solitaria emerging from very moist soils.

The effect of soil salinity on egg development and on the hatchlings was studied. Concentrations of artificial sea water less than the LD<sub>50</sub> concentration affected the quality of the hatchlings. Their fresh weights were less than those from non-saline soil, while their dry weights were greater. Thus, their water reserves were decreased.

Egg membranes were found to be partially permeable to Na and K ions.

The water Kinetics of the eggs in different concentrations of sea water and glucose were studied. Results suggested that water absorption by S. gregaria eggs can be explained in terms of a physical osmo-regulatory mechanism.

The effect of environmental conditions on phase dynamics was discussed and it is suggested that phase gregaria is a competitive phase while phase solitaria is a protective phase.

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