

STUDIES ON SOIL ARTERPODS PARTICULARLY IN RELATION
TO POPULATION ASSESSMENT

By

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ABSTRACT

An international survey of methods used by soil zoologists to extract arthropods from soil was made to determine details of the apparatus and the ways in which they were most commonly used. The relative efficiency of eleven of the most representative extraction methods were compared for the major groups of soil arthropods on a clay-loam soil under woodland, pasture and fallow habitats. Dynamic or behavioural methods were more efficient than mechanical methods for extracting the active stages of most arthropod groups, but the relative efficiency of mechanical methods improved on fallow soil. The Macfadyen high-gradient funnel apparatus was outstandingly efficient for extracting most arthropod groups from the soil in each habitat.

The relative efficiency of two contrasting methods, commonly used to extract a wide range of soil arthropod species, were compared on sand, peat and three clay soil types. A dry-funnel method, the Rothamsted Berlese-Tullgren funnel apparatus and a wet-sieving and flotation method, the Salt and Hollick washing apparatus, were compared on woodland, pasture and fallow arable sites on each of the soil types. Most soil arthropods were extracted in greater numbers by the dry-funnel method than by the wet-sieving method. Onychiurid Collembola were usually extracted in significantly greater numbers by the wet-sieving method and by mechanical methods generally. Large arthropods such as diptera larvae, beetles, root aphids, thrips and spiders and podurid Collembola were also extracted relatively efficiently by most mechanical methods, particularly on the fallow arable sites where there was less undecomposed plant material in the soil. The comparison on fen-peat soil showed that the Salt and Hollick method was not always less efficient than the dry-funnel method on soils with high organic matter content, but

the amount of time spent extracting arthropods from this soil by the Salt and Hollick method and the difficulties of distinguishing arthropods that were alive from those that were dead at the time of sampling, made the method impractical. The mechanical methods always recovered arthropods in a damaged condition, unsuitable for detailed identification, freezing the soil samples during storage was considered to contribute to this damage.

Various factors that affect the efficiency of dynamic extraction methods were investigated. Extraction efficiency was greatest when soil cores were placed intact and in an inverted position on funnel sieves, compared with soil cores orientated in other ways, or broken into pieces before placing them onto the funnel sieve. Greater depths of soil in the funnel sieve decreased efficiency of extraction of onychiurid Collembola and Diptera larvae, but different diameters of soil cores had little effect. Light and heat combined, extracted greater numbers of most arthropods than did heat alone. Alcohol as a collecting fluid in the dry-funnel method usually extracted more arthropods than did water, but water and picric acid extracted more Diptera larvae than did alcohol. Storing grassland cores for up to four weeks at 5°C prior to extraction by dry-funnel methods did not significantly affect the numbers of arthropods recovered.

An automatic collecting device for dry-funnel methods was devised and emergence patterns of arthropods were examined under different temperature regimes. Different arthropod groups emerged in two peak periods, when soil temperatures increased and a critical level of soil moisture content was reached.

The most suitable extraction methods for extracting different groups of arthropods are summarised.

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I. GENERAL INTRODUCTION

Populations of small invertebrate animals spending most of their life-cycle in soil are extremely large, reaching numbers as high as a quarter of a million per square metre. They are important constituents of soil ecosystems in promoting breakdown of organic matter and the turnover and aeration of soil. They vary greatly in size, ranging from 100μ to several centimetres in length. It would be quite impracticable and almost impossible to count all the animals in a unit area of soil so populations have to be estimated from the numbers of arthropods recovered from small samples of soil. These samples can be cores or cubes of soil of known surface area or volume. The numbers of arthropods recovered from the samples can then be converted into populations per unit area of soil providing the number and size of samples taken is adequate.

Reliable estimates of soil arthropod populations are necessary for many purposes. But it is in the reliability of these estimates that most of the problems concerning population assessment are encountered. Most arthropods are not randomly distributed, and some are very strongly aggregated, so choosing the optimum size and number of samples adequate for accurate population estimation is difficult, particularly because these differ for almost every group of arthropods. Moreover, soil is a complex medium and the problem of extracting from soil large numbers of animals, that differ in size, distribution, habits and physiology, has not yet been adequately resolved.

The number and size of the soil samples to be taken and the pattern of sampling and the statistical treatment of the data are all important aspects of assessment of populations of these animals. The

statistical problems of sample size and distribution have been discussed by several workers (Hartenstein, 1961; Debauche, 1962; Healey, 1962; Hughes, 1962; Skellam, 1962; Macfadyen, 1962a; Cancela da Fonseca, 1965; Berthet, 1971), and although not completely resolved will not be considered at length in this study.

Many different methods of extracting animals from soil have been developed during the last eighty years, but, although a number of workers have compared two or three methods for a few groups of soil animals (Evans, 1951; Macfadyen, 1953, 1955, & 1962a; Macklin and Montgomery, 1957; Auerbach and Crossley, 1960; Nef, 1960; Satchell and Nelson, 1962; Block, 1963 & 1967; Aucamp et al., 1964; Hale, 1964; Wood, 1965; Kikuzawa et al., 1967; Lasebikan, 1970; Huhta, 1972; Marshall, 1972), there have been no comprehensive studies of the relative efficiency of extraction methods for most of the common soil arthropods.

The great need for such comparative assessments became obvious during the early stages of development of the International Biological Programme. Standardized methods were essential if productivity in a variety of terrestrial ecosystems could be satisfactorily compared. It was for this reason that the present study was begun and its satisfactory conclusion was made possible by the provision of a research grant by the Royal Society. The major part of the research was concluded by 1968, in time for the data to be utilized by some of the I.B.P. projects.

The various methods of extraction of arthropods from soil have been reviewed often. Probably, the most comprehensive of these was by Murphy (1962 a & b) whose review particularly emphasized an earlier one edited by Balogh (1958). Other reviews of extraction methods are by Ladell (1936), Gilyarov (1941), Van der Drift (1951), Macfadyen (1955,

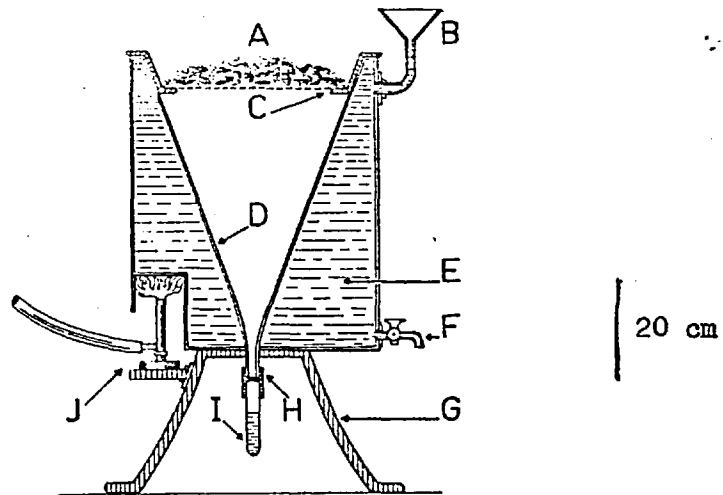
1957, 1962 a), Kuhnelt (1961), Kevan (1955, 1962), Rajski (1963), Southwood (1966), Vannier (1970 a) and Wallwork (1970),

The methods of extracting animals from soil that are currently available can be divided into two main types; (a) those where animals leave the sample in response to either physical or chemical repellents or attractants, referred to as "behaviour methods" (Macfadyen, 1957) or "dynamic methods" (Murphy, 1962 a), and (b) mechanical methods which separate the arthropods from soil by physical means or depend on the oleophilic and hydrophobic properties of the arthropod cuticle. Dynamic methods have the advantage that animals are recovered undamaged and very suitable for taxonomic studies whereas mechanical methods, although tending to damage specimens, yield data on resting stages of arthropods, particularly eggs and pupae.

Behaviour or dynamic methods of extracting arthropods from soil are divided into two main types, dry funnel methods and wet funnel methods.

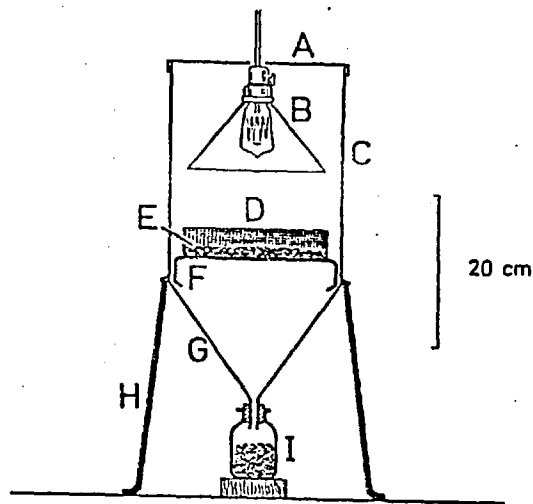
The dry funnel apparatus described by Berlese (1905) was one of the first behaviour or dynamic methods. It consisted of a large copper funnel (0.3 m or 0.5 m diameter by 0.8 m deep) surrounded by a water jacket containing heated water (Fig. 1). The sample was spread out on a sieve near the top of the funnel and the arthropods were collected in a vessel containing alcohol, fixed to the base of the funnel (Howard, 1906). An earlier apparatus, described by Ormay (1890), used tobacco smoke to drive arthropods from plant and litter samples (Vannier, 1970a). The Berlese funnel apparatus was modified, first by Williams (1913), then by Krausse (1915), who replaced the hot water jacket around the funnel with a heated water bath above and around the sample. Tullgren (1918) then substituted an electric light bulb for the heated water bath (Fig. 2)

Fig.1. - Berlese Funnel Apparatus.
(Berlese, 1905, after Vannier, 1970a)



- A - Sample material
- B - Water inlet
- C - Sample container with sieve
- D - Funnel
- E - Hot water jacket
- F - Water outlet
- G - Support stand
- H - Rubber sleeve
- I - Collecting tube with alcohol
- J - Bunsen burner

Fig. 2. - Tullgren Funnel Apparatus
(Tullgren, 1917, after Vannier, 1970a)



- A - Cover
- B - Electric light
- C - Metal cylinder
- D - Sieve
- E - Sample material
- F - Sieve support
- G - Funnel
- H - Support stand
- I - Collecting tube with damp paper

and it is on this modification of the Berlese apparatus that most modern dry funnel apparatus are based. Ford (1937) adapted the dry funnel technique for quantitative work by using a large number of small funnels. Haarlov (1947) improved the efficiency of such funnels by having a gap between sieve and funnel to prevent condensed water forming on the funnel walls and trapping the animals. Macfadyen (1953, 1955, 1961 and 1962b) considered that steep gradients of temperature and humidity from the upper to the lower surfaces of the soil samples improved the efficiency of dry funnels and he designed extraction apparatus incorporating these gradients (Macfadyen, 1961). Many other modifications of the dry funnel technique were suggested, such as different types of heat source, collecting fluids, sizes of sample, temperature regimes, and methods of preventing contamination of the collecting vessel with debris that falls from the sample (see Murphy, 1962a). Repellent chemicals instead of a heat source have also been used to drive animals from the sample (Macfadyen, 1953; Lewis, 1960, Muchmore, 1966), but are effective for only a few groups of arthropods.

Macfadyen (1962b) and Kempson et al. (1963) attempted to control the humidity at the base of the soil sample and avoid animals sticking to the sides of funnels, by collecting the animals into cylindrical vessels of the same horizontal diameter as the sample container. Lussenhop (1971) described a simplified canister-type soil arthropod extractor. A horizontal extractor (Duffey, 1962) to obtain spiders from grass was a further modification of the dry extraction technique without the use of funnels. A novel method of extraction was described by Vannier (1970a) in which high frequency electric impulses were passed through the soil sample, applying a physical repellent to stimulate soil animals to move out of samples.

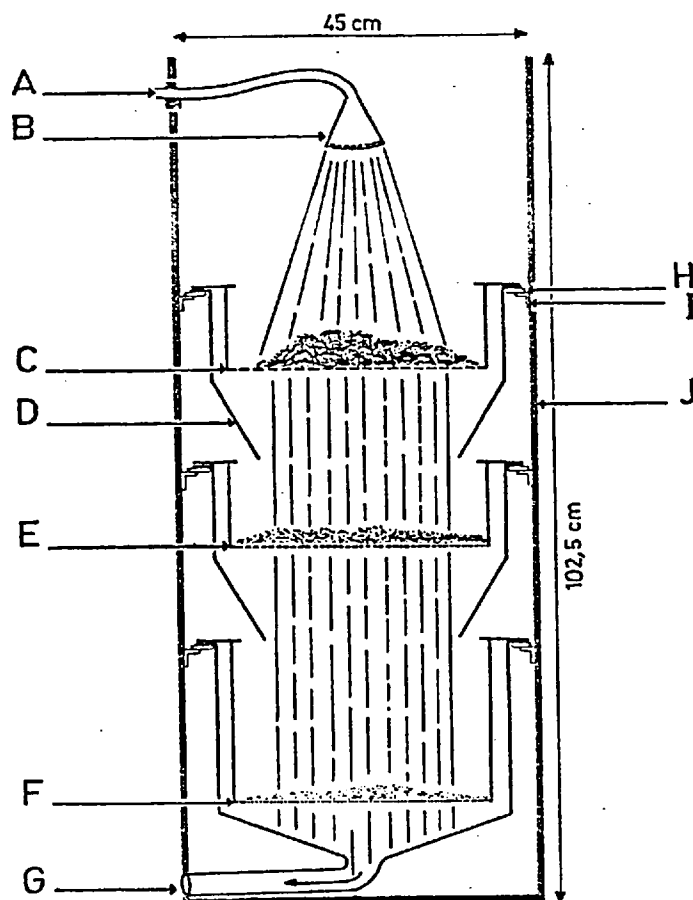
Wet funnel extraction techniques devised by Baermann (1917) use heat applied to soil samples under water. Modifications such as those of Maercks (1943), Milne et al. (1958) and Williams (1960) have been used successfully to extract some arthropod animals from soil, particularly dipterous larvae and tardigrades (see Healey et al. 1970). However these wet extraction techniques are usually more efficient when extracting non-arthropod fauna particularly enchytraeid worms and nematodes (see Murphy, 1962a).

Mechanical extraction processes for separating animals from soil are many and varied, (Murphy, 1962b). They range from hand sorting to complex flotation and elutriation methods. The laborious hand-sorting methods of Diem (1903), Cameron (1918) and Morris (1921), are not used much now, except to test the efficiency of other extraction methods. Reitter (1908) passed soil through a series of sieves sorting animals in each, in order to reduce the amount of material to be examined. Lane and Shirk (1936) and Lange, Akesson and Carlson (1954) more recently developed motorised versions of this technique.

Morris (1922) devised a wet sieving technique (Fig. 3) which involved washing the soil sample through a series of three sieves and allowing soil particles in suspension in the water to escape, thereby reducing the amount of material to be examined and at the same time breaking up the soil particles, releasing the enclosed animals.

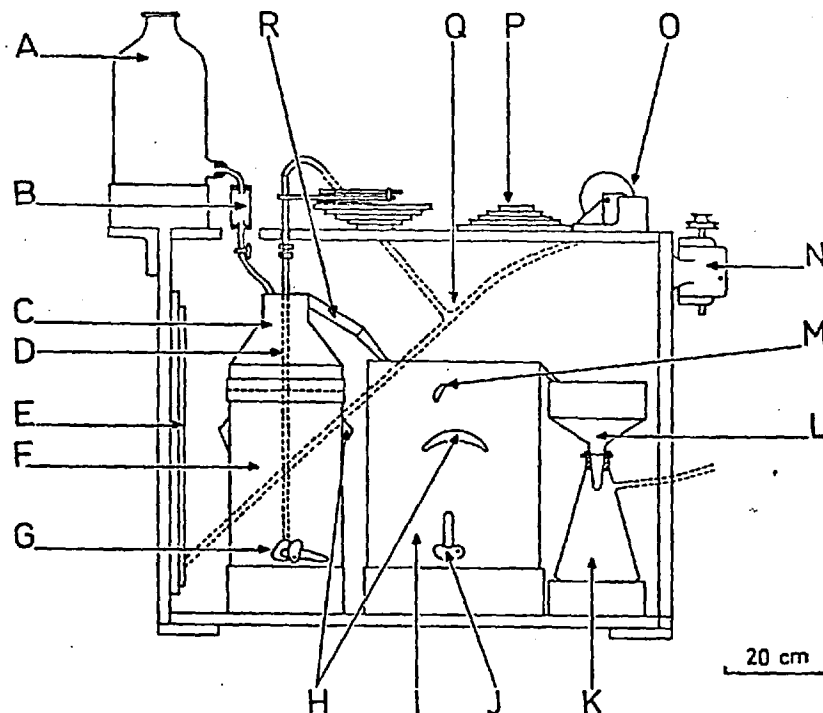
Winkler (1912) separated Coleoptera from the soil by immersing soil samples in water so the animals floated free. Berlese (1921) used saturated sodium chloride solution to separate animals from debris that fell into the collecting tube of a funnel extractor. Ladell's apparatus (1936) (Fig. 4) involved both a stage of washing through sieves and subsequent flotation on magnesium sulphate solution (S.G. 1.2)

Fig. 3. - Morris' wet-sieving apparatus.
(Morris, 1922, after Vannier, 1970a).



- A - Water inlet
- B - Rose
- C - First sieve (3.5 mm diameter holes)
- D - Funnel shaped collector
- E - Second sieve (1.5 mm diameter holes)
- F - Third sieve (0.25 mm diameter holes)
- G - Water outlet
- H - Shelf
- I - Ledge
- J - Galvanised metal stand

Fig. 4. - Ladell's washing and flotation apparatus.
(Ladell, 1936, after Vannier, 1970a).

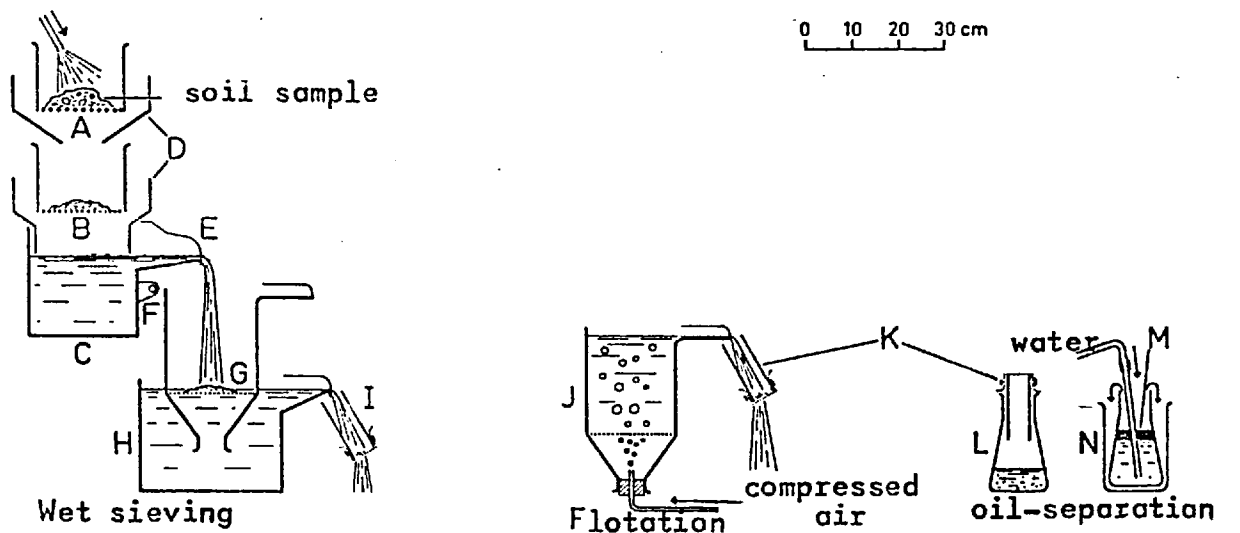


- A - Reservoir containing magnesium sulphate solution
- B - Flow meter
- C - Conical head to mixing cylinder
- D - Stirrer, carrying compressed air
- E - Manometer
- F - Mixing cylinder
- G - Water and silt outlet
- H - Handles
- I - Sedimentation tank
- J - Water and silt outlet
- K - Filtration flask
- L - Buchner funnel
- M - Overflow pipe
- N - Electric motor, driving stirrer
- O - Air pump
- P - Pulley drive
- Q - Compressed air pipes
- R - Overflow chute

to separate animals from the soil. His apparatus was improved by Salt and Hollick (1944) who separated the animals from the plant debris using an oil-water flotation process (Fig. 5). The floating material in the magnesium sulphate solution was decanted off, washed and shaken with water and either xylene or benzene. As the two layers separated, the plant material remained below the interface in the water layer and the animals, coated with the organic solvent, could be picked off the upper surface of the xylene-water interface. Edwards and Dennis (1962) modified this method to extract Symphyla from soil. The vapours of xylene and benzene can be harmful to breathe and Edwards et al. (1970) suggested that "Dekalin" (decahydro-napthalene) was a better substitute. The Salt and Hollick process has been further modified by Cockbill et al. (1945), Raw (1955, 1956a), Macklin et al. (1957), Fraser (1964), Feeney (1967), Wilcocks & Oliver (1971), and Stewart (1974). Edwards et al. (1970) mechanised the flotation stage and Heath (1965) and Sugimoto (1967) described elaborations of the oil-water separation stage.

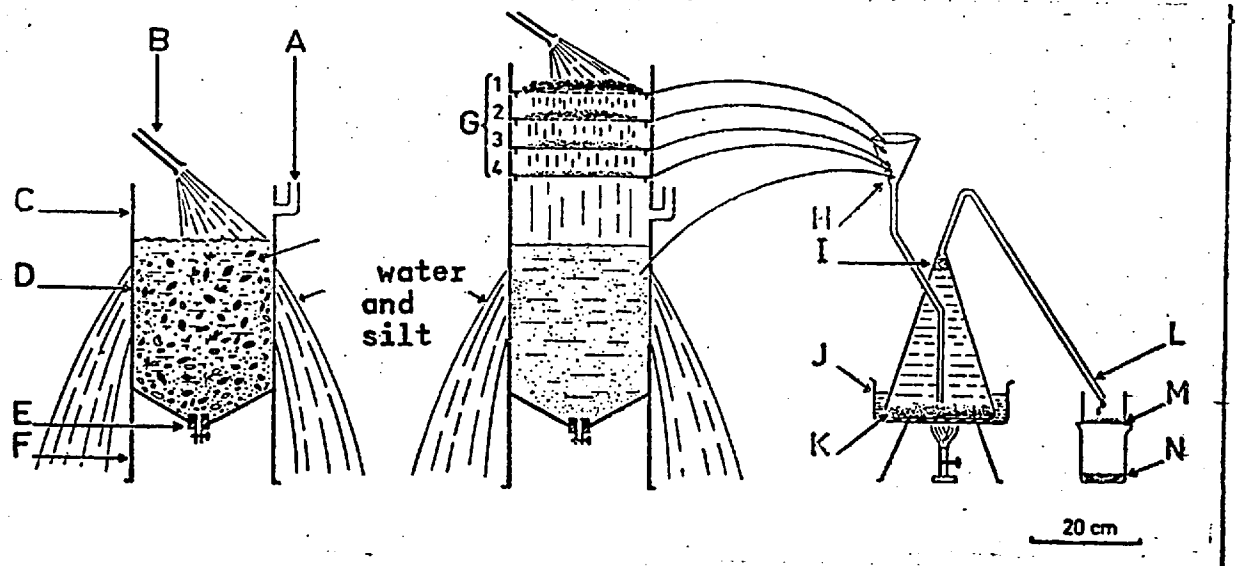
d'Aguilar et al. (1957) described another wet-sieving and flotation method. The soil sample was first washed through a coarse sieve and all the larger stones and large pieces of organic matter were removed. The residue was placed in a cylindrical vessel and agitated by a strong jet of water (Fig. 6). The finer silt particles together with the excess water, passed out through the fine wire-gauze wall of the vessel. This preliminary removal of the fine mineral particles is the opposite to the procedure in the Salt and Hollick process. Further sieving and flotation with potassium bromide solution (S.G. 1.35), in a specially designed flotation flask, completed the extraction.

Fig. 5. - Salt and Hollick wet sieving, flotation and oil-separation apparatus.
(Salt and Hollick, 1944, after Vannier 1970a).



- A - First sieve - 7 mm mesh
- B - Second sieve - 2.5 mm mesh
- C - Reservoir
- D - Funnel shaped collectors
- E - Overflow lip
- F - Pivot for tilting reservoir
- G - Ladell flotation vessel with final sieve - 0.2 mm mesh
- H - Sedimentation tank
- I - Tube with bolting silk mesh
- J - Ladell flotation vessel filled with magnesium sulphate solution
- K - Tube with bolting silk mesh
- L - Flask receiving material retained by bolting silk
- M - Organic solvent layer containing the arthropods
- N - Beaker to collect the organic solvent and arthropods

Fig. 6. - D'Aguilar et al. washing and flotation apparatus.
(d'Aguilar, Bernard and Beesard, 1957, after Vannier 1970a)



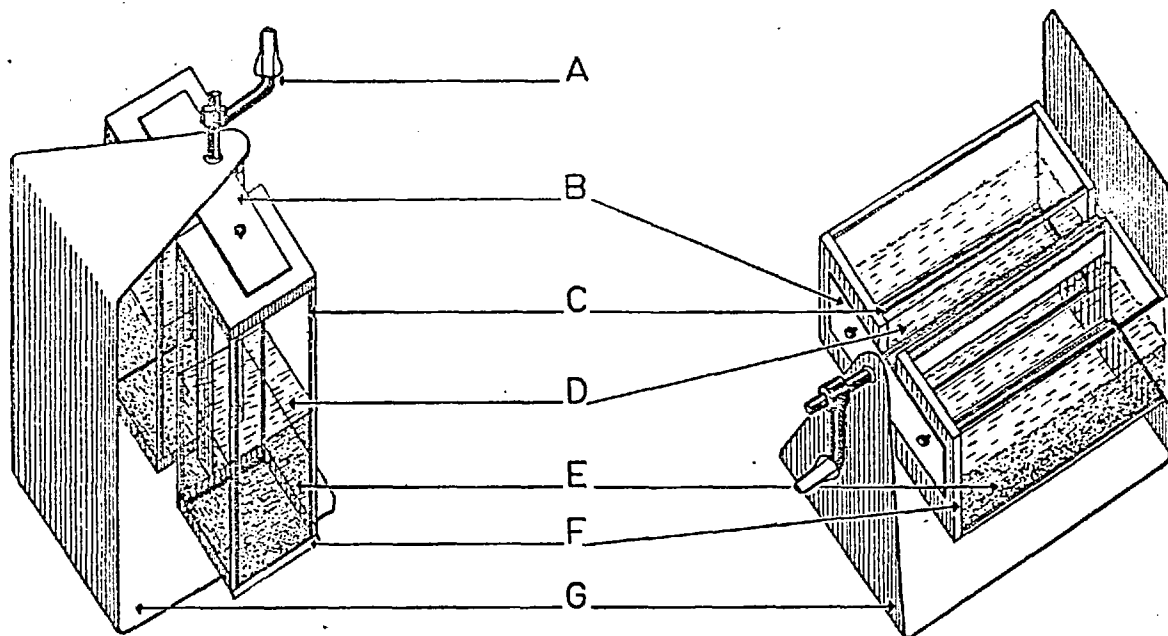
- A - Air vent
- B - Water jet
- C - Plastic washing vessel for removal of fine silt particles
- D - Sieve wall of washing vessel, 0.05 mm mesh
- E - Drain
- F - Support stand
- G - Sieve series - 1. 0.80 mm mesh
2. 0.25 mm mesh
3. 0.12 mm mesh
4. 0.07 mm mesh
- H - Funnel and tube through which the sieved sample is added to the flotation flask
- I - Animal and plant material
- J - Water-bath at 50°C
- K - Mineral material
- L - Outlet tube through which floating material passes to sieve
- M - Sieve, 0.05 mm mesh
- N - Beaker

Hale (1964) described a flotation technique for use with soils containing much organic matter. The soil samples were first soaked in water and subjected to a reduced atmospheric pressure at room temperature. This made the air-free plant material sink and the arthropods come to the surface of the water due to the combination of the hydrophobic nature of their cuticles and the agitation caused by stirring and bubbling air through the liquid. The animals were collected through the overflow side-arm of the flotation vessel.

Davies (see Macfadyen, 1955) used the differential sedimentation rates of organic and inorganic components of a soil sample to separate the animals from the soil. Elutriation which uses upward currents of water to separate soil and animals was used by Törne (1962b) to separate Pauropoda and small Collembola from light mineral soils with low contents of organic matter. Müller and Maglitsch (1957) and Müller (1962) put soil samples in saturated sodium chloride solution and centrifuged them to collect the arthropods. The supernatant liquid was decanted and the residual animals counted and identified and the procedure was repeated until no more animals were recovered.

Aucamp and Ryke (1964 & 1965) and Aucamp (1969) developed an extraction method which used the oleophilic and hydrophobic properties of the arthropod cuticle with removable sliding plates coated with lanolin or petroleum jelly (Fig. 7). The containers were rotated for fifteen minutes at 16 revs/min; the animals stuck in the grease and the plant and mineral particles remained in suspension. The plates were then removed and the animals counted and identified; unfortunately the animals are often recovered in rather a poor condition for identification. Speight (1973) described an automated grease belt technique for the extraction of arthropods from organic debris and Bel field (1976), an expedition version of the grease film apparatus.

Fig. 7. - Aucamp's Grease-Film Apparatus.
(Aucamp and Ryke, 1964, after Vannier 1970a).



- A - Handle
- B - Clamp, removed during loading
- C - Removable grease coated plates
- D - Plastic tank with greased plates held in position
- E - Sample material in suspension in water
- F - Framework of plastic tank
- G - Metal stand

Other mechanical methods of separation include suction methods (e.g. Johnson et al. 1957, Wallace 1972) to collect animals from the soil surface and the examination of thin sections of impregnated soil to count arthropods in situ (Haarlov and Weis Fogh (1953); Alexander and Jackson (1955); Vanier and Vidal (1964); Anderson and Healey (1970)). Pande and Berthet (1973) compared Tullgren funnel and soil section methods for surveying oribatid mite populations.

All the methods described so far, were developed to meet a need for quantitative data. They were designed to increase the efficiency of recovery of animals from soil, or decrease the amount of time spent extracting the arthropods, or both. In addition to these improvements in the methods of extraction there were improvements in the pre-extraction techniques for dealing with soil samples.

Chemical dispersal agents, e.g. sodium hexametaphosphate, sodium carbonate (Raw, 1955), sodium citrate (d'Aguilar et al. 1957) and sodium oxalate (Seinhorst, 1962) were used to disperse soil particles before using various wet sieving methods. Wetting and freezing soil samples (Salt and Holl  ck, 1944) and decreasing the atmospheric pressure over samples immersed in water (Raw, 1955; Hale, 1964) were also techniques used to disperse soil particles before wet sieving. The break-down in soil structure caused by these pretreatments allowed a more efficient separation of organic material from inorganic material at a subsequent stage in the mechanical extraction procedure. For some heavy clay soils these pretreatments are essential before using wet-sieve methods.

The efficiency of dynamic methods may also be improved by the use of pre-extraction techniques. Many authors have stressed the importance

of the nature of the sample substrate and its condition in relation to the ease with which animals are able to escape from it, but few have considered the importance of sample preparation for funnel extraction methods (Murphy, 1958a and 1962a). When dry funnel methods were first used, the sample material was fragmented and the pieces spread on the sieve of the sample container. Jacot (1936) and Hammer (1944) suggested that samples should be placed intact and inverted with their upper surface downwards on the sieve to increase the efficiency of the apparatus and Murphy (1958a) made a similar recommendation but his results on the efficiency of extraction from intact, inverted subsamples of raw humus were not conclusive. Murphy (1958a) also investigated the effect of different depths of soil in the sample containers over the funnels in his split-funnel apparatus. Shallow undisturbed cores of raw humus, 1.3 - 1.9 cm deep, were better for recovering Acarina than similar cores 4-5 cm deep. Sample disturbance and compression may arise during collection and subsequently during its preparation for extraction. Apparatus and methods of obtaining undisturbed soil cores have been discussed by many workers (Hughes, 1954; Murphy, 1958 a and b; Macfadyen, 1953, 1962a; O'Connor, 1957; Törne, 1962a; Vannier and Vidal, 1965 and Tanton, 1969). Few authors have considered the influence of collecting fluids (especially volatile ones) on the numbers of arthropods recovered from soil by dry-funnel extraction methods. Macfadyen (1955) compared alcohol, glycerol and water, and concluded that although collecting fluids had little effect in funnel apparatus where the evaporating surface was small and there was plenty of ventilation, in canister extractions, alcohol in the confined space reduced the numbers of animals recovered.

The mechanisms underlying the operation of the extraction methods used to extract arthropods from soil samples are remarkably little understood. The efficiency of the oil-water separation stage of the Salt and Hollock method, and the grease film method, are dependent upon the physical and chemical properties of both the separating fluids and animal and plant cuticles (Nicholson et al. 1960 and Murphy, 1962b). With dynamic methods, Trägårdh, 1933, thought desiccation the most important factor influencing the egression of fauna from soil samples, but also suggested a small negatively phototactic response. Dietrick et al. (1959) improved the efficiency of a funnel apparatus by shining a spotlight beam up through the collecting vessel on to the base of herbage samples. Responses to changes in temperature and water content of the soil sample (and hence humidity of soil air) are suggested by most authors as the main factors responsible for the egression of soil fauna in dry-funnel extractions (Haarlov, 1947; Macfadyen, 1953 and 1955; Hughes, 1954 and Murphy, 1958a, 1962a). Hughes (1954) and Macfadyen (1968) investigated the effects of using different construction materials on the thermal gradients within samples extracted by modifications of the dry funnel. Brady (1969) demonstrated the importance of temperature and humidity gradients and suggested microarthropods move along these gradients employing a series of kinesis rather than taxes. Vannier (1970a) claimed that above 30°C, an increase in temperature was the most important factor causing microarthropods to leave the soil sample during dry-funnel extractions. Between 10°C and 30°C, desiccation beyond a critical threshold of the humidity level in soil, the pF value, was the main factor determining the egression of soil microarthropods. The pF value is a measure of the force of retention which is exerted by the dry matter in soil on

the available water, and which determines the accessibility of this water to the various groups of soil arthropods.

The length of time between taking soil samples in the field and extracting the animals in the laboratory is another important factor affecting the numbers of soil arthropods recovered. Soil samples for extraction by mechanical methods, were stored successfully for several months at temperatures below 0°C (Raw, in lit.). Soil samples for extraction by dynamic methods are not stored easily. Murphy (1958a) found the numbers of Acarina lessened after 12 days storage at ca 4°C. Hughes (1954) showed that numbers of Collembola recovered were unaffected after storage periods lasting from 1-9 days, but found some increases, after storage, in numbers of Collembola from samples taken in the Spring. Rapoport and Oros (1969), stored soil samples in different types of container and showed these could reduce the numbers of arthropods extracted by a funnel method.

It is difficult to measure either the absolute or the relative efficiency of the methods described or their modifications. Macfadyen (1962b) attempted to measure the absolute efficiency of his controlled draught funnels by putting marked animals into soil samples. Feeney (1967), Kempson et al. (1963) and Marshall (1972) measured the efficiency of their apparatus by hand-sorting the remaining bodies of soil arthropods from soil which had been used in their extraction apparatus. Forsslund (1948), Macfadyen (1953), Hughes (1954) and Haarlov (1962) compared the numbers of animals recovered using different methods with those counted by careful hand sorting of soil from the same sites, efficiency being expressed as a percentage of the numbers recovered by hand-sorting. Van der Drift (1951), Kempson et al. (1963), Aucamp and Ryke (1964), Hale (1964), Block (1966, 1967), Brady (1969) and Marshall (1972), all measured the efficiency of various

methods by attempting to recover known numbers of animals previously introduced into sterile soil samples.

All these techniques involve problems. The methods available for marking animals in soil before extraction are unreliable (Macfadyen, 1962a). If the smaller soil arthropods are damaged during handling before they are put in soil samples, they may not emerge from soil normally and anyway the animals would not be occupying their normal ecological niche. Soil sterilisation usually alters the structure of the soil, and hand-sorting, which is an extremely laborious and slow procedure, can be used only for very small soil samples and so may not represent the numbers present in a larger sample.

Some workers have compared the relative efficiency of extraction processes, by using soil from the same habitat and extracting the arthropods by different methods but few workers have compared more than two methods and usually this was done on one soil type only.

Different forms of the Salt and Hollick process (1944) have been compared with variations of the Tullgren funnel apparatus by Evans (1951), Macfadyen (1953), Macklin et al. (1957), El-Kifl (1957) and Wood (1965). Evans (1951) found no significant difference between the mean numbers of Collembola, Parasitiformes (Mesostigmata) and Sarcoptiformes (Astigmata and Cryptostigmata) recovered by the two methods but the Tullgren apparatus extracted more Trombidiformes (Prostigmata). Macfadyen (1953) found flotation to be as efficient as the funnel method for larger insects and more so for aphids, but less efficient for Acarina and Collembola. El Kifl (1957) recovered more Thysanoptera, Aphididae, Coleoptera, Hymenoptera, Araneae, Thysanura and Myriapoda by flotation than funnel methods and stated that the funnels were more efficient in extracting Acarina, Collembola and Hemiptera, particularly psocids. Wood (1965), using three different

soil types, found the Murphy split-funnel method recovered significantly more of most groups of Acarina than the Salt and Hollick technique although there were no significant differences between the numbers of Astigmata and adult Cryptostigmata recovered. The mean numbers of Collembola recovered by the two methods were not significantly different.

Satchell and Nelson (1962) described a comparison of Raw's (1955) modification of the Salt and Hollick technique with Tullgren funnels for extracting Acarina from moder and mull woodland soils. The differences between the mean numbers of Acarina extracted by the two methods on the mull site were not significant, but significantly more Oippia spp. were recovered by the flotation method. On the moder site they found that hypopi of Astigmata, scutacarids and the nymphs and larvae of Steganacarus magna were extracted in significantly higher numbers by the flotation method used, whereas Nothrus sylvestris and Tectocephus spp., nymphs and larvae were extracted in significantly higher numbers by the funnel method.

Müller and Maglitsch (1957) and Müller (1962) compared a centrifugal flotation method with modified Tullgren funnels (Balogh, 1938; Franz, 1950) using three soil types. Significantly more Acarina and Collembola were recovered using centrifugal flotation than by using funnels.

Different types of Tullgren funnels have been compared by Macfadyen (1953, 1955, 1962b) Auerbach and Crossley (1960), Aucamp et al. (1964), Kikuzawa et al. (1968) and Huhta (1972). Most of these workers found that methods incorporating steep gradients of temperature and humidity increased the efficiency of extraction.

Hef (1960, 1962) and Rappoport and Gros (1966) studied the effects of varying the temperature and humidity regimes in Tullgren funnels. Hef (1962)

suggested desiccation was the factor mainly responsible for the movement of Acarina and Collembola out of litter samples, in the Tullgren funnel method of extraction.

Changes of temperature and humidity during the extraction period were discussed by Tragardh (1933), Haarlov (1947), Macfadyen (1953, 1962b), Hef (1962), Kempson et al. (1963), Vannier (1964), Margowski (1965), Block (1966) and Deb et al. (1966). They attempted to relate the results of their work to the patterns of movement of animals from soil during extraction.

The Salt and Hollick (1944) technique has been compared with various modifications of this method by Heath (1965) and Feeney (1967). The modifications were considered to be improvements either to techniques and/or apparatus with the aim of increasing efficiency.

Aucamp (1967) compared his grease film apparatus with a modified high gradient funnel extractor for extracting Acarina from loam soil. Many more Cryptostigmata were recovered by the grease film method than by the funnel method. The Mesostigmata were recovered equally well by both extractors and the Prostigmata and Astigmata more efficiently by the funnel method.

Hale (1964) compared his flotation process with a modified Macfadyen high gradient canister apparatus for extracting Collembola from peat soil. Block (1967) compared Hale's (1964) flotation apparatus with a modified Macfadyen high gradient canister apparatus for extracting Acarina from peat and mineral soil. Significantly more Acarina were recovered by the high gradient canister on both types of soil.

The Terrestrial Productivity section (P.T.) of the International Biological programme entitled "The biological basis of productivity and

human welfare", provides a unique opportunity for obtaining comparable data about a large number of varied habitats and their associated flora and fauna. Part of the Terrestrial Productivity section is concerned with the role of soil-dwelling animals in the decomposition cycle and their inter-relation with the microflora in secondary production. To provide information on the role of arthropod animals in soils it is necessary to make accurate estimates of the populations. To compare results from different parts of the world, methods must either be standardised or the relative efficiency of the different forms of apparatus must be known.

Both dynamic and mechanical methods for the extraction of soil arthropods were originally developed for qualitative studies of soil arthropods. Their adoption for quantitative purposes has presented many practical difficulties and there has been considerable criticism (Macfadyen, 1955). The basic problem, inherent in soil arthropod population studies, is the lack of practical means for determining the absolute number of animals in any given volume of soil. With existing methods of extraction this problem will continue to occur, particularly when dealing with such a heterogeneous group of animals which are differentially extracted by various methods and when such factors as soil type and pre-treatment of the sample material affect the efficiency of all methods of extraction (Raw, 1955; Nef, 1960; Murphy, 1962 a and b).

No single extraction method will efficiently recover all the different groups of arthropods from all types of soil, nor is it practical to recommend one method for use in all regions. For example, washing methods, requiring large volumes of water, are impractical in arid regions, and Tullgren methods are difficult for field trips and are unable to extract immobile stages of animals.

The aim of this work is, having determined which methods are most used, to compare as many of the different forms of extraction apparatus and techniques using a range of soils and to select and recommend those methods giving consistently high recoveries of specific arthropod groups from the soil types and habitats studied.

II. A SURVEY OF THE EXTRACTION METHODS CURRENTLY USED

A questionnaire was prepared to determine which methods of extraction of soil animals were most used. This was sent to one hundred and fifty soil zoologists and ecologists in eighteen countries. Of these, eighty-two were completed and returned, although not all recipients answered all questions. The questionnaire comprised three sections, one concerned Berlese-Tullgren funnel methods of extraction, one flotation methods and modifications of these, and the third, with other methods of extraction used.

In the first section the questions concerned the size and shape of Tullgren funnels, the power of the source of heat and its distance from the soil surface, whether the funnels were cooled, how long the extraction took and which preservative liquid was used in the collecting vessel. In the second section the details of the flotation methods that were asked included the type of flotation the nature and specific gravity of the flotation medium, whether an oil/water separating stage or freezing was used and other details. The last section was more general, involving descriptions of other methods.

Replies were sometimes incomplete, sometimes more information was given than was requested and it was often difficult to correlate the information but it was possible to draw general conclusions. The comparative frequency of use of different extraction methods is summarized

in Fig. 8. Many workers (approximately 50%) used only a simple method for the recovery of the different types of arthropods from soil, this being almost exclusively some modification of the Tullgren funnel extractor. The others used either both Tullgren methods and flotation methods (approximately 30%), Tullgren methods with hand-sorting and/or dry sieving for large insects, or one of a variety of miscellaneous methods (approximately 20%). Seventy percent of all the replies indicated that the correspondent used some form of Tullgren funnel and 60% of these used a relatively standard type of funnel with an electric light bulb as a heat source. The few that used neither light nor heat were mostly concerned with taxonomy. Seven workers used some modification of the Macfadyen air-conditioned apparatus with steep gradients of heat and humidity produced by cooling and humidifying the lower part of the sample.

Of the 26% of the correspondents using flotation methods, 41% used the Salt and Hollick flotation method or some modification of this. Only four workers used a simple flotation method of immersing soil in dense solutions and agitating these for general studies of soil arthropods, but several others used flotation with sugar solution to recover animals for taxonomic studies. These latter workers were not concerned with the quantitative aspect.

Only three workers hand-sorted soil samples for the larger arthropod animals, either in the field or in the laboratory. Most of the other methods listed in the returns were used only by those workers who devised them, for example, the Müller and Naglitsch centrifugal flotation method, d'Aguilar flotation and the Aucamp and Ryke grease-film extraction.

The form of the Tullgren apparatus and the method of using it varied greatly between different workers. The diameter of the funnels at their widest point, ranged from 5 cm to 40 cm. Funnels of 10 cm, 15 cm and 20 cm diameter were most commonly used (Fig. 9).

FIG. 8.

METHODS OF EXTRACTION MOST COMMONLY USED

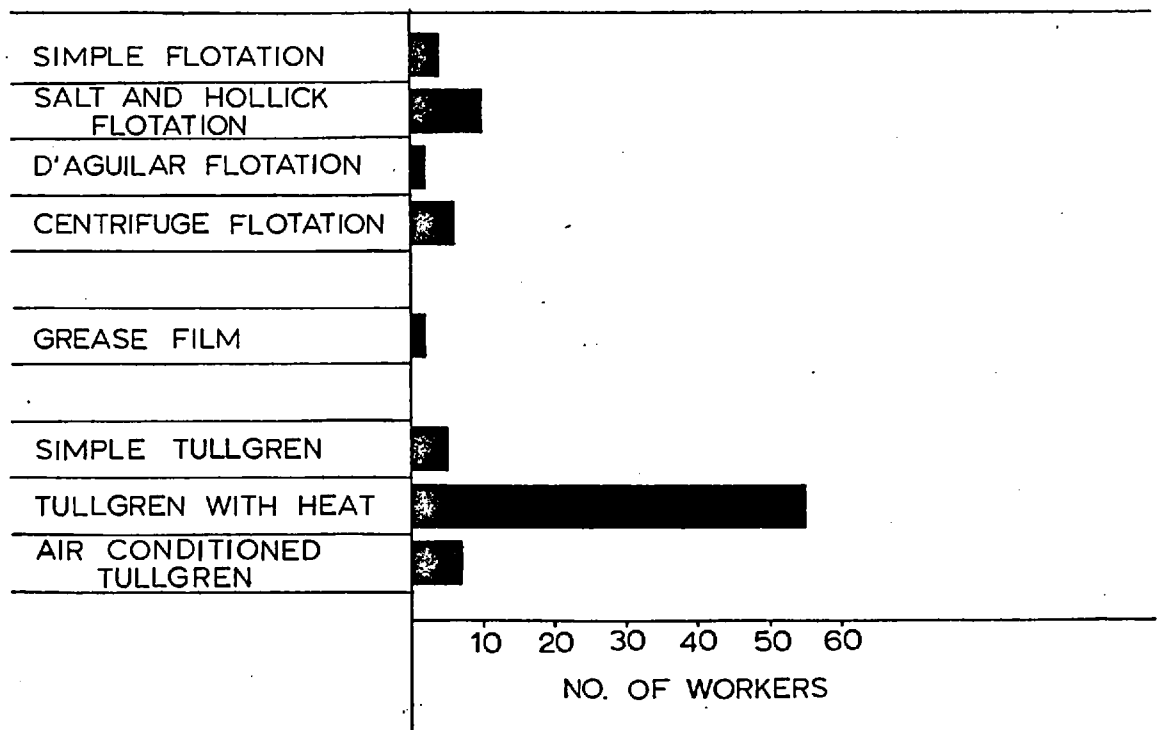
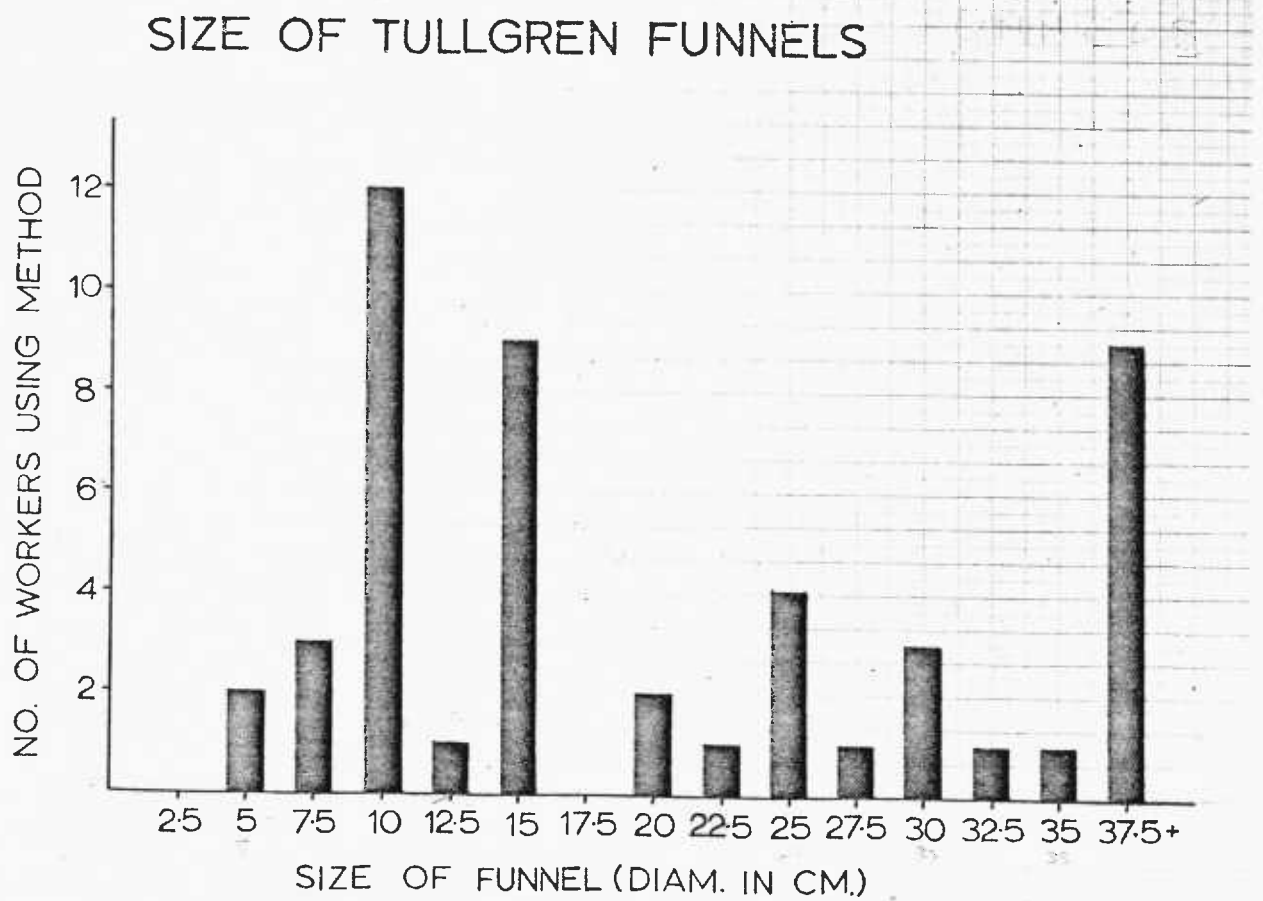


FIG. 9.



10 cm = 4"
25 cm = 10"

arbitrary sizes

Workers who used Tullgren funnels were asked whether they placed their soil samples in the funnels with as little disturbance as possible or broke them up before putting them in the sample containers; only seventeen answered this question and of these, nine did not disturb the sample and eight used broken samples (Fig. 10).

The power of the heat source used varied greatly (Fig. 13); workers commonly used electric light bulbs of between 25 watts and 60 watts, but most used light bulbs of less than 35 watts and a few workers used 100 watt bulbs and one 200 watts or even heating elements. This wide range in heat source meant that the time taken to complete extraction (Fig. 12) ranged from one day to more than twelve days. The time taken to extract animals on most Tullgren funnels was three to four days but was sometimes more than seven days. Many workers who took the longer period to extract their samples claimed their extraction was more efficient. The replies suggest that many workers extracted animals from samples for an arbitrary time without fully testing whether this time was adequate for all soils they investigated.

Most workers used ethyl alcohol of about 70% dilution in the collecting vessels below the funnels, but a few used water and a minority other fixatives, especially picric acid (Fig. 11).

The answers to the questionnaires enabled the most commonly used methods to be chosen and tested in the present studies. They showed that most workers preferred dynamic methods, especially Berlese Tullgren funnels, probably because these methods are simpler, less laborious and recover relatively undamaged animals.

III. DESCRIPTIONS OF EXTRACTION APPARATUS AND METHODS TESTED

1. Dynamic Methods

The different types of funnel apparatus were all based on the original Tullgren principle but differed enough in detail and sophistication to justify testing seven versions or methods of operation.

FIG. 11.

COLLECTING FLUID USED IN TULLGREN FUNNELS

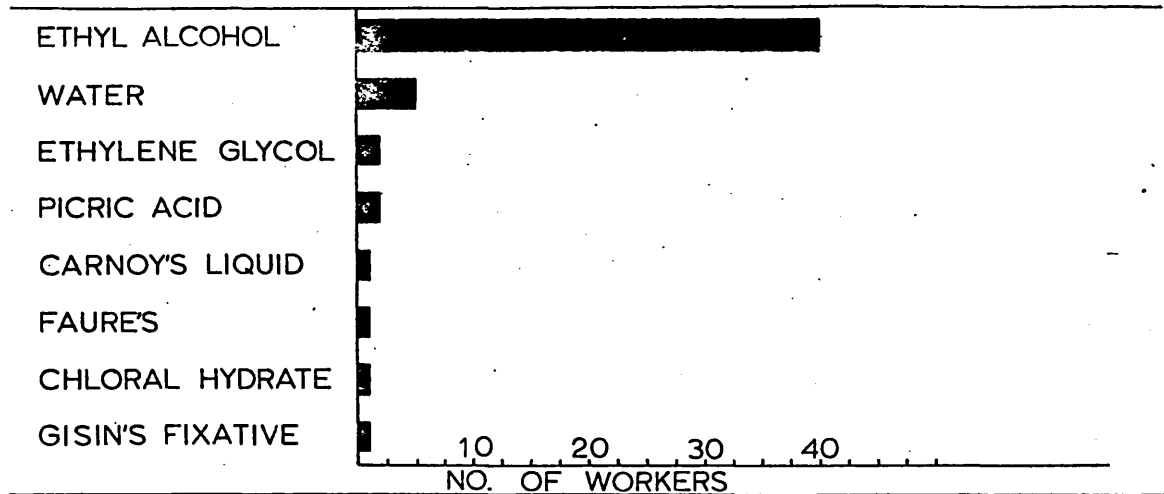


FIG. 10.

METHOD OF PLACING SAMPLE IN SIEVE

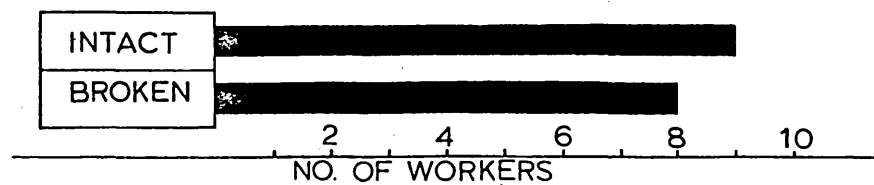


FIG 12.

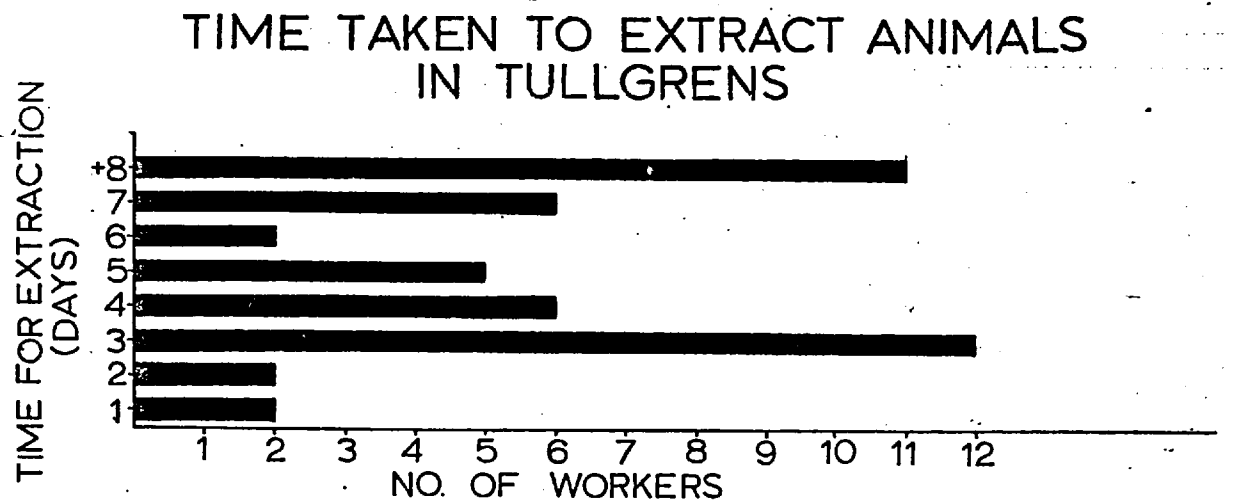
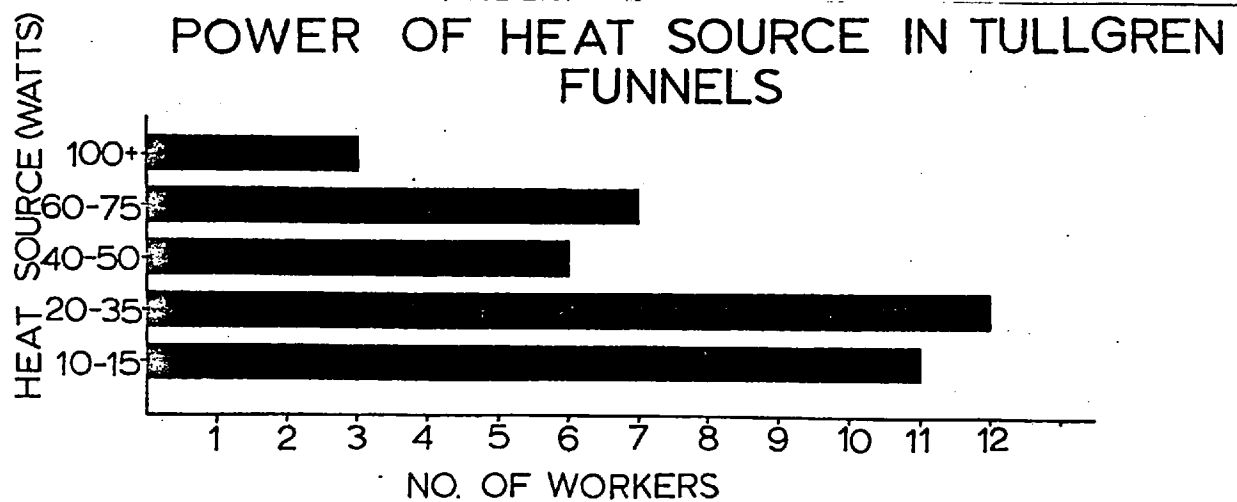


FIG 13.



All the methods tested were used by several groups of workers.

(a) Simple plastic funnel without light or heat source

A battery of sixteen domestic plastic funnels was supported by plywood boards with circular holes to support each funnel, arranged so as to keep the funnels vertical (Plate 1). The funnels, 16.5 cm diameter and 16.8 cm deep with an included angle of 60° , narrowed to an opening 1.2 cm diameter, where the collecting vials, 2.5 cm diameter by 5 cm deep glass tubes, were held in position by rubber bungs. Soil samples, 10 cm diameter and 5 cm deep, were placed, intact and inverted, into aluminium sample containers 12.8 cm diameter and 7.5 cm deep with a 10 mesh 23 S.W.G., stainless steel sieve at the bottom. The sieves which were held in position by wire supports from three outwardly directed brackets 1.2 cm long, at the base of the sample container could be easily changed for a different mesh as required. The animals were collected in vials containing 70 per cent v/v aqueous ethyl alcohol solution and glycerol (ratio 20:1). The samples were extracted for nine days, in a room thermostatically maintained at $20^{\circ}\text{C} \pm 3^{\circ}\text{C}$.

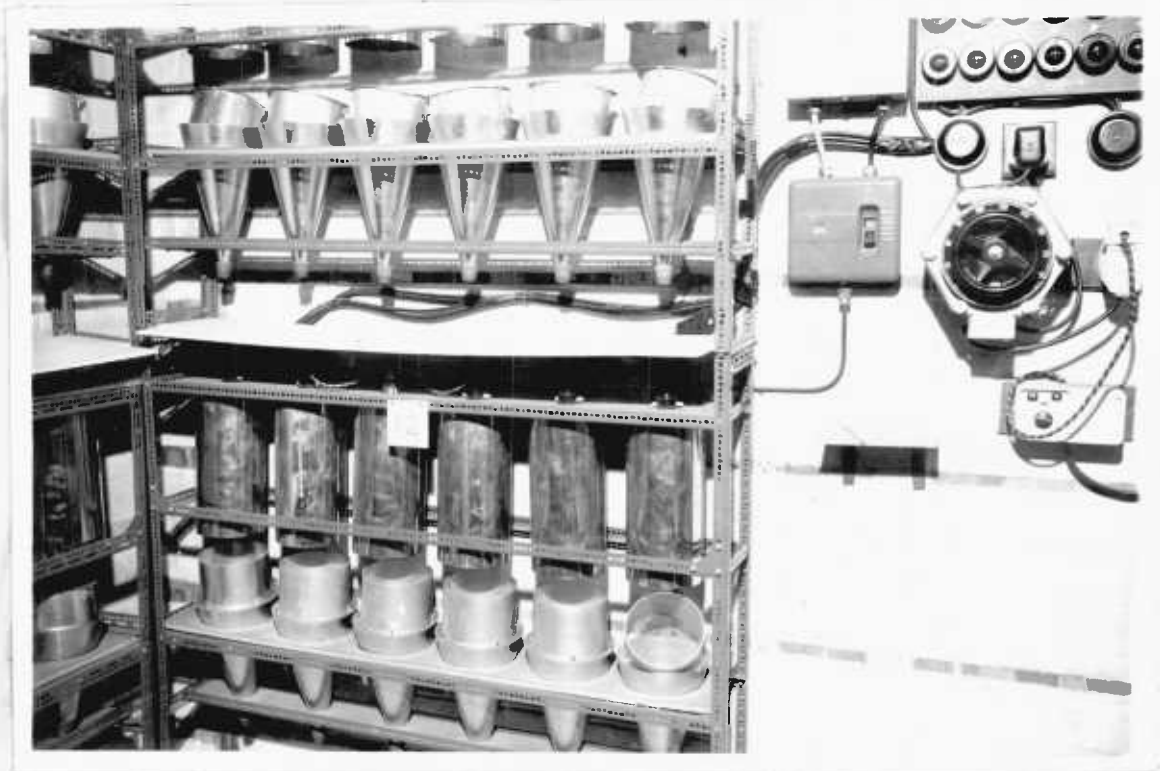
(b) The Rothamsted funnel extractor without light or heat source

This consisted of a battery of sixteen spun anodised aluminium funnels which were mounted in holes 12.8 cm diameter and 4.2 cm diameter in two plywood boards, held one above the other in an angle iron framework (Plate 2). The funnels were 15 cm diameter at the top and 25 cm deep, had an included angle of 32° , and narrowed to an opening 1.2 cm diameter. Glass vials, 2.5 cm diameter and 5 cm deep, were supported at the lower end by being pushed on to a rubber bung. Intact, inverted soil samples, 10 cm diameter and 5 cm deep, were supported at the top

Plate - 1. Simple plastic funnels.



Plate - 2. Rothamsted Berlese-Tullgren funnels.



of the funnels by a 10 mesh 23 S.W.G., stainless steel sieve, at the bottom of anodised aluminium sample containers, 12.8 cm diameter by 7.5 cm deep. The sieves were held in position by wire supports from four outwardly directed brackets 1.2 cm long at the base of the sample container. Sample containers were supported in the top of funnels on these brackets leaving a gap between the edge of the sieves and the funnels to prevent condensation inside the funnels. The samples were extracted for nine days in a room thermostatically maintained at $20^{\circ}\text{C} \pm 3^{\circ}\text{C}$. The animals were collected into vessels containing 70 per cent v/v aqueous ethyl alcohol and glycerol (ratio 20:1).

(c) The Rothamsted funnel extractor with light and heat source

The apparatus was similar to that described in the last section (b), but over each sample a tinned metal cylinder, 12.8 cm diameter and 26.6 cm high was suspended, containing a 25 W pearl electric light bulb 25 cm from the upper surface of the soil sample. The electric light bulbs, wired in parallel from a 240 v. mains were controlled by a heavy duty rheostat which was adjusted so that the temperature of the soil closest to the light bulb, increased from about 35°C after the first twelve hours of heating to approximately 39°C after five days. The room temperature and therefore the temperature of the lower surface of the soil in the sieves was controlled at $20^{\circ}\text{C} \pm 5^{\circ}\text{C}$ during the whole of the extraction period.

(d) The Murphy split funnel extractor (Murphy 1958a)

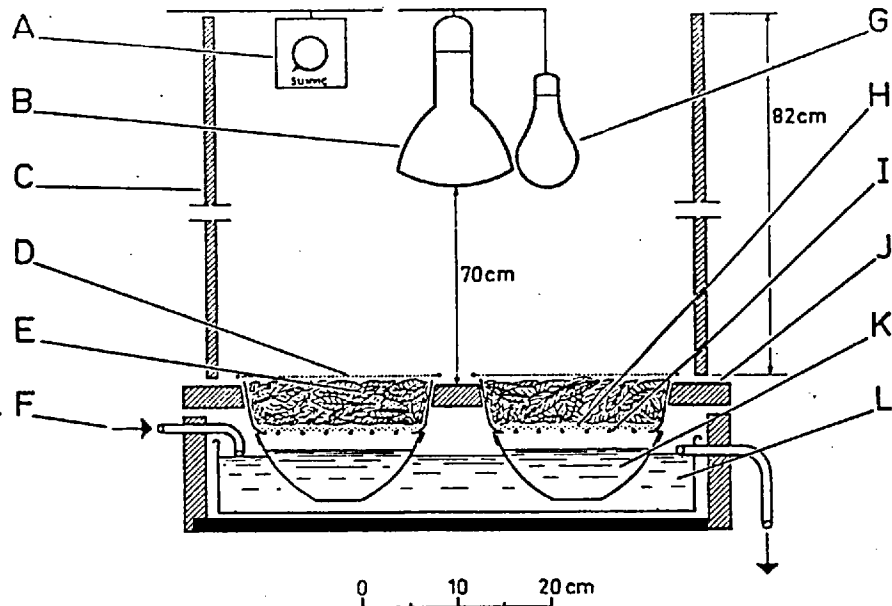
This apparatus consisted of eighteen small funnels mounted on a wood and metal framework, and a battery of eighteen cylinders containing electric light bulbs suspended above (Plate 3). The cylinder unit was counterpoised and could be raised for access to the funnels for inserting soil samples and lowered to cover the sample containers. The funnels, 8 cm diameter and 24.2 cm high with an included angle of 15° ,

narrowed to an opening 1.6 cm diameter where collecting vials 2.5 cm diameter and 5 cm deep were held in position by rubber bungs. The sample containers, supported above the funnel, were 5 cm diameter and 5 cm deep and had three inwardly directed brackets at their bases supporting 14 mesh 26 S.W.G. sieves, which were held 0.5 cm below the lower rim of the sample containers leaving a gap at the sides. These units were supported on larger sieves of 4 mesh, 20 S.W.G., which rested near the top of the funnel. The cylinders 7.5 cm diameter and 30 cm deep each contained a 15 W clear electric light bulb. The soil samples 5 cm diameter and 5 cm deep were intact and inverted when extracted. The animals were collected into vessels containing 70 per cent v/v ethyl alcohol and glycerol (ratio 20:1). The samples were extracted for six days at room temperature ($16^{\circ}\text{C} - 20^{\circ}\text{C}$) with the air temperature at the top of the sample approximately $30^{\circ}\text{C} - 35^{\circ}\text{C}$.

(e) The Kempson-Lloyd-Ghelardi infra-red extractor (Kempson 1963)

The apparatus (Fig.14) consisted of a rectangular cabinet of fibre board, ca 1.0 m high by 1.0 m broad and 0.6 m deep, open at the top, supported by a framework of slotted angle iron. A horizontal fibre baffle board separated the cabinet into two discrete compartments. The lower smaller compartment contained a fibre glass tray, 90 cm by 54 cm by 10 cm deep with water passing through it. In the upper compartment, two 250 W infra-red lamps were suspended 51.5 cm above the baffle board wired in parallel to a "Sunvic Simmerstat" time switch (type TXY - B) and to two 100 W electric light bulbs, so that when the infra-red lamps were switched off, the 100 W bulbs automatically switched on. The sample holders were made from round bowl-shaped plastic dishes, 12.5 cm diameter

Fig. 14. - The Oxford infra-red extractor.
Kempson, Lloyd and Ghelardi (1963) (After Vannier, 1970a).

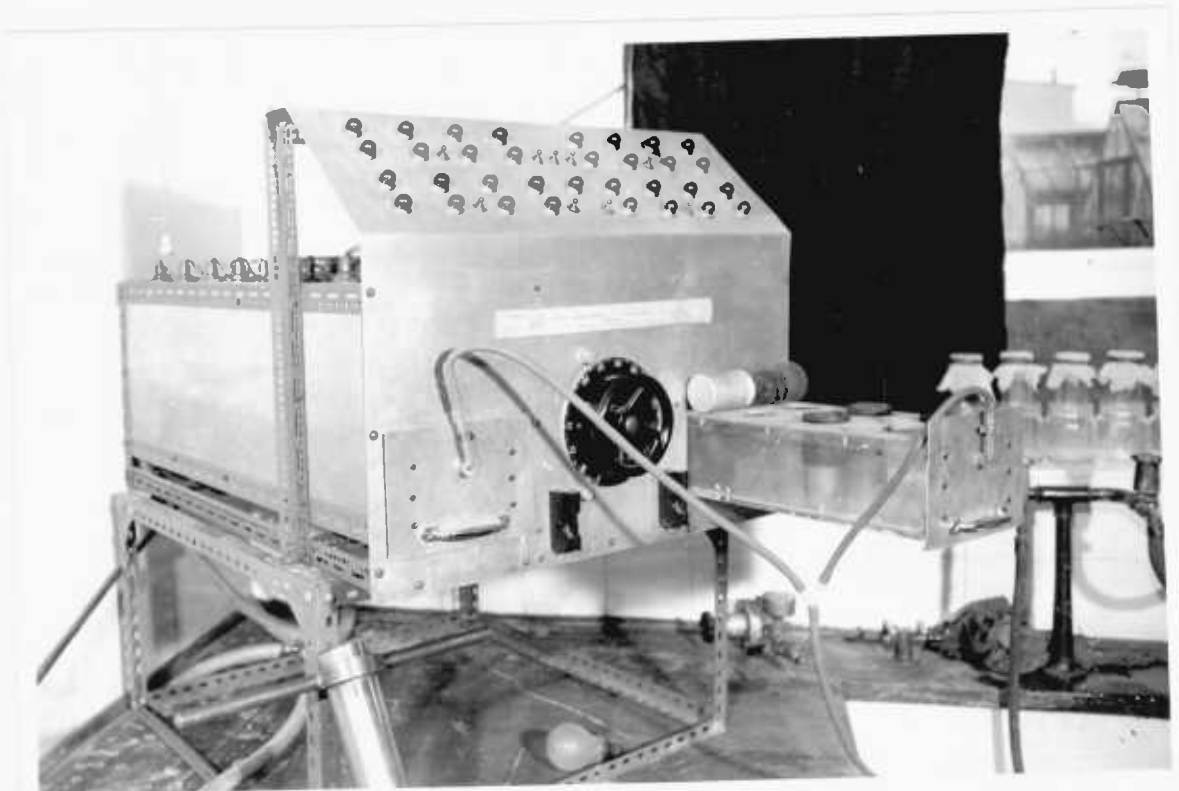


- A - Simmerstat
- B - 250W Infra-red lamp
- C - Fibre-board cabinet - open at the top
- D - Protective cover
- E - Sample material (leaf litter)
- F - Inflow pipe for cold water
- G - 100W electric light bulb
- H - Cotton fillet net (mesh size 2.5 mm)
- I - Supporting plastic grid (mesh size 20 mm)
- J - Fibre baffle board
- K - Picric acid solution
- L - Water bath

Plate - 3. Murphy Split funnels.



Plate - 4. Macfadyen high-gradient canister apparatus.



and 5 cm deep from which the bottoms were cut out and fitted with a grid of stiff plastic mesh (approximately 1 cm aperture). The sample holders fitted tightly into holes cut in the fibre baffle board, so that the top of each dish was level with the top of the baffle board. Another plastic dish containing saturated picric acid solution, was suspended below each sample container and held to it by a tightly fitting rubber ring 5 cm wide cut from a car inner tube. Sixteen of these units, each containing a soil sample, were placed in holes in the horizontal baffle board so that the dishes containing the collecting fluid were partially immersed in the cold water bath. The intact, inverted soil samples, 10 cm diameter and 5 cm deep were placed on circles of cotton fillet net (eleven threads per 2.5 cm each warp and weft) supported by the plastic grid. The gap between the sides of each soil sample and its container were filled with expanded polystyrene to prevent heat transfer between the upper and lower compartments. The door of the cabinet was then closed. No heat was used at first, but after three days the simmerstat time switch was turned on to a low setting. During the fourth and fifth days, the heating period was gradually increased by adjusting the simmerstat, and by the end of the sixth day the lamps were left on all the time, until extraction was complete on the eighth day. Temperatures at the soil surface gradually rose from 20°C at the beginning of the extraction period to 60°C at the end.

(f) The Macfadyen high-gradient canister extractor (Macfadyen 1961)

This apparatus, modified by Hale (1962) dispensed with funnels and collected arthropods directly into cylindrical aluminium canisters of the same diameter as the sample holders (Plate 4). Soil cores, 3.8 cm diameter and 3 cm deep, were taken with a soil sampling tool similar to that

described by Macfadyen (1961). The sampling tool contained inserts made from laminated plastic rings which held the soil cores and also formed the sample containers in the extraction apparatus. The plastic rings, together with the soil cores they contained, were placed intact and inverted on a metal gauze (10 mesh 23 S.W.G.) fitted to the top of each of 32 cylindrical aluminium canisters. These canisters were held to the base of the plastic rings, (now sample containers) by tight fitting rubber bands cut from bicycle inner tubes. Each canister contained distilled water to a depth of 1 cm, which acted as a collecting fluid for the arthropods extracted from the soil core, (Block, 1963).

Each of the 32 assemblies of soil core, sample container, sieve and collecting canister were then carefully transferred to the extraction apparatus. The apparatus was divided into two identical extraction units, each accommodating 16 of the sample assemblies prepared as above and operating independently. Each unit, held together in a steel angle frame, was an elongate rectangular box (85 cm x 35 cm x 45 cm high) made from asbestos sheet. In the bottom half of each box was an elongate rectangular water bath (84 cm x 34 cm x 20 cm) made of perspex mounted on sliding tracks, to facilitate the loading and unloading of the soil samples. The sample assemblies were inserted into holes in an asbestos baffle plate, forming the cover over each water bath, in such a way that the top of the sample containers fitted flush with the surface of the baffle plate, and the canisters were immersed in the cold water circulating through each water bath. The water baths were then pushed into position under the heating units, in the form of two banks of sixteen 60 W electric light bulbs and these were switched on. The light bulbs were suspended from the top of each extraction unit, one bulb over each of the soil samples. Thus, each of the extraction units was effectively divided into an upper heated compartment and a lower

cooled compartment enclosed within heat-proof cladding. Operating switches and pilot bulbs were mounted on a facia panel across the front of the apparatus. The pilot bulbs indicated when a light bulb inside the heating compartment has ceased to function. There was no controlled draught system in this apparatus. A steep temperature gradient was created through each soil sample by heating it from above with a 60 W pearl electric light bulb and cooling the collecting canister below by circulating cooled water at a temperature of $3 - 5^{\circ}\text{C}$ through the bath. A "Zenith Variac" transformer (type 100M) controlled the voltage passing through the electric light bulbs above each unit and hence the heating. The animals falling from the sample were collected into distilled water in the canisters. Soil samples were extracted for three days with the heating controlled at the following voltages: 60 volts for 24 hours, 100 volts for 24 to 48 hours and 140 volts for 48 - 72 hours. The temperature at the soil surface rose from 20°C at the beginning of the extraction to approximately 100°C by the end of the extraction period.

(g) The Macfadyen air-conditioned funnel extractor (Macfadyen, 1961)

This apparatus was completely enclosed in a rectangular chip-board cabinet, 123 cm x 90 cm x 74 cm, supported on an angle framework and lined with expanded polystyrene (Plate 5). The funnels, arranged in six rows of three, were 25 cm high and 15 cm diameter with an included angle of 32° narrowing to an opening 1.2 cm diameter. They fitted tightly into holes in removable chip-board trays and collecting vials, 2.5 cm diameter and 5 cm deep were held in position on the bottom of the funnels by rubber sleeves. The sample containers, 10.2 cm diameter and 5 cm deep, were suspended above the funnels, in holes in the baffle board, supported by horizontal metal rods across the top of each funnel so that the upper rim of the sample containers fitted flush with the surface of the baffle

Plate - 5. Macfadyen air-conditioned funnel apparatus.



board. The upper part of the cabinet, which contained the heater assembly, rested on the baffle board above the sample and was completely isolated from the lower chamber. It was suspended on a pulley system and could be raised to insert the sample containers and then lowered again. The heaters were lengths of 20 gauge nichrome wires of 7.5 ohm resistance, stretched between ceramic insulators. Each of these provided the heat for three funnels and they were arranged in pairs on each side of vertical ducts. A fan circulated air in the lower compartment, with ducts arranged so the air currents passed over a cold water bath, through the coils of an evaporator from a refrigerator unit, and passed over the lower surface of the soil samples. The air then returned through holes in a false back-plate, back to the fan. The air passages behind the false back-plate were of equal length, to ensure an even air flow to all funnels. The evaporator coils were attached to long lengths of flexible copper pipe which completed the circuit between the compressor and condenser unit housed beneath the cabinet. The compressor was driven by a $\frac{1}{4}$ h.p., capacitor start induction motor (230 V 50 cycles. single phase). The air temperature in the cabinet was controlled by a thermostat. Intact soil cores, 10 cm diameter and 5 cm deep, were placed in an inverted position on the sieves (10 mesh, 23 S.W.G.,) at the bottom of the sample containers. Soil samples were extracted for nine days and the animals were collected in 70 per cent v/v aqueous ethyl alcohol and glycerol (ratio 20:1). For the first seven days, the air in the lower cabinet was cooled and moistened regularly, using an atomizer driven by a compressor to maintain a relative humidity greater than 85 per cent. The temperature at the upper surface of the soil sample increased from approximately 20°C to about 45°C. The refrigerator unit was switched off on the seventh day and the relative humidity allowed

to fall.

2. Mechanical Methods

These are nearly all based on the same form of flotation on a dense liquid or upon the lipophilic properties of the insect cuticle. Four methods were chosen.

(a) Simple flotation with brine

Soil samples, 10 cm diameter and 5 cm deep, were immersed individually in a saturated sodium chloride solution (S.G. 1.2) in a galvanised metal can, 30 cm diameter x 30 cm deep, and stirred until most of the soil was in suspension in the solution. The suspension was then allowed to settle and the floating material was decanted into a 150 mesh sieve. The process was repeated to ensure the collection of all floating material. The collected material was washed free from brine and transferred together with about 100 ml of water, to a 500 ml, wide-necked conical flask. Approximately 50 ml of xylene was added and the mixture shaken. The contents of the flask were then poured into a 1 litre beaker, and the xylene-water interface brought to the top of the beaker by carefully adding more water. The interface was examined under a binocular microscope at X 16 and X 32 magnifications, with wide-field eye-pieces, and the animals picked out with a small spoon, made from wire flattened at the end, and counted.

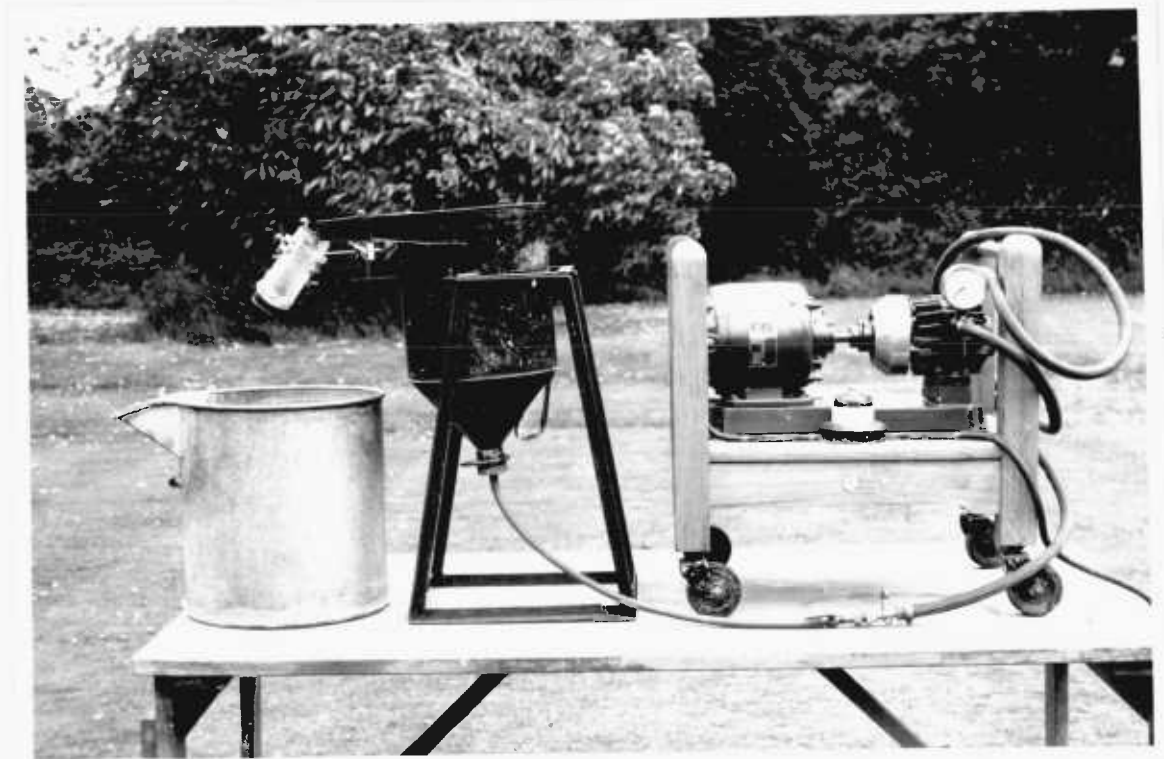
(b) The Salt & Hollick method of flotation (Salt & Hollick, 1944)

The method and apparatus used was modified slightly from that described by Salt & Hollick (Plates 6 & 7). Soil samples 10 cm diameter and 5 cm deep, were put in water-tight cans, water added and they were then frozen at -10°C and stored at this temperature. Each sample was thawed before processing and the soil washed under a high pressure jet of water through two sieves with successively smaller mesh into a

Plate - 6. Salt & Hollick wet-sieving apparatus.



Plate - 7. Salt & Hollick flotation apparatus.



reservoir below. The meshes of the two sieves were 7 mm and 2.5 mm respectively. Material retained by the 7 mm mesh was washed, teased apart if necessary washed again and then discarded, and fragments retained by the 2.5 mm mesh were washed into the reservoir can at the bottom of the apparatus. Excess water and material in suspension overflowed from the reservoir into another deep container with an overflow lip and a 120 mesh (43 S.W.G.) sieve in the bottom, termed a "Ladell" container. The water and fine silt particles passed through the 120 mesh sieve (aperture 0.12 mm) and out to the drain. After all the material was washed from the sieves the reservoir was tilted and the contents washed into the "Ladell" container, which was then allowed to drain and placed on a stand on which it could be pivoted and tilted.

A saturated solution of magnesium sulphate (S.G.1.2) was added to the "Ladell" container so that the organic material would float to its surface. Compressed air, passed through the base of the "Ladell" container, agitated the soil and released trapped organic particles which floated to the surface. The organic material on the surface was then decanted into a cylindrical glass tube, 5 cm diameter and 17.5 cm long, covered at the base with a piece of 180 mesh bolting silk held by an elastic band. The organic material retained by the bolting silk was washed, then shaken in a flask with water and xylene, transferred to a 1-litre beaker and the animals were picked off the xylene-water interface with a small wire spoon as in (a).

(c) The Edwards & Heath method of flotation (Edwards & Heath, 1962)

This apparatus was a mechanisation of the Salt & Hollick apparatus (Plate 8). The "Ladell" container was of black polythene with a 180 mesh sieve at the bottom. Four of these modified "Ladell" containers rested in four large plastic funnels which could rotate about their vertical

Plate - 8. Edwards & Heath wet-sieving and flotation method.

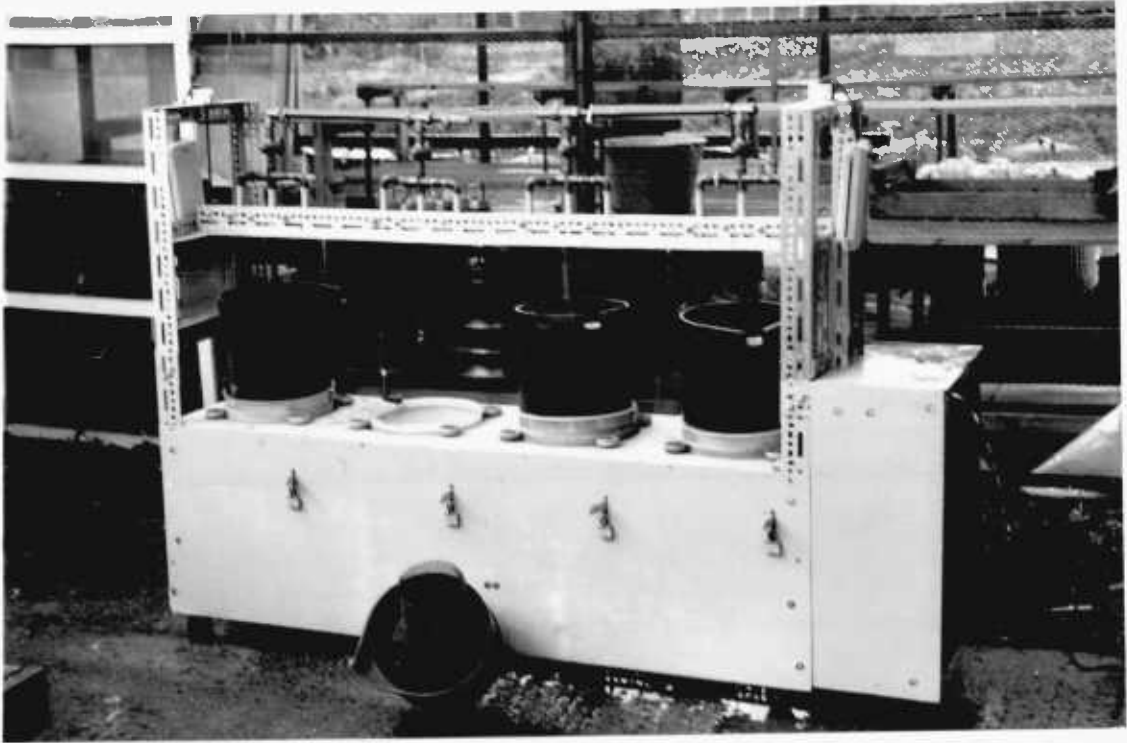
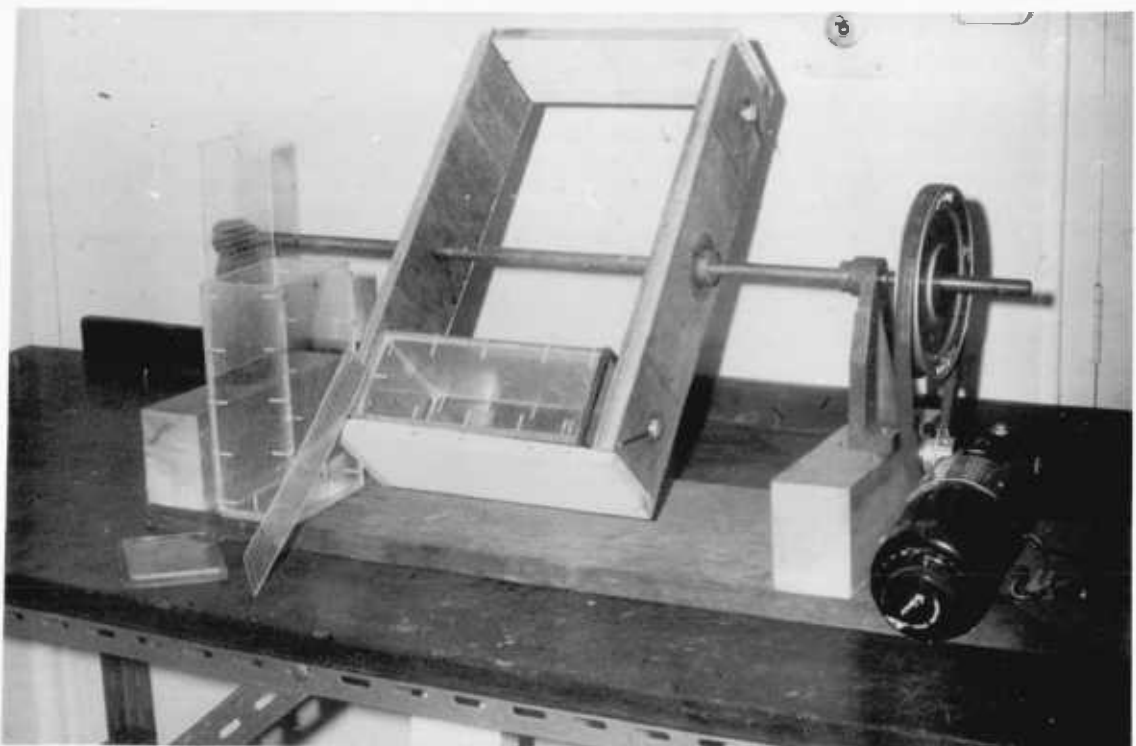


Plate - 9. Aucamp's grease film apparatus.



axes. The funnels were held loosely in holes in a plywood frame by four small freely rotating wheels. Attached to the stem of each funnel was a wooden disc, around the perimeter of which the drive wheels moved. The drive was supplied to each unit by belt and pulley arrangements, independently attached to a common longitudinal driving shaft, powered by a $\frac{1}{4}$ h.p. electric motor. This arrangement allowed each "Ladell" container and the funnel in which it was resting, to be rotated independently. The soil samples stored at -10°C , were thawed and placed in wire mesh baskets (4 mesh, S.W.G.) standing on wire feet resting on the "Ladell" sieve. Each soil sample was sprayed with water from two flat fish-tail jets. One played across the base of the sieve to prevent it blocking with silt and the other was directed vertically downwards to break up the soil as the container rotated. The water and fine silt particles that passed through the sieve were collected in the funnels supporting the "Ladell" containers, then flowed along channel-ways to a settling tank and then to the drain. The water jets were fixed to a counter-poised bar, which could be raised to allow the "Ladell" containers to be removed and the samples replaced. Each soil sample was washed for 10 - 30 minutes depending on the soil type and any material retained in the wire basket was washed above the "Ladell" container, teased apart if necessary washed again and discarded. The subsequent procedure was similar to the Salt & Hollick method with a flotation and xylene/water separation stage, (Edwards et al., 1970).

(d) The grease film method of extraction (Aucamp & Ryke 1965)

This apparatus which was modified from that originally described (Plate 9) consisted of two rectangular plastic tanks (7.5 cm x 10 x 20 cm) each containing two removable plastic plates 20 cm x 10 cm which slid

into tracks in the walls of the tank so they were held against the inner surfaces. These plates were coated on the inner surface with a thin layer of Shell white petroleum jelly. The soil samples, 5 cm diameter and 5 cm deep, were stored at -10°C , then thawed and allowed to stand in beakers of water, with occasional stirring, for one hour. This broke up soil particles and separated any tangled roots present. The water-soil mixtures were poured into the two plastic tanks, with one sample per tank and water added to make them of equal weight. A lid, fitted onto each tank, was made water-tight with a rubber seal and clamp device. The tanks were then fitted into a frame which rotated about its horizontal axis, and could be tilted to a vertical position to facilitate loading. The frame rotated at 16 revolutions per minute on a central axis, driven by a variable speed electric motor. Each pair of samples was rotated for 15 minutes. The grease plates were removed and examined under a binocular microscope ($\times 25$ magnification). Parallel grid lines were marked on each grease plate to ensure a complete examination was made. Most of the animals could be identified while still embedded in the grease.

IV. A comparison of the relative efficiencies of eleven commonly used extraction methods on a single soil-type in woodland, pasture and fallowed-arable habitats.

1. Introduction

The relative efficiencies of the methods of extraction described in section III were compared for most of the different groups of soil arthropods. Samples were taken from each of a woodland, pasture and arable site, all on a single silt-clay loam type of soil at Rothamsted farm.

The three sampling sites were situated thirty metres apart, at the point where the three different habitats (Manor Wood, Bones Close and

Pastures) meet. Each site was sampled separately, Manor Wood (a mixed deciduous woodland) on October 31st, 1966, Bones Close field (permanent pasture) on November 30th, 1966, and Pastures field (fallowed arable) on March 6th, 1967.

At each site a uniform area, 6 m sq., was cleared of surface litter such as undecomposed leaves and the larger plant debris and vegetation taller than 2 cm was cut with clippers and removed before sampling. The size of soil samples taken for this comparison was determined by the extraction apparatus. For most of the extraction methods, soil cores 10 cm diameter and 5 cm deep were used. The Murphy split-funnel apparatus and the grease-film method of extraction used soil cores 5 cm diameter and 5 cm deep and Macfadyen's high-gradient canister apparatus used soil cores 3.8 cm diameter and 3 cm deep.

Sixteen replicates of the standard 10 cm diameter and 5 cm deep cores, and thirty-two replicates of the smaller soil cores were taken for each method at each site. To account for the discrepancy in soil sample size when comparing the relative efficiencies of the different extraction methods, the numbers of arthropods extracted from the smaller samples were multiplied by a correction factor based on the volume of soil in each sample.

2. Methods

Soil samples were taken from a uniform square area at each site which was marked with wooden pegs and string. The area (6 m sq.) was large enough to provide all the samples required, and was sub-divided into 16 grid-units each 1.5 m square. All soil samples included surface litter and vegetation, but large litter particles and vegetation taller than 2 cm had been carefully removed from the sampling area. The sixteen replicate soil cores, which were used for most of the extraction methods, were taken

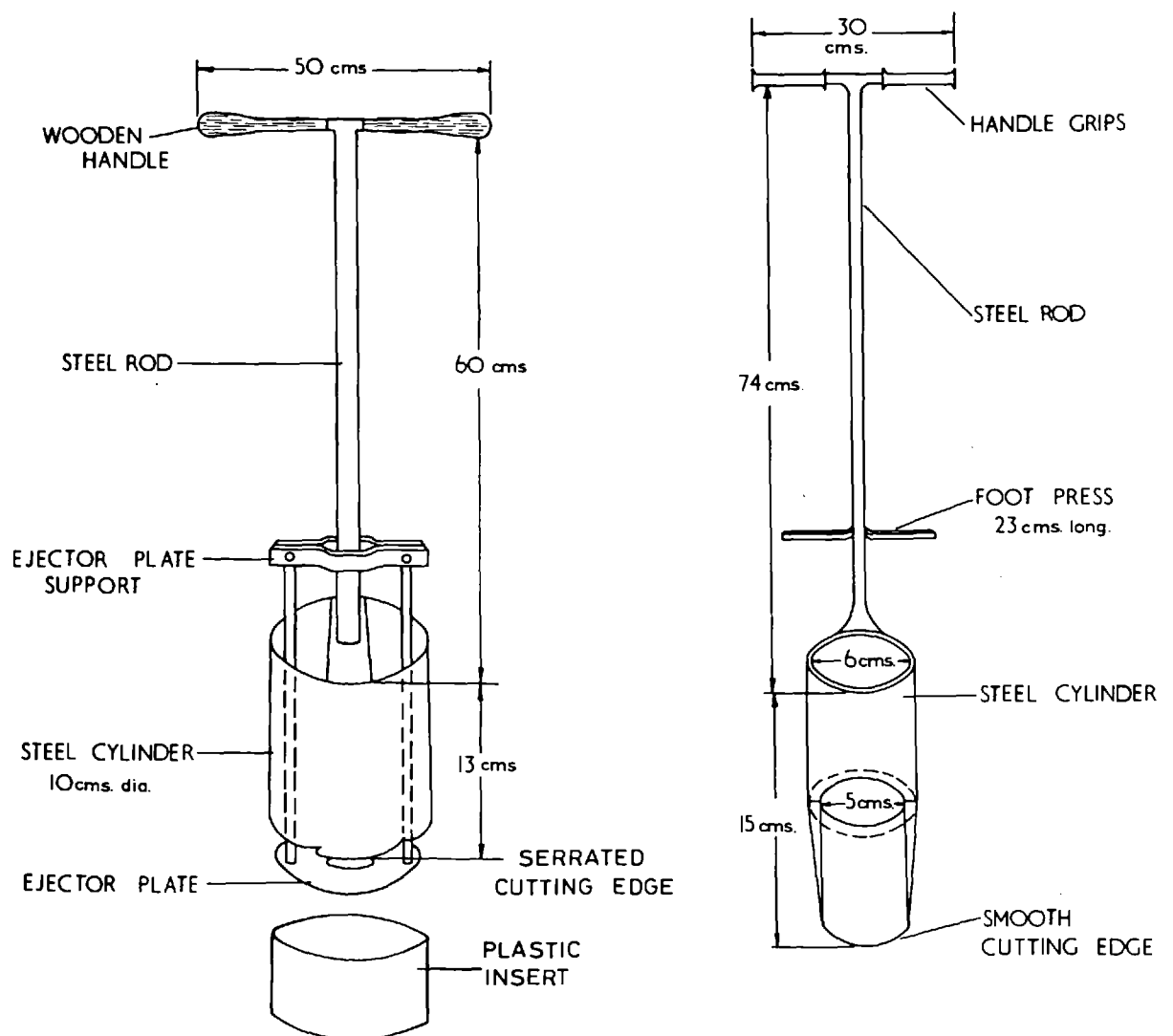
at random from each one of the sixteen grid units. For those methods that required thirty-two samples, two soil cores were taken at random from each grid-unit. This stratified random sampling pattern was used to minimise variation due to the uneven distribution of animals expected within the sampling area.

All the larger soil cores (10 cm diameter, 5 cm deep), except those to be extracted by the Macfadyen high-gradient funnel extractor, were taken with a modified turf renovating tool (Fig. 15a). This consisted of a steel cylinder (10 cm internal diameter and 58 cm long), one end of which was sharpened to a cutting edge, the other attached to a shaft (75 cm long) with a cross-bar for a handle. A metal ejector plate was freely suspended from the shaft, allowing a piston-like action of the ejector plate inside the steel cylinder, which aided the removal of the soil cores from the cylinder. Macfadyen (1961) was critical of sampling tools with ejector plates because of the sample compression caused when removing the soil core from the steel cylinder. To overcome these criticisms, the steel cylinder was fitted with a plastic insert, a 5 cm length of rainwater pipe, 10 cm internal diameter, before each sample was taken. The soil cores were then ejected from the sampling tool by the pressure exerted on the upper lip of the plastic insert, thus avoiding extra compression of the soil sample.

The sampling tool was held vertical to the soil surface and twisted whilst applying downward pressure so that the cutting edge was driven to just below the required depth of 5 cm. The soil core was broken from the underlying soil by a complete revolution of the sampling tool and removed from the cylinder using the ejector plate. The steel cutting edge of the sampler was sharpened regularly and care was taken to minimize compression and disturbance of the soil core.

Samples to be used on the Macfadyen air-conditioned funnel apparatus

Fig. 15.

A.B.THE SOIL SAMPLERS

(10 cm diameter, 5 cm deep) were taken using the welded steel plate rims of the sample holders. These sample holders, removed from the apparatus, were driven into the soil by hand using a block of wood and released from the underlying soil using a sharp knife.

The smaller samples, 5 cm diameter by 5 cm deep and 3.8 cm diameter by 3 cm deep, were taken from the soil using cylindrical, plastic pill-boxes (supplied by Pioneer Plastics Ltd., Feltham, Essex). The lids of these pill-boxes were removed and the plastic cylinders were driven into the soil by hand. A sharp knife released the soil core from the underlying soil.

All the soil cores, obtained as described, were trimmed to the required depth and placed in pre-labelled polythene bags before being transported to the laboratory. The samples for extraction on the Macfadyen high-gradient canister apparatus and the Murphy split-funnel extractor, retained in their plastic pill-boxes, were parcelled in cardboard boxes with shock-proof packing and posted respectively to Dr. Springett, The Nature Conservancy, Merlewood, Lancs., and Dr. Murphy, The School of Agriculture, Sutton Bonington, Notts. It had been previously arranged that upon receipt of these samples, Dr. Springett and Dr. Murphy would place the samples on their extraction equipment immediately, and that the arthropods recovered would be preserved and returned by post. All the samples to be extracted by dry-funnel methods at Rothamsted were stored for three days at 5°C so all samples were extracted at approximately the same time.

All the dry-funnel samples were placed in the extraction apparatus intact and in an inverted position. Samples were extracted into 70% aqueous ethyl alcohol containing glycerol (ratio 20 : 1), (except for the Macfadyen canister apparatus, which used distilled water and the Kempson infra-red extractor which used saturated picric acid solution).

The soil samples extracted by mechanical methods were soaked in tap-water and stored in tins; the others were stored in individual polythene bags. It was anticipated that variations in the numbers of arthropods recovered from adjacent soil samples by the same method could be considerable. From earlier data collected at Rothamsted, sixteen sample units was the minimum number required to assess the relative numbers of most groups of arthropods with an accuracy within 20%.

The smaller the populations of animals are, or the more they are aggregated, the more samples are necessary to obtain a population estimate of the same accuracy. Samples were limited to a depth of 5 cm. because more than 80% of soil arthropods occur in this layer at the times of the year when samples were taken.

The arthropods collected with the different methods of extraction were stored in 70% aqueous ethyl alcohol containing glycerol (ratio 20 : 1) until they could be sorted into taxonomic categories. The categories were chosen so that the arthropods could be relatively easily sorted into them. The total number of animals that had to be examined in order to obtain data with statistical validity, was so great, that further identification was impossible. For instance, in this stage of the investigation alone, 576 soil samples were examined, each containing between 50 and 1000 animals. Most of the counting and identification was done using a binocular microscope and incident lighting. Many of the microarthropods in the collecting tubes floated on the surface of the alcohol mixture. Before counting and identification began, the open tubes were placed in an oven at 60°C for a short period. The addition of a small drop of ether to each tube, together with the heating process, caused most animals remaining at the surface to sink to the bottom (Macfadyen, 1962a). The contents of each storage tube were washed with alcohol (70%) into a square flat-bottomed perspex dish with sloping

sides, and with the base marked with a grid of squares. The tray was on a sliding stage, which allowed each square of the grid to be examined separately. Arthropods that could not be identified in this way were picked from the dish with a wire spoon, mounted in lactic acid, and identified with transmitted light under a more powerful microscope.

Results

The data from the comparisons are summarised in Figs. 16-25. The numbers of animals recovered from the smaller soil samples were multiplied by volume conversion factors, making data comparable with the 10 cms. diameter 5 cms. deep samples.

Soil arthropods are usually aggregated in soil (Debauch, 1962; Healy, 1962; Hughes, 1962) which accounts for the variation in the numbers of animals recovered from adjacent soil samples. Soil animals are seldom randomly distributed in the soil, so all data were transformed to $\log(n + 1)$ before statistical analysis. Significant differences between extraction methods were assessed using Tukey's (1953) w-procedure based on the standard error of a treatment mean multiplied by a factor obtained from a table of the "Upper percentage points of the Studentized range". The comparisons are summarized for the three habitats in Tables 1, 2 and 3 and the significant differences in Figs. 26-28. Highly significant differences occurred between sites, methods, taxonomic categories and interactions.

The woodland soil contained most animals, and the arable fewest. It is presumed that no method extracted all the animals from a soil sample, so the absolute efficiency of the techniques could not be estimated, but the relative efficiency for each different group of arthropods could be assessed, although these varied for the different sites. Mechanical methods, previously believed to be more efficient

FIG. 16.

COMPARISON OF METHODS WOODLAND

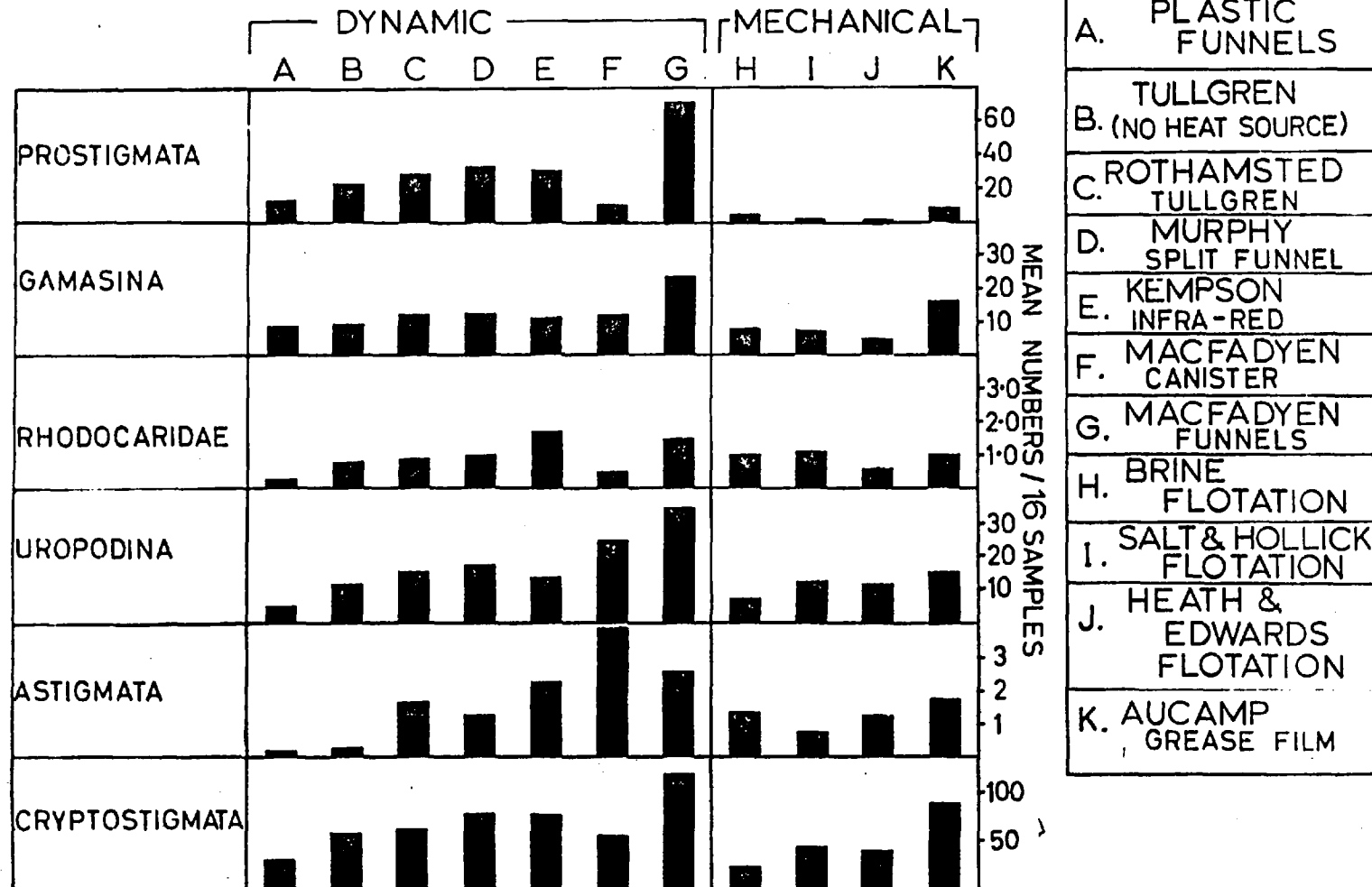


FIG. 17.

COMPARISON OF METHODS WOODLAND

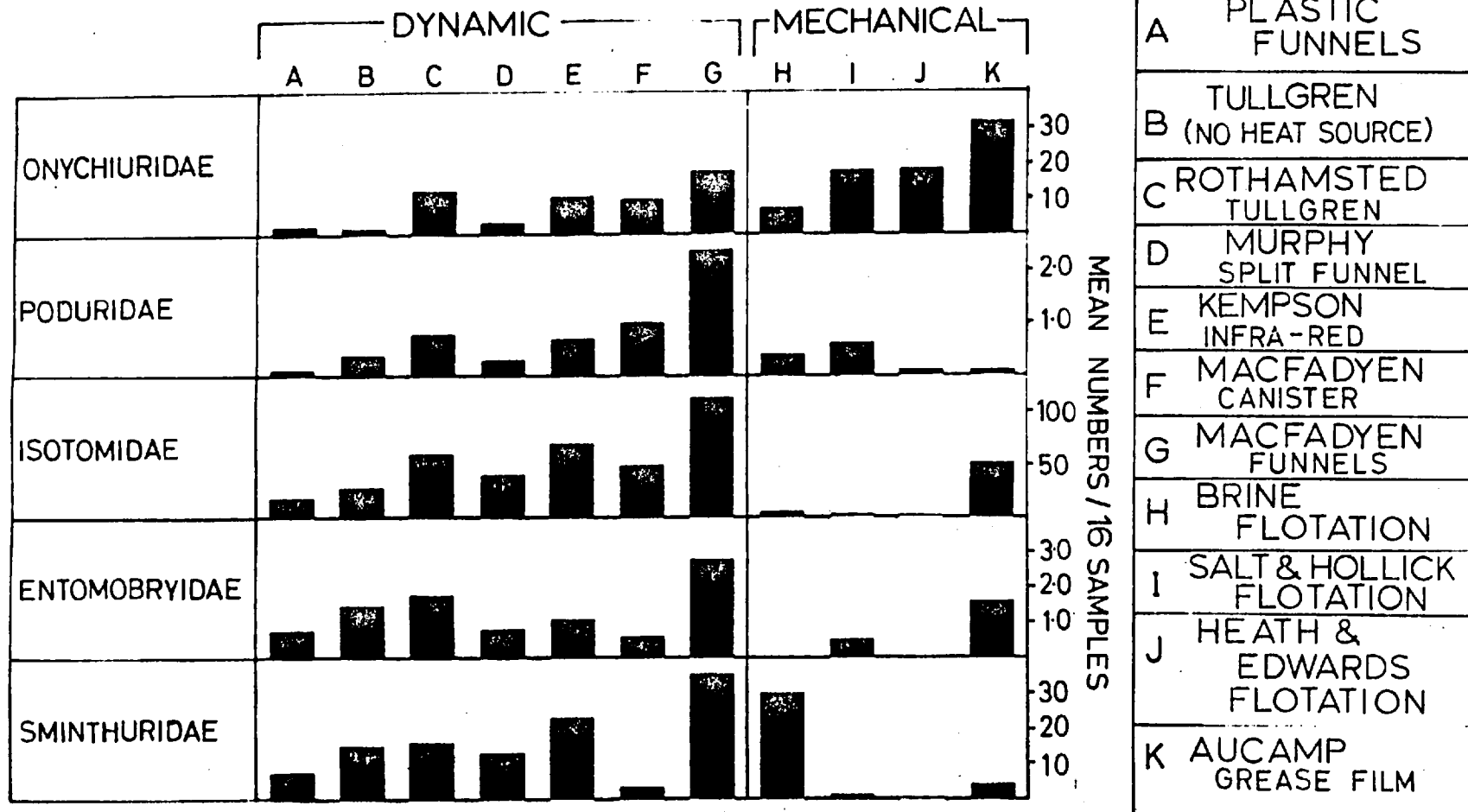


FIG. 18.

COMPARISON OF METHODS WOODLAND

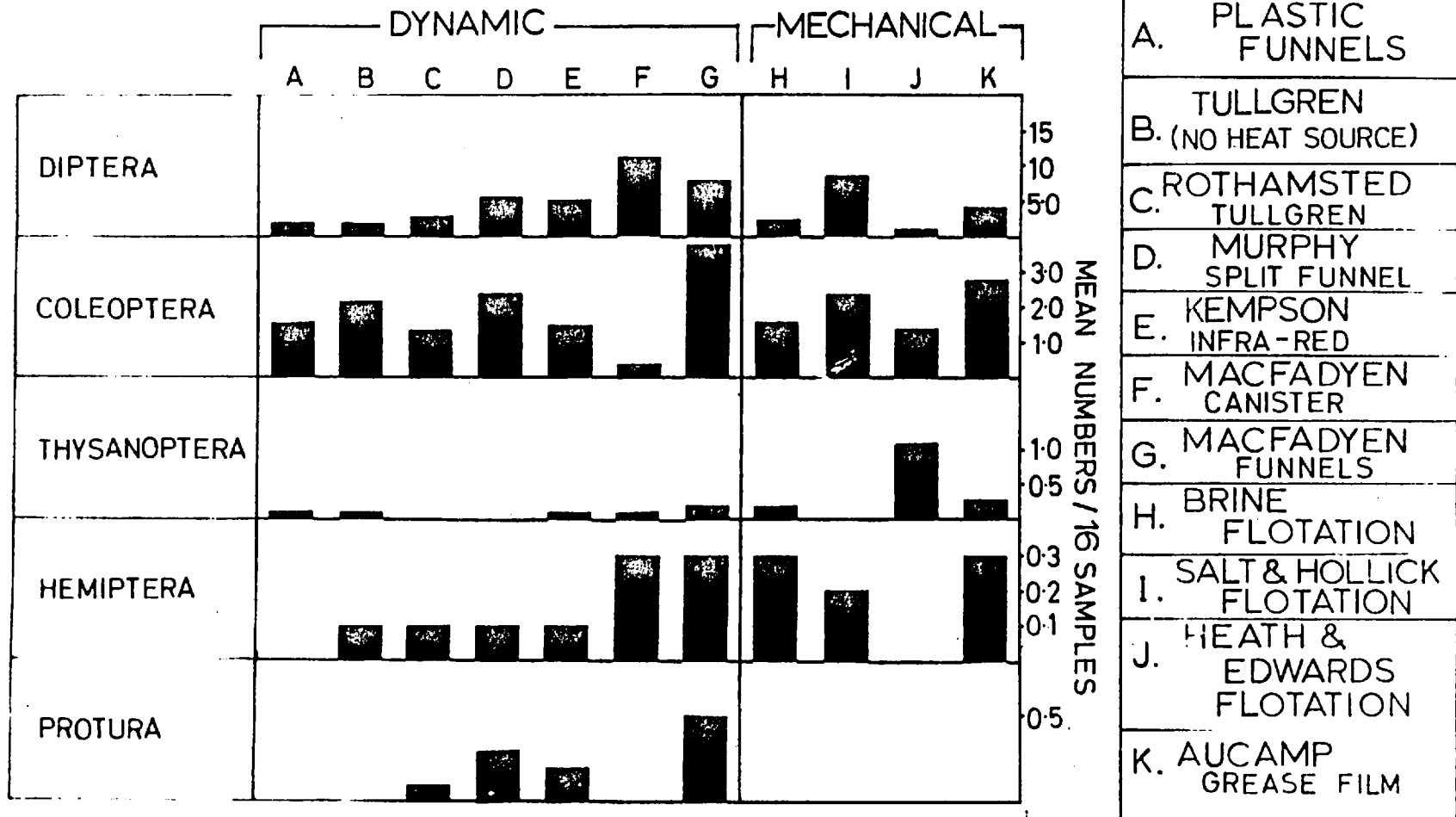


FIG. 19.

COMPARISON OF METHODS WOODLAND

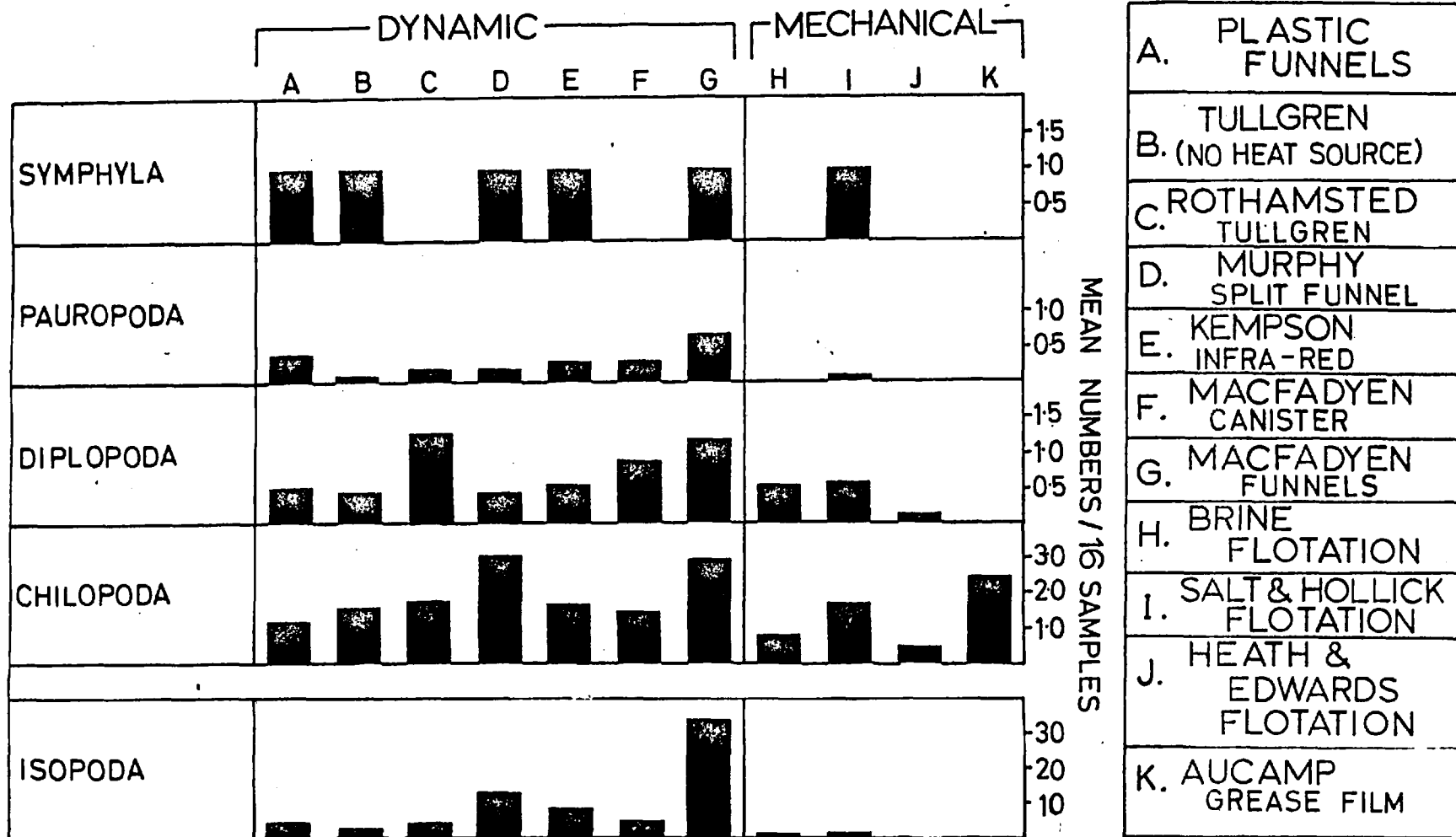


FIG. 20.

COMPARISON OF METHODS. PASTURE.

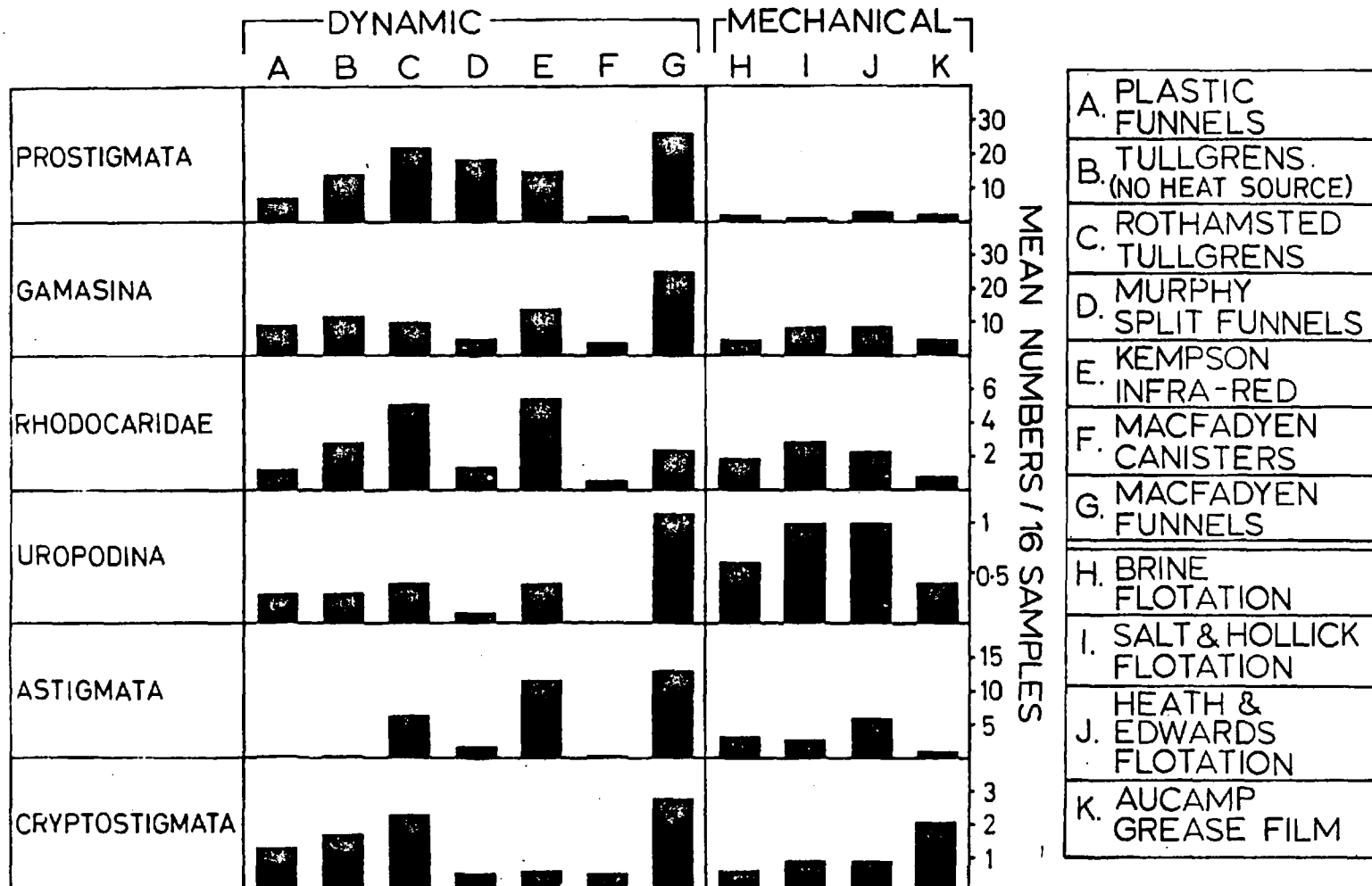


FIG. 21.

COMPARISON OF METHODS. PASTURE.

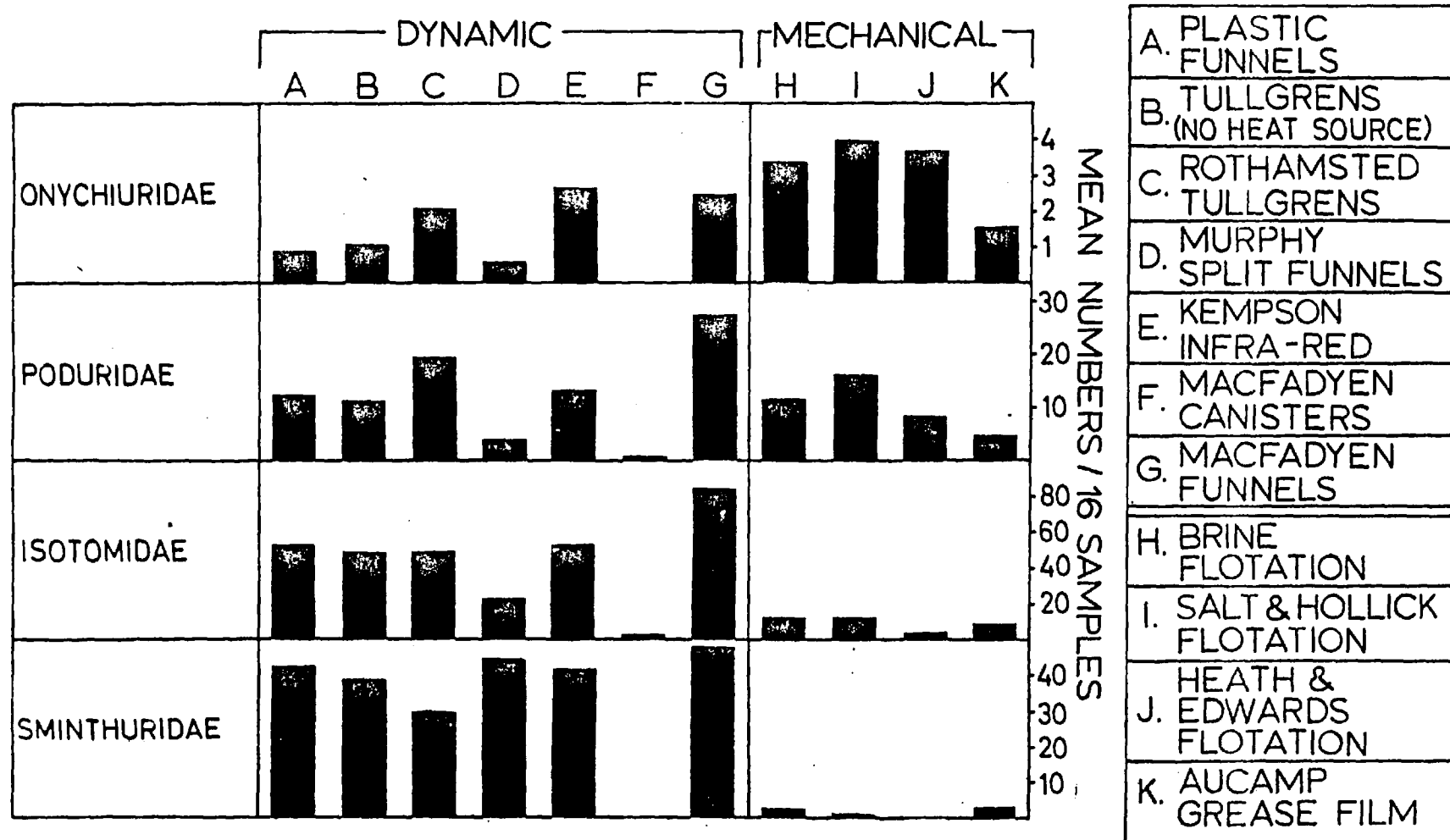


FIG. 22.

COMPARISON OF METHODS. PASTURE.

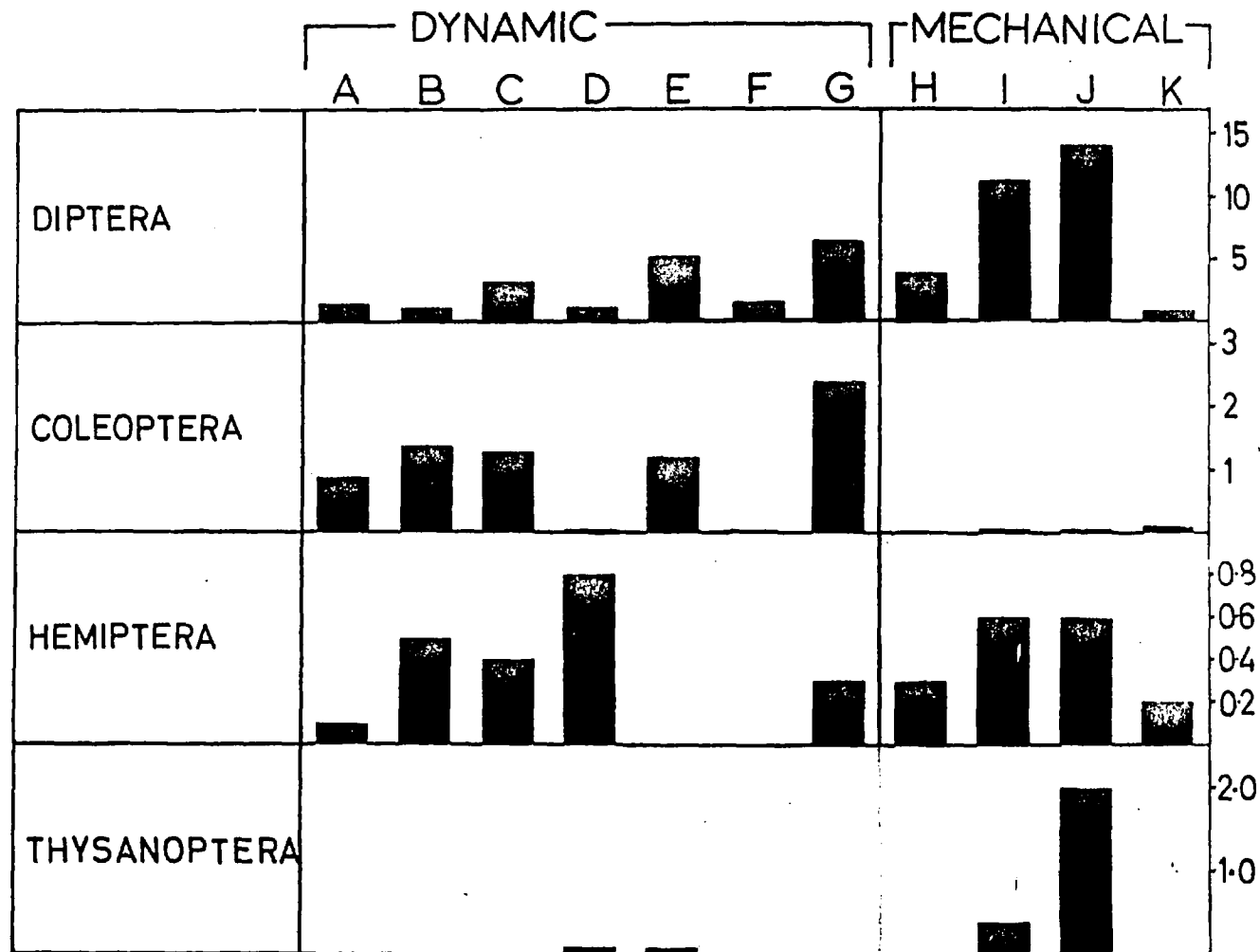


FIG. 23.

COMPARISON OF METHODS. FALLOW.

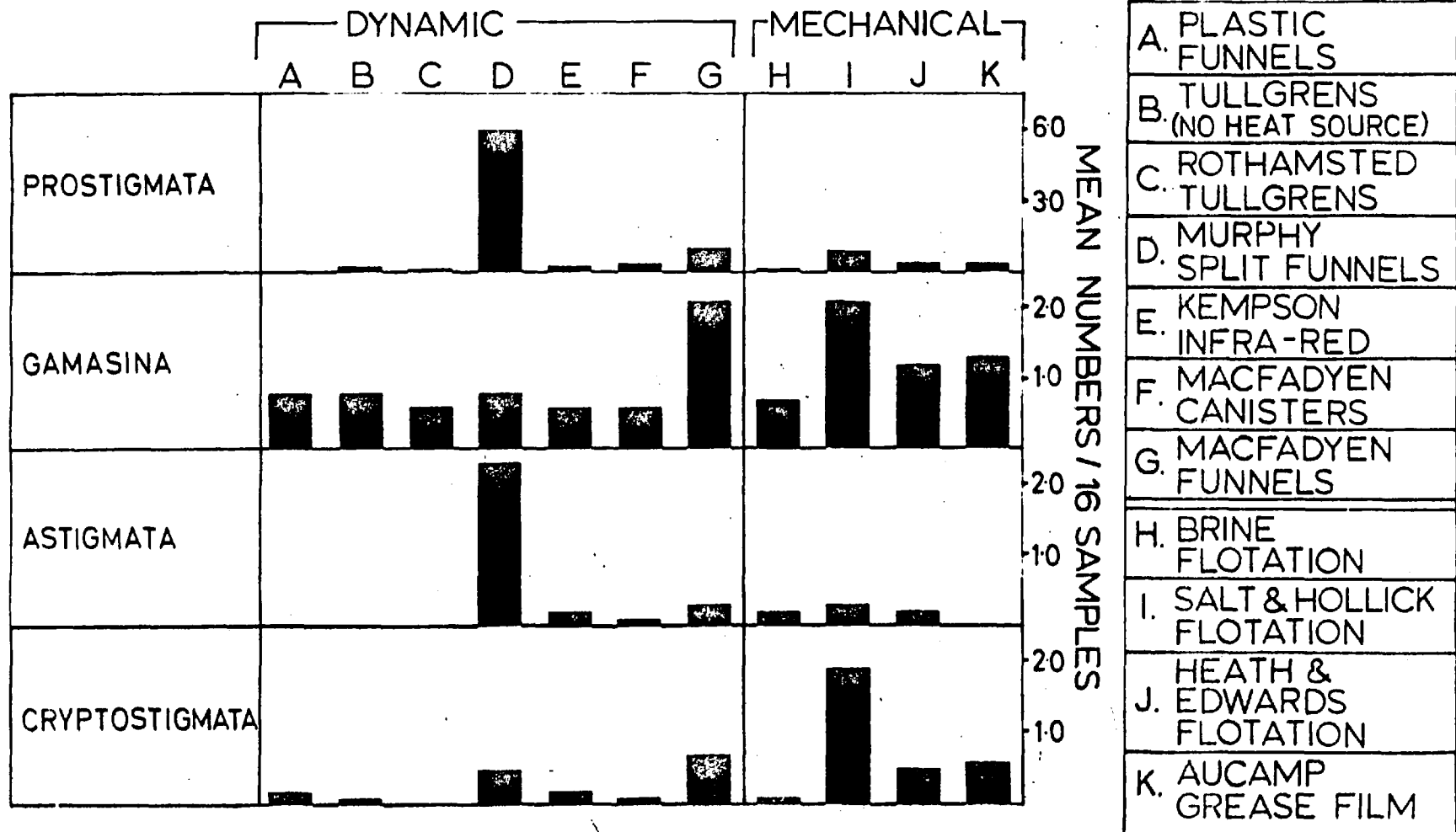


FIG. 24.

COMPARISON OF METHODS. FALLOW.

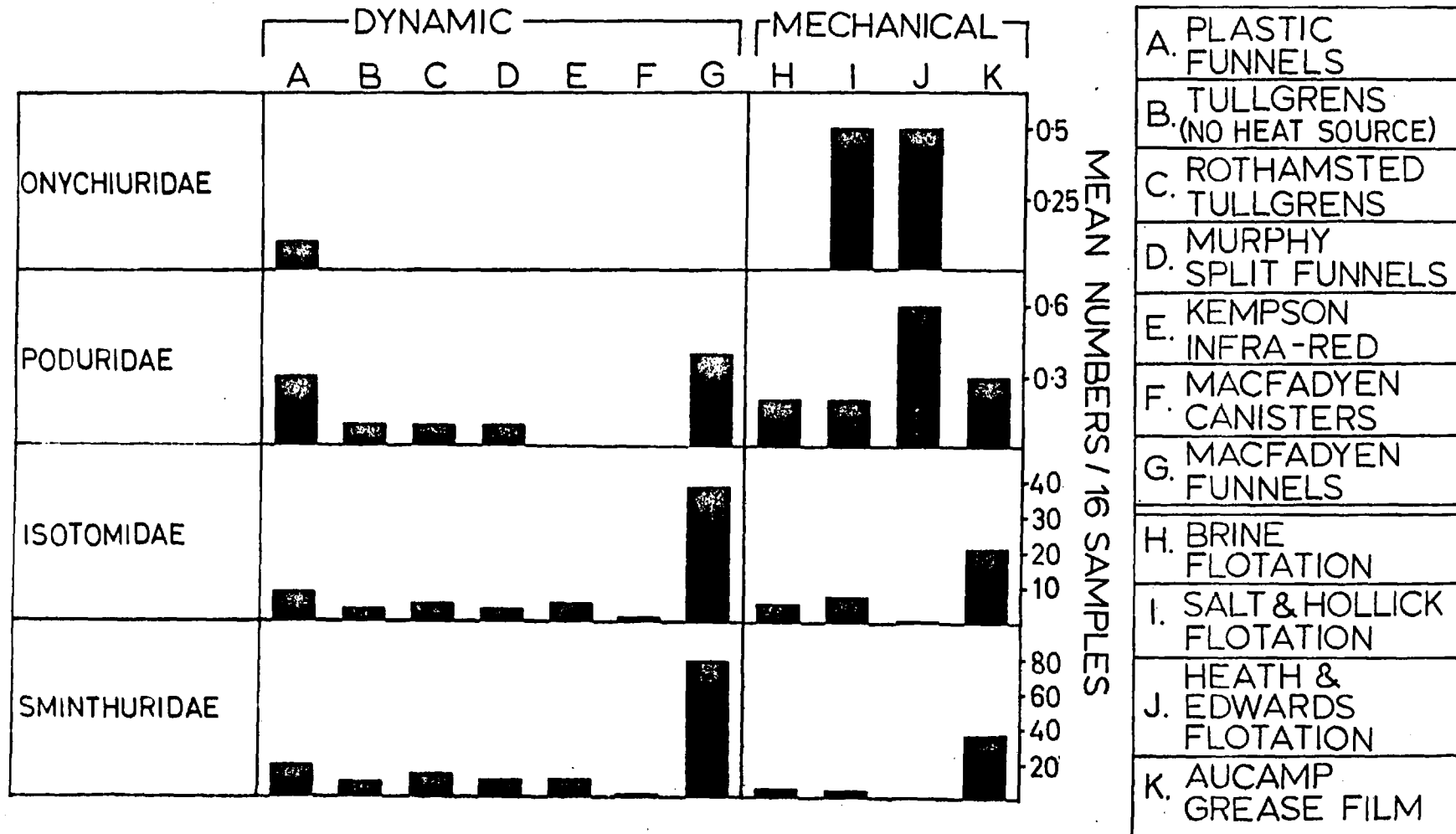
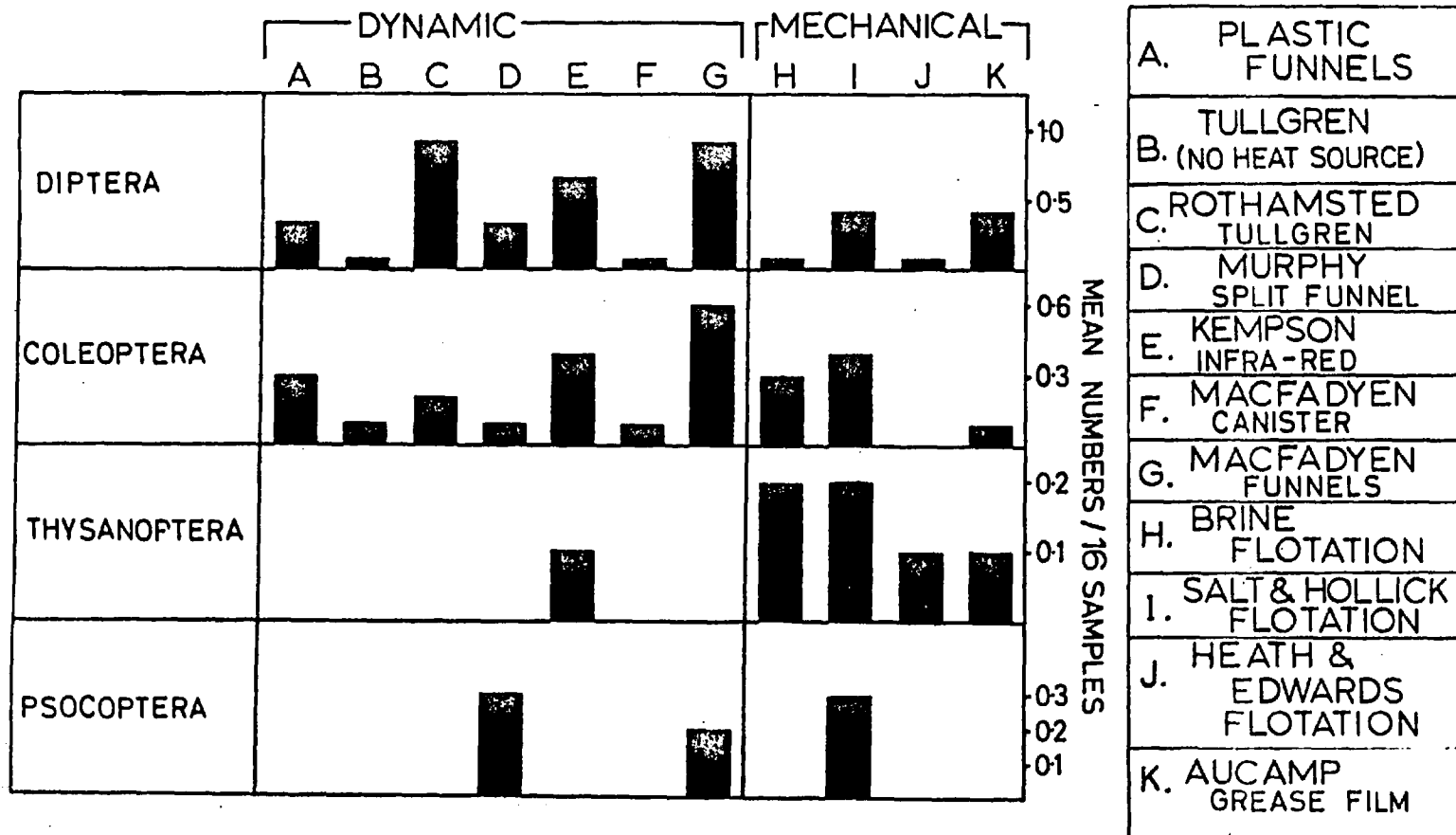


FIG. 25.

COMPARISON OF METHODS. FALLOW.



Legend for Tables I, II and III

- A. Simple plastic funnel
- B. Rothamsted Berlese/Tullgren funnel (without heat)
- C. Rothamsted Berlese/Tullgren funnel (with heat)
- D. Murphy split funnel
- E. Oxford infra-red extractor
- F. Macfadyen small canister extractor
- G. Macfadyen high gradient funnel
- H. Simple brine flotation
- I. Salt and Hollick flotation
- J. Edwards and Heath flotation
- K. Grease film extractor

** Differences significant at the 1% probability level

* Differences significant at the 5% probability level

Table 1. A COMPARISON OF ELEVEN METHODS OF EXTRACTING ARTHROPOD FAUNA FROM WOODLAND SOIL

(Animal count as Log (n + 1) mean of 16 soil cores)

ANIMAL GROUP	EXTRACTION METHOOS (SEE LEGEND p.74)												TUKEY'S		F	
	A	B	C	D	E	F	G	H	I	J	K	S.E.	L.S.O.	0.05		0.01
ARACHNIOA																
PSEUOOSCORPIONES	0.037	0.153	0.067	0.059	0.075	0.053	0.200	0.086	0.194	0.048	0.194	0.047	0.124	0.216	0.250	2.273*
ARANEAE	0.134	0.184	0.142	0.147	0.056	0.106	0.292	0.067	0.180	0.123	0.402	0.062	0.163	0.285	0.329	2.708*
ACARI																
PROSTIGMATA	1.145	1.386	1.506	1.515	1.415	1.142	1.857	0.606	0.466	0.340	0.927	0.091	0.270	0.419	0.483	28.314**
MESOSTIGMATA																
GAMASINA	0.986	1.008	1.117	1.127	1.083	1.132	1.387	0.959	0.903	0.767	1.245	0.076	0.200	0.350	0.403	4.828**
(LESS)RHOOACARIOAE	0.116	0.247	0.283	0.310	0.432	0.185	0.391	0.294	0.327	0.216	0.295	0.080	0.210	0.368	0.424	1.295
UROPOOINA	0.785	1.105	1.209	1.259	1.164	1.413	1.553	0.918	1.126	1.111	1.201	0.078	0.205	0.359	0.414	6.455**
ASTIGMATA	0.067	0.123	0.435	0.367	0.517	0.694	0.562	0.387	0.251	0.370	0.451	0.077	0.203	0.354	0.409	5.081**
CRYPTOSTIGMATA	1.525	1.760	1.778	1.896	1.759	1.746	2.070	1.399	1.672	1.633	1.961	0.054	0.142	0.248	0.286	12.912**
INSECTA																
COLLEMBOLA																
ONYCHIURIOAE	0.547	0.498	1.126	0.685	1.066	1.071	1.278	0.942	1.283	1.296	1.522	0.100	0.263	0.460	0.530	11.002**
POOURIOAE	0.048	0.142	0.256	0.099	0.221	0.334	0.536	0.150	0.199	0.037	0.048	0.064	0.168	0.294	0.340	5.201**
ISOTOMIOAE	1.292	1.466	1.794	1.628	1.853	1.707	2.064	0.777	0.665	0.232	1.734	0.075	0.197	0.345	0.398	59.191**
ENTOMOBRYIOAE	0.243	0.400	0.441	0.245	0.321	0.211	0.584	0	0.172	0	0.416	0.066	0.174	0.304	0.350	7.663**
SMINTHURIOAE	0.943	1.212	1.240	1.152	1.383	0.700	1.499	1.492	0.369	0.097	0.738	0.085	0.224	0.391	0.450	31.313**
OIPTERA	0.485	0.488	0.593	0.822	0.800	1.083	0.960	0.512	0.945	0.326	0.717	0.102	0.268	0.469	0.540	5.224**
COLEOPTERA	0.408	0.504	0.385	0.537	0.393	0.175	0.696	0.408	0.476	0.377	0.580	0.079	0.208	0.363	0.419	3.123**
THYSANOPTERA	0.029	0.048	0	0	0.056	0.053	0.067	0.086	0.019	0.322	0.111	0.042	0.110	0.193	0.222	4.436**
HEMIPTERA	0	0.048	0.029	0.029	0.043	0.122	0.108	0.105	0.086	0	0.097	0.046	0.121	0.212	0.244	0.892
HYMENOPTERA	0	0.018	0.018	0.029	0	0.053	0.037	0.067	0.056	0.105	0	0.028	0.074	0.129	0.148	1.376
PSOCOPTERA	0	0.037	0.037	0.043	0.075	0	0.056	0	0.048	0.037	0.097	0.032	0.084	0.147	0.170	0.925
PROTURA	0	0	0.037	0.103	0.075	0	0.178	0.018	0.018	0	0	0.033	0.087	0.152	0.175	3.123**
DIPLURA	0	0	0	0.029	0	0	0	0	0	0	0	0.010	0.026	0.046	0.056	1.000
MYRIAPOOA																
CHILOPOOA	0.340	0.418	0.451	0.617	0.427	0.439	0.598	0.258	0.372	0.169	0.393	0.078	0.205	0.359	0.414	2.749*
OIPLOPOOA	0.172	0.150	0.423	0.149	0.202	0.281	0.386	0.194	0.184	0.131	0	0.060	0.158	0.276	0.319	3.837**
SYMPHYLA	0.037	0.037	0	0.029	0.056	0	0.048	0	0.037	0	0	0.022	0.058	0.101	0.116	1.133
PAUROPOOA	0.131	0.056	0.067	0.073	0.105	0.106	0.238	0.018	0.029	0	0	0.047	0.110	0.193	0.223	2.695*
CRUSTACEA																
ISOPOOA	0.770	0.598	0.756	1.157	0.983	0.843	1.546	0.353	0.416	0.037	0.122	0.093	0.245	0.428	0.494	23.298**

Table II. A COMPARISON OF ELEVEN METHODS OF EXTRACTING ARTHROPOD FAUNA FROM GRASSLAND SOIL

(Animal count as Log (N + 1) mean of 16 soil cores)

ANIMAL GROUP															TUKEY'S		F VALUE
															D		
	A	B	C	D	E	F	G	H	I	J	K	S.E.	L.S.D.	0.05	0.01		
ARACHNIDA																	
ARANEAE	0.018	0	0.018	0	0.018	0	0	0.018	0.037	0.067	0.038	0.020	0.053	0.092	0.105	1.191	
ACARI																	
PROSTIGMATA	0.920	1.188	1.367	1.297	1.203	0.460	1.440	0.471	0.370	0.597	0.507	0.102	0.268	0.469	0.530	16.906**	
MESOSTIGMATA																	
GAMASINA	1.038	1.115	1.044	0.784	1.183	0.786	1.416	0.764	0.973	0.982	0.756	0.096	0.252	0.442	0.546	4.927**	
(LESS) RHODACARIDAE	0.368	0.591	0.792	0.384	0.815	0.281	0.537	0.460	0.588	0.524	0.259	0.081	0.213	0.373	0.456	5.840**	
UROPODINA	0.100	0.103	0.134	0.059	0.154	0	0.316	0.216	0.306	0.299	0.155	0.069	0.181	0.317	0.400	2.334*	
ASTIGMATA	0.067	0.150	0.875	0.416	1.100	0.175	1.149	0.629	0.579	0.825	0.314	0.089	0.234	0.409	0.520	18.207**	
CRYPTOSTIGMATA	0.356	0.438	0.520	0.162	0.217	0.202	0.583	0.206	0.284	0.270	0.487	0.082	0.216	0.377	0.445	3.264**	
INSECTA																	
COLLEMBOLA																	
ONYCHIURIDAE	0.277	0.318	0.485	0.201	0.570	0	0.545	0.642	0.699	0.670	0.409	0.093	0.245	0.428	0.508	5.658**	
PODURIDAE	1.068	1.115	1.313	0.713	1.160	0.325	1.478	1.106	1.233	0.972	0.762	0.085	0.224	0.391	0.466	14.388**	
ISOTOMIDAE	1.730	1.697	1.698	1.394	1.731	0.653	1.935	1.142	1.143	0.724	1.020	0.090	0.237	0.414	0.505	24.861**	
ENTOMOBRYIDAE	0	0.037	0.048	0	0	0	0.056	0	0.056	0.018	0	0.020	0.053	0.092		1.424	
SMINTHURIDAE	1.641	1.606	1.496	1.663	1.635	0.158	1.696	0.516	0.296	0.105	0.607	0.061	0.160	0.281	0.344	126.980**	
DIPTERA	0.372	0.350	0.622	0.351	0.787	0.439	0.870	0.681	1.090	1.176	0.223	0.079	0.208	0.363	0.442	16.351**	
COLEOPTERA	0.270	0.388	0.359	0.122	0.335	0.158	0.529	0.123	0.197	0.273	0.060	0.063	0.166	0.290	0.340	5.015**	
THYSANOPTERA	0	0.018	0.018	0.029	0.056	0	0.018	0	0.169	0.481	0	0.044	0.116	0.202	0.230	11.270**	
HEMIPTERA	0.037	0.153	0.100	0.258	0	0	0.105	0.108	0.197	0.197	0.083	0.053	0.139	0.244	0.277	2.448*	
HYMENOPTERA	0	0	0	0.059	0	0	0.018	0	0	0.018	0	0.014	0.037	0.064	0.073	1.584	
PSOCOPTERA	0	0	0	0	0	0	0.048	0	0	0.029	0	0.014	0.037	0.064	0.073	1.441	
PROTRURA	0	0	0	0	0	0	0	0.018	0	0	0	0.002	0.005	0.009	0.010	1.000	
MYRIAPODA																	
PAUROPODA	0	0.037	0	0	0	0	0	0	0	0	0.029	0.010	0.026	0.046	0.052	1.347	
CRUSTACEA																	
ISOPODA	0	0	0	0	0	0	0.018	0	0	0	0	0.002	0.005	0.009	0.010	1.000	

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Table III. A COMPARISON OF ELEVEN METHODS OF EXTRACTING ARTHROPOD FAUNA FROM FALLOW ARABLE SOIL

(Animal count as Log (n + 1) mean of 16 soil cores)

ANIMAL GROUP	A	B	C	D	E	F	G	H	I	J	K	S.E.	L.S.D.	TUKEY'S D		F VALUE
														0.05	0.01	
ARACHNIDA																
ARANEAE	0.056	0.019	0.038	0.060	0.019	0	0.038	0.146	0.169	0.086	0.062	0.037	0.097	0.170	0.199	1.963
ACARI																
PROSTIGMATA	0	0.075	0.038	0.842	0.075	0.160	0.276	0.056	0.225	0.124	0.097	0.054	0.142	0.248	0.282	19.452**
MESOSTIGMATA																
GAMASINA	0.254	0.254	0.206	0.255	0.195	0.288	0.486	0.240	0.497	0.338	0.365	0.073	0.192	0.336	0.373	2.197*
(LESS) RHODACARIDAE	0	0.019	0	0	0	0	0	0	0	0.019	0	0.010	0.026	0.046	0.052	0.903
UROPODINA	0	0	0	0	0	0	0	0	0.019	0	0	0.002	0.005	0.009	0.010	1.000
ASTIGMATA	0.019	0.019	0.019	0.513	0.019	0.053	0.116	0.067	0.124	0.086	0	0.047	0.124	0.216	0.218	9.293**
CRYPTOSTIGMATA	0.094	0.049	0.019	0.163	0.075	0.053	0.229	0.038	0.460	0.162	0.208	0.052	0.137	0.239	0.283	5.904**
INSECTA																
COLLEMBOLA																
ONYCHIURIDAE	0.038	0.019	0	0	0.019	0	0	0	0.162	0.162	0	0.026	0.068	0.120	0.136	5.980**
PODURIDAE	0.097	0.038	0.029	0.030	0	0	0.151	0.094	0.086	0.207	0.097	0.039	0.103	0.179	0.197	2.827*
ISOTOMIDAE	0.976	0.667	0.787	0.670	0.794	0.517	1.594	0.798	0.918	0.229	1.344	0.092	0.242	0.423	0.468	16.982**
ENTOMOBRYIDAE	0.056	0.038	0.105	0	0.030	0	0.086	0.038	0.056	0	0	0.026	0.068	0.120	0.136	1.809
SMINTHURIDAE	1.299	1.020	1.174	1.061	1.076	0.555	1.901	0.843	0.764	0.392	1.577	0.084	0.221	0.386	0.444	27.317**
DIPTERA	0.100	0.049	0.274	0.112	0.241	0.053	0.289	0.038	0.143	0.056	0.146	0.054	0.142	0.248	0.279	3.027**
COLEOPTERA	0.105	0.049	0.075	0.030	0.132	0.053	0.210	0.097	0.151	0.019	0.049	0.042	0.110	0.193	0.223	1.948
THYSANOPTERA	0	0	0	0	0.038	0	0.019	0.086	0.094	0.056	0.049	0.026	0.068	0.120	0.142	1.799
HEMIPTERA	0	0	0	0	0	0	0	0.019	0	0	0.049	0.014	0.037	0.064	0.073	0.932
HYMENOPTERA	0	0	0	0.030	0	0	0	0	0	0	0	0.010	0.022	0.046	0.052	1.000
PSOCOPTERA	0	0.019	0.019	0.119	0.019	0	0.078	0	0.105	0	0	0.026	0.068	0.120	0.135	3.046
MYRIAPODA																
CHILOPODA	0	0	0	0	0	0	0	0	0.019	0	0	0.002	0.005	0.009	0.010	1.000
DIPLOPODA	0	0	0	0	0.019	0	0	0.019	0	0	0	0.010	0.026	0.046	0.052	0.903
SYMPHYLA	0	0	0	0	0.019	0	0	0	0	0	0	0.002	0.005	0.009	0.010	1.000
PAUROPODA	0	0	0.189	0	0	0	0	0	0	0	0	0.002	0.005	0.009	0.010	1.000

FIG. 26.

COMPARISON OF METHODS MIXED DECIDUOUS WOODLAND ON SILT-CLAY LOAM

H : HIGHEST MEAN NUMBERS RECOVERED

- : NOT SIGNIFICANTLY LESS THAN H. AT 1% LEVEL

* : SIGNIFICANTLY LESS THAN H. AT 1% LEVEL

METHODS	ACARINA						COLLEMBOLA					OTHER ARTHROPODA						
	PROSTIGMATA	GAMASINA	RHODACARIDAE	UROPODINA	ASTIGMATA	CRYPTOSTIGMATA	ONYCHIURIDAE	PODURIDAE	ISOTOMIDAE	ENTOMOBRYIDAE	SMINTHURIDAE	PAUROPODA	CHILOPODA	DIPLOPODA	DIPTERA	COLEOPTERA	ARANEIDA	ISOPODA
Simple plastic funnels	*	-	-	*	*	*	*	*	*	-	*	-	-	-	*	-	-	*
Rothamsted Tullgrens (no heat)	-	-	-	*	*	*	*	*	*	-	-	-	-	-	*	-	-	*
Rothamsted Tullgrens	-	-	-	-	-	*	-	-	-	-	-	-	-	H	-	-	-	*
Murphy split funnels	-	-	-	-	-	-	*	*	*	-	-	-	H	-	-	-	-	-
Kempson infra-red extractor	-	-	H	-	-	*	-	-	-	-	-	-	-	-	-	-	*	*
Macfadyen high gradient canisters	*	-	-	-	H	*	-	-	-	*	*	-	-	-	H	*	-	*
Macfadyen air-conditioned funnels	H	H	-	H	-	H	-	H	H	H	H	H	-	-	-	H	-	H
Simple brine flotation	*	*	-	*	-	*	*	*	*	*	-	-	-	-	*	-	*	*
Salt and Hollick flotation	*	*	-	*	*	*	-	-	*	*	*	-	-	-	-	-	-	*
Heath and Edwards flotation	*	*	-	*	-	*	-	*	*	*	*	*	*	-	*	-	-	*
Grease film extraction	*	-	-	-	-	-	H	*	-	-	*	*	-	*	-	-	H	*

FIG. 27.

COMPARISON OF METHODS PASTURE ON SILT-CLAY LOAM

H : HIGHEST MEAN NUMBERS RECOVERED
 — : NOT SIGNIFICANTLY LESS THAN H AT 1% LEVEL
 * : SIGNIFICANTLY LESS THAN H AT 1% LEVEL

METHODS	ACARINA					COLLEMBOLA					OTHER ARTHROPODA								
	PROSTIGMATA GAMASINA RHODACARIDAE UROPODINA ASTIGMATA CRYPTOSTIGMATA						ONYCHIURIDAE PODURIDAE ISOTOMIDAE ENTOMOBRYIDAE SMINTHURIDAE						PAUROPODA CHILOPODA DIPLOPODA DIPTERA COLEOPTERA ARANEIDA ISOPODA						
Simple plastic funnels	—	—	*	—	*	—	—	—	—	—	—	—	—	—	*	—			
Rothamsted Tullgrens (no heat)	—	—	—	—	*	—	—	—	—	—	—	—	—	—	*	—			
Rothamsted Tullgrens	—	—	—	—	—	—	—	—	—	—	—	—	—	—	*	—			
Murphy split funnels	—	*	*	—	*	—	*	*	*	—	—	—	—	—	*	*			
Kempson infra-red extractor	—	—	H	—	—	—	—	—	—	—	—	—	—	—	—	—			
Macfadyen high gradient canisters	*	*	*	—	*	—	*	*	*	*	—	—	—	—	*	*			
Macfadyen air-conditioned funnels	H	H	—	H	H	H	—	H	H	H	—	—	—	—	—	H			
Simple brine flotation	*	*	—	—	*	—	—	—	*	*	—	—	—	—	*	*			
Salt and Hollick flotation	*	—	—	—	*	—	H	—	*	*	—	—	—	—	—	—			
Heath and Edwards flotation	*	—	—	—	—	—	—	*	*	*	—	—	—	—	H	—			
Grease film extraction	*	*	*	—	*	—	—	*	*	*	—	—	—	—	*	*			

FIG. 28.

COMPARISON OF METHODS FALLOW ON SILT-CLAY LOAM

H : HIGHEST MEAN NUMBERS RECOVERED

— : NOT SIGNIFICANTLY LESS THAN H AT 1% LEVEL

* : SIGNIFICANTLY LESS THAN H AT 1% LEVEL

METHODS	ACARINA					COLLEMBOLA					OTHER ARTHROPODA					
	PROSTIGMATA GAMASINA RHODACARIDAE UROPODINA ASTIGMATA CRYPTOSTIGMATA					ONYCHIURIDAE PODURIDAE ISOTOMIDAE ENTOMOBRYIDAE SMINTHURIDAE					PAUROPODA CHILOPODA DIPLOPODA DIPTERA COLEOPTERA ARANEIDA ISOPODA					
Simple plastic funnels	*	—		*	*	—	*	*				—	—			
Rothamsted Tullgrens (no heat)	*	—		*	*	—	*	*				—	—	—	—	
Rothamsted Tullgrens	*	—		*	*	—	*	*				—	—	—	—	
Murphy split funnels	II	—		II	*	—	*	*				—	—	—	—	
Kempson infra-red extractor	*	—		*	*	*	*	*	*	*		—	—	—	—	
Macfadyen high gradient canisters	*	—		*	*	*	*	*	*	*		—	—	—	—	
Macfadyen air-conditioned funnels	*	—		*	—	—	II	II	II			II	II			
Simple brine flotation	*	—		*	*	—	*	*	*			—	—	—	—	
Salt and Hollick flotation	*	II		*	II	—	*	*	*			—	—	—	—	
Heath and Edwards flotation	*	—		*	*	II	*	*	*			—	—	—	—	
Grease film extraction	*	—		*	—	—	—	—	—			—	—	—	—	

than dynamic methods for heavy clay soils, were found to be less efficient for most groups of arthropods in woodland and pasture but the relative efficiency of mechanical methods increased, and for some groups of arthropods exceeded that of dynamic methods on the fallow site. Probably this was because there was less undecomposed organic matter on the fallow site to interfere with the xylene/water flotation stage or to stick to the grease-film. It was very clear that the most efficient method used on all sites for most groups of arthropods was the Macfadyen high-gradient funnel apparatus. This method extracted the highest mean number of most groups of soil arthropods on all sites, and often the increase in the relative efficiency was greater than 50%. Other comparatively efficient methods were Kempson's infra-red apparatus, Murphy's split funnels and the Rothamsted Tullgren funnels. The total numbers of soil arthropods extracted by these three methods were approximately equal, but the relative efficiency differed greatly for different groups of arthropods and different sites. The plastic funnels with no heat and the Rothamsted Tullgren funnels with no heat were the least efficient of all the dynamic methods, but the numbers of arthropods extracted by them sometimes equalled and occasionally exceeded the numbers extracted by the more sophisticated dynamic methods. Relatively low numbers of most groups of arthropods were recovered with the Macfadyen canister apparatus.

The numbers of arthropods extracted by mechanical methods were usually fewer than those extracted by dynamic methods. All of the mechanical methods tended to recover similar numbers of arthropods, although, as with dynamic methods, their relative efficiency differed greatly for different sites and different groups of arthropods. Only on the fallow

site, did the number of arthropods recovered by mechanical methods compare favourably with those recovered by dynamic methods. Not all groups of soil arthropods were extracted inefficiently by mechanical methods. On all sites, mechanical methods usually recovered more of the larger arthropod animals than the dynamic methods, (particularly Insecta) although few of these differences were significant. It is possible that in some cases the mesh size of the sieves used in the dynamic methods was too small for the efficient recovery of these larger animals. Mechanical methods usually extracted more onychiurid springtails from all sites than did dynamic methods, and to a lesser extent more podurid springtails were extracted by mechanical methods except on the woodland site.

Dynamic methods were markedly more efficient than mechanical methods for extracting prostigmatid mites and isotomid and sminthurid springtails from the woodland and pasture sites but were only equal in efficiency to mechanical methods for these groups on the fallow site. Significantly more Isopoda were extracted by dynamic methods on the woodland site than by mechanical methods; more Symphyla, Pauropoda, Diplopoda and Chilopoda were also extracted by dynamic methods from woodland soil than by mechanical methods but these differences were not significant. Few of these arthropods were found in either the pasture or fallow sites so it is difficult to compare data.

The same basic principles of steep gradients of temperature and relative humidity are used in both the Macfadyen high-gradient canister apparatus and air-conditioned funnels to extract the arthropod fauna from soil cores. The relative efficiency of the canister apparatus was often much less than that of other apparatus, particularly the air-conditioned funnels. To determine the reasons for this large difference in efficiency between apparatus based on similar principles,

the canister apparatus was brought to Rothamsted and its efficiency was compared with the funnel apparatus, using soil cores from the pasture site. The results of this comparison, summarized in Table 4, show that efficiency of the canister apparatus relative to the previous comparison improved. In particular, two groups of soil arthropods, the Astigmata and the Diptera, were extracted more efficiently by the canister apparatus than by the air-conditioned funnels. Although the funnel apparatus was still more efficient for most other groups of soil arthropods in this second comparison, the difference between the numbers of arthropods extracted by the two methods was not as great as that found in the first comparison of methods. A third, comparison of these two methods was made in an attempt to explain the large differences obtained in the original comparison. In this, the recommended temperature regime of the canister apparatus was changed and made comparable with that used for the air-conditioned funnel apparatus, rising from 20°C to 35°C in the first 12 hr. period, and then gradually to 45°C towards the end of the extraction period. At these lower temperatures the soil cores in the canister apparatus dried very slowly and the extraction could not be considered completed until the tenth day. The results of the third comparison, Table 5, show the canister apparatus to be much less efficient when lower temperatures are used, even when the extraction is continued over a much longer period. The comparison of methods on different sites used the recommended temperature regimes of Block (1966) for the high-gradient canister apparatus, but, if for some unknown reason, the soil samples did not desiccate, and there was no controlled draught system in the design of this apparatus, this could explain why relatively low numbers of arthropods were recovered. Another possibility is that the small

TABLE 4. COMPARISON OF METHODS

TREATMENT - MACFADYEN HIGH-GRADIENT CANISTER APPARATUS v
MACFADYEN AIR-CONDITIONED FUNNEL APPARATUS.

SOIL TYPE - BATCOMBE SILT-CLAY LOAM

SITE - GRASSLAND, HIGHFIELD, ROTHAMSTED

SAMPLES - 32 x 3.8 cm diameter and 3 cm deep cores v
16 x 10 cm diameter and 5 cm deep cores.

(Arthropods from canister samples multiplied
by volume conversion factor to allow direct
comparison.)

ANIMAL GROUP	METHOD	ADJUSTED MEANS MEANS OF OF 16 32 CORES 'CORES		TRANSFORMED MEANS-LOG (n + 1)			MORE EFFIC/ IENT METHOD	LEVEL OF SIGNI/ FICANCE
		CANISTER	FUNNEL	C.	F.	S.E.		
<u>ARACHNIDA</u>								
Acari								
Prostigmata		22.5	25.4	1.160	1.297	0.1183	-	-
Mesostigmata								
Gamasina (less)		20.4	31.6	1.115	1.460	0.1218	-	-
Rhodacaridae		0.7	1.2	0.106	0.236	0.0721	F	**
Uropodina		2.3	5.8	0.194	0.513	0.1239	-	-
Astigmata		94.1	21.7	1.785	1.286	0.0900	C	**
Cryptostigmata		81.7	71.0	1.696	1.660	1.1316	-	-
<u>INSECTA</u>								
Collembola								
Onychiuridae		12.6	24.1	0.857	1.182	0.1342	-	-
Poduridae		7.4	22.6	0.651	1.253	0.1315	F	**
Isotomidae		28.1	130.0	1.239	1.963	0.1283	F	**
Entomobryidae		0.0	0.4	0.000	0.113	0.0329	F	*
Sminthuridae		2.1	31.9	0.268	1.414	0.0985	F	**
Diptera		31.2	7.3	1.423	0.849	0.0693	C	**
Coleoptera		4.3	3.5	0.335	0.598	0.1044	-	-
Thysanoptera		7.5	2.1	0.106	0.374	0.0755	F	*
Hemiptera		0.0	1.7	0.000	0.305	0.0562	F	**
Hymenoptera		0.0	0.3	0.000	0.075	0.0307	-	-
Psocoptera		0.0	0.8	0.000	0.186	0.0429	F	**

C - canister apparatus more efficient

F - funnel apparatus more efficient

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different.

TABLE 5. COMPARISON OF METHODS

TREATMENT - MACFADYEN HIGH-GRADIENT CANISTER APPARATUS v.
MACFADYEN AIR-CONDITIONED FUNNEL APPARATUS
(REPEAT - USING LOW TEMPERATURE REGIME IN THE
MACFADYEN HIGH-GRADIENT CANISTER APPARATUS)

SOIL TYPE - BATCOMBE SILT-CLAY LOAM

SITE - GRASSLAND, HIGHFIELD, ROTHAMSTED

SAMPLES - 32 x 3.8 cm diameter and 3 cm deep cores v.
16 x 10.2 cm diameter and 5.1 cm deep cores.

(Arthropods from canister samples multiplied
by volume conversion factor to allow direct
comparison)

ANIMAL GROUP	METHOD	ADJUSTED MEANS MEANS OF OF 16 32 CORES CORES		TRANSFORMED MEANS-LOG (n + 1)			MORE EFFIC/ IENT METHOD	LEVEL OF SIGNI/ FICANCE
		CANISTER	FUNNEL	C.	F.	S.E.		
<u>ARACHNIDA</u>								
Acari								
	Prostigmata	4.2	23.5	0.513	1.337	0.0944	F	**
	Mesostigmata							
	Gamasina	13.3	18.6	0.654	1.178	0.1318	-	-
	Astigmata	5.4	18.8	0.508	1.240	0.1050	F	**
	Cryptostigmata	25.2	70.0	0.927	1.388	0.1764	-	-
<u>INSECTA</u>								
Collembola								
	Onychiuridae	2.7	9.9	0.247	0.980	0.0928	F	**
	Poduridae	0.7	3.2	0.106	0.495	0.0790	-	-
	Isotomidae	20.1	105.1	0.919	1.617	0.1577	-	-
	Sminthuridae	8.4	31.7	0.675	1.456	0.1141	F	**
	Diptera	8.6	6.8	0.518	0.852	0.1115	-	-
	Coleoptera	3.9	5.3	0.426	0.748	0.1004	-	-
	Thysanoptera	0.4	1.2	0.306	0.053	0.0529	-	-
	Psocoptera	0.4	0.2	0.053	0.049	0.0445	-	-

C - canister apparatus more efficient

F - funnel apparatus more efficient

** - significant difference between means at the 1% level

- - means not significantly different

size of the soil cores decreased the efficiency of extraction due to the increased edge effects which occur when the soil core is taken (Murphy, 1962a) Hale's modification of the original Macfadyen canister apparatus included decreasing the surface area of the soil sample from 50 cm^2 to 11.35 cm^2 .

Discussion

This part of the study compared seven dynamic methods and four mechanical methods for extracting arthropods from the same type of soil. Three comparisons were made, in different ecological habitats, woodland, grassland and fallow arable sites. The apparatus and techniques used in these comparisons were usually those described in the literature by their authors, but some of them were modified. For instance, the Macfadyen high-gradient canister apparatus was that modified by Hale and the use of the Kempson, Lloyd and Ghelardi (K.L.G.) infra-red extractor, which had previously extracted only woodland litter, were obvious examples of such modifications in construction and use.

The results of these comparisons show very large differences in the numbers of arthropods extracted from a small area of the same soil by the different methods at any one site, and also that the relative efficiency of any one method changes when used on different habitats. The number of samples and the sampling procedure were chosen to minimise variability in results caused by natural aggregations of soil arthropod populations, and the large variability of the results from each site largely reflects the wide range of efficiency of the methods and techniques used. The results show that ^{by} using an unsuitable extraction method, it is possible to greatly underestimate the number of soil arthropods present, particularly because the highest mean number of

arthropods obtained at any one site by any extraction method may still be a underestimate of the actual numbers present (Forsslund, 1949; Macfadyen, 1953). The relative efficiency of most methods is different when used to extract fauna from the different habitats, and it is possible for an extraction method which is particularly efficient for some arthropods at one site, to be relatively inefficient when extracting the same group of arthropods at a different site. Lasebikan (1970) showed that, even at the same site, the relative efficiency of some dynamic methods may differ with the season. Obviously, a complex interrelationship between the material to be extracted, its physical characteristics at the time of sampling and the conditions to which the sample is subsequently subjected, all affect the ease with which arthropods can be separated from it. It is unfortunate that the relative efficiency of the different methods is not the same for all groups of arthropods. However, the relatively good performance of the Macfadyen high-gradient apparatus makes it a clear first choice for quantitative studies where a number of groups of arthropods are to be studied.

V. A comparison of dynamic and mechanical methods for extracting arthropods from different soil types

Introduction

In Section IV, eleven methods for extracting arthropods from a single type of soil were compared in three different habitats. The relative efficiency of extraction varied not only with the extraction method but also with the habitat, and a major factor thought to be affecting the efficiency was the differing amounts of undecomposed

organic matter in the soil at the different sites. However, it was also possible that other factors such as particle size and water holding capacity were also influencing efficiency. Ideally, it would be desirable to compare all the methods on a range of soil types, but because this was logistically impossible, two greatly differing methods were compared on several soils. These were the Rothamsted funnel method and the Salt and Hollick flotation method. The relative efficiency of these two methods was then determined, by extracting soil samples by each method, from woodland, grassland and fallow arable habitats on four different soil types. These soil types were peat soil from the Woodwalton Fen area in Huntingdonshire, a clay loam soil and a silt-clay-loam soil, both of the Batcombe series from Rothamsted, and a sandy-loam soil from Woburn Experimental Farm. Unfortunately the samples from the woodland habitat on the clay-loam soil at Rothamsted proved to be unsuitable due to the presence of small particles of tar in the soil. The tar, presumably from a road-surfacing operation, interfered with the oil-water separation stage of the Salt and Hollick flotation method. These particular woodland samples were therefore discarded and replaced by samples from a heavy clay soil at Meathop Wood, the I.B.P. research site in Lancashire. No fallow arable site was available at Woodwalton Fen, so samples were taken from the bare soil between the ridges of a potato crop as representing "fallow" soil. It was thought that using such contrasting soil types with differing amounts of undecomposed organic matter, would indicate both the range of soil types and habitats on which these methods could be usefully employed and also identify the more important characteristics of the soils that were directly affecting the efficiency of the extraction methods.

Methods

The woodland, grassland and fallow arable sampling sites on a single soil type were chosen to be as close to each other as possible to minimize localized variations in soil type. It was assumed that the arthropod populations in the different habitats would not be directly comparable. Sixteen pairs of soil cores, each pair adjacent to each other, were taken at random from apparently uniform areas of ground in each habitat. With the exception of the Meathop Wood samples, the three habitats on each soil type were sampled on the same day. One soil core from each pair was extracted by the Rothamsted Tullgren funnel method, the other by the Salt and Hollick flotation method.

The size of the soil cores used in this comparison were either 10 cm diameter and 5 cm deep cores, used on the peat, silt-clay-loam and sandy loam soils, or 5 cm diameter and 15 cm deep cores, used on the heavy clay soil of Meathop Wood and the clay-loam soil at Rothamsted.

The 10 cm diameter 5 cm deep cores were taken with the sampling tool described in Section IV (Fig. 15a). The 5 cm diameter 15 cm deep cores were taken with a similar, but smaller sampling tool (Fig. 15b) comprising a steel cylinder 15 cms long with an internal diameter of 5 cm at the cutting edge of the cylinder, widening to 6 cm internal diameter. This allowed soil cores to be removed easily from the open end of the cylinder opposite the cutting edge. At this open end was welded a steel shaft 74 cm long, to which a handle (30 cm wide) and a foot press (23 cm wide) were attached at right angles.

The samples were placed into polythene bags and transported to the laboratory; those samples which were extracted by the Salt and Hollick method were soaked in tap water and stored at -10°C until required; those samples which were extracted by the Rothamsted Tullgren funnels were

placed on the apparatus immediately upon returning to the laboratory. The 10 cm diameter by 5 cm deep soil cores were placed undisturbed, intact and inverted onto the sieves of the sample containers. The 5 cm diameter 15 cm deep soil cores were broken into small pieces and scattered onto the sieves of the sample containers. Arthropods were collected into alcohol and glycerol (in the ratio 20 : 1). Both methods were used as described in Section III.

Results

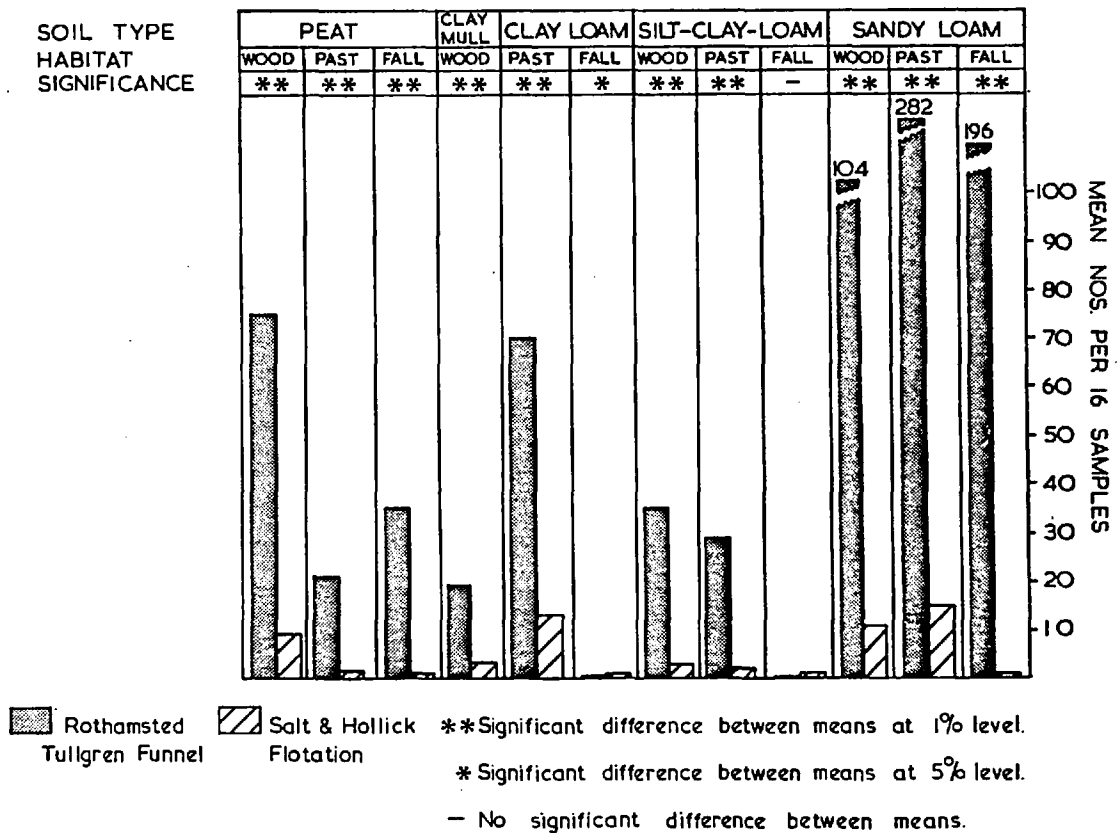
Data from these comparisons are summarised in Figs. 29 - 38. Significant differences at the 5% and 1% levels of probability, are summarised in Table 6.^(p101) Most of the significant differences obtained were in agreement with the conclusions reached in Section IV, when eleven methods were compared on a single soil type. (Summarised in Tables 7 - 18).

The total numbers of arthropods extracted from samples from any habitat or soil type were usually greater when extracted by the Rothamsted Tullgren funnel method, but the relative efficiency of the funnel and flotation methods varied for each taxonomic group of arthropods as well as with habitat and soil type. For example, although significantly more Collembola were recovered from samples from the woodland site on peat soil by the Rothamsted Tullgren funnel method than by flotation, significantly more onychurid and podurid Collembola were recovered by the Salt and Hollick flotation method than by the funnels on this site (Table 7).^(p102) In general, more micro- and mesoarthropods (especially Acarina and Collembola) were extracted by the funnel method than by the flotation method from most of the soils and habitats sampled. However, more Acarina and Collembola were extracted by the flotation method than by the funnel method from samples taken from fallow sites on clay soils.

Prostigmatid mites were almost always extracted in significantly greater numbers by the funnel method than by flotation, the cores from (to p114)

FIG. 29.

A COMPARISON OF METHODS ON DIFFERENT SOIL TYPES
ACARINA - PROSTIGMATA



WOOD: Mixed deciduous woodland PAST: Pasture FALL: Fallow

FIG. 30.

A COMPARISON OF METHODS ON DIFFERENT SOIL TYPES
ACARINA—MESOSTIGMATA

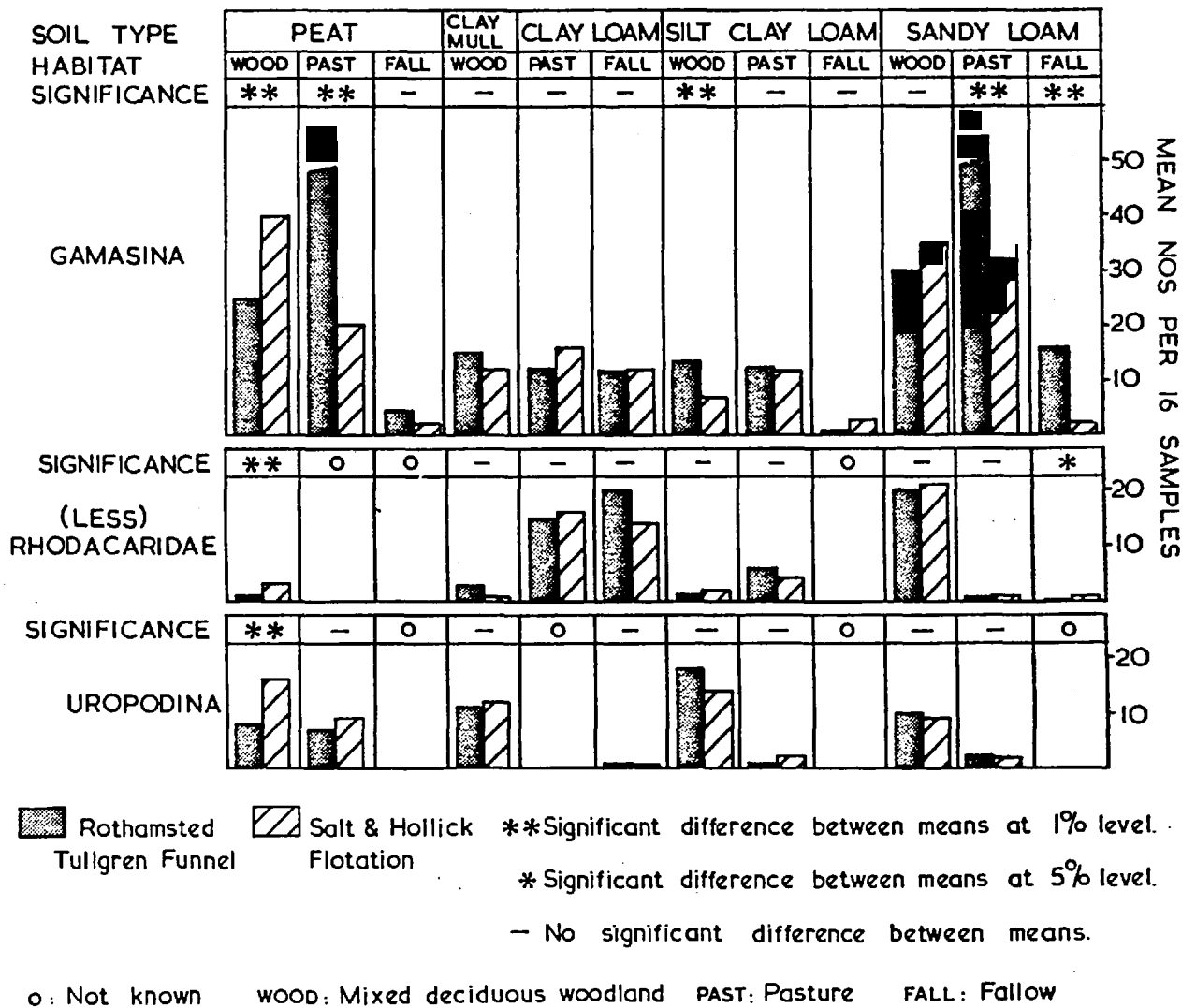


FIG. 31

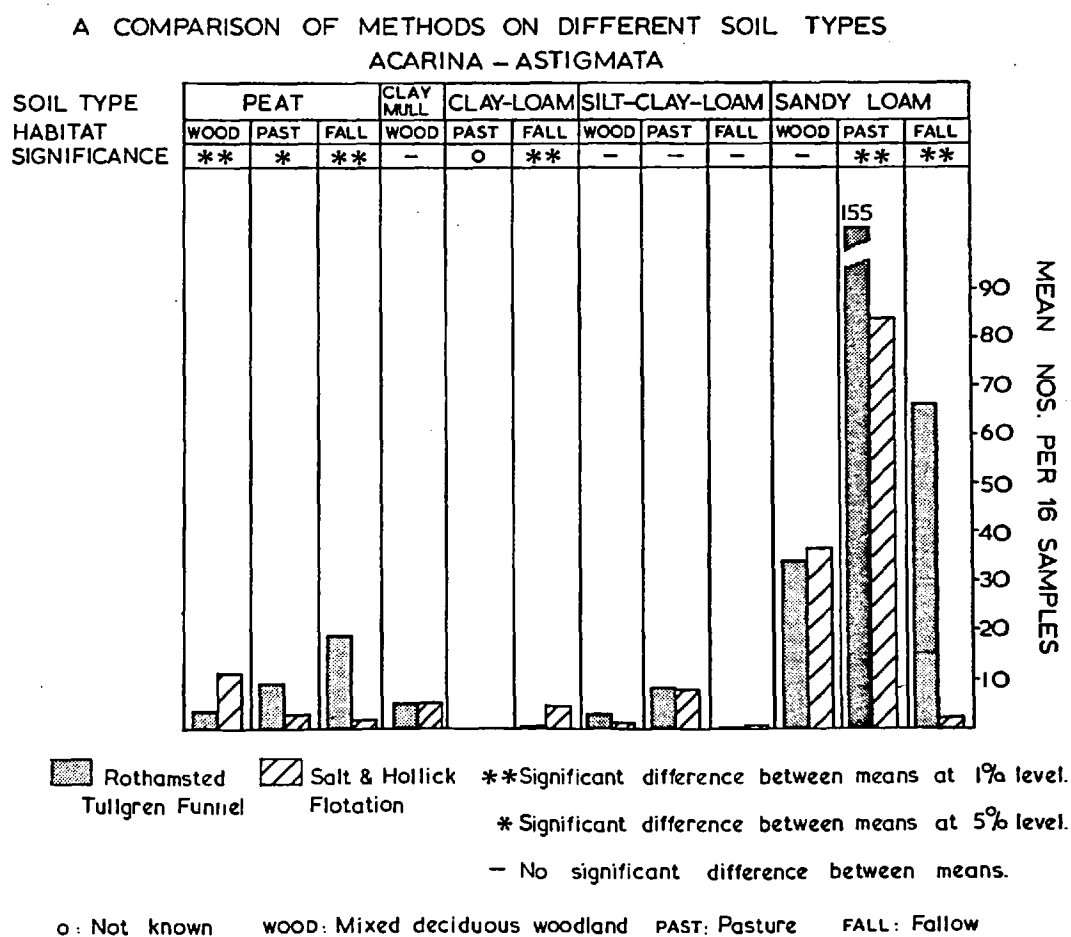


FIG. 32.

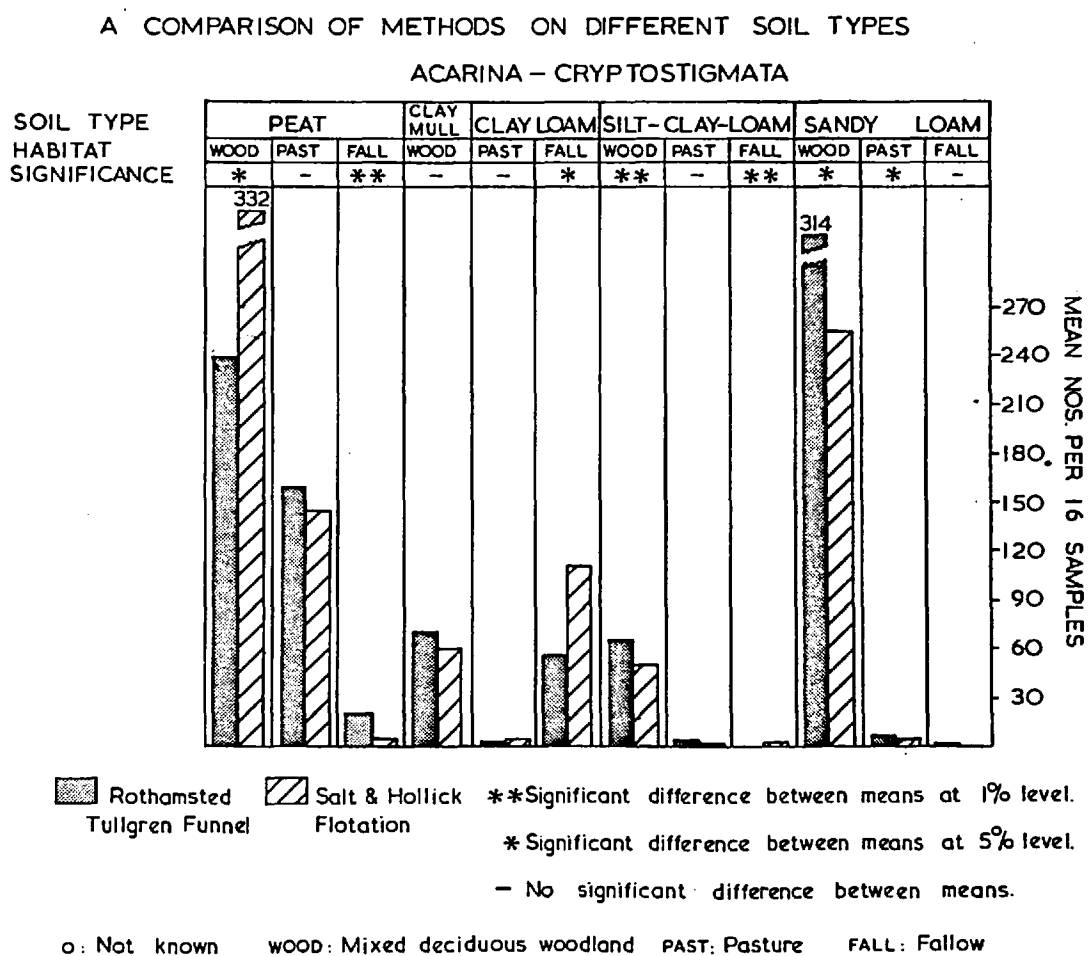


FIG. 33.

A COMPARISON OF METHODS ON DIFFERENT SOIL TYPES
COLLEMBOLA

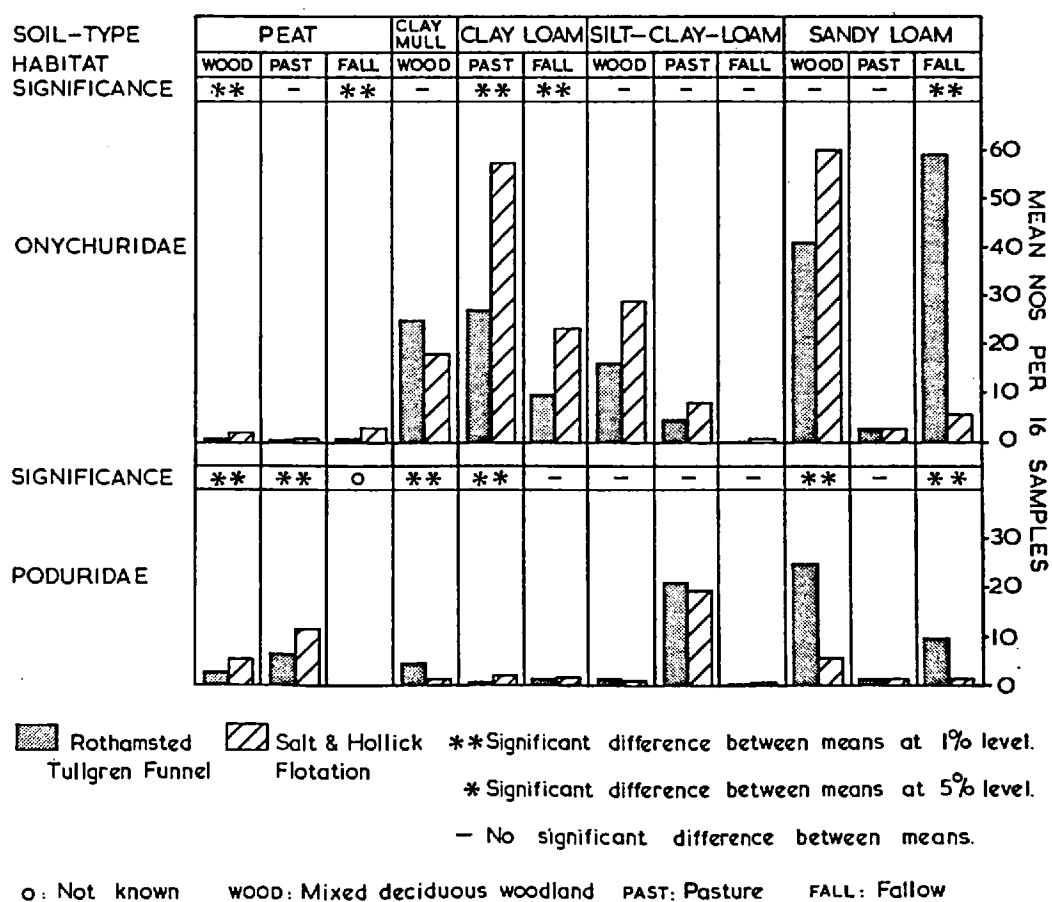


FIG. 34.

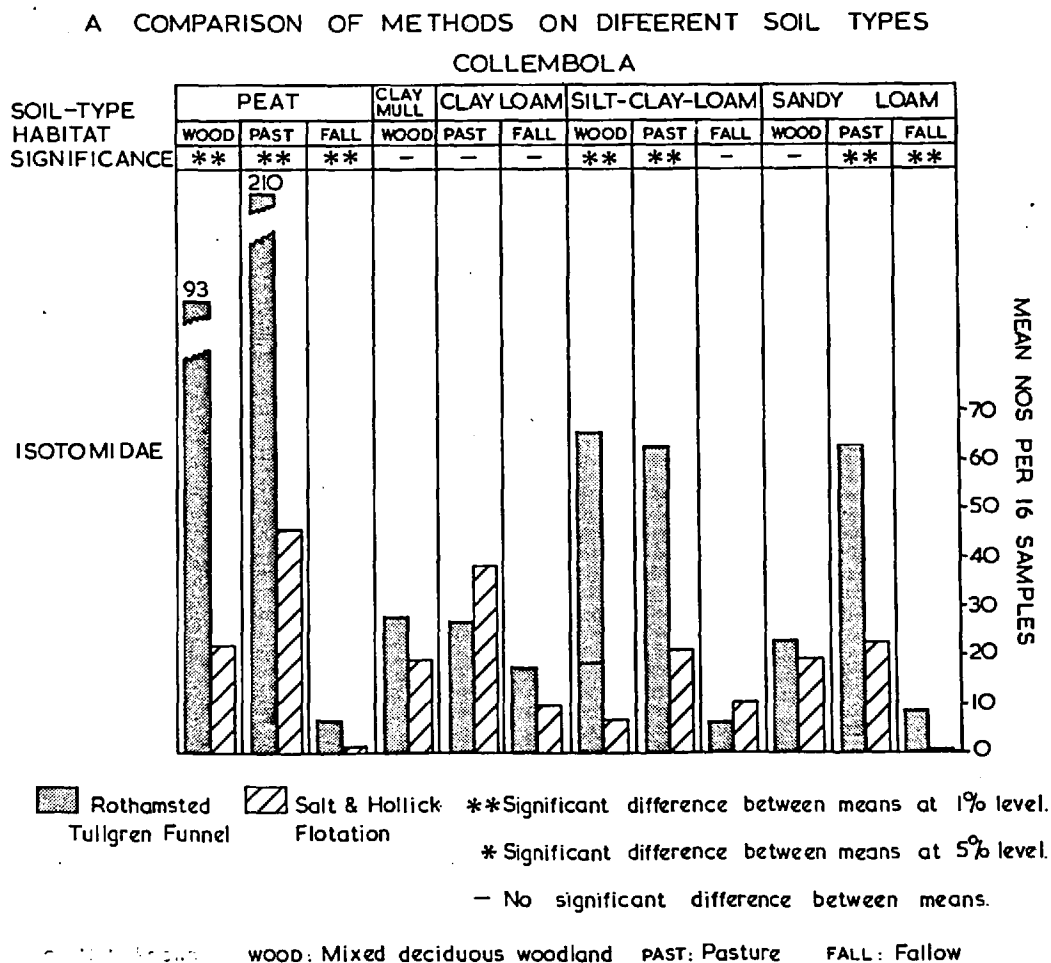


FIG. 35.

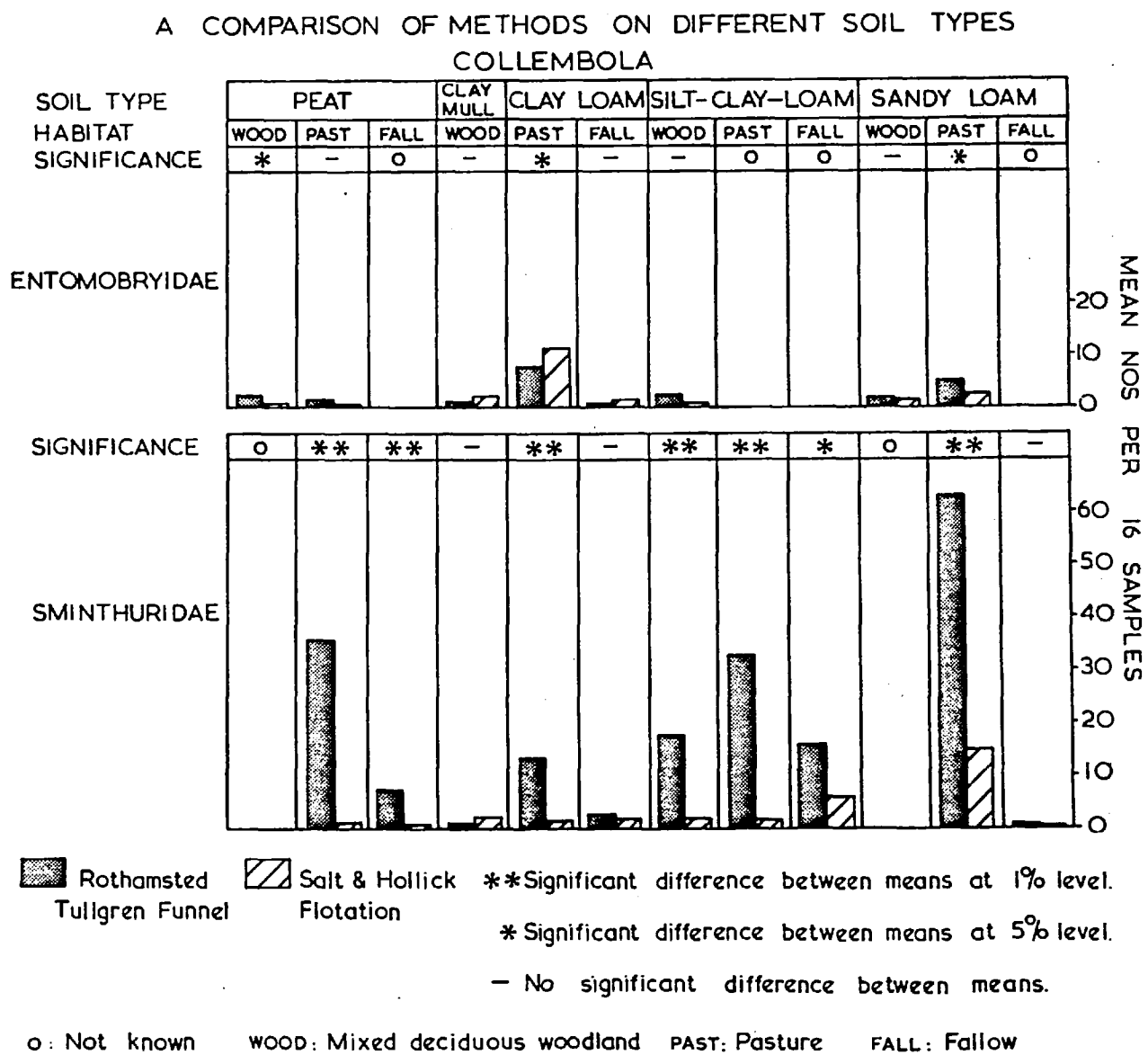
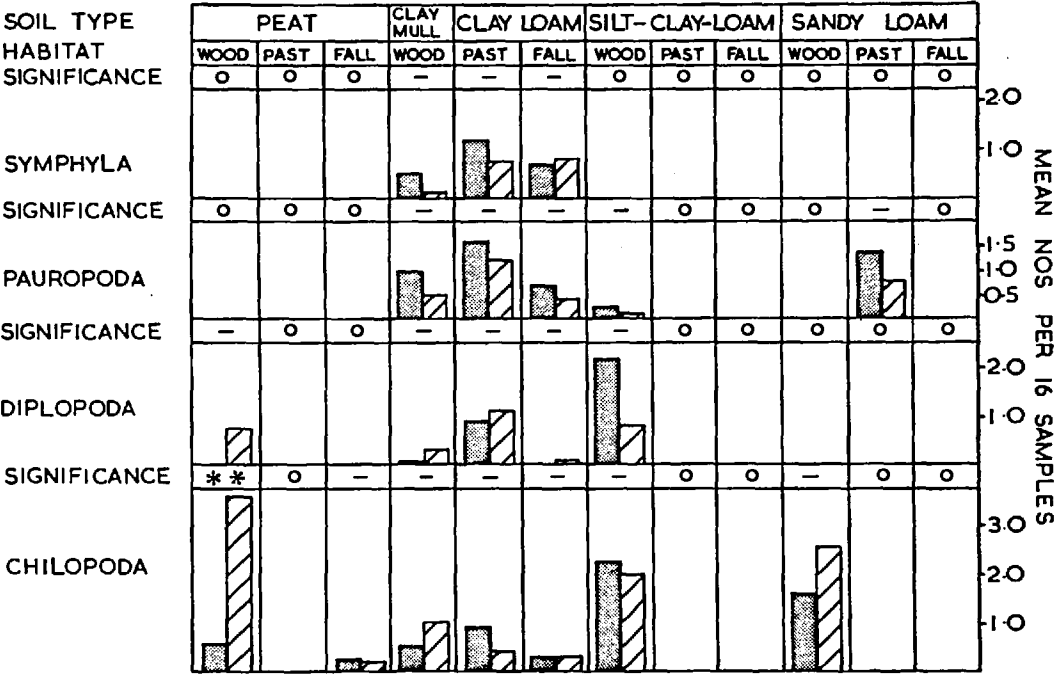


FIG. 36.

A COMPARISON OF METHODS ON DIFFERENT SOIL TYPES
MYRIAPODA

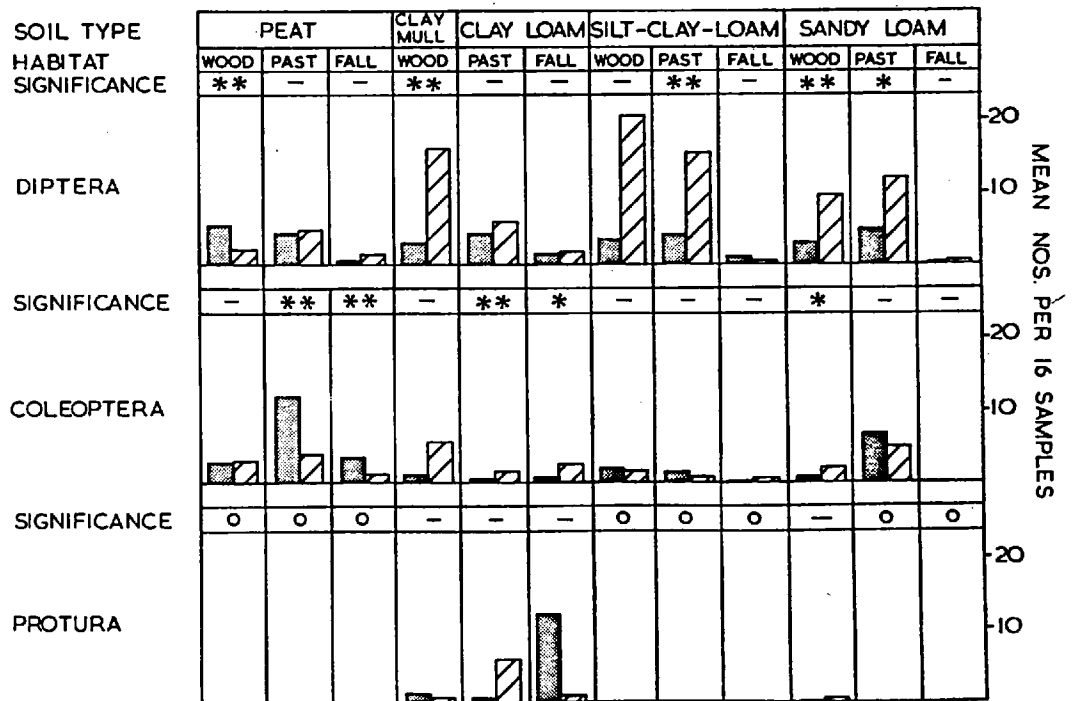


■ Rothamsted Tullgren Funnel ▨ Salt & Hollick Flotation ** Significant difference between means at 1% level.
* Significant difference between means at 5% level.
- No significant difference between means.

o: Not known WOOD: Mixed deciduous woodland PAST: Pasture FALL: Fallow

FIG. 37

A COMPARISON OF METHODS ON DIFFERENT SOIL TYPES
OTHER INSECTS



■ Rothamsted
Tullgren Funnel

▨ Salt & Hollick
Flotation

** Significant difference between means at 1% level.

* Significant difference between means at 5% level.

- No significant difference between means.

o: Not known

WOOD: Mixed deciduous woodland

PAST: Pasture

FALL: Fallow

FIG. 38.

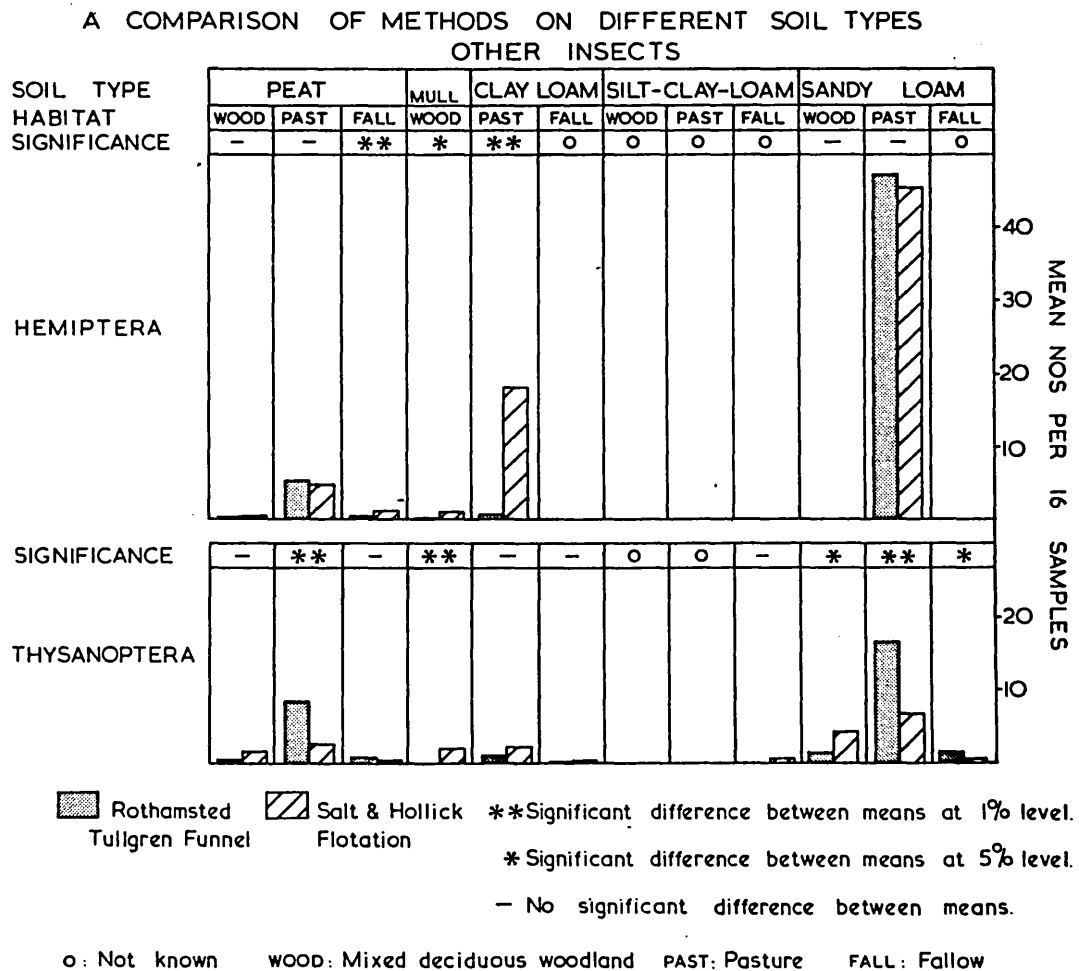


Table 6. SUMMARY OF COMPARISON OF TWO EXTRACTION METHODS ON DIFFERENT SOIL TYPES

SOIL TYPE	PEAT			HEAVY CLAY	CLAY LOAM	SILT-CLAY LOAM	SANDY LOAM		
HABITAT	WOODLAND	PASTURE	FALLOW	WOODLAND	PASTURE	FALLOW	WOODLAND	PASTURE	FALLOW
ANIMAL GROUP	WOODLAND	PASTURE	FALLOW	WOODLAND	PASTURE	FALLOW	WOODLAND	PASTURE	FALLOW
ARACHNIDA									
ARANEAE	-	-	-	0	0	0	-	0	-
ACARI									0
PROSTIGMATA	**D	**D	**D	**D	**D	*M	**D	**D	-
MESOSTIGMATA									
GAMASINA	**M	**D	-	-	-	-	**D	-	-
(less)RHODACARIDAE	**M	0	0	-	-	-	-	-	*M
UROPODINA	**M	-	0	-	0	-	-	-	0
ASTIGMATA	**M	*D	**D	-	0	**M	-	**D	**D
CRYPTOSTIGMATA	*M	-	**D	-	-	*M	**D	-	**M
INSECTA									
COLLEMBOLA									
ONYCHIURIDAE	**M	-	**M	-	**M	**M	-	-	**D
PODURIDAE	*M	*M	0	*D	*M	-	**D	-	**D
ISOTOMIDAE	**D	**D	**D	-	-	-	**D	**D	-
ENTOMOBRYIDAE	*D	-	0	-	*M	-	0	0	0
SMINTHURIDAE	0	**D	**D	-	**D	-	**D	**D	*D
DIPTERA	**D	-	-	**M	-	-	-	**M	-
COLEOPTERA	-	**D	**D	-	*M	**M	-	*M	-
THYSANOPTERA	-	**D	-	**M	-	-	0	0	-
HEMIPTERA	-	-	*M	*M	**M	0	0	0	0
HYMENOPTERA	*D	-	0	-	0	0	0	0	0
PROTURA	0	0	0	-	0	-	0	0	0
DIPLURA	0	0	0	0	0	0	0	0	0
PSOCOPTERA	0	0	0	0	0	0	0	0	0
MYRIAPODA									
CHILOPODA	**M	0	-	-	-	-	-	0	0
DIPLOPODA	0	0	0	-	-	-	-	0	0
SYMPHYLA	0	0	0	-	-	-	0	0	0
PAUROPODA	0	0	0	-	-	-	-	0	0
CRUSTACEA									
ISOPODA	0	0	0	-	0	0	-	0	0

LEGEND:-

- : No significant difference between means at 5% and 1% levels.
- * : Significant difference between means at 5% level.
- ** : Significant difference between means at 1% level.
- D : Berlese-Tullgren funnel method more efficient.
- M : Salt and Hollick wet sieving and flotation method more efficient.
- 0 : Not known - animals not present in samples.

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - FEN PEAT

SITE - MIXED DECIDUOUS WOODLAND - WOODWALTON FEN - CAMBRIDGESHIRE

SAMPLES - 10 cm diameter x 5 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae	0.2	0.3	0.056	0.094	0.0333	-	-
Acari							
Prostigmata	75.2	7.9	1.827	0.815	0.0744	F	**
Mesostigmata							
Gamasina	24.9	40.3	1.214	1.568	0.0756	FL	**
(Less)-	1.2	3.2	0.119	0.536	0.0774	FL	**
Rhodacaridae							
Uropodina	7.8	16.2	0.721	1.170	0.0884	FL	**
Astigmata	3.6	11.2	0.483	0.975	0.0911	FL	**
Cryptostigmata	240.1	331.6	2.293	2.490	0.0589	FL	*
<u>Insecta</u>							
Collembola							
Onychiuridae	0.4	1.7	0.094	0.373	0.0538	FL	**
Poduridae	2.5	5.5	0.431	0.696	0.0832	FL	*
Isotomidae	92.9	22.5	1.834	1.201	0.1063	F	**
Entomobryidae	2.4	0.7	0.424	0.184	0.0675	F	*
Sminthuridae							
Diptera	5.4	2.1	0.769	0.405	0.0611	F	**
Coleoptera	2.8	3.0	0.499	0.545	0.0649	-	-
Thysanoptera	0.4	1.5	0.124	0.348	0.0492	-	-
Hemiptera	0.3	0.3	0.086	0.078	0.0415	-	-
Hymenoptera	0.9	0.2	0.235	0.067	0.0463	F	*
Psocoptera							
Protura							
Diplura							
<u>Myriapoda</u>							
Chilopoda	0.6	3.6	0.135	0.544	0.0722	FL	**
Diplopoda							
Symphyla							
Pauropoda							
<u>Crustacea</u>							
Isopoda							

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - FEN PEAT

SITE - GRASSLAND - WOODWALTON FEN - CAMBRIDGESHIRE

SAMPLES - 10 cm diameter x 5 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae	1.0	1.1	0.210	0.270	0.0608	-	-
Acari							
Prostigmata	20.9	1.4	1.197	0.281	0.0862	F	**
Mesostigmata							
Gamasina	51.9	19.7	1.639	1.258	0.0662	F	**
(Less)-							
Rhodacaridae							
Uropodina	6.7	8.8	0.743	0.899	0.0839	-	-
Astigmata	8.8	2.6	0.810	0.484	0.0907	F	*
Cryptostigmata	159.5	135.9	2.162	2.097	0.0486	-	-
<u>Insecta</u>							
Collembola							
Onychiuridae	0.2	0.2	0.049	0.075	0.0339	-	-
Poduridae	6.3	11.5	0.769	1.018	0.0717	FL	*
Isotomidae	209.5	45.6	2.268	1.621	0.0581	F	**
Entomobryidae	1.6	0.5	0.291	0.143	0.0647	-	-
Sminthuridae	40.5	0.9	1.456	0.227	0.0975	F	**
Diptera	4.3	4.7	0.646	0.614	0.0789	-	-
Coleoptera	11.8	3.9	1.092	0.602	0.0549	F	**
Thysanoptera	8.6	2.6	0.880	0.467	0.0752	F	**
Hemiptera	5.3	4.8	0.632	0.669	0.0904	-	-
Hymenoptera	0.6	0.6	0.146	0.154	0.0526	-	-
Psocoptera							
Protura							
Diplura							
<u>Myriapoda</u>							
Chilopoda							
Diplopoda							
Symphyla							
Pauropoda							
<u>Crustacea</u>							
Isopoda							

TABLE 9

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - FEN PEAT

SITE - FALLOW ARABLE, WOODWALTON FEN, CAMBRIDGESHIRE

SAMPLES - 10 cm diameter x 5 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFL- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae	0.8	0.1	0.105	0.038	0.0526	-	-
Acari							
Prostigmata	35.4	0.1	1.446	0.257	0.0726	F	**
Mesostigmata							
Gamasina	4.5	2.0	0.592	0.415	0.0849	-	-
(Less)-							
Rhodacaridae							
Uropodina							
Astigmata	18.9	1.7	1.006	0.329	0.1086	F	**
Cryptostigmata	21.4	5.0	1.111	0.713	0.1000	F	**
<u>Insecta</u>							
Collembola							
Onychiuridae	0.4	2.9	0.116	0.482	0.0661	FL	**
Poduridae							
Isotomidae	6.9	1.4	0.786	0.302	0.0717	F	**
Entomobryidae							
Sminthuridae	7.6	0.8	0.849	0.202	0.0634	F	**
Diptera	0.7	1.4	0.184	0.315	0.0580	-	-
Coleoptera	3.4	1.1	0.544	0.254	0.0741	F	**
Thysanoptera	0.7	0.2	0.103	0.056	0.0524	-	-
Hemiptera	0.2	1.2	0.049	0.284	0.0472	FL	**
Hymenoptera							
Psocoptera							
Protura							
Diplura							
<u>Myriapoda</u>							
Chilopoda	0.2	0.2	0.075	0.056	0.0320	-	-
Diplopoda							
Symphyla							
Paupoda							
<u>Crustacea</u>							
Isopoda							

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - HEAVY CLAY OVER LIMESTONE

SITE - MIXED DECIDUOUS WOODLAND, MEATHOPS WOOD, LANCASHIRE.

SAMPLES - 5 cm diameter x 15 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	19.1	2.8	1.190	0.470	0.0771	F	**
Mesostigmata							
Gamasina	15.0	12.4	1.152	1.070	0.0591	-	-
(less)-							
Rhodacaridae	3.2	1.1	0.459	0.230	0.0805	-	-
Uropodina	10.6	11.9	0.974	1.069	0.0720	-	-
Astigmata	4.9	4.6	0.518	0.512	0.0903	-	-
Cryptostigmata	71.0	60.0	1.757	1.606	0.0966	-	-
<u>Insecta</u>							
Collembola							
Onychiuridae	24.8	18.2	1.291	1.218	0.0961	-	-
Poduridae	3.2	0.7	0.481	0.191	0.0725	F	*
Isotomidae	28.1	18.7	1.354	1.160	0.0884	-	-
Entomobryidae	1.2	2.1	0.240	0.363	0.0941	-	-
Sminthuridae	0.7	1.6	0.175	0.280	0.0712	-	-
Diptera	2.8	16.5	0.492	0.985	0.0920	FL	**
Coleoptera	1.3	3.8	0.307	0.320	0.0740	-	-
Thysanoptera	-	2.1	-	0.291	0.0590	FL	**
Hemiptera	0.1	1.1	0.019	0.240	0.0490	FL	*
Hymenoptera	0.1	0.2	0.030	0.075	0.0313	-	-
Psocoptera							
Protura	1.3	0.7	0.285	0.169	0.0627	-	-
Diplura							
<u>Myriapoda</u>							
Chilopoda	0.5	0.7	0.119	0.168	0.0452	-	-
Diplopoda	0.1	0.4	0.019	0.097	0.0312	-	-
Symphyla	0.1	0.5	0.038	0.124	0.0366	-	-
Paupoda	0.8	0.5	0.184	0.119	0.0566	-	-
<u>Crustacea</u>							
Iso-poda	0.6	0.6	0.154	0.143	0.0459	-	-

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - BATCOMBE SERIES CLAY-LOAM

SITE - GRASSLAND, HIGHFIELD, ROTHAMSTED.

SAMPLES - 5 cm diameter x 15 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	69.6	12.7	1.656	1.072	0.0860	F	**
Mesostigmata							
Gamasina	12.1	15.8	1.061	1.132	0.0681		-
(Less)-							
Rhodacaridae	14.7	15.7	1.111	1.161	0.0679		-
Uropodina							
Astigmata							
Cryptostigmata	3.1	3.7	0.473	0.542	0.0872		-
<u>Insecta</u>							
Collembola							
Onychiuridae	26.9	57.3	1.398	1.669	0.0667	FL	**
Poduridae	0.4	1.9	0.097	0.337	0.0642	FL	*
Isotomidae	26.8	38.2	1.380	1.545	0.0613		-
Entomobryidae	5.9	11.2	0.717	0.993	0.0852	FL	*
Sminthuridae	13.4	1.3	1.071	0.306	0.0675	F	**
Diptera	4.2	5.9	0.628	0.564	0.0947		-
Coleoptera	0.4	1.5	0.086	0.316	0.0572	FL	**
Thysanoptera	1.1	2.1	0.200	0.399	0.0730		-
Hemiptera	0.7	18.2	0.142	0.845	0.0948	FL	**
Hymenoptera							
Psocoptera							
Protura							
Diplura							
<u>Myriapoda</u>							
Chilopoda	0.9	0.4	0.135	0.105	0.0443		-
Diplopoda	0.9	1.1	0.196	0.236	0.0647		-
Symphyla	0.7	1.2	0.199	0.284	0.0536		-
Pauropoda	1.6	1.2	0.337	0.259	0.0677		-
<u>Crustacea</u>							
Iso-poda							

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - BATCOMBE SERIES CLAY-LOAM

SITE - FALLOW ARABLE, HIGHFIELD, ROTHAMSTED

SAMPLES - 5 cm diameter x 15 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	0.1	10.6	0.038	0.165	0.0400	FL	*
Mesostigmata							
Gamasina	11.8	12.1	1.051	1.010	0.0691		-
(Less)-							
Rhodacaridae	20.1	14.7	1.203	1.048	0.0944		-
Uropodina	0.9	0.8	0.133	0.173	0.0678		-
Astigmata	0.4	4.6	0.105	0.604	0.0757	FL	**
Cryptostigmata	56.1	116.0	1.579	1.926	0.0984	FL	*
<u>Insecta</u>							
Collembola							
Onychiuridae	9.5	23.2	0.964	1.304	0.0690	FL	**
Poduridae	1.1	1.5	0.257	0.285	0.0692		-
Isotomidae	17.6	9.7	1.098	0.895	0.0955		-
Entomobryidae	0.7	1.4	0.180	0.287	0.0618		-
Sminthuridae	2.6	1.6	0.489	0.309	0.0707		-
Diptera	1.4	1.7	0.262	0.331	0.0773		-
Coleoptera	0.8	2.5	0.210	0.442	0.0676	FL	*
Thysanoptera	0.1	0.3	0.038	0.086	0.0335		-
Hemiptera							
Hymenoptera							
Psocoptera							
Protura	1.0	12.1	0.232	0.524	0.1228		-
Diplura							
<u>Myriapoda</u>							
Chilopoda	0.3	0.3	0.078	0.075	0.0433		-
Diplopoda	0	0.1	0	0.019	0.0133		-
Symphyla	0.8	0.7	0.146	0.199	0.0555		-
Paupoda	0.7	0.4	0.180	0.094	0.0518		-
<u>Crustacea</u>							
Isopoda							

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - BATCOMBE SERIES SILT-CLAY LOAM

SITE - MIXED DECIDUOUS WOODLAND - MANOR WOOD - ROTHAMSTED

SAMPLES - 10 cm diameter x 5 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae	0.6	0.7	0.244	0.180	0.0630	-	-
Acari							
Prostigmata	34.6	3.1	1.681	0.466	0.0862	F	**
Mesostigmata							
Gamasina	13.5	7.0	1.338	0.903	0.0760	F	**
(Less)-	1.3	1.8	0.570	0.327	0.0821	-	-
Rhodacaridae							
Uropodina	18.0	14.0	1.433	1.126	0.0764	-	-
Astigmata	2.9	1.1	0.554	0.252	0.0820	-	-
Cryptostigmata	65.4	50.7	1.980	1.672	0.0528	F	**
<u>Insecta</u>							
Collembola							
Onychiuridae	16.3	29.0	1.322	1.283	0.1017	-	-
Poduridae	1.2	0.8	0.218	0.199	0.0654	-	-
Isotomidae	65.8	6.8	2.017	0.665	0.0739	F	**
Entomobryidae	2.2	0.6	0.472	0.173	0.0757	-	-
Sminthuridae	17.4	1.8	1.551	0.370	0.0842	F	**
Diptera	3.6	20.6	0.647	0.945	0.1051	-	-
Coleoptera	1.7	2.7	0.457	0.476	0.0818	-	-
Thysanoptera							
Hemiptera							
Hymenoptera							
Psocoptera							
Protura							
Diplura							
<u>Myriapoda</u>							
Chilopoda	2.2	2.0	0.517	0.372	0.0795	-	-
Diplopoda	2.2	0.8	0.234	0.184	0.0620	-	-
Symphyla							
Paupoda	0.2	0.1	0.191	0.030	0.0492	-	-
<u>Crustacea</u>							
Iso-poda	6.4	2.5	0.756	0.416	0.0985	-	-

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - BATCOMBE SERIES SILT-CLAY LOAM

SITE - PASTURE, 'BONES CLOSE', ROTHAMSTED

SAMPLES - 10 cm diameter x 5 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	22.3	1.3	1.367	0.370	0.1002	F	**
Mesostigmata							
Gamasina	10.1	8.4	1.045	0.973	0.1033		-
(Less)-	5.2	2.9	0.792	0.589	0.0862		-
Rhodacaridae							
Uropodina	0.4	1.0	0.135	0.307	0.0756		-
Astigmata	6.5	2.8	0.875	0.579	0.0983		-
Cryptostigmata	2.3	0.9	0.520	0.285	0.0842		-
<u>Insecta</u>							
Collembola							
Onychiuridae	2.1	4.0	0.486	0.700	0.0960		-
Poduridae	19.6	16.1	1.313	1.234	0.0881		-
Isotomidae	49.0	12.9	1.699	1.144	0.0955	F	**
Entomobryidae							
Sminthuridae	30.4	1.0	1.497	0.296	0.0650	F	**
Diptera	3.2	11.3	0.622	1.090	0.0836	FL	**
Coleoptera	1.3	0.6	0.359	0.197	0.0642		-
Thysanoptera							
Hemiptera							
Hymenoptera							
Psocoptera							
Protura							
Diplura							
<u>Myriapoda</u>							
Chilopoda							
Diplopoda							
Symphyla							
Paupoda							
<u>Crustacea</u>							
Iso-poda							

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - BATCOMBE SERIES - SILT-CLAY LOAM

SITE - FALLOW ARABLE - 'PASTURES' ROTHAMSTED

SAMPLES - 10 cm diameter x 5 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae	0.1	0.6	0.038	0.169	0.0380		-
Acari							
Prostigmata	0.1	1.1	0.038	0.225	0.0540		-
Mesostigmata							
Gamasina	0.9	2.7	0.206	0.498	0.0714		-
(Less)-							
Rhodacaridae							
Uropodina							
Astigmata	0.1	0.6	0.019	0.124	0.0417		-
Cryptostigmata	0.1	2.5	0.019	0.460	0.0541	FL	**
<u>Insecta</u>							
Collembola							
Onychiuridae							
Poduridae	0.1	0.4	0.030	0.086	0.0377		-
Iso tomidae	6.3	10.4	0.787	0.918	0.0894		-
Entomobryidae							
Sminthuridae	15.8	5.8	1.174	0.764	0.0849	F	*
Diptera	1.2	0.5	0.274	0.143	0.0533		-
Coleoptera	0.2	0.6	0.075	0.151	0.0427		-
Thysanoptera	-	0.4	-	0.094	0.0272		-
Hemiptera							
Hymenoptera							
Psocoptera	0.1	0.4	0.019	0.105	0.0258		-
Protura							
Diplura							
<u>Myriapoda</u>							
Chilopoda							
Diplopoda							
Symphyla							
Pauropoda							
<u>Crustacea</u>							
Iso poda							

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - BROWN EARTH - SAND TO SANDY LOAM

SITE - MIXED DECIDUOUS WOODLAND - WOBURN - BEDFORDSHIRE

SAMPLES - 10 cm diameter x 5 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae	0.4	0.9	0.105	0.228	0.0433	-	-
Acari							
Prostigmata	104.5	10.6	1.930	0.810	0.0986	F	**
Mesostigmata							
Gamasina	30.1	34.8	1.414	1.477	0.0886	-	-
(Less)-	20.2	20.9	1.192	1.183	0.1072	-	-
Rhodacaridae							
Uropodina	9.6	8.9	0.810	0.846	0.1278	-	-
Astigmata	33.9	36.5	1.406	1.449	0.0890	-	-
Cryptostigmata	313.2	254.4	2.460	2.274	0.0480	F	*
<u>Insecta</u>							
Collembola							
Onychiuridae	40.9	59.8	1.490	1.626	0.0866	-	-
Poduridae	24.7	5.5	1.275	0.696	0.0923	F	**
Isotomidae	22.9	19.2	1.301	1.199	0.0797	-	-
Entomobryidae	1.7	1.3	0.327	0.262	0.0497	-	-
Sminthuridae							
Diptera	3.1	9.6	0.535	0.963	0.0639	FL	**
Coleoptera	0.9	2.1	0.205	0.419	0.0705	FL	*
Thysanoptera	1.3	4.3	0.318	0.588	0.0831	FL	*
Hemiptera	0.1	0.2	0.019	0.056	0.0266	-	-
Hymenoptera	0.1	0.2	0.019	0.056	0.0266	-	-
Psocoptera							
Protura	0.2	0.4	0.056	0.105	0.0458	-	-
Diplura	1.6	3.7	0.257	0.034	0.1157	-	-
<u>Myriapoda</u>							
Chilopoda	1.6	2.6	0.321	0.409	0.0901	-	-
Diplopoda							
Symphyla							
Pauropoda							
<u>Crustacea</u>							
Iso-poda							

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - BROWN EARTH - SAND TO SANDY LOAM

SITE - GRASSLAND - WOBURN - BEDFORDSHIRE

SAMPLES - 10 cm Diameter x 5 cm deep cores

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae	0.9	0.7	0.124	0.199	0.0570	-	-
Acari							
Prostigmata	282.0	14.6	2.434	1.093	0.0548	F	**
Mesostigmata							
Gamasina	81.0	32.1	1.862	1.456	0.0452	F	**
(Less)-	0.7	1.0	0.186	0.224	0.0559	-	-
Rhodacaridae							
Uropodina	2.4	1.9	0.259	0.183	0.0412	-	-
Astigmata	155.0	84.0	2.104	1.856	0.0369	F	**
Cryptostigmata	6.1	4.5	0.770	0.589	0.0625	F	*
<u>Insecta</u>							
Collembola							
Onychiuridae	2.7	2.6	0.497	0.357	0.0714	-	-
Poduridae	1.2	1.2	0.270	0.194	0.0533	-	-
Isotomidae	63.0	22.5	1.728	1.335	0.0641	F	**
Entomobryidae	5.0	2.5	0.595	0.385	0.0712	F	*
Sminthuridae	63.0	15.8	1.746	1.178	0.0505	F	**
Diptera	4.8	12.0	0.673	0.936	0.0684	FL	*
Coleoptera	6.7	4.8	0.810	0.726	0.0628	-	-
Thysanoptera	15.0	6.9	1.115	0.857	0.0580	F	**
Hemiptera	47.2	45.5	1.641	1.612	0.0550	-	-
Hymenoptera	1.5	1.5	0.362	0.316	0.0670	-	-
Psocoptera							
Protura							
Diplura							
<u>Myriapoda</u>							
Chilopoda							
Diplopoda							
Symphyla							
Pauropoda	1.4	0.8	0.283	0.173	0.0532	-	-
<u>Crustacea</u>							
Isopoda							

COMPARISON OF METHODS

TREATMENTS - BERLESE-TULLGREN FUNNEL v SALT AND HOLLICK FLOTATION

SOIL TYPE - BROWN EARTH - SAND TO SANDY LOAM

SITE - FALLOW ARABLE - WOBURN - BEDFORDSHIRE

SAMPLES - 10 cm diameter x 5 cm deep

** - significant difference between means at the 1% level

* - significant difference between means at the 5% level

- - means not significantly different

F - funnel

FL - flotation

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFI- CIENT METHOD	LEVEL OF SIGNIF- ICANCE
	FUNNEL	FLOTATION	FUNNEL	FLOTATION	S.E.		
<u>Arachnida</u>							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	196.5	0.9	2.284	0.196	0.0503	F	**
Mesostigmata							
Gamasina	15.8	2.3	1.103	0.376	0.0837	F	**
(Less)-	0.1	0.7	0.019	0.173	0.0405	FL	*
Rhodacaridae							
Uropodina							
Astigmata	66.6	2.1	1.746	0.313	0.0838	F	**
Cryptostigmata	1.4	0.9	0.348	0.216	0.0518	-	-
<u>Insecta</u>							
Collembola							
Onychiuridae	59.3	5.7	1.609	0.629	0.1053	F	**
Poduridae	9.6	1.4	0.921	0.268	0.0810	F	**
Isotomidae	8.8	0.7	0.884	0.191	0.0657	F	**
Entomobryidae	0.9	0.2					
Sminthuridae			0.201	0.075	0.0480	-	-
Diptera	0.2	0.5	0.075	0.135	0.0408	-	-
Coleoptera	0.1	0.2	0.038	0.056	0.0281	-	-
Thysanoptera	1.7	0.7	0.381	0.210	0.0506	F	*
Hemiptera							
Hymenoptera							
Psocoptera							
Protura							
Diplura							
<u>Myriapoda</u>							
Chilopoda							
Diplopoda							
Symphyla							
Paupoda							
<u>Crustacea</u>							
Iso-poda							

fallow sites on clay soils being the only samples where the flotation method recovered as many or more prostigmatid mites than the funnel method. Most other mites were extracted equally efficiently by both methods, but most of the significant differences that were observed showed the funnel method to be more efficient than the flotation method for extracting these animals (except when extracting soil samples from fallow sites on clay soils). Exceptionally, on the woodland site on peat soil, all mites except the Prostigmata were recovered more efficiently by the flotation method than by funnels. This result was completely against the trend of results for other sites, where it was difficult to extract arthropods by flotation from soils containing large amounts of undecomposed organic matter.

One group of Collembola seemed to differ from others in relative efficiency of extraction, in that Onychiuridae were extracted considerably better by the flotation method than by the funnel method from all but the woodland clay soil and the fallow sandy-loam soil. Podurid Collembola also tended to be recovered in larger numbers by the flotation method although significantly fewer podurids were recovered by flotation from the woodland site on clay soil and the woodland and fallow sites on sandy-loam soil. Other Collembola particularly Sminthuridae were invariably extracted more efficiently by the funnel method from all but clay-soil sites. Of the larger insects, Diptera larvae, Coleoptera larvae and adults, Thysanoptera and Hemiptera were more efficiently extracted by the flotation method than by the funnel method except from peat soil where significantly greater numbers of Diptera larvae, Thysanoptera and Hemiptera were obtained by the funnel method.

Few myriapods, isopods and spiders were extracted from any of the samples in this comparison; the only significant difference obtained was an increased number of centipedes extracted by the flotation method from the woodland site on peat soil.

Discussion and Conclusions

The most important results of this part of the investigation are to show that the funnel method of extracting arthropods from soils can recover greater numbers of most arthropod groups from different soil types than the Salt and Hollick flotation method. However the flotation method was more efficient than the funnel method for certain groups of arthropods or certain soil types or habitats. The variability in numbers of animals extracted from comparable soil samples showed that it was difficult to define precisely which method is most efficient in extracting each of the different groups of animals from the different habitats but some conclusions and inferences could be made.

Prostigmatid mites and sminthurid springtails, were extracted in significantly larger numbers by the funnel method. Conversely, onychurid springtails and to a lesser extent, podurid springtails and the insect groups Diptera, Coleoptera, Thysanoptera and Hemiptera tended to be extracted more efficiently by the flotation method. Other groups of arthropods tended to be extracted equally efficiently by both methods but the method which extracted the greatest number of animals was influenced considerably by the soil type and the amount of organic matter it contained.

When comparing the relative efficiencies of two extraction methods on different sites and soil types the observed changes in the relative efficiency of the two methods may be due to either an increase in the efficiency of one method or a decrease in the efficiency of the other

method or both. For example, the numbers of mites and springtails recovered by the two methods from the fallow sites on clay soils show that the efficiency of the funnel method was decreased in relation to that of the flotation method. This could be due to an increase in the efficiency of the flotation method because the soil contained less undecomposed organic matter, (the organic matter floats on the surface of the oil/water interface and obscures arthropods from view), or to a decrease in the efficiency of the funnel method, because animals are trapped in clay soils either by the shrinking and distortion of the soil core as it dries or because they adhere to the surface of wet clay particles at the beginning of the extraction. Possibly, both factors contributed to the decreased relative efficiency of the funnel method on these sites.

The relative efficiency of the flotation method decreased when the different methods were compared on soils with large amounts of undecomposed organic matter, particularly woodland soils. The reasons for this may be because of the increased amounts of floating organic matter which obscure arthropods from view at the oil/water separation stage of the flotation method or may also be due to a real increase in the efficiency of the funnel method for these soils. Neither of these reasons would explain the results for the woodland peat soil, where flotation was significantly more efficient than the funnel method for all the mite groups except Prostigmata. It is possible that this can be explained because it was difficult on this particular site to distinguish between mites that were dead at the time of sampling but were sufficiently intact to be counted as live. It has been noted by Murphy (1962b) and Satchell & Nelson (1962) that flotation methods can overestimate soil arthropod populations in this way.

The condition of most of the specimens recovered by the flotation method was poor, the arthropods being damaged during the wet sieving stage of the process. This, coupled with the time taken to complete a flotation extraction which was at least three and often as much as ten times the number of man-hours taken to complete a funnel extraction, tended to encourage the choice of a funnel method for estimating the populations of most soil arthropods, even if for some arthropod groups, this involved a marginal loss of accuracy in the results.

SECTION VI. FACTORS AFFECTING THE RELATIVE EFFICIENCY OF DRY-

FUNNEL METHODS

Introduction

The effects of sample treatment on the efficiency of the extraction process when using dry-funnel methods has been discussed by several workers (Murphy, 1962a). The survey of extraction methods, described in Section II, showed that most soil zoologists used some form of Berlese/Tullgren funnel in their ecological studies, and in Sections IV and V it was demonstrated that for most soil arthropod groups, dry-funnel methods extracted more arthropods from soil cores than did mechanical methods. Dry-funnel methods seem to be used much more than other methods, so a detailed study of their mode of action was made in order to determine their best possible use and to suggest ways of increasing their efficiency. To achieve this aim, various factors thought to affect the relative efficiency of the Rothamsted pattern Berlese/Tullgren funnel apparatus were studied.

1) The condition and orientation of the soil core during the extraction

Many factors affect the condition of the soil core before

extraction by dry-funnel methods. Macfadyen (1962a), Murphy (1962a) and von Törne (1962a) all stressed the importance of taking soil cores with a properly designed soil core to keep the disturbance of the soil in the core to a minimum. The efficiency of the most carefully designed extraction apparatus can be adversely affected by compression of the sample during its collection, transportation or preparation for extraction (Macfadyen, 1955; Murphy, 1958a; Hughes, 1954; Lussenhop, 1971).

Several workers (Jacot, 1936; Hammer, 1944; Murphy, 1958a) have suggested that animals escape more easily from samples placed undisturbed in an inverted position on the funnel sieve. This may be because the natural passageways within an undisturbed soil core are not blocked by compression or debris or it may be because most arthropods are usually found in the top 3 cm of the soil profile. The distance travelled by the arthropods from the soil core to the collecting funnel would be much shorter when samples were inverted on the funnel sieve than when the soil core was placed upright on the sieve. Other workers break soil cores into small pieces and distribute the pieces evenly over the funnel sieves. This process is aimed at releasing arthropods trapped in the centre of the soil core and make it easier for them to escape from the surrounding soil. Breaking up soil cores could be disadvantageous in wet clay soils, where smearing of the soil surface may effectively encase the enclosed arthropods and prevent them escaping (Murphy 1958a, 1962a).

a) Methods

Several comparisons were made to determine the effects of the different way of soil core preparation on the relative efficiency of the Rothamsted pattern Berlese/Tullgren funnel apparatus. For each

comparison, soil cores were taken with the appropriate diameter sampling tool (Fig. 15a & b). The sampling procedure was to remove pairs of soil cores randomly from a small uniform area at each site. Sixteen pairs of soil cores were taken for each comparison and the numbers of arthropods recovered from the two sets of sixteen sample units were compared. The arthropods were extracted into 70% aqueous ethyl alcohol and glycerol (ratio, 20 : 1).

(i) Sixteen intact soil cores, 10 cm diameter and 5 cm deep, taken from a permanent pasture site on Batcombe series silt-clay-loam soil, were placed undisturbed in an upright position (i.e. their upper surface away from the funnel sieves) above sixteen funnel units. Sixteen other soil cores were placed similarly but in an inverted position (i.e. their upper surfaces next to the funnel sieves). Care was taken to ensure the minimum compression and disturbance of each soil core.

(ii) Sixteen intact soil cores taken as above, were placed in an intact inverted position on the sieves of sixteen funnel units. Sixteen other soil cores, but first broken into small pieces by hand, were placed separately on the sieves of sixteen other funnels.

(iii) Sixteen soil cores, 5 cm diameter and 15 cm deep, again taken from the same pasture site, were broken into small pieces and spread over the funnel sieves as above; sixteen other undisturbed intact cores, 5 cm diameter and 15 cm deep, were laid in a sideways position in the sample containers, so that the vertical sides of the soil cores were in contact with the funnel sieves.

(iv) Sixteen soil cores, 5 cm diameter and 15 cm deep, taken from the same site were broken into small pieces and spread evenly

on the surface of the funnel sieves forming a relatively shallow layer. These were compared with sixteen other soil cores which were broken into small pieces and placed into much deeper cylindrical holes in blocks of expanded polystyrene. Each hole was 5 cm diameter and 15 cm deep and the blocks were shaped to fit inside the sample containers of the funnel units with no appreciable gaps.

b) Results and Discussion

The results are summarized in Figs. 39 - 42, and significant differences in Tables 19 - 22.

The comparison of numbers of animals recovered from intact samples placed upright on the funnel sieve with those from intact samples which were placed in an inverted position shows that almost all of the animal groups present in the soil samples were extracted in greater numbers when the soil cores were inverted on the funnel sieves than when they were upright. In particular, significantly more prostigmatid and gamasid mites and thrips were recovered from inverted soil cores than from upright ones at the 1% level of probability. Significantly more isotomid springtails, fly larvae and beetles were also recovered from inverted than from upright soil cores at the 5% level of probability. There were no significant differences between the numbers of cryptostigmatid mites, onychiurid or sminthurid springtails recovered from the two treatments. From these data it seems that for most soil arthropods the efficiency of this extraction method is improved when intact samples are placed in an inverted position rather than an upright position on the funnel sieve.

FIG. 39.

TULLGREN FUNNEL EXTRACTION
THE EFFECT OF SOIL SAMPLE TREATMENT ON THE
NUMBERS OF ARTHROPODS EXTRACTED

A COMPARISON OF INTACT-INVERTED SOIL SAMPLES
WITH INTACT-UPRIGHT SOIL SAMPLES

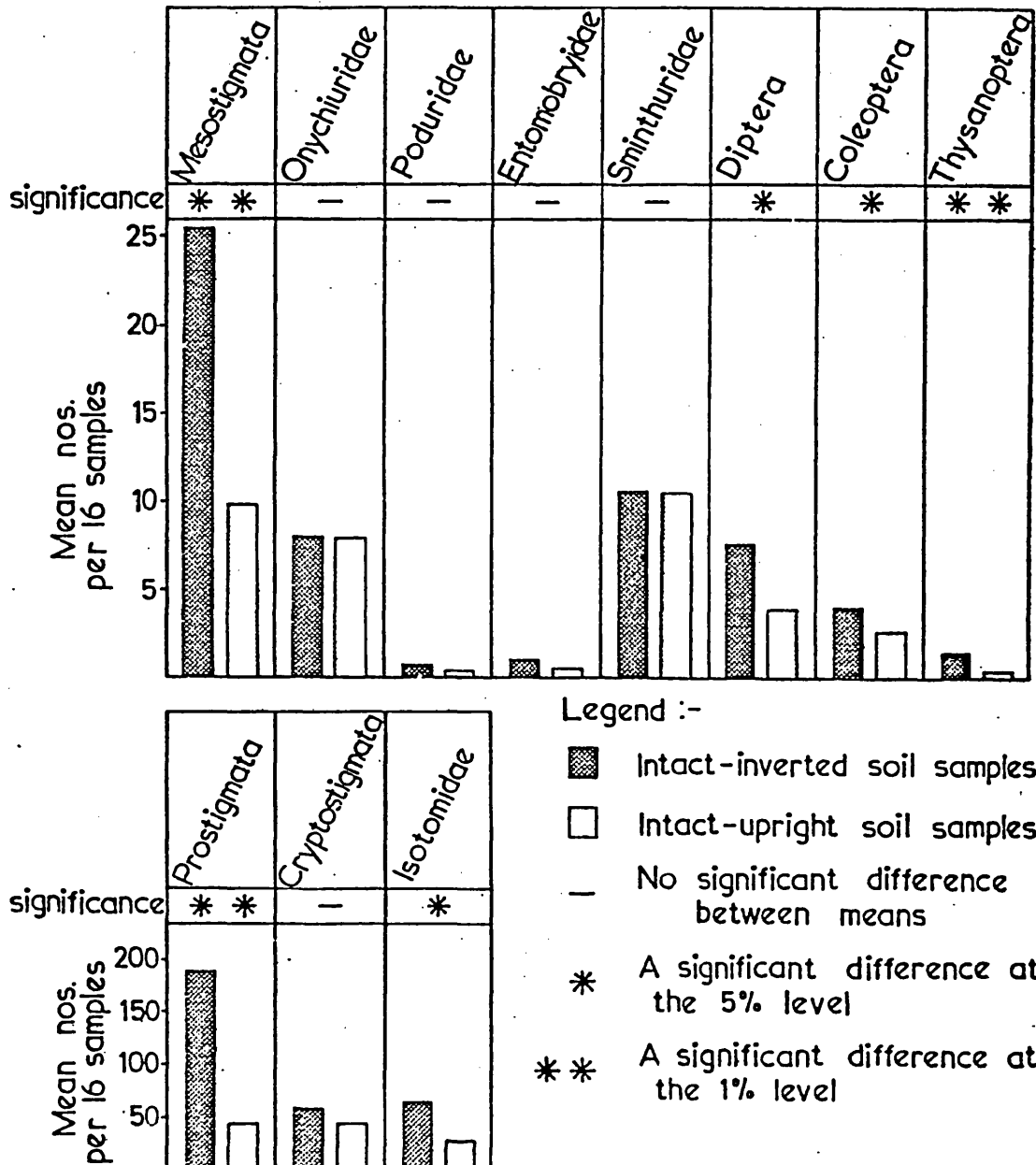


FIG. 40.

TULLGREN FUNNEL EXTRACTION
THE EFFECT OF SOIL SAMPLE TREATMENT ON THE
NUMBERS OF ARTHROPODS EXTRACTED

A COMPARISON OF INTACT-INVERTED SOIL SAMPLES
WITH BROKEN SOIL SAMPLES

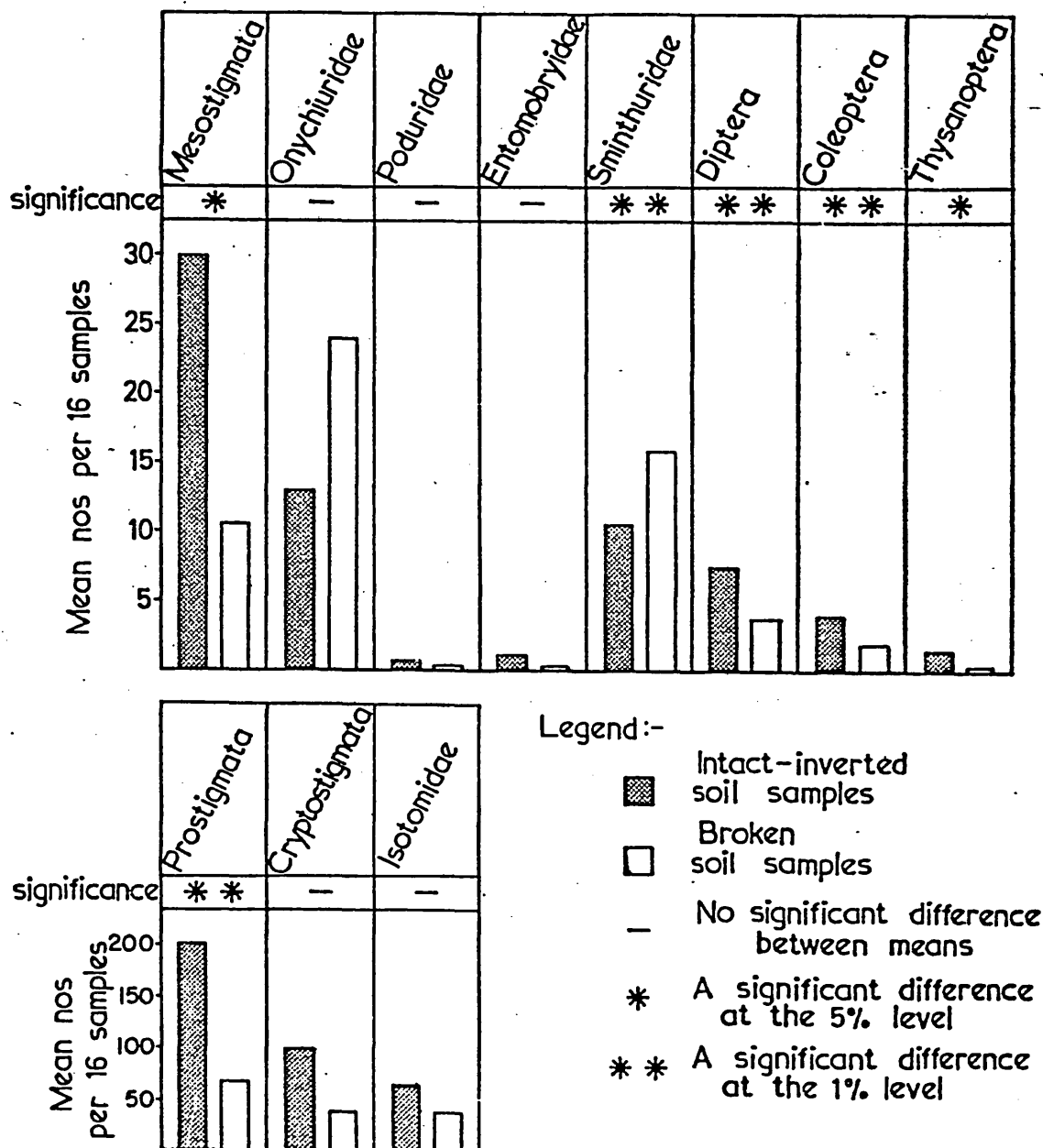


FIG. 41.

TULLGREN FUNNEL EXTRACTION.
THE EFFECT OF SOIL - SAMPLE TREATMENT ON THE
NUMBERS OF ARTHROPODS EXTRACTED.

A COMPARISON OF BROKEN SAMPLES WITH INTACT SAMPLES
PLACED ON THEIR SIDES ON THE SIEVES.

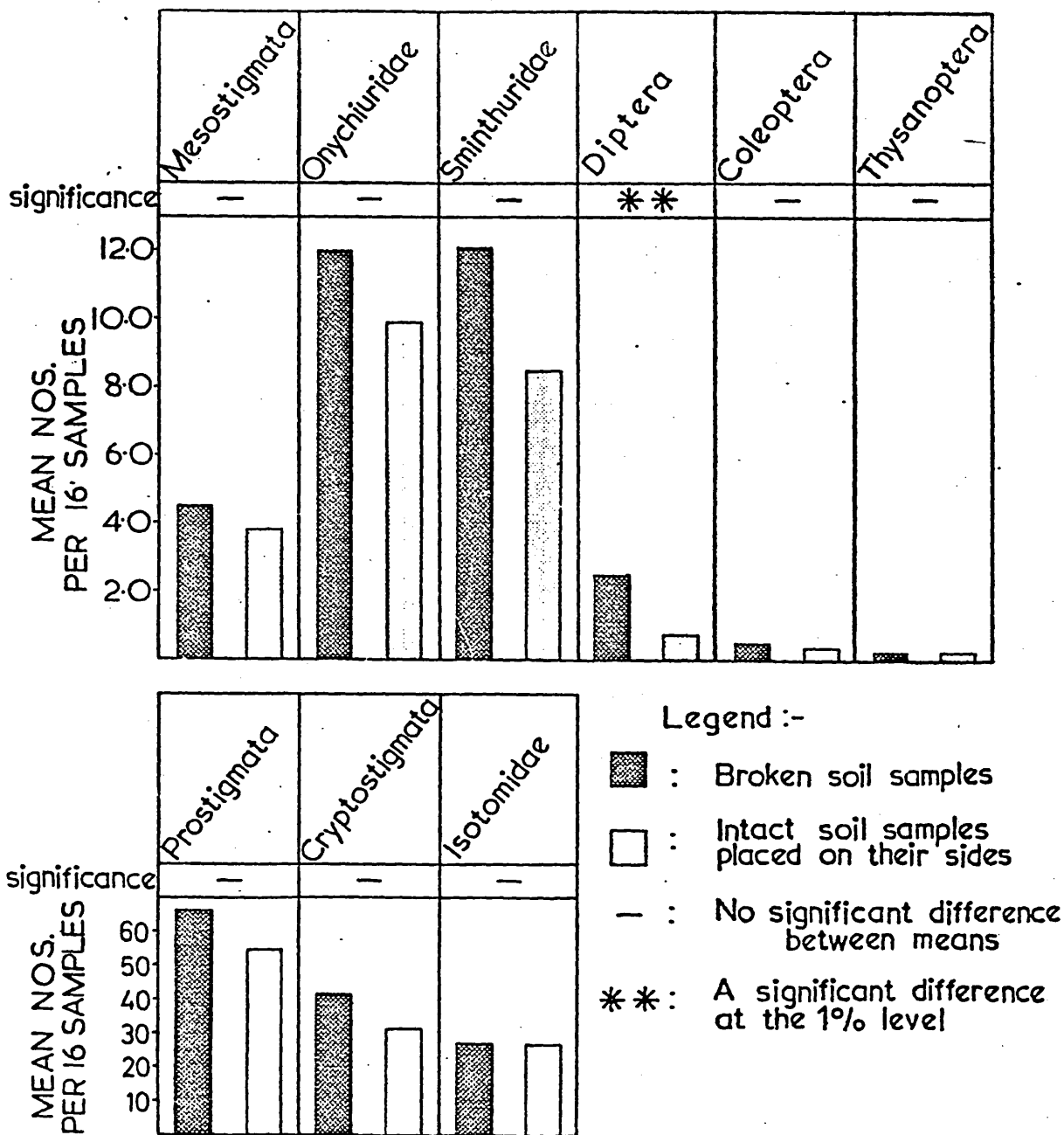


FIG. 42.

TULLGREN FUNNEL EXTRACTION

THE EFFECT OF SOIL-SAMPLE TREATMENT ON THE
NUMBERS OF ARTHROPODS EXTRACTED

A COMPARISON OF BROKEN SAMPLES EXTRACTED AS 12½ cm. DIAM.
2-3 cm. DEEP UNITS WITH BROKEN SAMPLES EXTRACTED AS 5 cm.
DIAM. 15 cm. DEEP UNITS

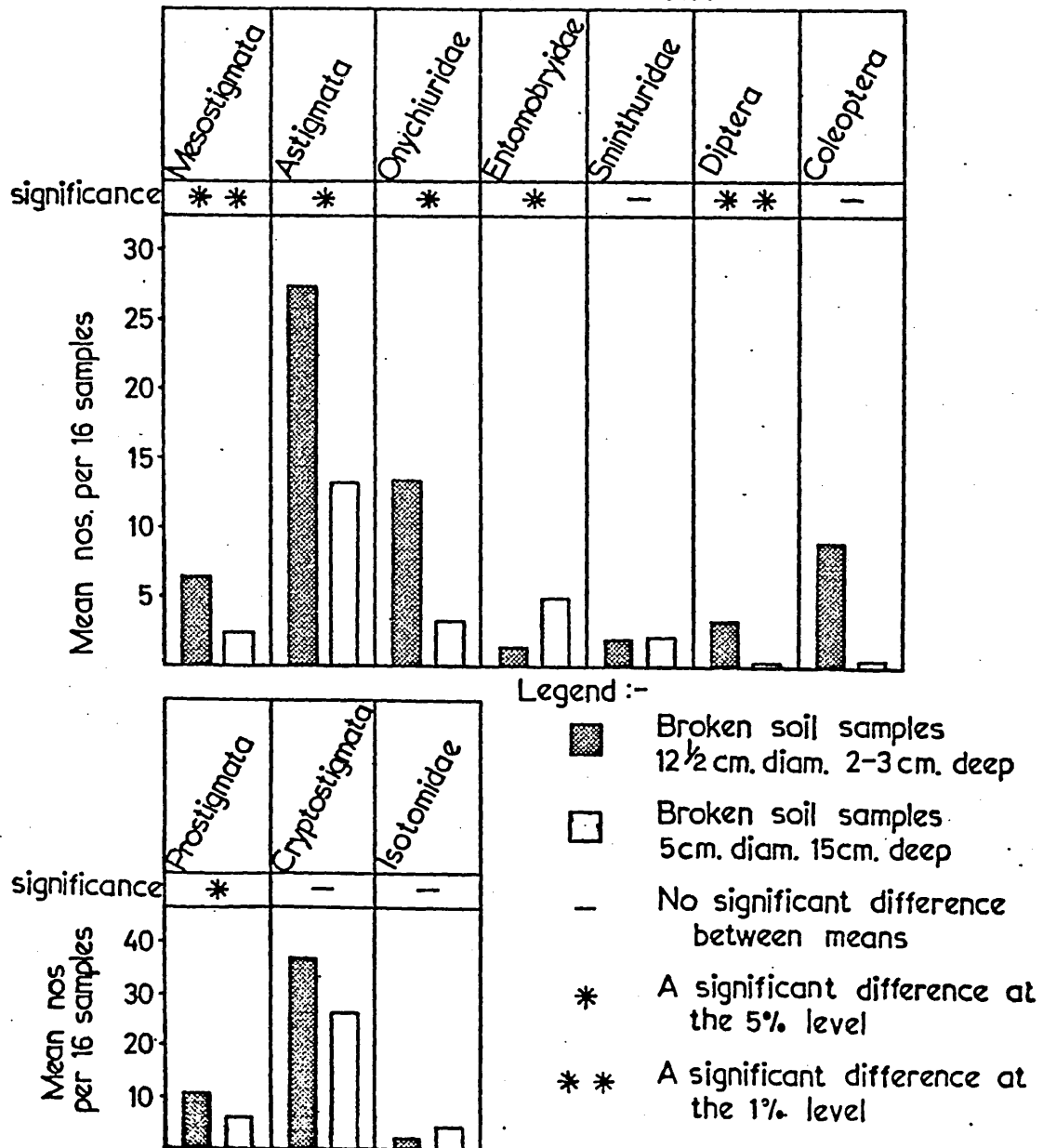


TABLE 19

COMPARISON OF SOIL CORE TREATMENTS

Treatments - Intact upright soil cores v intact inverted soil cores Soil type - Batcombe series clay loam
Site - grassland, Highfield, Rothamsted Samples - 10 cm diameter x 5 cm deep

* - significant difference between means at the 5% level ** - significant difference between means at the 1% level
 - - means not significantly different

Method Animal Group	Arithmetic means of 16 soil cores		Transformed means - log (n + 1)			More efficient method	Level of significance
	Intact upright	Intact inverted	Intact upright	Intact inverted	S.E.		
Arachnida							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	44.1	188.0	1.553	2.114	0.0863	Intact inverted	**
Mesostigmata							
Gamasina	9.8	25.5	0.916	1.305	0.0950	Intact inverted	**
(less) Rhodacaridae							
Uropodina							
Astigmata							
Cryptostigmata	44.1	57.7	1.404	1.757	0.1281		-
Insecta							
Collembola							
Onychiuridae	7.9	8.0	0.746	0.927	0.1085		-
Poduridae	0.4	0.7	0.166	0.184	0.0481		-
Isotomidae	27.7	65.8	1.318	1.647	0.0974	Intact inverted	*
Entomobryidae	0.5	1.1	0.127	0.230	0.0593		-
Sminthuridae	10.5	10.6	0.909	0.997	0.0776		-
Diptera	3.9	7.6	0.575	0.843	0.0774	Intact inverted	*
Coleoptera	2.6	4.1	0.481	0.668	0.0569	Intact inverted	*
Thysanoptera	0.4	1.5	0.124	0.342	0.0502	Intact inverted	**

TABLE 20

COMPARISON OF SOIL CORE TREATMENTS

Treatments - Broken soil cores v intact inverted soil cores Soil type - Batcombe series clay loam
Site - grassland, Highfield, Rothamsted Samples - 10 cm diameter x 5 cm deep

* - significant difference between means at the 5% level ** - significant difference between means at the 1% level
 - - means not significantly different

Method Animal Group	Arithmetic means of 16 soil cores		Transformed means - log (n + 1)			More efficient method	Level of significance
	Broken	Intact inverted	Broken	Intact inverted	S.E.		
Arachnida							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	67.9	203.2	1.638	2.114	0.1003	Intact inverted	**
Mesostigmata							
Gamasina	10.7	30.0	0.918	1.305	0.0927	Intact inverted	*
(less) Rhodacaridae							
Uropodina							
Astigmata							
Cryptostigmata	38.6	101.3	1.362	1.787	0.1154	-	-
Insecta							
Collembola							
Onychiuridae	23.6	13.2	1.274	0.927	0.0990	-	-
Poduridae	0.2	0.7	0.075	0.184	0.0445	-	-
Isotomidae	37.2	65.6	1.488	1.647	0.0846	-	-
Entomobryidae	0.2	1.1	0.038	0.230	0.0542	-	-
Sminthuridae	15.8	10.6	1.132	0.997	0.0598	Broken	**
Diptera	3.9	7.6	0.631	0.843	0.0624	Intact inverted	**
Coleoptera	1.9	4.1	0.368	0.668	0.0603	Intact inverted	**
Thysanoptera	0.4	1.5	0.081	0.342	0.0511	Intact inverted	*

TABLE 21

COMPARISON OF SOIL CORE TREATMENTS

Treatments - Broken soil cores v intact horizontal soil cores Soil type - Batcombe series clay loam

Site - grassland, Highfield, Rothamsted Samples - 10 cm diameter x 5 cm deep

* - significant difference between means at the 5% level ** - significant difference between means at the 1% level

- - means not significantly different

Method Animal Group	Arithmetic means of 16 soil cores		Transformed means - $\log(n + 1)$			More efficient method	Level of significance
	Broken	Intact horizontal	Broken	Intact horizontal	S.E.		
Arachnida							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	66.4	54.7	1.779	1.638	0.0830	-	-
Mesostigmata							
Gamasina	4.5	3.8	0.587	0.566	0.0919	-	-
(less) Rhodacaridae	0.6	0.7	0.130	0.168	0.0438	-	-
Uropodina							
Astigmata							
Cryptostigmata	41.9	31.2	1.525	1.409	0.0959	-	-
Insecta							
Collembola							
Onychiuridae	12.1	9.9	1.005	0.914	0.0817	-	-
Poduridae							
Isotomidae	27.2	27.0	1.361	1.328	0.0753	-	-
Entomobryidae							
Sminthuridae	12.1	8.5	1.030	0.933	0.0617	-	-
Diptera	2.5	0.7	0.479	0.184	0.0586	Broken	**
Coleoptera	0.5	0.4	0.124	0.113	0.0480	-	-
Thysanoptera	0.2	0.2	0.075	0.067	0.0314	-	-

TABLE 22

COMPARISON OF SOIL CORE TREATMENTS

Treatments - Thin layer of broken soil core v column of broken soil core Soil type - Batcombe series clay loam
Site - grassland, Highfield, Rothamsted Samples - 10 cm diameter x 5 cm deep

* - significant difference between means at the 5% level ** - significant difference between means at the 1% level
 - - means not significantly different

Method Animal Group	Arithmetic means of 16 soil cores		Transformed means - log (n + 1)			More efficient method	Level of significance
	Thin layer	Column	Thin layer	Column	S.E.		
Arachnida							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	10.9	6.3	1.158	0.900	0.0700	Thin layer	*
Mesostigmata							
Gamasina	6.3	2.4	0.932	0.559	0.0663	Thin layer	**
(less) Rhodacaridae	2.0	0.4	0.437	0.165	0.0774	Thin layer	*
Uropodina	0.6	0.1	0.188	0.050	0.0568	-	-
Astigmata	27.3	13.1	1.463	1.241	0.0737	Thin layer	*
Cryptostigmata	37.0	26.4	1.630	1.525	0.0658	-	-
Insecta							
Collembola							
Onychiuridae	13.4	3.3	1.057	0.646	0.1270	Thin layer	*
Poduridae	0.4	0.6	0.115	0.201	0.0598	-	-
Isotomidae	2.4	4.6	0.502	0.749	0.0997	-	-
Entomobryidae	1.4	4.9	0.321	0.706	0.1030	Column	*
Sminthuridae	2.1	2.2	0.347	0.478	0.1105	-	-
Diptera	3.3	0.3	0.698	0.100	0.0583	Thin layer	**
Coleoptera	9.1	0.5	0.432	0.190	0.1240	-	-
Thysanoptera							
Protura	1.9	0.4	0.411	0.108	0.0837	Thin layer	*

The comparison of intact cores placed inverted on the funnel sieve with similar ones broken into small pieces, showed that significantly greater numbers of prostigmatid mites, fly larvae, beetles (at the 1% probability level) gamasid mites and thrips (at the 5% probability level) were recovered when samples were placed intact and inverted on the sieves than when broken up. Cryptostigmatid mites and podurid, isotomid and entomobryid springtails were also recovered in greater numbers from intact inverted soil cores, but these differences were not significant. However, greater numbers of sminthurid and onychiurid springtails were recovered from the broken samples than from intact ones. Most arthropod groups seemed to be extracted more efficiently from clay loam soil by this extraction method, when samples were placed intact and inverted, rather than broken, on the funnel sieves.

When 5 cm diameter soil cores were either laid intact in a horizontal position on the sieves or broken into small pieces and spread evenly on the sieves there were few differences between treatments. Significantly more dipterous larvae were recovered from broken samples than from horizontal ones but although more prostigmatid and cryptostigmatid mites, and onychiurid and sminthurid springtails were recovered from broken soil cores, the increases in numbers were not significant.

When broken samples were either spread evenly on the funnel sieve or confined in a deeper layer in polystyrene baffles to a central part of the sieve, greater numbers of most groups of soil arthropods were recovered from soil cores which were broken and spread evenly on the funnel sieves. Significantly greater numbers (at the 1% probability level) of gamasid mites and dipterous larvae were recovered from the samples that were spread evenly on the funnel sieve than from confined

ones. Prostigmatid, rhodacarid and astigmatid mites, onychiurid springtails and protrura were also extracted in significantly greater numbers ($p < 0.05$) from the broken soil cores spread evenly on the funnel sieve than from the broken-pieces held in the polystyrene baffles. Conversely, significantly more (at the 5% probability level) entomobryid springtails were recovered from the broken samples held in the polystyrene baffles than from the broken samples spread evenly on the funnel sieve. Other springtails, except for onychiurids, were also extracted in greater numbers from these samples, but the differences were not significant.

Most soil arthropods were extracted more efficiently from the broken-soil cores spread thinly over the sieves than from either intact cores laid horizontally on the sieve or from broken samples held in polystyrene baffles. These results suggest that the best of these three methods of extracting arthropods from broken soil samples was to spread the soil evenly over the funnel sieve. However, for most soils it was preferable when possible to use intact, undisturbed soil cores and place them surface downwards on the funnel sieve. The reasons for the increased efficiency of extraction obtained in this way are still not fully understood, and results may differ for other extraction methods, sizes of soil core or soil type. Since more arthropods were extracted from the broken samples spread ^{on the sieves} than from intact samples laid horizontally it seems that most arthropods are not damaged by the sample disturbance; and that possible smearing of the clay when breaking the sample into pieces is not an important factor, at least for the clay loam soil tested. The results from all these comparisons suggest that the increased number of soil arthropods obtained from intact inverted soil cores, are due to

more arthropods being placed nearer to the funnel sieve before the extraction begins.

2) The size of the soil core and the depth of soil placed on the sieve over the collecting funnel

The number and size of soil cores or sampling units required to give statistically accurate estimations of soil arthropods populations have been discussed by (Healey, 1962; Debauche, 1962; Moreau, 1965; Cancela da Fonseca et al., 1967; Berthet, 1971). However, their results are largely empirical and do not take account of possible large changes in populations and distribution of soil arthropods through the season (Southwood, 1966) or of the relative efficiencies of the techniques and methods used for extracting arthropods from soil. When extracting a range of soil arthropod groups of very different sizes, distribution and population densities, the dimensions of the samples used must be large enough to allow for populations of those animals present at low densities to be estimated: but not so large as to cause difficulties in sorting and counting those animals present in large numbers. Soil arthropod populations consist of a mixture of both scarce and abundant species, therefore no one size or number of sample units can be ideal for the study of all the different species within a population. The aim of the present investigations was not to determine the optimum number and size of sampling units required to estimate the number of arthropods present in a population, but rather to determine which physical parameters of sample units affected the efficiency of dry-funnel extraction methods.

In the following comparisons, the effects on efficiency of the diameter and depth of intact soil cores and the depth of broken soil

cores used in funnels were investigated.

A. The effect of soil core diameter on the relative efficiency of the Rothamsted funnels

The influence of soil core diameter on the efficiency of dry-funnel methods of extraction is particularly difficult to determine. This is because the number of arthropods recovered from sample units of different surface areas is closely related to the size and mobility of the different species and their degrees of aggregation. For this reason Debauche (1962) stressed that comparisons should be made only with samples consisting of an equal number of units of the same size. Despite these objections, a comparison of samples of different diameters was made in order to assess the importance of sample diameter on the efficiency of one type of dry-funnel extraction technique, namely Rothamsted pattern Berlese/Tullgren.

a) Methods

Sixteen pairs of soil cores, 10 cm diameter and 5 cm diameter, and each 5 cm deep, were taken from woodland and grassland habitats on Batcombe series silt-clay loam soil at Rothamsted. They were taken from uniform areas of land on the two sites with the sampling tools described on page 60. The soil cores were placed undisturbed, intact and inverted on the funnel sieves and the arthropods were collected into 70% aqueous ethyl alcohol and glycerol (ratio 20 : 1). Before statistical analyses the data from the smaller soil cores were multiplied by correction factors based on the differences in volume of the samples. A further comparison of the same type was made between 12.7 cm diameter and 10 cm diameter soil cores, both 5 cm deep, on a different permanent pasture site on clay loam soil at Rothamsted.

b) Results

The results are summarized in Tables 23 - 25. The comparison between 10 cm and 5 cm diameter soil cores shows that the only significant difference recorded was the increased numbers of sminthurid springtails recovered from the 10 cm diameter samples on the pasture site. Significantly more sminthurid springtails were also recovered from the 12.7 cm diameter soil cores than from the 10 cm diameter soil cores on the other pasture site. Conversely, significantly more fly larvae ($P < 0.01$) and beetles ($P < 0.05$) were extracted from the 10 cm diameter soil cores than from the 12.7 cm diameter soil cores.

c) Discussion

The few significant differences, in numbers extracted, observed in these comparisons suggest that for most groups of soil arthropods the diameter of the soil cores within the range tested was of little importance in relation to the efficiency of this extraction method. However, it is possible that other factors influenced the results. For example, the different surface area to volume ratio of the different-sized soil cores meant that the edge effects caused by removing the soil cores from the ground were greater in the smaller samples. Different-sized soil cores would also influence the rates of heating and desiccation operating within the core. These factors, together with the inherent difficulties of comparing different-sized sampling units mentioned earlier, may combine to mask any direct effects of soil core diameter on the efficiency of dry-funnel extraction methods.

B. The effect of the depth of the soil sample on the relative efficiency of Rothamsted funnels

The depth of the sample material in the sieve containers in funnel

TABLE 23. COMPARISON OF SOIL CORE TREATMENTS
DIAMETER OF SOIL CORES

TREATMENTS - 5 cm diameter x 5 cm deep soil cores v.
10 cm diameter x 5 cm deep soils cores

SOIL TYPE - BATCONE SERIES SILT-CLAY LOAM

SITE - MIXED DECIDUOUS WOODLAND, MANOR WOOD, ROTHAMSTED

SAMPLES - AS ABOVE. - EXTRACTED INTACT AND INVERTED INTO
ALCOHOL 5 cm diameter cores converted to 10 cm
diameter for comparison.

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFIC/ IENT METHOD	LEVEL OF SIGNI/ FICANCE
	5 cm. diam.	10 cm. diam.	5 cm. diam.	10 cm. diam.	S.E.		
<u>ARACHNIDA</u>							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	57.7	34.7	1.681	1.507	0.0701	-	-
Mesostigmata							
Gamasina (less)	25.2	13.6	1.338	1.118	0.0628	-	-
Rhodacaridae	4.2	1.3	0.570	0.284	0.0877	-	-
Uropodina	35.6	18.1	1.432	1.209	0.0736	-	-
Astigmata	6.0	2.9	0.554	0.435	0.1074	-	-
Cryptostigmata	106.2	65.4	1.980	1.778	0.0530	-	-
<u>INSECTA</u>							
Collembola							
Onychiuridae	32.2	16.1	1.317	1.126	0.1025	-	-
Poduridae	1.2	1.2	0.218	0.257	0.0761	-	-
Isotomidae	116.7	65.9	2.017	1.795	0.0529	-	-
Entomobryidae	5.5	2.2	0.472	0.441	0.1064	-	-
Sminthuridae	42.5	17.4	1.566	1.240	0.0557	-	-
Diptera	6.5	3.6	0.044	0.038	0.0408	-	-
Coleoptera	4.0	1.7	0.457	0.386	0.0941	-	-
Thysanoptera							
Memiptera							
Hymenoptera							
Psocoptera							
Protura							
Diplura							
<u>MYRIAPODA</u>							
Chilopoda	3.7	2.2	0.517	0.451	0.0872	-	-
Diplopoda	1.5	2.2	0.234	0.424	0.0822	-	-
Symphyla							
Paupoda	1.2	0.2	0.191	0.067	0.0666	-	-
<u>CRUSTACEA</u>							
Isopoda	6.5	6.37	0.657	0.756	0.1063	-	-

* - significant difference between means at the 5% level

** - significant difference between means at the 1% level

- - means not significantly different

TABLE 24. COMPARISON OF SOIL CORE TREATMENTS
DIAMETER OF SOIL CORESTREATMENTS - 5 cm diameter x 5 cm deep v. 10 cm diameter x
5 cm deep

SOIL TYPE - BATCOMBE SERIES SILT CLAY LOAM

SITE - GRASSLAND, BONES, CLOSE, ROTHAMSTED

SAMPLES - AS ABOVE EXTRACTED INTACT AND INVERTED
OVER ALCOHOL (5 cm diameter cores converted
to 10 cm diameter for comparison)

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFIC/ IENT METHOD	LEVEL OF SIGNI/ FICANCE
	5 cm. diam.	10 cm diam.	5 cm. diam.	10 cm. diam.	S.E.		
<u>ARACHNIDA</u>							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	27.0	29.3	1.365	1.367	0.0762	-	-
Mesostigmata							
Gamasina (less)	20.7	12.3	0.952	1.045	0.1275	-	-
Rhodacaridae	17.7	6.5	1.063	0.792	0.1025	-	-
Uropodina	6.7	0.6	0.127	0.135	0.0979	-	-
Astigmata	15.2	8.2	0.829	0.875	0.1216	-	-
Cryptostigmata	2.0	3.4	0.266	0.520	0.0943	-	-
<u>INSECTA</u>							
Collembola							
Onychiuridae	4.0	4.5	0.400	0.486	0.1165	-	-
Poduridae	19.2	21.2	1.163	1.313	0.086	-	-
Isotomidae	54.0	62.8	1.353	1.699	0.1153	-	-
Entomobryidae							
Sminthuridae	8.7	32.7	0.862	1.497	0.0766	10 cm diam.	**
Diptera	7.5	4.2	0.758	0.622	0.0976	-	-
Coleoptera	1.0	1.5	0.175	0.359	0.0659	-	-
Thysanoptera							
Hemiptera							
Hymenoptera							
Psocoptera							
Protura							
Diplura							
<u>MYRIAPODA</u>							
Chilopoda							
Diplopoda							
Symphyla							
Pauropoda							
<u>CRUSTACEA</u>							
Isopoda							

* - significant difference between means at the 5% level

** - significant difference between means at the 1% level

- - means not significantly different.

TABLE 25. COMPARISON OF SOIL CORE TREATMENTS
DIAMETER OF SOIL CORESTREATMENTS - 12.7 cm diameter and 5 cm deep soil cores v.
10 cm diameter and 5 cm deep soil cores

SOIL TYPE - BATCOMBE SERIES CLAY LOAM

SITE - GRASSLAND, HIGHFIELD, ROTHAMSTED

SAMPLES - AS ABOVE, EXTRACTED INTACT AND INVERTED OVER
ALCOHOL

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 CORES		TRANSFORMED MEANS - LOG (n + 1)			MORE EFFIC/ IENT METHOD	LEVEL OF SIGNI/ FICANCE
	12.7cm. diam.	10 cm. diam.	12.7cm. diam.	10 cm. diam.	S.E.		
<u>ARACHNIDA</u>							
Pseudoscorpiones							
Araneae							
Acari							
Prostigmata	128.9	203.9	2.010	2.114	0.0834	-	-
Mesostigmata							
Gamasina (less)	26.9	26.3	1.271	1.305	0.0916	-	-
Rhodacaridae							
Uropodina							
Astigmata							
Cryptostigmata	66.6	99.4	1.635	1.757	0.1203	-	-
<u>INSECTA</u>							
Collembola							
Onychiuridae	5.5	13.3	0.763	0.927	0.0858	-	-
Poduridae	0.7	0.7	0.188	0.184	0.0502	-	-
Isotomidae	48.9	65.6	1.630	1.647	0.0847	-	-
Entomobryidae	2.2	1.1	0.342	0.230	0.0792	-	-
Sminthuridae	41.7	10.6	1.500	0.997	0.0706	12.7 cm diam.	**
Diptera	2.3	7.6	0.437	0.843	0.0722	10 cm. diam.	**
Coleoptera	2.8	4.2	0.558	0.683	0.0391	10 cm. diam.	*
Thysanoptera	1.5	1.5	0.346	0.342	0.0558	-	-
Hemiptera							
Hymenoptera							
Psocoptera	0.5	0.1	0.147	0.038	0.0291	12.7 cm diam.	*
Protura							
Diplura							
<u>MYRIAPODA</u>							
Chilopoda							
Diplopoda							
Symphyla							
Pauropoda							
<u>CRUSTACEA</u>							
Isopoda							

* - significant difference between means at the 5% level

** - significant difference between means at the 1% level

- - means not significantly different.

extraction may be a very important factor affecting efficiency. Animals must physically penetrate the soil and large volumes of sample material can form a barrier which prevents arthropods reaching the collecting funnel (Murphy, 1958a). Conversely, if the volumes of soil in the sieve are small, the temperature and humidity gradients through the sample, that are believed to be necessary for the efficient extraction of soil arthropods, may not be established. The detection of differences in extraction efficiency due to the effect of the depth of sample material on the sieve, was investigated in two ways; either by using intact soil cores, carefully sliced to different thicknesses with a sharp knife or by using different depths of broken sample material spread evenly on the funnel sieve.

a) Methods

(i) Comparisons of different depths of intact soil cores placed in an inverted position on the funnel sieve.

Samples from a mixed-deciduous woodland site and a fallow-arable site both on a Batcombe series silt-clay loam soil were used in these comparisons. Three sets each of sixteen soil cores were taken from each site. At the woodland site, soil cores 5 cm diameter and 5 cm deep were taken in groups of three as close together as possible. At the fallow site, soil cores 10 cm diameter and 5 cm deep were taken in the same way. The soil cores were taken with a sampling tool of the appropriate diameter (Fig. 15a & b). One soil core from each set of three was placed undisturbed in an intact and inverted position on a single Rothamsted Berlese/Tullgren funnel unit. The second soil core was cut horizontally into an upper and a lower half, each 2.5 cm deep, and each half was placed separately in an intact and inverted position on two

TABLE 26. COMPARISON OF DEPTH OF SAMPLE MATERIAL
INTACT SOIL CORES SUB-DIVIDED AND PLACED INVERTED ON THE
FUNNEL SIEVE

TREATMENTS - 5 cm diameter and 5 cm deep v. 2 x 5 cm
diameter, 2.5 cm deep v. 4 x 5 cm diameter
and 1.25 cm deep

SOIL TYPE - BATCOMBE SERIES CLAY LOAM

SITE - MIXED DECIDUOUS, WOODLAND - MANOR WOOD,
ROTHAMSTED

SAMPLES - 5 cm diameter and 5 cm deep

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 CORES			TRANSFORMED (MEANS - LOG (n + 1))				MORE EFFIC/ IENT METHOD	LEVEL OF SIGNI/ FICANCE
	5cm.	2.5cm	1.25 cm	5cm	2.5cm	1.25 cm	S.E.		
<u>ARACHNIDA</u>									
Pseudoscorpiones									
Araneae	0.4	0.6	0.1	0.113	0.154	0.038	0.069	-	-
Acari									
Prostigmata	14.4	12.6	12.6	1.115	1.092	1.035	0.068	-	-
Mesostigmata									
Gamasina(less)	6.3	5.5	5.4	0.803	0.751	0.769	0.057	-	-
Rhodacaridae	1.1	0.8	2.2	0.270	0.173	0.451	0.060	Sub-Div.	**
Uropodina	8.9	9.2	7.7	0.887	0.877	0.827	0.084	-	-
Astigmata	1.5	0.9	1.9	0.278	0.232	0.250	0.068	-	-
Cryptostigmata	26.5	27.2	21.2	1.393	1.352	1.323	0.061	-	-
<u>INSECTA</u>									
Collembola									
Onychiuridae	8.3	6.7	16.6	0.806	0.804	1.179	0.080	Sub-Div.	**
Poduridae	0.3	0.2	0.6	0.094	0.075	0.143	0.041	-	-
Isotomidae	29.2	25.4	35.3	1.430	1.369	1.477	0.064	-	-
Entomobryidae	1.4	0.5	0.9	0.244	0.124	0.232	0.062	-	-
Sminthuridae	10.6	11.0	10.4	1.005	1.004	0.999	0.060	-	-
Diptera	1.6	2.5	2.6	0.330	0.408	0.439	0.083	-	-
Coleoptera	1.0	0.7	0.6	0.227	0.191	0.180	0.051	-	-
Thysanoptera									
Hemiptera									
Hymenoptera									
Psocoptera									
Protura									
Diplura									
<u>MYRIAPODA</u>									
Chilopoda	0.9	0.5	1.7	0.243	0.103	0.359	0.058	Sub-Div.	*
Diplopoda	0.4	0.7	0.4	0.105	0.180	0.097	0.045	-	-
Symphyla									
Pauropoda	0.3	0.6	0.5	0.086	0.151	0.135	0.044	-	-
<u>CRUSTACEA</u>									
Isopoda	1.6	2.5	2.6	0.336	0.369	0.485	0.044	-	-

* - significant difference between means at the 5% level

** - significant difference between means at the 1% level

- - means not significantly different.

COMPARISON OF DEPTH OF SAMPLE MATERIAL

INTACT SOIL CORES SUB-DIVIDED AND PLACED INVERTED ON THE FUNNEL SIEVE

TREATMENTS - 10 cm diam. x 5 cm deep v 2 x 10 cm diam. x 2.5 cm deep
v 4 x 10 cm diam. x 1.25 cm deep

SOIL TYPE - Batcombe silt-clay loam

SITE - Fallow arable, Pastures, Rothamsted

SAMPLES - 10 cm diameter x 5 cm deep

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 SOIL CORES			TRANSFORMED MEANS - LOG (n + 1)				MORE EFFI/ CIENT METHOD	LEVEL OF SIGNIF/ ICANCE
	1 x 5cm deep	2 x 2.5cm deep	4 x 1.25cm deep	1 x 5cm deep	2 x 2.5cm deep	4 x 1.25cm deep	S.E.		
<u>Arachnida</u>									
Pseudoscorpiones									
Araneae									
Acari									
Prostigmata	0.1	0.1	0.3	0.038	0.038	0.075	0.0286	-	-
Mesostigmata									
Gamasina	0.6	1.0	1.13	0.162	0.254	0.265	0.0551	-	-
(Less) -									
Rhodacaridae									
Uropodina									
Astigmata	0.2	0.1	0.1	0.056	0.019	0.038	0.0254	-	-
Cryptostigmata	0.2	0.4	0.3	0.049	0.086	0.075	0.0393	-	-
<u>Insecta</u>									
Collembola									
Onychiuridae									
Poduridae									
Isotomidae	6.6	5.8	4.2	0.787	0.755	0.658	0.0721	-	-
Entomobryidae									
Sminthuridae	17.8	17.9	10.6	1.195	1.209	1.044	0.0592	-	-
Diptera	0.6	0.8	0.7	0.173	0.210	0.176	0.0509	-	-
Coleoptera	0.5	0.7	0.4	0.143	0.188	0.113	0.0426	-	-
Thysanoptera									
Hemiptera									
Hymenoptera									
Psocoptera									
Protura									
Diplura									
<u>Myriapoda</u>									
Chilopoda									
Diplopoda									
Symphyla									
Pauropoda									
<u>Crustacea</u>									
Isopoda									

- - means not significantly different

more funnel units. The third soil core, from each group of three, was cut horizontally into four slices, each 1.25 cm deep, and each of these sections was placed separately, again intact and inverted, on four more funnel units. For each site, sixteen replicate samples were extracted either as on 5 cm deep, two 2.5 cm deep and four 1.25 cm deep sample units. The numbers of arthropods recovered from each subdivision of a soil core were summed for statistical analysis.

(ii) A comparison of different depths of broken soil cores placed on the funnel sieve

Three sets of sixteen soil cores, each 10 cm diameter and 5 cm deep were taken from a permanent pasture site on a Batcombe series clayloam soil. The soil cores were taken in groups of three as close together as possible as in the previous comparison. Two soil cores from each set of three were broken by hand into small pieces and the pieces were mixed together before being spread on the sieve of a single funnel unit. The third sample was broken into small pieces in the same way and placed on the sieve of another funnel unit. This process was repeated for all samples so that sixteen funnel units contained double, broken soil cores and sixteen funnel units contained single ones. All the samples were extracted simultaneously on the same apparatus. The numbers of arthropods obtained from the single broken samples were doubled to allow a direct comparison to be made between the different depths of sample material.

b) Results and Discussion

Results of the effects of depth of intact soil cores on the efficiency of extraction are summarized in Tables 26 & 27. . Few arthropods were recovered from the samples taken from the fallow site,

despite the use of 10 cm diameter cores, and many groups of soil arthropods were not represented. Consequently, valid comparisons for the fallow site were few, and no significant differences between intact and sub-divided cores were recorded. Isotomid and sminthurid springtails, the only arthropod groups present in large numbers in these samples, were recovered in greater numbers from the deeper soil cores, but the differences were not significant.

Many more arthropods were recovered from the 5 cm diameter cores taken from the woodland site, but again few significant differences between treatments were recorded. The only significant differences showed that rhodacarid mites, onychiurid springtails and centipedes were extracted in greater numbers from the shallow sub-divided soil cores than from the whole ones. Astigmatid mites, podurid springtails, dipterous larvae, pauropods, diplopods and isopods were all extracted in greater numbers from shallow, sub-divided soil cores than from whole cores but the differences were not significant. Conversely, more prostigmatid, mesostigmatid, (except for rhodacarids), and cryptostigmatid mites, isotomid and entomobryid springtails, beetles and spiders were extracted from deeper samples, but again these differences were not significant. The effects of compression and disturbance probably influenced the results of this comparison in favour of the deeper soil cores, some compression and disturbance being unavoidable when sub-dividing the soil cores. It was impossible to determine how important compression and disturbance were in these results but was obviously not an important factor for those groups that were extracted in significantly greater numbers from the sub-divided soil cores.

In the comparison of different depths of broken samples the

effects of compression and disturbance were the same. (Table 28).

Onychiurid springtails and dipterous larvae were again extracted in greater numbers from the shallow samples. Possibly, these groups have greater difficulty than other soil arthropods in moving through the soil, or are less able to detect or respond to temperature and humidity gradients. There seemed to be a tendency for the deeper dwelling, euedaphic fauna to be more efficiently extracted from the shallow soil samples than were the surface-living hemiedaphic forms. Some soil arthropods were extracted in greater numbers from the deeper soil samples. For instance, gamasid mites, podurid, isotomid and sminthurid springtails and psocids were extracted in significantly greater numbers from these samples. Increased numbers of cryptostigmatid mites and entomobryid springtails recovered from the deeper soil samples were not significant. Possibly, those arthropods that were recovered more efficiently from deeper soil samples were able to move more easily through the greater depth of soil or respond better to steeper or more stable temperature and humidity gradients. It is possible that physical conditions, within the deeper layers of soil, allowed these arthropods to survive for longer periods and this prolonged activity possibly increased their chances of escape from the soil sample. Less extreme conditions, prevailing for longer periods, may also allow eggs and other immobile stages time to transform into mobile forms, able to escape from the soil core.

c) Conclusions

Few definite conclusions could be reached on the effects of depth of sample material on the efficiency with which most arthropod groups were extracted from soil. Clay soil was chosen for these comparisons

TABLE 28

COMPARISON OF DEPTH OF SAMPLE MATERIAL
BROKEN SOIL CORES EXTRACTED AS SINGLE OR DOUBLE UNITS

TREATMENTS - BROKEN SAMPLES DOUBLE DEPTH V. BROKEN SAMPLES SINGLE DEPTH
SOIL TYPE - BATCOMBE SERIES CLAY LOAM
SITE - GRASSLAND HIGHFIELD ROTHAMSTED
SAMPLES - 10 cm diameter x 5 cm deep cores (DOUBLE SAMPLE RESULTS HALVED)

- * - SIGNIFICANT DIFFERENCE BETWEEN MEANS AT THE 5% LEVEL
** - SIGNIFICANT DIFFERENCE BETWEEN MEANS AT THE 1% LEVEL
- - MEANS NOT SIGNIFICANTLY DIFFERENT

Animal Group	Method	Arithmetic means of 16 soil cores		Transformed Means- Log (n + 1)			More Efficient Method	Level of Significance
		Double Broken	Single Broken	Double Broken	Single Broken	S.E.		
ARACHNIDA								
PSEUDOSCORPIONES								
ARANEAE								
ACARI								
PROSTIGMATA		55.2	67.9	1.612	1.638	0.1003		-
MESOSTIGMATA								
GAMASINA (LESS)		21.6	10.7	1.228	0.918	0.0927	Double	*
RHODACARIDAE								
UROPODINA								
ASTIGMATA								
CRYPTOSTIGMATA		58.9	40.8	1.646	1.362	0.1157		-
INSECTA								
COLLEMBOLA								
ONYCHIURIDAE		16.2	23.6	0.990	1.274	0.0990	Single	*
PODURIDAE		0.9	0.2	0.236	0.075	0.0445	Double	*
ISOTOMIDAE		78.9	37.2	1.818	1.488	0.0846	Double	**
ENTOMOBRYIDAE		0.7	0.2	0.182	0.038	0.0542		-
SMINTHURIDAE		39.7	15.8	1.597	1.132	0.0598	Double	**
DIPTERA		1.4	3.9	0.339	0.631	0.0624	Single	**
COLEOPTERA		1.6	1.9	0.370	0.368	0.0603		-
THYSANOPTERA		0.6	0.4	0.161	0.081	0.0511		-
HEMIPTERA								
HYMENOPTERA								
PSOCOPTERA		1.0	0.1	0.266	0.019	0.0298	Double	**
PROTURA								
DIPLURA								
MYRIAPODA								
CHILOPODA								
DIPLOPODA								
SYMPHYLA								
PAUROPODA								
CRUSTACEA								
ISOPODA								

because it is probably the most difficult soil from which to extract soil arthropods. Any differences in the numbers of arthropods recovered, that were due to the effects of sample depth, would be greater in clay soil than on most other soils because it is probably the most difficult soil for arthropods to move through. Onychiurid springtails and dipterous larvae were extracted more efficiently from thin layers of clay soil than from thick layers. Moreover, these two groups of arthropods were extracted more efficiently by mechanical methods than by dry-funnel methods in Sections IV and V. Probably the soil cores used in the dry-funnel methods were too thick to allow efficient extraction of these groups. However, the extraction of other groups of soil arthropods, except perhaps for the truly euedaphic forms, is not improved by using thin layers of sample material on the funnel sieve.

3. The effect of collecting fluids on the relative efficiency of dry-funnel methods

Macfadyen (1961) postulated that the collecting fluids used in dry-funnel extraction methods should be odourless, non-repellent, non-volatile and should kill animals falling into it. The questionnaires, described in Section II, indicated that many soil zoologists used some form of ethyl alcohol as a collecting fluid, although some favoured other fixatives or water. For example, saturated picric acid solution was recommended for use in the Oxford infra-red extractor (Kempson et al., 1963). Therefore it seemed of value to compare the efficiency of some of the commonly-used collecting fluids so a comparison was made of the effects of distilled water, ethyl alcohol and picric acid solution as collecting fluids, on the efficiency of the Rothamsted Berlese/Tullgren funnel apparatus.

a) Methods

Three sets of sixteen soil cores, 10 cm diameter and 5 cm deep, were taken from a uniform area of grassland on a Batcombe series silt-clay loam soil. Groups of three soil cores were taken as closely together as possible with a sampling tool (Fig. 15a). One soil core from each set of three was extracted into 70% aqueous ethyl alcohol, (industrial methylated spirits, containing < 5% wood naptha) with glycerol added (in the ratio of 20 : 1) in the collecting vial at the base of the funnel. The second soil core was extracted into distilled water and the third into a saturated aqueous solution of picric acid. Each group of three soil cores received the same treatment and all the cores were placed undisturbed in an intact, inverted position on the funnel sieves.

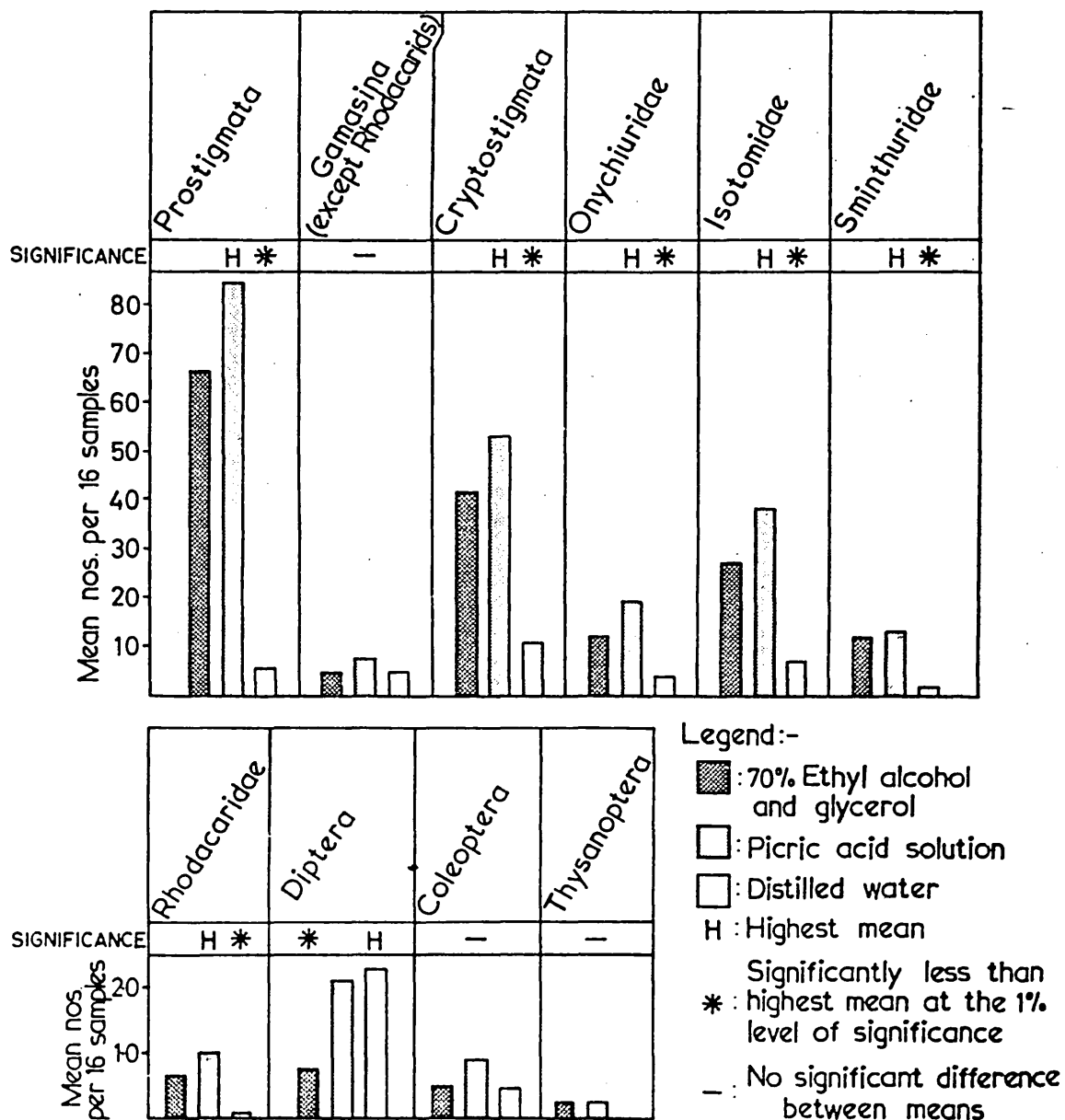
b) Results and discussion

The results, summarized in Fig. 45, show that many more arthropods were collected into those vials containing alcohol and picric acid solutions than into those containing water. Most groups of mites and springtails were collected in significantly greater numbers ($P < 0.01$) when using alcohol or picric acid solutions than when using distilled water as the collecting fluid. Greater numbers of most arthropod groups were collected when using saturated picric acid solution than when either alcohol or distilled water were used as collecting fluids, but these differences were not significant. Exceptionally, dipterous larvae were collected in significantly greater numbers into distilled water and picric acid solution than into aqueous ethyl alcohol and glycerol mixture.

It seems that the nature of the collecting fluid used in this type of dry-funnel apparatus had a particularly important effect upon

FIG. 43.

TULLGREN FUNNEL EXTRACTION
THE EFFECT OF COLLECTING FLUIDS ON THE
NUMBERS OF ARTHROPODS RECOVERED
A COMPARISON OF ALCOHOL, PICRIC ACID, SOLN. AND WATER



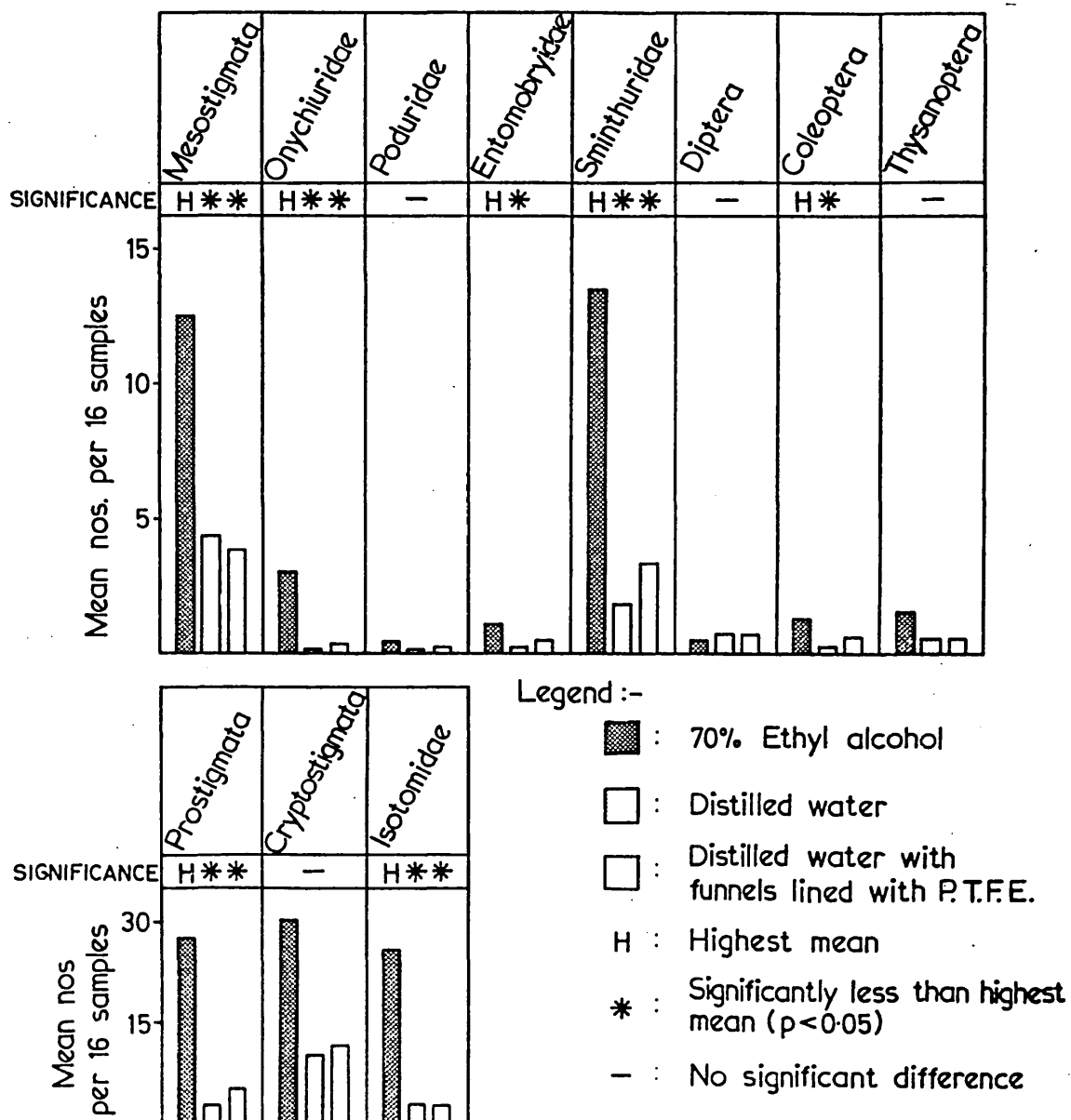
the numbers of arthropods recovered from these soil samples. Further comparisons were made to discover why this was so.

Firstly, the possibility that arthropods were escaping from those funnels with distilled water in the collecting vials was tested. Three sets of sixteen soil cores, 10 cm diameter and 5 cm deep, were taken in groups of three from the same grassland site as in previous comparisons. One set of sixteen cores were extracted into ethyl alcohol and glycerol, and another into distilled water as before. The third set was also extracted into distilled water, but the funnels used for these samples had inside surfaces which were coated with "Fluon" (an aqueous suspension of polytetrafluorethylene). This non-stick compound was painted onto the inside linings of the funnels and when dry, prevented any arthropods from crawling up the inside walls of the funnels and escaping from the apparatus in this way. The results in Fig.44, show that significantly greater numbers of arthropods were collected into vials containing ethyl alcohol than into distilled water even with the coated funnels. Again more dipterous larvae were collected into distilled water than into ethyl alcohol but this time, differences were not significant. There were no significant differences between the number of arthropods collected into the vials containing distilled water beneath the Fluon-coated and those collected by the uncoated funnels, indicating that few, if any arthropods were escaping from the apparatus because they were not killed by the collecting fluid.

Possibly the greater numbers of arthropods collected into ethyl alcohol could be due to the volatile properties of the liquid (although this was unlikely to be the cause of the effectiveness of picric acid solution, which has a vapour pressure very similar to water (Sidgwick and Aldous, 1921)). To test this theory and to confirm previous results, four sets of sixteen soil cores were taken in groups of four from the

FIG. 44.

TULLGREN FUNNEL EXTRACTION
THE EFFECT OF COLLECTING FLUIDS ON THE
NUMBERS OF ARTHROPODS RECOVERED
A COMPARISON OF ALCOHOL, DISTILLED WATER AND
DISTILLED WATER WITH FUNNELS LINED WITH P.T.F.E.



same grassland site. One sample from each set was extracted into 70% aqueous ethyl alcohol with glycerol in the collecting vial, one was extracted into specially constructed collecting vials containing distilled water but with a small quantity of ethyl alcohol contained in a side-arm projecting from each collecting vial (Fig. 45). The third soil core was extracted into distilled water as previously and a fourth into distilled water containing a drop of detergent liquid to reduce the surface tension. The results in Fig. 46, demonstrate that significantly more prostigmatid and gamasid mites, onychiurid and sminthurid springtails and thrips, fell into those collecting vials containing ethyl alcohol, either as the collecting fluid or in the side-arms, than into distilled water, with or without detergent. Greater numbers of most other groups of arthropods were also found in those vials containing ethyl alcohol than those containing only distilled water or distilled water and detergent, but these differences were not significant at the 5% probability level. The numbers of dipterous larvae collected into distilled water, with or without detergent, were also much greater than the numbers recovered when using ethyl alcohol as the collecting fluid or in the side-arm. Comparisons of collecting fluids are summarised in Tables 29 - 31.

In an attempt to explain these differences more fully, the soil cores that had already been extracted over distilled water and those extracted over 70% aqueous ethyl alcohol and glycerol were carefully removed from the dry-funnel apparatus, soaked in tap water and stored at -10°C . Later these samples were extracted using the Salt and Hollick flotation method to discover what proportion of the various groups of arthropods could be recovered from soil cores that had either been extracted over distilled water and over ethyl alcohol in the collecting vial. Table 32, shows that only a few groups of arthropods could be extracted

FIG. 45.

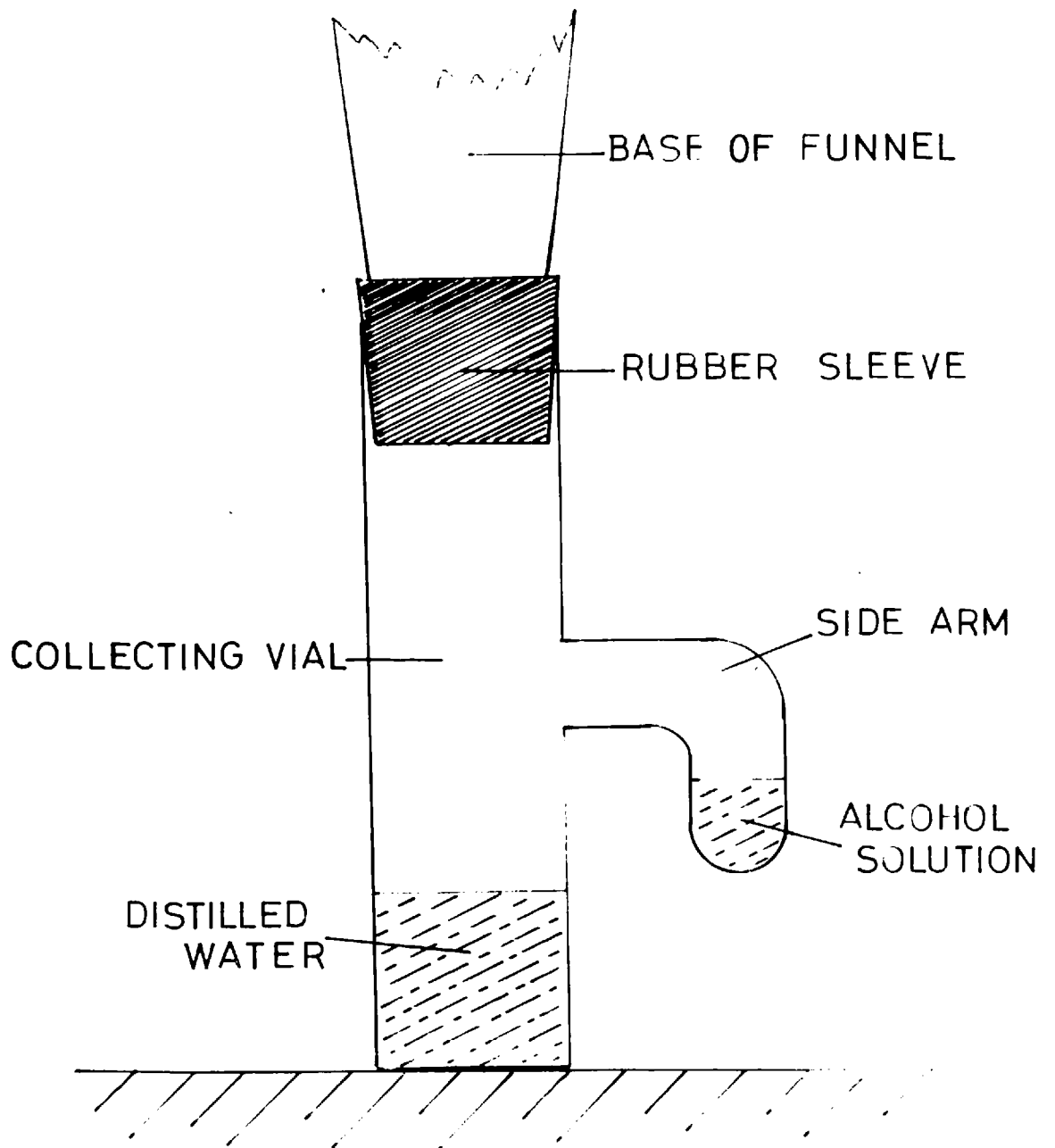
COLLECTING VIAL WITH SIDE ARM

FIG. 46.

TULLGREN FUNNEL EXTRACTION
THE EFFECT OF COLLECTING FLUIDS ON THE
NUMBERS OF ARTHROPODS RECOVERED

A COMPARISON OF ALCOHOL, DISTILLED WATER, DISTILLED
WATER WITH ALCOHOL IN SIDE-ARM OF COLLECTING
TUBE, AND DISTILLED WATER WITH DETERGENT ADDED

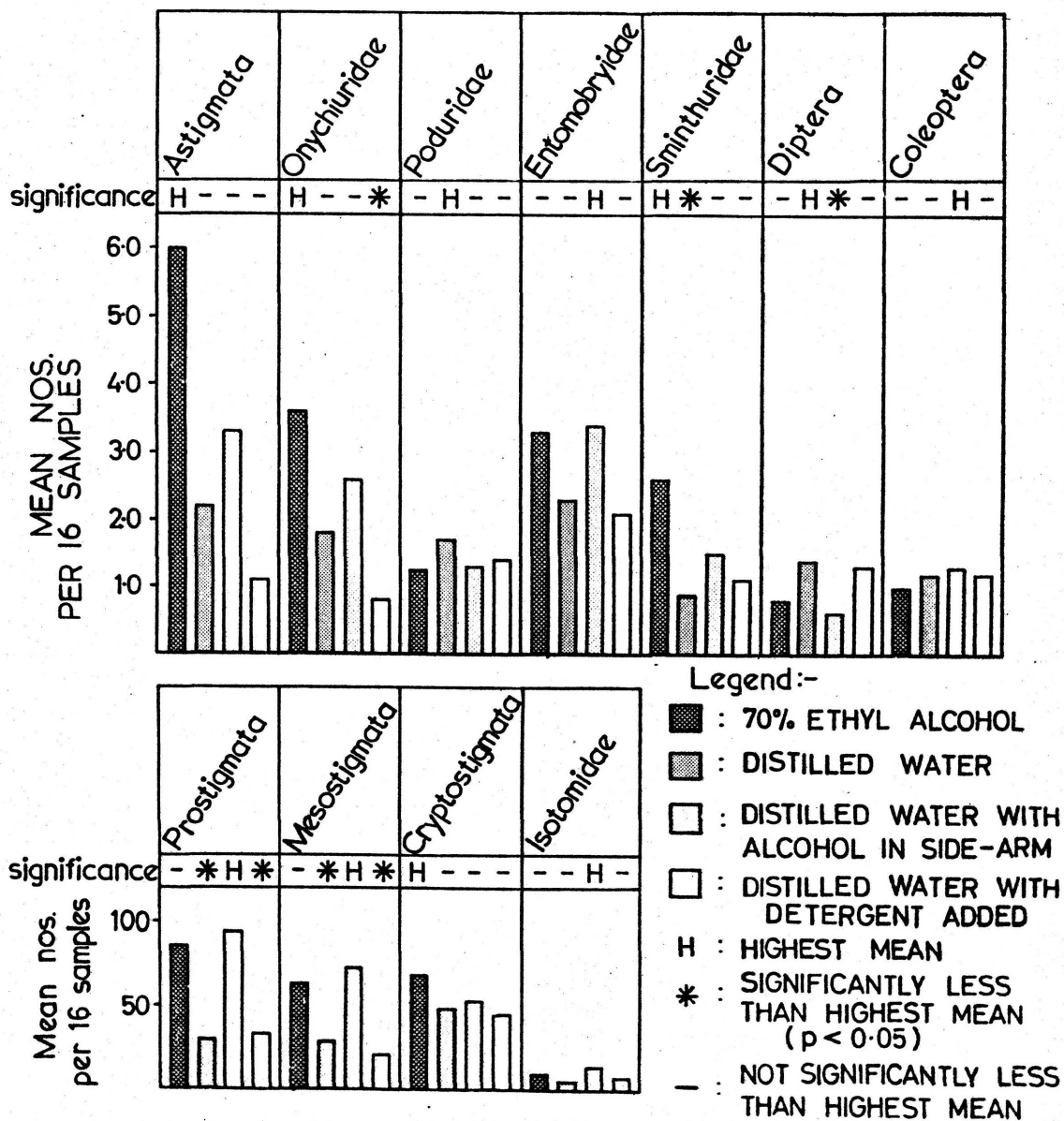


TABLE 29. COMPARISON OF COLLECTING FLUIDS

TREATMENTS - 70% METHYL ALCOHOL + GLYCEROL v. DISTILLED WATER v. PICRID ACID SOLUTION

SOIL TYPE - BATCOMBE SERIES SILT-CLAY LOAM

SITE - GRASSLAND, HIGHFIELD, ROTHAMSTED

SAMPLES - 5 cm diameter and 15 cm deep - BROKEN ONTO FUNNEL SIEVE.

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 16 CORES			TRANSFORMED MEANS - LOG (n + 1)				MORE EFFIC/IENT METHOD	LEVEL OF SIGNI/FICANCE
	A.	W.	P.A.	A	W	P.A.	S.E.		
<u>ARACHNIDA</u>									
Pseudoscorpiones									
Araneae									
Acari									
Prostigmata	66.4	5.7	84.5	1.779	0.596	1.879	0.0830	A. & P.A.	-
Mesostigmata									
Gamasina (less)	4.5	4.6	7.5	0.587	0.579	0.824	0.0919		-
Rhodacaridae	0.6	0.1	1.0	0.180	0.038	0.262	0.0438	R.A.	-
Uropodina									
Astigmata									
Cryptostigmata	41.9	10.7	53.2	1.525	0.830	1.633	0.0959	A. & P.A.	-
<u>INSECTA</u>									
Collembola									
Onychiuridae	12.1	3.9	19.4	1.005	0.582	1.218	0.0817	A. & P.A.	-
Poduridae									
Isotomidae	27.3	7.1	38.5	1.361	0.811	1.534	0.0753	A. & P.A.	-
Entomobryidae									
Sminthuridae	12.1	2.0	13.4	1.080	0.452	1.084	0.0617	A. & P.A.	-
<u>DIPTERA</u>	0.7	2.3	2.1	0.184	0.493	0.420	0.0586	W. & R.A.	**
Coleoptera	0.5	0.4	0.9	0.124	0.124	0.213	0.0480	-	-
Thysanoptera	0.2	0	0.2	0.075	0.000	0.067	0.0314	-	-
Hemiptera									
Hymenoptera									
Psocoptera									
Protura									
Diplura									
<u>MYRIAPODA</u>									
Chilopoda									
Diplopoda									
Symphyla									
Pauropoda									
<u>CRUSTACEA</u>									
Isopoda									

A.- Alcohol W.- Water P.A. - Picric Acid

* - significant difference between means at the 5% level

** - significant difference between means at the 1% level

- - means not significantly different.

TREATMENTS - 70% methyl alcohol + glycerol v distilled water
with 'fluon' lined funnels v distilled water

SITE - Grassland, Highfield, Rothamsted

funnel sieve

* - significant difference between means at the 5% level

** - significant difference between means at the 1% level

- - means not significantly different

A - alcohol

[illegible]

TABLE 31

COMPARISON OF COLLECTING FLUIDS

TREATMENTS - 70% METHYL ALCOHOL + GLYCEROL V. DISTILLED WATER V. DISTILLED WATER
+ DETERGENT V. DISTILLED WATER WITH ALCOHOL IN SIDE-ARM

SOIL TYPE - BATCOMBE SERIES SILT CLAY LOAM

SITE - GRASSLAND, HIGHFIELD, ROTHAMSTED

SAMPLES - 10 cm diameter, 5 cm deep - intact and inverted on funnel sieve

Animal Group \ Method	Arithmetic means of 16 soil cores				Transformed means Log (n + 1)					More Effic- method	Level of Signi- ficance
	Alcohol	Water	Water with alcohol in side-arm	Water and detergent	Alcohol	Water	Water with alcohol in side-arm	Water and detergent	S.E.		
ARACHNIDA											
ACARI											
PROSTIGMATA	87.1	30.6	94.8	31.9	1.865	1.469	1.869	1.377	0.0815	Alcohol	**
MESOSTIGMATA											
GAMASINA	63.7	29.9	72.9	21.3	1.789	1.442	1.817	1.307	0.0497	Alcohol	**
UROPODINA	0.1	0.4	0.3	0.4	0.038	0.097	0.075	0.086	0.0416	-	-
ASTIGMATA	6.0	2.2	3.4	1.1	0.439	0.387	0.449	0.230	0.0983	-	-
CRYPTOSTIGMATA	68.3	48.3	53.1	45.9	1.799	1.643	1.611	1.602	0.0706	-	-
INSECTA											
COLLEMBOLA											
ONYCHIURIDAE	3.3	1.8	2.6	0.8	0.551	0.318	0.464	0.176	0.0778	Alcohol	**
PODURIDAE	1.3	1.7	1.3	1.4	0.162	0.283	0.222	0.262	0.0836	-	-
ISOTOMIDAE	10.7	6.2	14.4	8.6	0.957	0.681	1.003	0.824	0.0986	-	-
ENTOMOBRYIDAE	3.3	2.3	3.4	2.1	0.502	0.412	0.456	0.360	0.0919	-	-
SMINTHURIDAE	2.6	0.9	1.5	1.1	0.466	0.194	0.351	0.262	0.0643	Alcohol	*
DIPTERA	0.5	1.8	0.4	1.1	0.135	0.321	0.124	0.259	0.0514	Water	*
COLEOPTERA	1.0	1.2	1.4	1.2	0.248	0.260	0.257	0.285	0.0641	-	-
THYSANOPTERA	2.1	0.8	0.8	0.6	0.440	0.213	0.202	0.151	0.0545	Alcohol	**
HEMIPTERA	0.4	0.3	0.3	0.6	0.081	0.075	0.062	0.094	0.0517	-	-

TABLE 32

TO DETERMINE WHETHER SOIL CORES EXTRACTED BY THE BERLESE-TULLGREN FUNNEL METHOD MAY BE FURTHER EXTRACTED BY THE SALT AND HOLLICK FLOTATION METHOD

Method Animal Group	ARITHMETIC MEANS OF SIXTEEN SOIL CORES					
	5 cm diam.15cm deep Broken onto funnel sieve into 70% alcohol		10 cm diam.5cm deep Intact inverted into 70% alcohol		10 cm diam.x 5cm deep Intact inverted into distilled water	
	Funnel Extraction	Subsequent Flotation	Funnel Extraction	Subsequent Flotation	Funnel Extraction	Subsequent Flotation
ARACHNIDA						
ARANEAE	0	0.2	0.4	0	0.1	0.1
ACARI						
PROSTIGMATA	65.9	1.3	87.1	1.1	30.6	1.12
MESOSTIGMATA						
GAMASINA (LESS)	3.4	1.1	63.7	6.6	29.9	1.62
RHODACARIDAE	0.4	0.5	0	0.8	0	0.6
UROPODINA			0.1	0.1	0.4	0.1
ASTIGMATA			6.0	4.4	2.2	3.4
CRYPTOSTIGMATA	50.0	3.0	68.3	3.2	48.3	2.5
INSECTA						
COLLEMBOLA						
ONYCHIURIDAE	8.5	3.7	3.6	3.4	1.8	1.5
PODURIDAE	0.1	0	1.2	0.4	1.7	0.6
ISOTOMIDAE	18.5	2.0	10.7	0.8	6.2	0.3
ENTOMOBRYIDAE	0.1	0.2	3.3	0.9	2.3	0.2
SMINTHURIDAE	10.5	0.5	2.6	2.9	0.9	65.5
DIPTERA	2.1	8.0	0.8	9.1	1.4	2.6
COLEOPTERA	0.4	0.5	1.0	0.7	1.2	1.0
THYSANOPTERA	0.1	0	2.1	15.6	0.8	8.4
HEMIPTERA	0	3.2	0.4	1.1	0.3	0.5
HYMENOPTERA			0.2	1.2	0.3	0.7
PSOCOPTERA			0.1	0.1		0.1
PROTRURA	0	0.7	0.2	0.4	0	0.2
DIPLURA						
MYRIAPODA						
CHILOPODA			0.1	0.1		
DIPLOPODA						
SYMPHYLA						
PAUROPODA	0.2	0	0.2	0	0.1	0

in greater numbers from samples that had been extracted into distilled water than from those that had been extracted into ethyl alcohol e.g. astigmatid mites, sminthurid springtails and thrips. Most of the results confirmed the findings in Section V when the relative efficiencies of the funnel and flotation method were compared. Arthropods that were poorly extracted by flotation then, were also only poorly extracted by the flotation method used after funnel extraction, e.g. prostigmatid mites. Some arthropods, e.g. onychiurid springtails, were extracted in large numbers by flotation even after the samples had first been extracted by the dry-funnel method into ethyl alcohol or water. Other arthropods were extracted in greater numbers by the subsequent flotation method after samples had been extracted into any of the different collecting fluids used in the original funnel extraction. This may indicate that some eggs had hatched in the intervening period between the two extractions. Certainly, the numbers of sminthurid springtails, recovered by flotation after funnel extraction over water, are very large, especially when earlier comparisons had shown sminthurid springtails were only poorly recovered by flotation methods. A greater number of dipterous larvae were extracted by the flotation method from those soil cores extracted into ethyl alcohol than from the soil cores extracted into water, confirming that ethyl alcohol is a particularly poor collecting fluid for these insect larvae.

Macfadyen (1961) made a similar study of collecting fluids with his canister apparatus and collected more animals when distilled water was used as the collecting fluid in the canister than when ethyl alcohol or potassium dichromate solution was used. Because these results were in complete disagreement with those from my study of the Rothamsted Berlese/Tullgren funnels, I compared ethyl alcohol and distilled water

as collecting fluids, using the Macfadyen canister apparatus described by Hale (1962). These results, Table 33, show that almost every group of arthropods was extracted in greater numbers into distilled water than into 70% aqueous ethyl alcohol in this apparatus as Macfadyen reported. These contrasting results are probably due to the construction of the apparatus. The collecting fluid is completely enclosed just beneath the soil core in the canister apparatus, so that a high concentration of alcohol vapour could kill the arthropods in the soil core before they were able to escape. In the Rothamsted pattern funnel, the alcohol vapour is less concentrated and may act only as an irritant or attractant, causing greater activity of the soil arthropods, so increasing the chances of them falling into the collecting fluid. However, although the vapour phase of ethyl alcohol is probably responsible for increasing or decreasing the number of arthropods recovered from a soil core, it seems unlikely that the vapour phase of picric acid solution could be the cause of increased numbers of arthropods being recovered when it is used as collecting fluid, so some other explanation is needed. It also seems unlikely that distilled water acts as an attractant or repellent in the Rothamsted pattern funnels, but obviously is important in maintaining a steep humidity gradient in the canister apparatus.

4. The effects of light on the relative efficiency of dry-funnel methods

Tullgren (1918) introduced the electric light bulb as a source of heat to dry out sample material and collect arthropods from it. Trägård (1933) suggested that light was an effective stimulus to extract negatively phototactic soil arthropods, particularly in the early stages

TABLE 33

COMPARISON OF COLLECTING FLUIDS
MACFADYEN HIGH-GRADIENT CANISTER APPARATUS

TREATMENTS - ALCOHOL AS COLLECTING FLUID V WATER AS COLLECTING FLUID

SOIL TYPE - BATCOMBE SILT-CLAY LOAM

SITE - GRASSLAND, HIGHFIELD, ROTHAMSTED

SAMPLES - 3.8 cm diameter 3 cm deep

* - SIGNIFICANT DIFFERENCES BETWEEN MEANS AT THE 5% LEVEL

** - SIGNIFICANT DIFFERENCES BETWEEN MEANS AT THE 1% LEVEL

- MEANS NOT SIGNIFICANTLY DIFFERENT

ANIMAL GROUP \ METHOD	ARITHMETIC MEANS OF 16 SOIL CORES		TRANSFORMED MEANS - LOG (n+1)			MORE EFFICIENT METHOD	LEVEL OF SIGNIFICANCE
	ALCOHOL	WATER	ALCOHOL	WATER	S.E.		
ARACHNIDA							
ACARI							
PROSTIGMATA	0	0.2	0	0.056	0.0307	-	-
MESOSTIGMATA							
GAMASINA	0.1	0.4	0.019	0.113	0.0297	WATER	*
ASTIGMATA	0	0.7	0	0.168	0.0589	-	-
CRYPTOSTIGMATA	0.2	0.7	0.056	0.173	0.0518	-	-
INSECTA							
COLLEMBOLA							
ONYCHIURIDAE	0.1	0.3	0.019	0.086	0.0311	-	-
PODURIDAE	0	0.1	0	0.019	0.0280	-	-
ISOTOMIDAE	0.3	3.8	0.086	0.279	0.0797	-	-
SMINTHURIDAE	0.1	0.6	0.019	0.169	0.0360	WATER	**
DIPTERA	0.1	0.1	0.038	0.019	0.0225	-	-
COLEOPTERA	0	0.1	0	0.019	0.0280	-	-
THYSANOPTERA	0.1	0.1	0.019	0.019	0.0188	-	-

of extraction. Dietrick et al. (1959) used a spotlight beam shining up through the collecting vessel and funnel, on to the base of herbage samples, to attract positively phototactic arthropods. Macfadyen (1962a) thought that light was unlikely to affect the extraction of soil arthropods except to deter animals escaping upwards at the start of the extraction. To determine the influence of light in dry-funnel extractors, the following experiment was made.

Methods

Two frameworks each supporting a sheet of clear or black polythene were made to cover ten funnel units each, in a modified high-gradient funnel apparatus. The polythene sheets were supported 5 cm. above the top of the sample containers and were left open at the sides to allow air circulation. Ten pairs of soil cores, 5 cm diameter and 15 cm deep, were taken with the sampling tool (Fig. 15b) from a permanent grassland site on clay-loam soil. The soil cores were broken onto the funnel sieves and each group of ten samples was covered over by either black or clear polythene frames. Soil temperatures under both black and clear polythene sheets were monitored using a Grant miniature temperature recorder. Thermistor beads incased in metal probes were placed on the surface of four soil samples in each treatment. When the extraction period began careful adjustment of the voltage controls to the electric light bulbs ensured that the soil surface temperatures under both black and clear polythene increased at the same rates, to approx. 35°C after the first 12 hrs. of heating and to 40°C after five days. The temperature in the lower part of the cabinet was maintained at 15°C $\pm$ 20°C. The arthropods were collected into 70 per cent v/v aqueous ethyl alcohol and glycerol (ratio 20 : 1).

Results and Discussion

The results are summarised in Table 34. Most arthropod groups were extracted in greater numbers from soil cores extracted under the clear polythene sheet, significant increases in the numbers of prostigmatid, gamasid and cryptostigmatid mites, onychiurid, isotomid and entomobryid springtails were observed. Almost all the arthropod groups examined were collected in greater numbers by the heat and light regime than by the heat regime alone.

Not surprisingly, light sensitive species are numerous among soil arthropods, onychiurids, symphylids and pauropods may be harmed by ultra-violet radiation in particular. Negative phototactic responses would prevent arthropods escaping upwards from those dry-funnel apparatus where sample containers are suspended in a heat-baffle, light may not have such a marked effect in apparatus where this escape route is not present.

VII. The effects of temperature and time on storage and extraction of arthropods from soil samples

A. Storage of soil samples before extraction

a) Storage before extraction by mechanical methods

There are few problems associated with the storage of soil samples before extraction by mechanical methods, because these methods do not depend on the locomotor activity of the arthropods as a means of separating them from the soil. Hence, it is recommended that the arthropods in soil samples that are stored at normal temperatures should be killed either by fumigation or by immersing the soil sample in a preservative liquid soon after they are taken. Care must be taken to ensure that the storage conditions prevent decomposition processes taking place within the

TABLE 34

COMPARISON OF SOIL CORE TREATMENTS

TREATMENTS - Rothamsted high-gradient funnel with light and heat
 v Rothamsted high-gradient funnel with heat only.
 SOIL TYPE - Batcombe silt-clay loam
 SITE - Grassland, Highfield, Rothamsted
 SAMPLES - 5 cm diameter and 15 cm deep

* - significant difference between means at the 5% level
 ** - significant difference between means at the 1% level
 - - means not significantly different
 HL - heat and light

METHOD ANIMAL GROUP	ARITHMETIC MEANS OF 12 SOIL CORES		TRANSFORMED MEANS - LOG (n + 1)				MORE EFFI/ CIENT METHOD	LEVEL OF SIGNIF ICANCE
	HEAT	HEAT & LIGHT	HEAT	HEAT & LIGHT	S.E.'s			
					HEAT	HEAT & LIGHT		
<u>Arachnida</u>								
Pseudoscorpiones								
Araneae								
Acari								
Prostigmata	26.9	49.8	1.371	1.629	0.079	0.064	HL	*
Mesostigmata								
Gamasina	11.3	26.1	1.018	1.323	0.072	0.088	HL	*
(Less) -								
Rhodacaridae	8.3	11.0	0.853	1.003	0.102	0.075	-	-
Uropodina	6.1	9.1	0.667	0.927	0.128	0.086	-	-
Astigmata	14.9	31.6	1.082	1.323	0.101	0.115	-	-
Cryptostigmata	226.3	503.1	2.190	2.580	0.115	0.099	HL	*
<u>Insecta</u>								
Collembola								
Onychiuridae	7.3	17.8	0.857	1.159	0.071	0.092	HL	*
Poduridae	0.2	1.1	0.050	0.223	0.034	0.084	-	-
Isotomidae	3.7	16.2	0.375	1.078	0.128	0.120	HL	**
Entomobryidae	10.6	26.8	0.866	1.262	0.111	0.131	HL	*
Sminthuridae	3.8	6.7	0.497	0.770	0.121	0.099	-	-
Diptera	3.6	5.5	0.584	0.553	0.082	0.125	-	-
Coleoptera	0.2	1.1	0.050	0.230	0.034	0.079	-	-
Thysanoptera	2.9	4.2	0.559	0.629	0.053	0.087	-	-
Hemiptera	0.4	1.5	0.083	0.173	0.061	0.106	-	-
Hymenoptera								
Psocoptera								
Protura								
Diplura								
<u>Myriapoda</u>								
Chilopoda	0.2	0.2	0.050	0.050	0.034	0.034	-	-
Diplopoda	0.1	0.1	0.025	0.025	0.025	0.025	-	-
Symphyla	0.9	0.8	0.255	0.173	0.048	0.078	-	-
Pauropoda								
<u>Crustacea</u>								
Isopoda								

soil core and most workers use cold storage at -5°C as recommended by Salt and Hollick (1944). Freezing and subsequent thawing also helps to break down the soil aggregates, particularly in clay soils and free the arthropods, although this pretreatment may result in some disintegration of the more delicate species during wet sieving (Stewart, 1974). In addition to freezing and thawing, Raw, (1955) introduced a chemical dispersion agent and air evacuation process to break down the crumb structure of the more dense clay soils, which otherwise may have been difficult to wash through the wet sieving stage. Samples were then frozen and stored at low temperatures until required (usually $< 5.0^{\circ}\text{C}$).

B. Storage before extraction by dynamic methods

Ideally, arthropods should be extracted from soil soon after samples are taken, but this may be impossible for many reasons. The samples may be too numerous for it to be possible to extract them all at the same time or, unless a portable expedition funnel unit is available (Macfadyen, 1953 and 1962a), extraction of animals from samples may be delayed because the journey from the sampling sites, back to the laboratory may take days or even weeks. When storing samples before extraction by dynamic methods, it is important to keep the arthropods they contain alive, which means that too low a temperature cannot be used. However, if storage is prolonged at higher temperatures, it is possible that the numbers of live animals in the different groups change, because some die or are eaten by predators and eggs hatch. Apparent changes in numbers of animals may also occur because the life cycles of most mites and springtails include immobile stages which may become active. Furthermore, physical changes within the soil samples, such as the rapid growth of fungal mycelia, can interfere with the ability of the arthropods to escape from the soil. Hughes (1954) stored

grassland soil cores for 1-9 days at unspecified temperatures and found that although the numbers of Collembola were not adversely affected, the time taken to extract these animals from soil increased the longer the samples were stored. It was considered that the effects of storage on the efficiency of dry-funnel extraction methods should be critically assessed, so comparisons of how many arthropods emerged from soil cores, stored at different temperatures and for different periods of time, were made.

a) Methods

Six sets of sixteen soil cores (5 cm diameter by 15 cm deep) were taken from a permanent pasture site on Batcombe series silt-clay loam soil. The soil cores were taken with the 5 cm diameter sampling tool described on page 60, and were removed in groups of six soil cores, taken as closely together as possible from a uniform area of grassland. Soil cores were placed individually into labelled polythene bags and sealed with rubber bands before transporting them back to the laboratory. From each set of six cores, two were placed in a 5°C and two in a 20°C constant temperature room. The remaining thirty-two cores were extracted immediately on Rothamsted Berlese/Tullgren funnels, each core being broken up on the funnel sieve and the arthropods collected into an alcohol-glycerol mixture (in the ratio of 20 : 1). After storage periods of twenty-eight and fifty-six days respectively, sixteen soil cores, one from each original set of six, were removed from each of the constant temperature rooms and extracted in the same way as the initial soil cores.

b) Results

The results of the extractions of arthropods from samples stored at each temperature are summarized in Tables 35 and 36 , and Figs 47 and 48.

COMPARISON OF SOIL CORE TREATMENTS
SAMPLE STORAGE BEFORE DRY-FUNNEL EXTRACTION AT 5°C

TREATMENTS - Control samples v 28 days storage v 56 days storage
SOIL TYPE - Batcombe silt-clay loam
SITE - Grassland, Highfield, Rothamsted
SAMPLES - 5 cm diameter and 15 cm deep - broken onto the funnel sieve
* - significant difference between means at the 5% level
** - significant difference between means at the 1% level
- - means not significantly different
I - increase after 56 days
D - decrease after 56 days

[illegible]

COMPARISON OF SOIL CORE TREATMENTS
SAMPLE STORAGE BEFORE DRY-FUNNEL EXTRACTION AT 20°C

TREATMENTS - Control samples v 28 days storage v 56 days storage
SOIL TYPE - Batcombe silt-clay loam
SITE - Grassland, Highfield, Rothamsted
SAMPLES - 5 cm diameter and 15 cm deep - broken onto the funnel sieve

* - significant difference between means at the 5% level
 ** - significant difference between means at the 1% level
 - - means not significantly different
 I - increase
 D - decrease

[illegible]

FIG. 47.

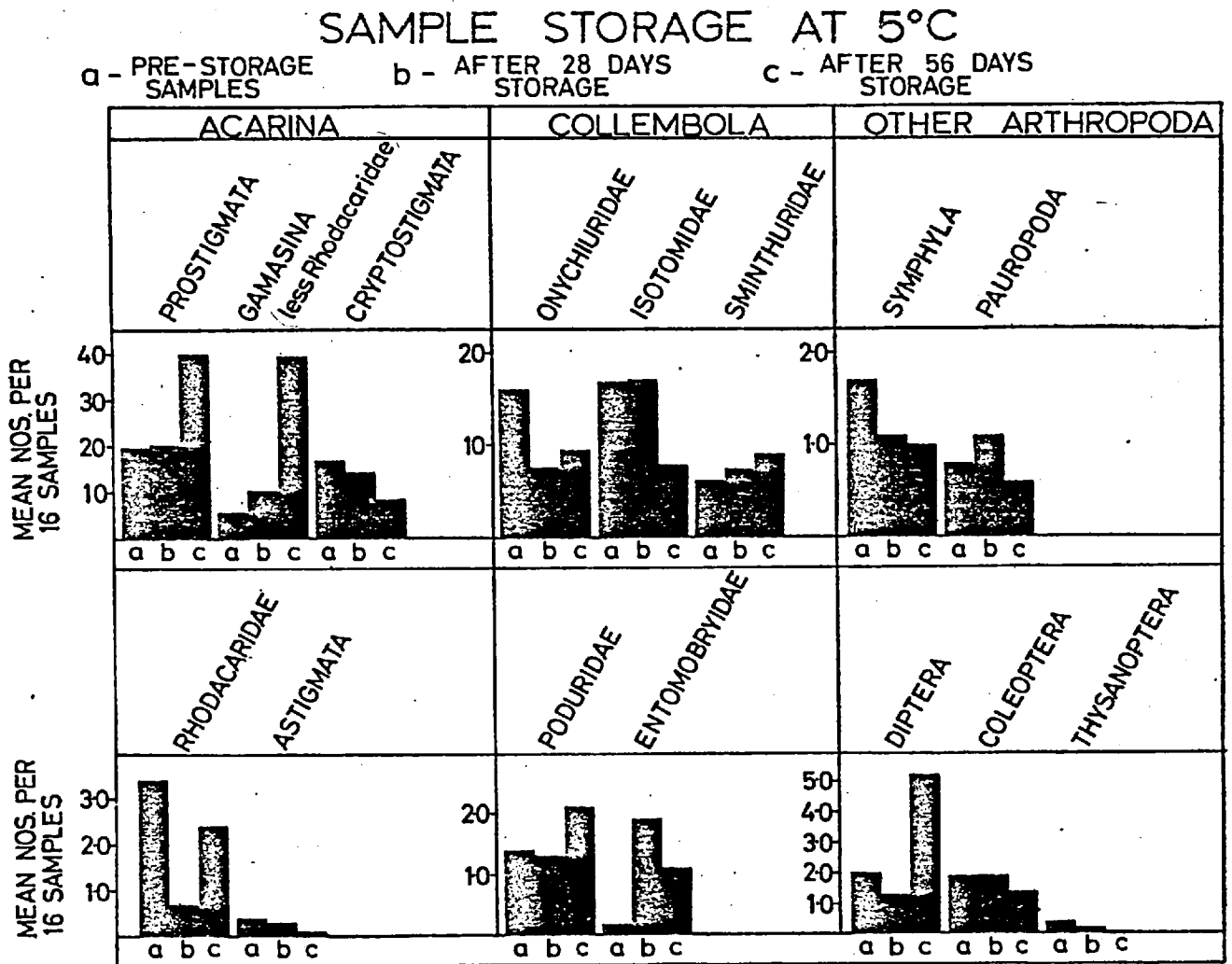
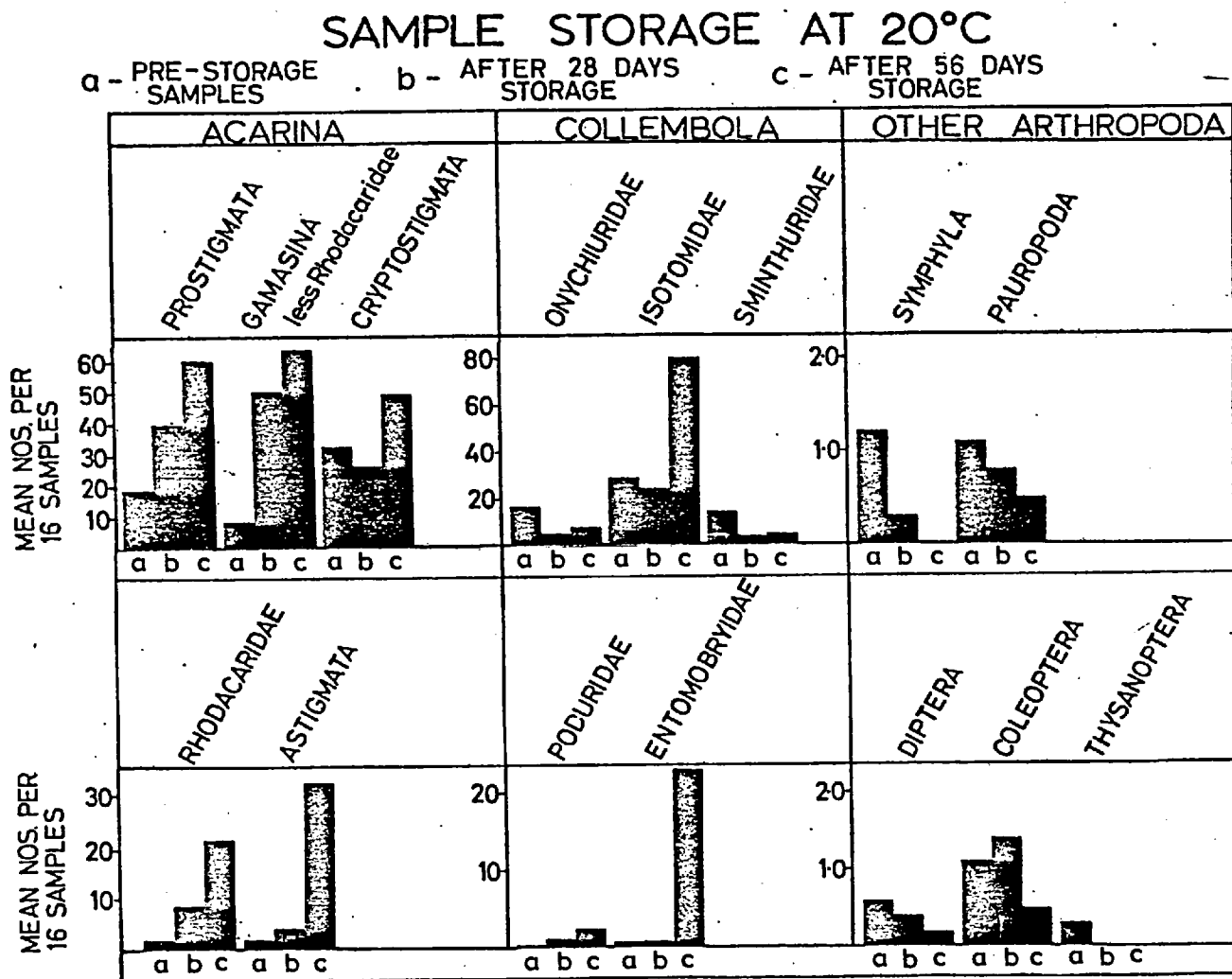


FIG. 48.



After storage for 28 days at 5°C, only rhodacarid mites were significantly decreased in numbers by comparison with the controls, but after 56 days, numbers of other gamasid mites had increased significantly and so had those of dipterous larvae presumably due to the emergence from eggs laid in the soil before the samples were taken. The numbers of thrips, which were very sparse in these samples, decreased significantly after 56 days. Changes in the numbers of most other groups of soil arthropods, even after storage for 56 days at 5°C, were not different at a statistically significant level ($p < 0.05$) and of those significant differences recorded, only gamasid mites changed in numbers consistently with the increasing storage period, e.g. the significant decrease in rhodacarid mites after 28 days did not recur in the samples extracted after 56 days. There was a tendency for numbers of prostigmatid mites and sminthurid springtails to increase after 28 days and even more so after 56 days storage, but these changes were not significant statistically. There were fewer onychiurid and isotomid springtails after 56 days storage at 5°C, probably because numbers of predatory mites increased (Edwards, 1965)..

In samples stored at 20°C, the numbers of arthropods extracted changed much more, even after the shorter period of storage. The numbers of gamasid and rhodacarid mites increased significantly after 28 days and even more by 56 days. The numbers of astigmatid, prostigmatid and cryptostigmatid mites increased with the length of the storage period, although these increases were not always statistically significant at the 5% probability level. The numbers of sminthurid and onychiurid springtails had decreased after 28 days and 56 days storage, sminthurid numbers significantly so ($P < 0.01$), again, presumably, because the

numbers of predatory mites increased (although numbers of some other springtails, notably isotomids, had increased after 56 days storage). At 20°C, the numbers of symphylids and pauropods decreased with storage, those of symphylids significantly so ($P < 0.05$) after 56 days had elapsed.

c) Discussion

These results indicate that storage of soil samples at 5°C even for as long as four weeks does not significantly affect the numbers of most groups of soil arthropods recovered by this dry-funnel extraction method. It is possible that undetected changes, of a continuous nature, e.g. temporary increases followed by temporary decreases were occurring within the stored soil samples but this seems unlikely. The samples were taken in mid-May, at a time when soil arthropods populations were increasing rapidly in field conditions. Hughes (1954) found large increases in the numbers of Collembola from stored samples obtained in the spring, and the hatching of eggs while the samples were in store may well have influenced the results obtained in these comparisons. Climatic effects may also influence the outcome of any storage comparisons and so optimum storage temperatures for soil samples taken at the extremes of the soil temperature range, may well differ. However, in these comparisons, storage of soil samples at 20°C produced large changes in the numbers of arthropods extracted from the soil after a 28 day storage period. Therefore, it would be unwise to store soil samples for long periods of time unless facilities for storage at ca 5°C, or some other optimum temperature, were available. If storage, prior to extraction by dry-funnel methods, is unavoidable, it would seem likely that periods of two to three weeks storage, at ca 5°C, would not cause much change in the accuracy of the results.

2. Extraction patterns of arthropods when extracted by a dry-funnel method

Introduction

Many workers have attempted to define and determine the relative importance of the stimuli that cause arthropods to leave the soil sample during extraction by dry-funnel methods. Most of them have measured the effects of various stimuli on the rate at which arthropods leave soil samples by periodically changing the collecting tubes at the base of the funnel, during the extraction process. Vannier (1964) described an automatic device which changed the collecting tubes at regular, predetermined intervals. An automatic device was also constructed by Bouché and Stawiecki (1973) to study the extraction patterns of animals emerging during a wet-funnel extraction process.

Trägårdh (1933), who investigated the extraction patterns from a dry-funnel method, concluded that desiccation was the main factor that made arthropods leave the soil samples. Haarløv (1947 and 1955) confirmed these results and concluded that the emergence of arthropods from soil samples were associated with changes in both temperature and humidity within soil samples, the springtail Megalothorax minimis (Willem) in particular, responding to a sudden change in temperature. Macfadyen (1961), using three different heating regimes and counting the number of arthropods that fell into the collecting tubes at three day intervals, found that the extraction period was prolonged and the efficiency of the extraction was less, when the lower temperature gradients across the samples were used. Nef (1962) suggested that light, temperature, desiccation and the effect of gravity were the most important factors concerned in the movement of micro-arthropods from samples when using a Tullgren funnel

extraction method. Although his earlier investigations had indicated that increases in temperature and desiccation were the most important factors affecting the egress of mites from soil samples, Nef (1970) considered that mites do not escape along downward desiccation gradients, but are influenced by the availability of soil water in relation to the water-retaining capacity of the sample material. Murphy (1958a) reported that the egress of soil mites from raw humus was closely correlated with desiccation and that the extraction of mites from larger volumes of soil took longer because the desiccation of these samples was slower. Kempson et al. (1963) suggested that although temperature may be an important factor, arthropods are first stimulated by the drying process and only then are they affected by the temperature gradient. Another suggestion made by Kempson and his colleagues was that animals move downwards under the stress of moisture loss, and that gravity, not temperature is the main factor affecting emergence during the extraction process. Block (1966) found that patterns of emergence for the constituent groups of mites and for springtails differed according to the reactions of the different species to the temperature gradient and humidity in the soil samples. Brady (1969) studied the extraction of three species of astigmatid mites from poultry deep-litter and made detailed measurements of temperature and humidity gradients and evaporation rates within the sample material. There was an initial peak of emergence from the medium for all three of the species studied, caused presumably, by the disturbance when preparing the sample for extraction. Thereafter, the pattern of emergence showed no obvious relationship with the temperature gradient. The author suggested that, depending on the type of sensory mechanism employed by these mites, they moved out of the samples

along relative humidity or evaporation rate gradients by a series of kineses. Vannier (1967a, 1967b, 1970b) in detailed studies of the relationships between soil microarthropods and soil-water, has shown that natural populations of these animals are seldom affected by naturally-occurring variations in the relative humidity within soils, rather, they are more likely to be affected by an excess of water than by a deficit. In his investigation of the extraction of arthropods from soil samples (Vannier, 1970b), he showed that at any constant temperature between 10°C and 30°C , the peak emergence of the species and groups examined, (mainly oribatid mites and isotomid springtails) occurred when a critical threshold of moisture content, measured as pF values, was reached. The pF values express the availability of water to plants and animals in different soil types, and are measured as degrees of retention or "suction" by the capillary forces in the soil. Above 30°C , temperature was the most important factor affecting the egress of arthropods from the soil; below 10°C , temperature decreased the number of arthropods recovered, irrespective of the moisture levels within the soil sample. All the experiments were made at a constant temperature level, using either natural convection within the apparatus or an electric fan to increase the rate of evaporation of water from the sample. At constant temperatures, between 10°C and 30°C , a sharp increase in the numbers of isotomid springtails and oribatid mites recovered from the samples, always occurred at those moisture levels corresponding to pF 4.2 and pF 5.0 respectively. Hence, the stimuli responsible for the egress of microarthropods from soil samples during the extraction process appear to be mainly associated with the moisture content of the soil in relation to its water-retaining capacity. Macfadyen (1953, 1955 and 1961) showed

that steep gradients of temperature and humidity through soil samples increased the numbers of arthropods that emerged. The following investigations were made in an attempt to evaluate the effects of different temperature gradients on the efficient extraction of microarthropods from soil.

a) Methods

Studies were made, using the Rothamsted Berlese/Tullgren funnel apparatus, on the patterns of emergence during the extraction process. Four Rothamsted Berlese/Tullgren funnel units were assembled in pairs inside a wooden cabinet, 82 cm wide, 38 cm deep and 105 cm high, with a metal top and hinged doors (Plate 10). The funnel construction was similar to that described in Section IIIc, but light bulbs of various wattages, together with a rheostat, were used to control the temperature of the extraction, and no collecting vials were attached to the base of the funnels. Instead, two flat perspex discs, 27 cm diameter, were positioned horizontally beneath the funnels. The upper surface of each disc was coated with "Stictite", an adhesive tree-banding composition. The discs were mounted on revolving platforms which rotated about their vertical axis at a rate of one revolution in seven days. The drive, from a synchronous electric motor, was direct to one disc and indirect, via a spring and pulley wheel assembly, to the other. The narrow opening at the base of each funnel was suspended about 5 mm above the surface of each disc, in such a way that one funnel covered an outer and ^{one} an inner circular track on each disc. Soil cores, 10 cm diameter and 5 cm deep, from a permanent pasture site on clay loam soil were taken with the sampling tool (Fig. 15a), and were placed intact and in an inverted position on the funnel sieves. Usually the soil samples were stored at 15°C for 12 hrs.

Plate - 10. Extraction pattern apparatus.



prior to extraction. The whole apparatus was placed in a 15°C constant temperature room and at the start of each extraction the discs were set in motion. As the extraction proceeded, the animals emerged from the soil sample and fell down the funnels and onto the discs. The sticky coating on the discs held all but lumbricids and large active arthropods in position at the point of impact. Care was taken to avoid any vibration of the apparatus once the process had begun and any large animals seen were removed, before the extraction began. The starting point of each circular track of extracted arthropods was clearly marked on the discs. Each extraction was completed within seven days and the discs were removed and mounted on a freely-rotating stage so that arthropods could be examined with a binocular microscope at x25 magnification while still embedded in the "Stictite". The perspex discs were superimposed over a Cambridge recorder chart (No. 656) and the identity and position of the arthropods were related to successive six-hourly periods after extraction began. Most arthropods were identified into major groups while still embedded in the "Stictite", although occasionally arthropods had to be removed, cleaned in xylene, and identified at higher magnifications. To ensure that this extraction procedure was not causing major changes in the numbers of arthropods being extracted, a similar group of four funnels, were assembled in different constant temperature rooms depending upon which experimental temperature regime was being examined. These funnels were used to extract similar soil cores into collecting vials containing 70% aqueous ethyl alcohol and glycerol (in the ratio of 20 : 1). Comparisons between the total numbers of arthropods, extracted by the two methods, then ensured that no abnormal differences occurred. (Table 37).

Continuous temperature measurements were made at various points in the soil samples under investigation, using a miniature temperature

recorder, manufactured by Grant Instruments, Cambridge. Thermistor beads, encased in metal probes, were inserted into the inverted soil cores at three points. One probe was placed at the top nearest the heat source, about 5 mm from the upper surface, another into the middle of the soil core, about 2.5 cm from the upper surface, and the third probe was inserted between the bottom of the soil core and the metal sieve. Other probes recorded air-temperature in the funnels and the surrounding air-temperature in the cabinet.

The relative humidity at various points within the soil core was measured using cobalt thiocyanate paper (Solomon, 1957). Strips of cobalt thiocyanate impregnated paper, encased in dialysis tubing (a semi-permeable membrane) were inserted in slits made in the soil core with a sharp knife. By removing the strips of paper at intervals throughout the extraction period and measuring the colour change along their length against permanent colour standards, it was possible to follow the changing humidity gradient within the soil sample. However when the soil samples were wet, the cobalt thiocyanate was leached from the paper; when the soil samples were dry, the disturbance caused by their removal, dislodged large amounts of sample material down the funnel and onto the "Stictite" coated discs making counting and identification of the arthropods impossible. Because of these difficulties, humidity measurements were abandoned at an early stage in the experiments.

Preliminary experiments, with light bulbs of various wattages and a rheostat control, established three standard temperature regimes for the extraction of arthropods from soil samples by this apparatus. Temperatures that were very similar to those recommended in Section III, for use with the Rothamsted Berlese/Tullgren funnel apparatus, are referred to as

'normal' extraction temperatures. Here the upper soil surface temperature reached 33°C during the first 24 hrs. and maintained a $15\text{--}20^{\circ}\text{C}$ differential from ambient during the rest of the extraction period. A 'low' temperature regime was created by allowing the upper soil surface temperature to reach 21°C during the first day and maintain a $5^{\circ}\text{C} - 10^{\circ}\text{C}$ differential thereafter. In the 'high' temperature regime, the upper soil surface temperature reached 48°C during the first day and maintained a $33^{\circ}\text{C} - 40^{\circ}\text{C}$ differential from ambient thereafter.

b) Results

Fig. 49 and 50 show typical extraction patterns for emerging arthropods when using the 'normal' temperature cycle. Preliminary results showed that relatively few arthropods were recovered by the experimental technique as compared with the numbers extracted from corresponding soil cores over vials containing alcohol and glycerol mixtures. However, it was found that by placing open dishes of the alcohol and glycerol mixture at the collecting level in the cabinet, comparable numbers of arthropods from the two extraction methods were obtained. Even so, only four major groups of soil arthropods were considered because the numbers of most arthropods recovered from single soil cores were too few for specific studies to be made.

From the histograms showing results when using 'normal' temperature regimes, in Figs. 51 - 57, it can be seen that most arthropods emerged in two peak periods, one at the beginning of the extraction period, corresponding to the time of rapid temperature increase within the soil core, and a second, usually larger peak, on the second, third or fourth day of the extraction. The second peak extraction period occurred when little or no change in temperature was recorded in the soil samples. Possibly,

FIG. 49.

THE EXTRACTION PATTERNS OF ARTHROPODS FROM
SOIL SAMPLES USING ROTHAMSTED TULLGREN FUNNELS
AT RECOMMENDED TEMPERATURES

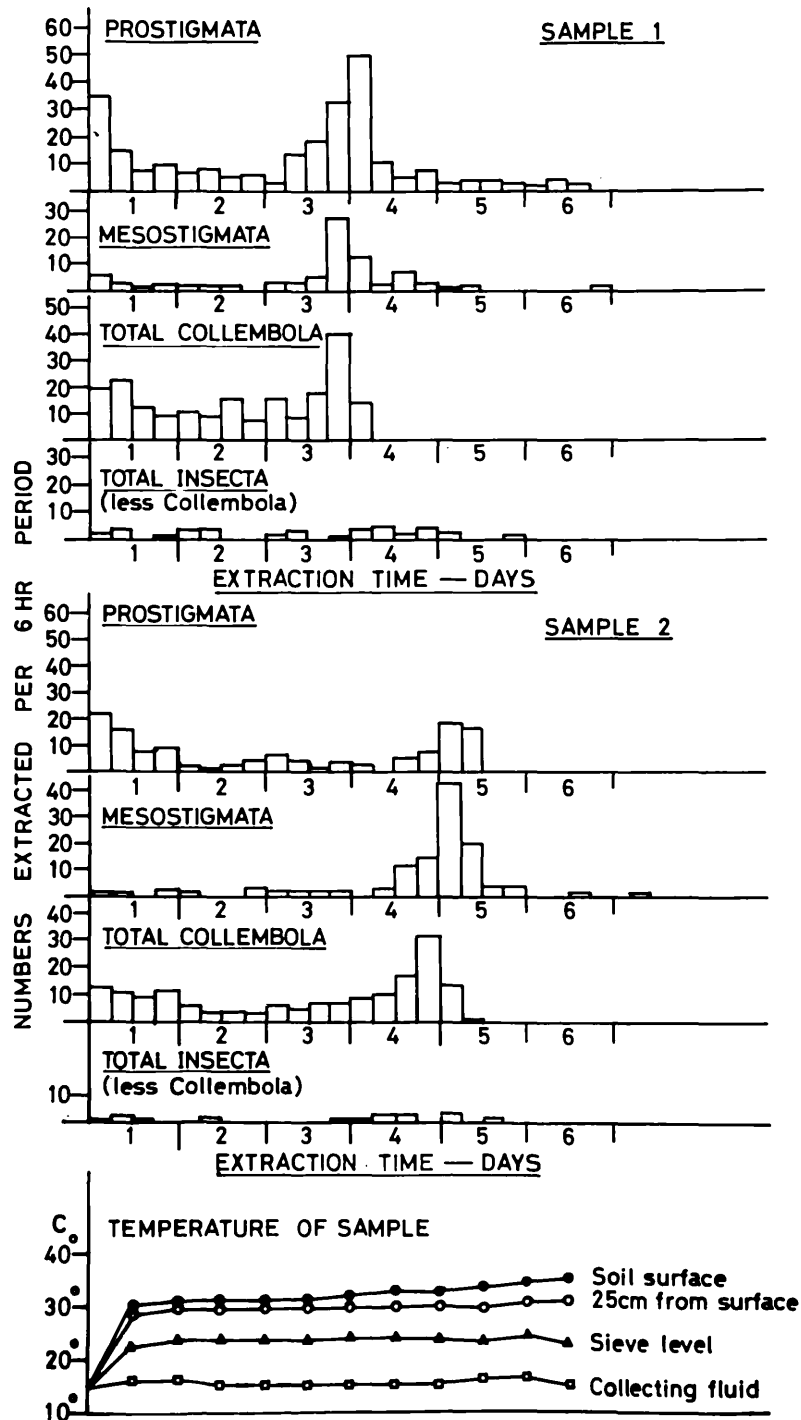


FIG. 50.

THE EXTRACTION PATTERNS OF ARTHROPODS FROM
SOIL SAMPLES USING ROTHAMSTED TULLGREN FUNNELS
AT RECOMMENDED TEMPERATURES

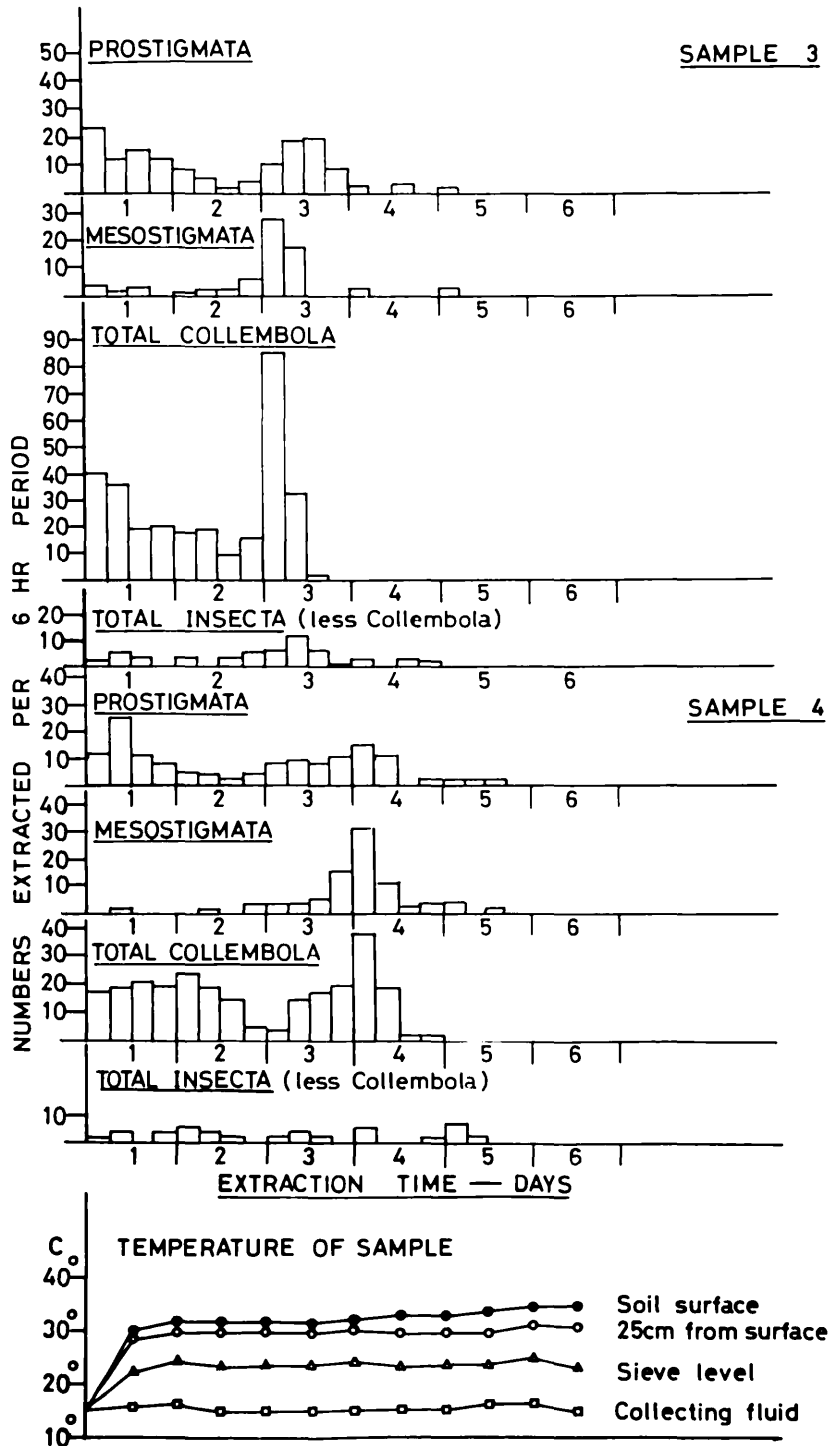
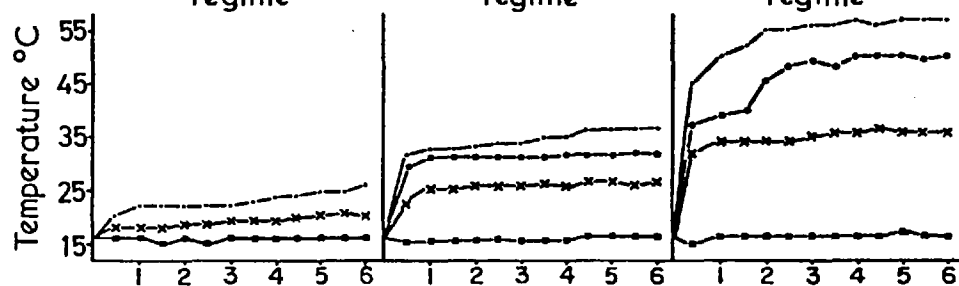


FIG. 51.

THE EXTRACTION PATTERNS OF ARTHROPODS FROM SOIL SAMPLES USING ROTHAMSTED TULLGREN FUNNELS

TEMPERATURES °C recorded at :-

----- Upper soil surface ●●●●● Collecting level
 - - - - - 2.5 c.m. from upper soil surface * * * * * Sieve level
 "Low" temperature regime "Normal" temperature regime "High" temperature regime



PROSTIGMATA

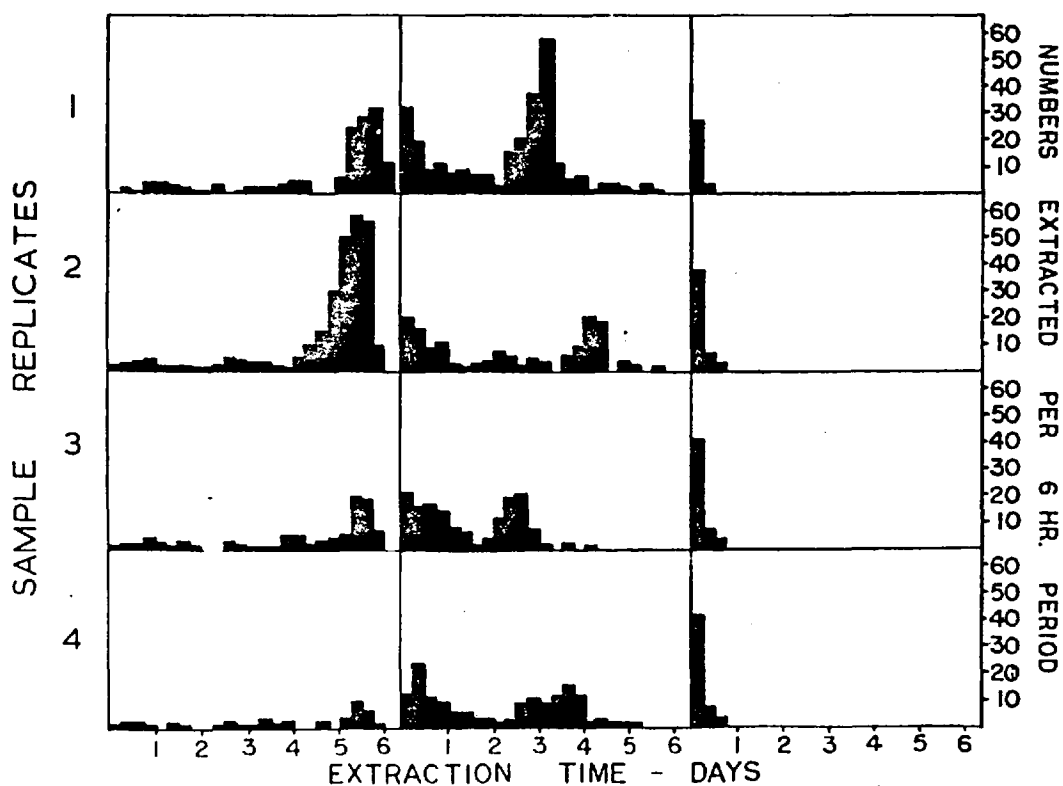
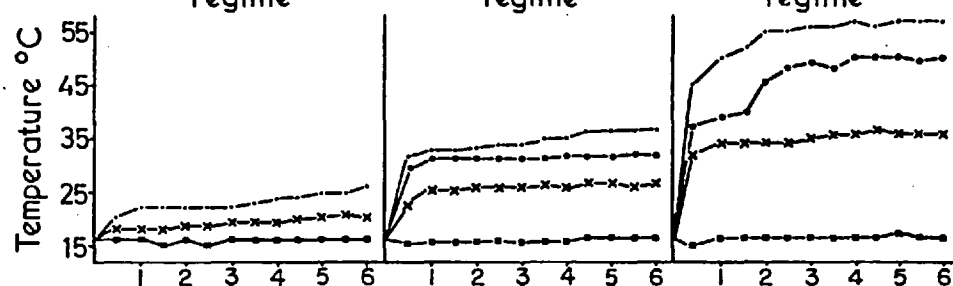


FIG. 52.

THE EXTRACTION PATTERNS OF ARTHROPODS FROM SOIL SAMPLES USING ROTHAMSTED TULLGREN FUNNELS

TEMPERATURES °C recorded at :-

----- Upper soil surface ●●●●● Collecting level
 - - - - - 2.5 c.m. from upper soil surface ××××× Sieve level
 "Low" temperature regime "Normal" temperature regime "High" temperature regime



MESOSTIGMATA

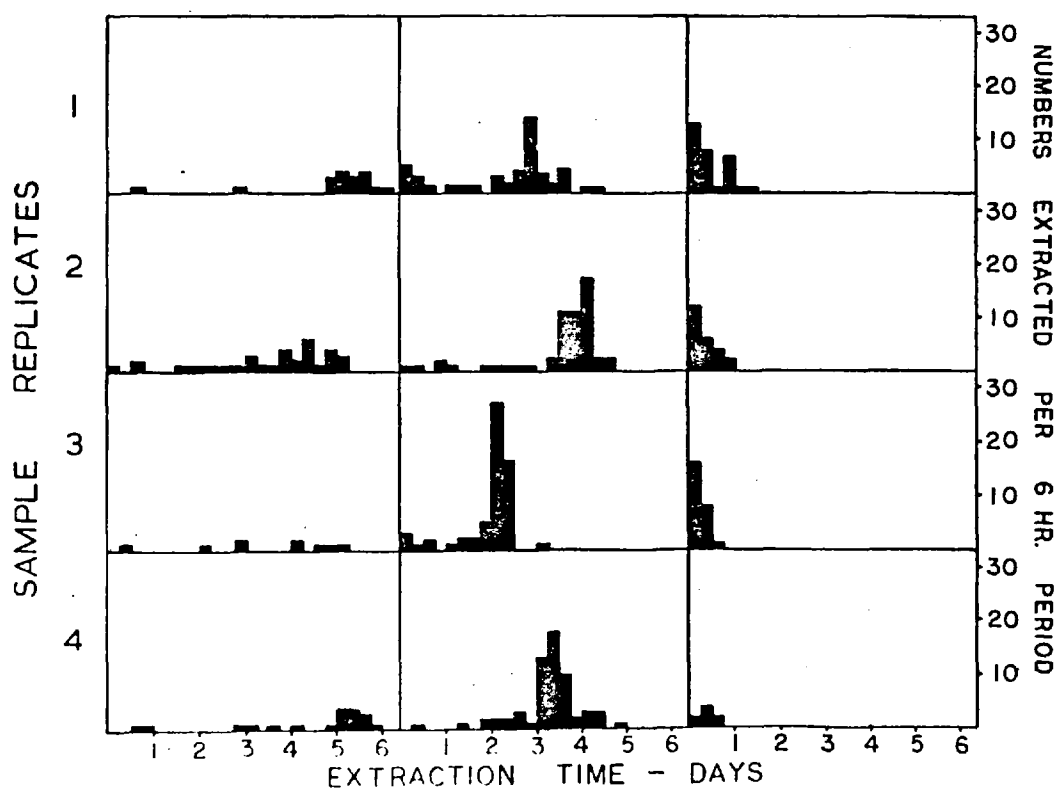
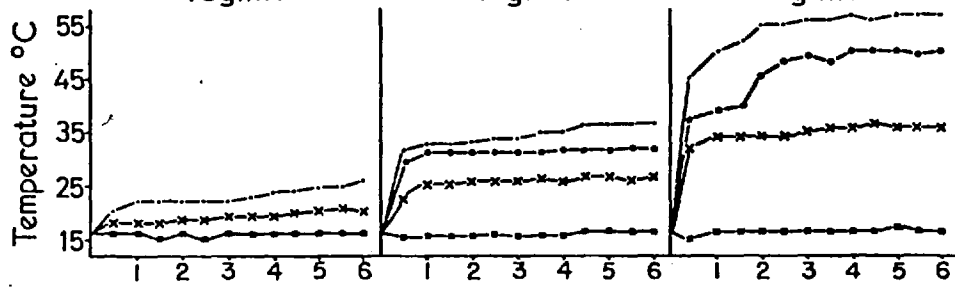


FIG. 53.

THE EXTRACTION PATTERNS OF ARTHROPODS FROM SOIL SAMPLES USING ROTHAMSTED TULLGREN FUNNELS

TEMPERATURES °C recorded at :-

----- Upper soil surface ●●●●● Collecting level
 - - - - - 2.5 c.m. from upper soil surface ××××× Sieve level
 "Low" temperature regime "Normal" temperature regime "High" temperature regime



OTHER ACARINA

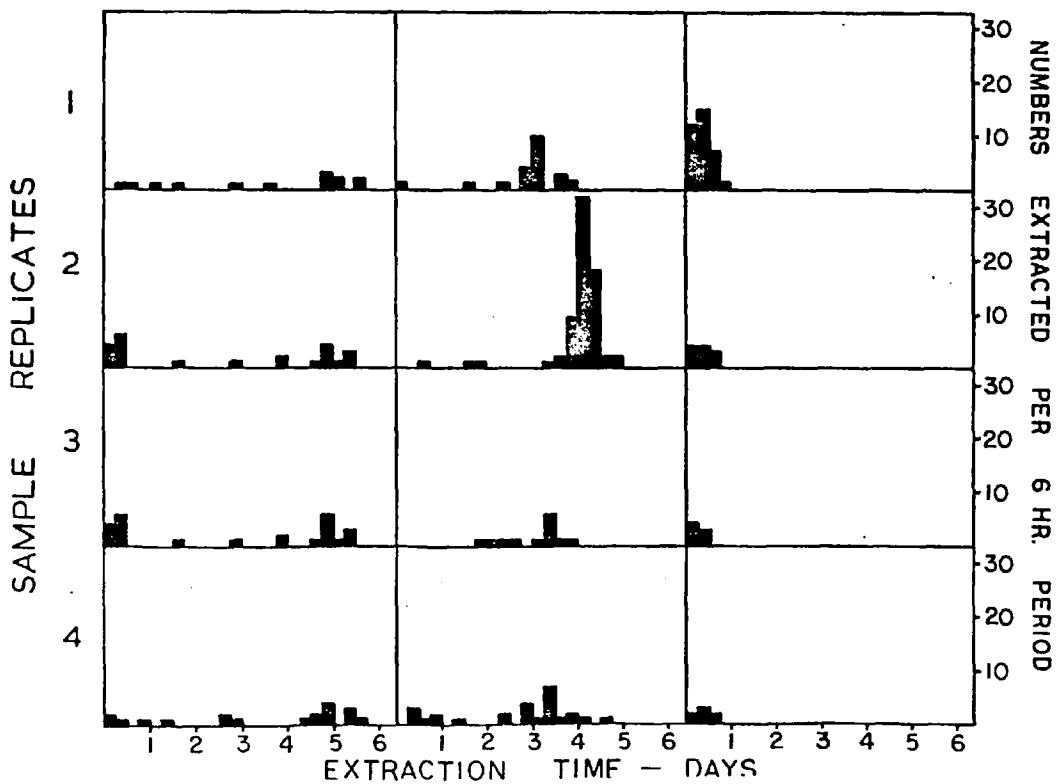
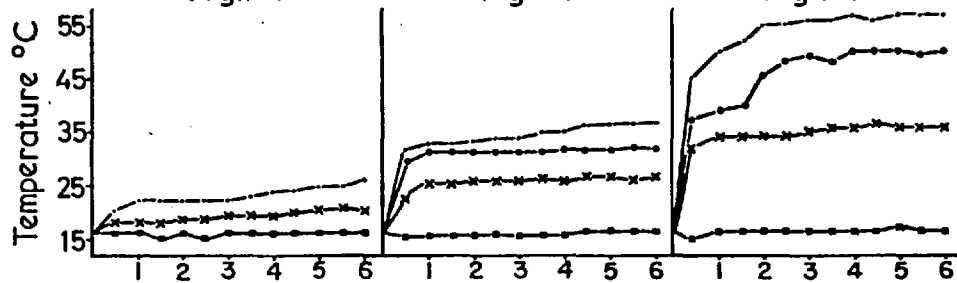


FIG. 54.

THE EXTRACTION PATTERNS OF ARTHROPODS
FROM SOIL SAMPLES USING ROTHAMSTED
TULLGREN FUNNELS

TEMPERATURES °C recorded at :-

— Upper soil surface — Collecting level
 — 2.5 c.m. from upper soil surface — Sieve level
 "Low" temperature regime "Normal" temperature regime "High" temperature regime



ONYCHIURIDAE AND PODURIDAE

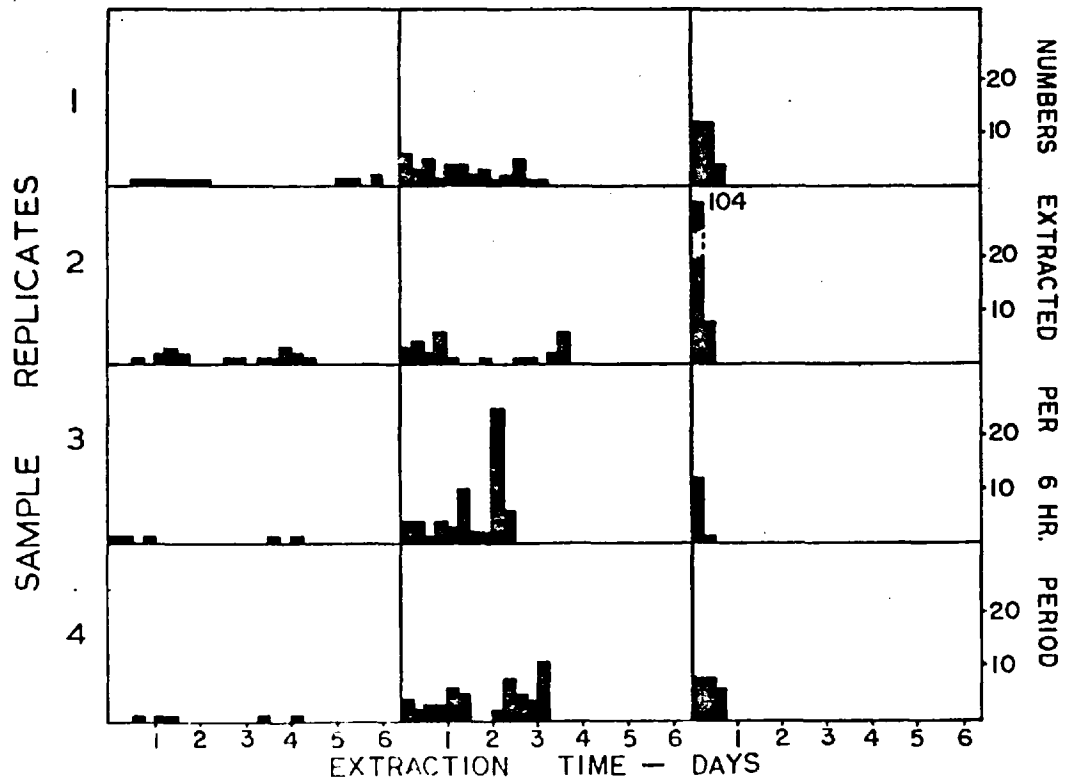
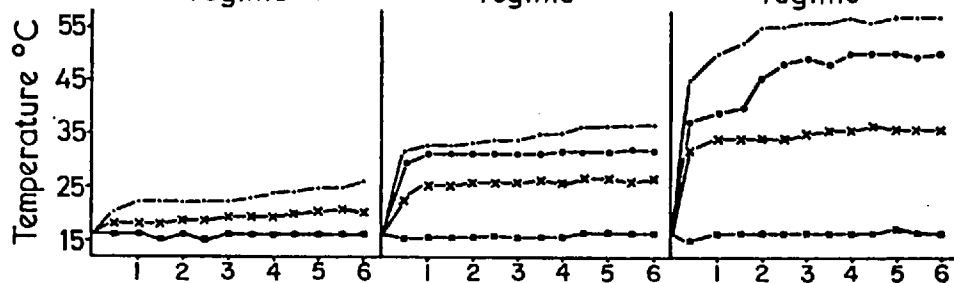


FIG. 55.

THE EXTRACTION PATTERNS OF ARTHROPODS FROM SOIL SAMPLES USING ROTHAMSTED TULLGREN FUNNELS

TEMPERATURES °C recorded at :-

----- Upper soil surface ●●●●● Collecting level
 - - - - - 2.5 c.m. from upper soil surface ××××× Sieve level
 "Low" temperature regime "Normal" temperature regime "High" temperature regime



ISOTOMIDAE AND ENTOMOBRYIDAE

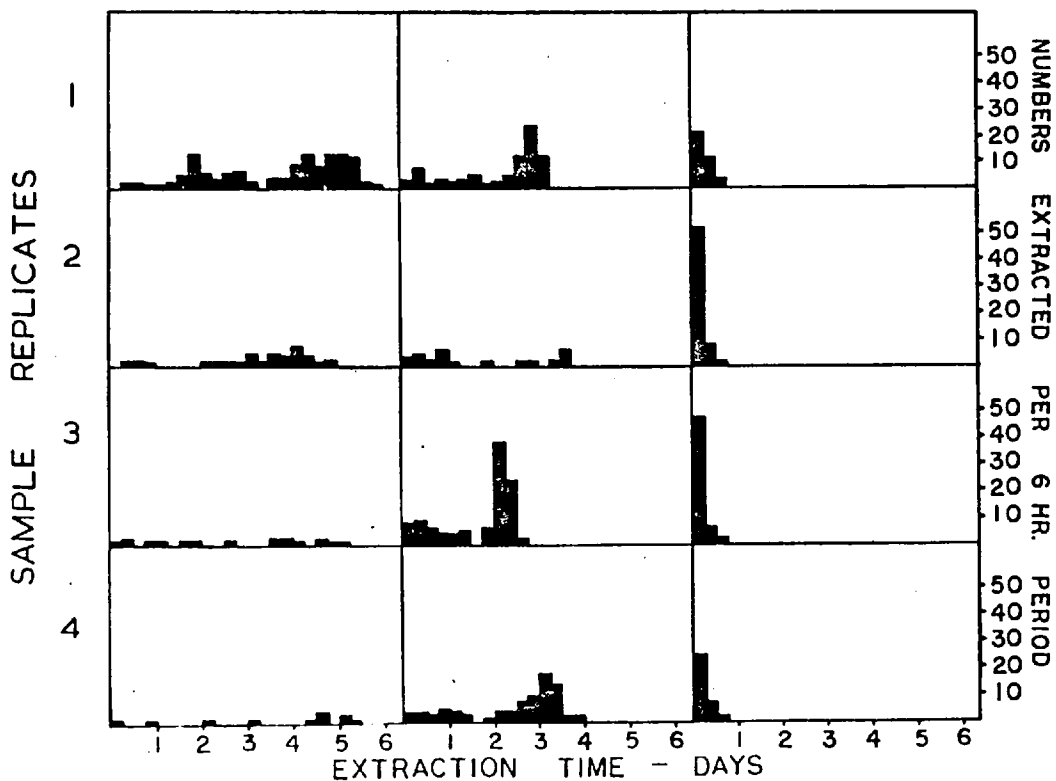
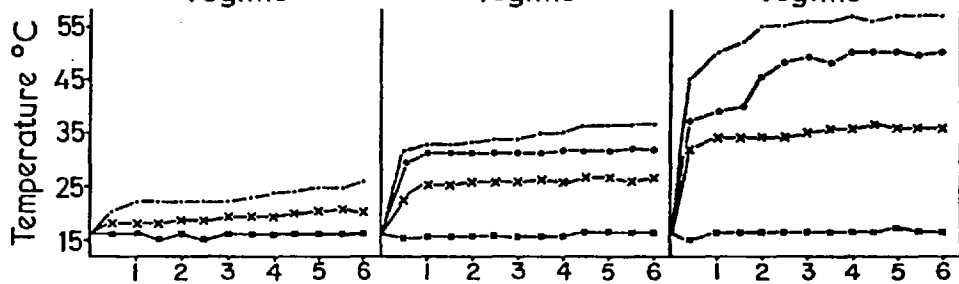


FIG. 56.

THE EXTRACTION PATTERNS OF ARTHROPODS
FROM SOIL SAMPLES USING ROTHAMSTED
TULLGREN FUNNELS

TEMPERATURES °C recorded at :-

----- Upper soil surface ●●●●● Collecting level
 ●●●●● 2.5 c.m. from upper soil surface ××××× Sieve level
 "Low" temperature "Normal" temperature "High" temperature
 regime regime regime



SMINTHURIDAE

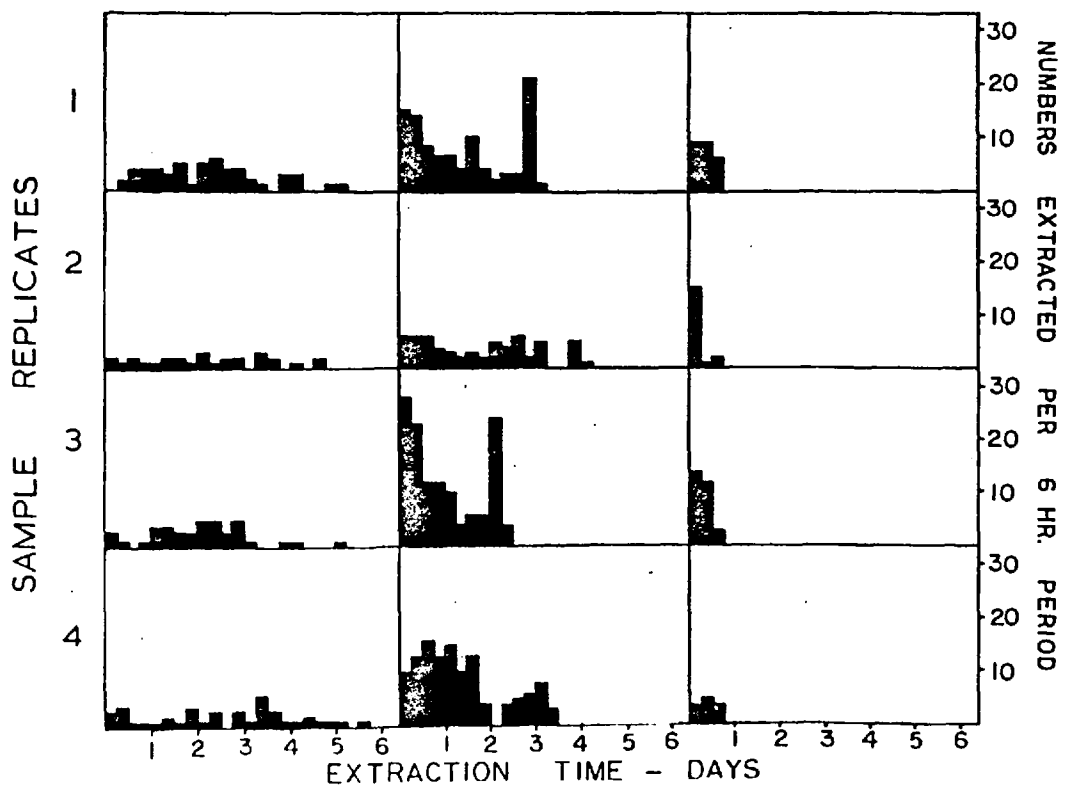
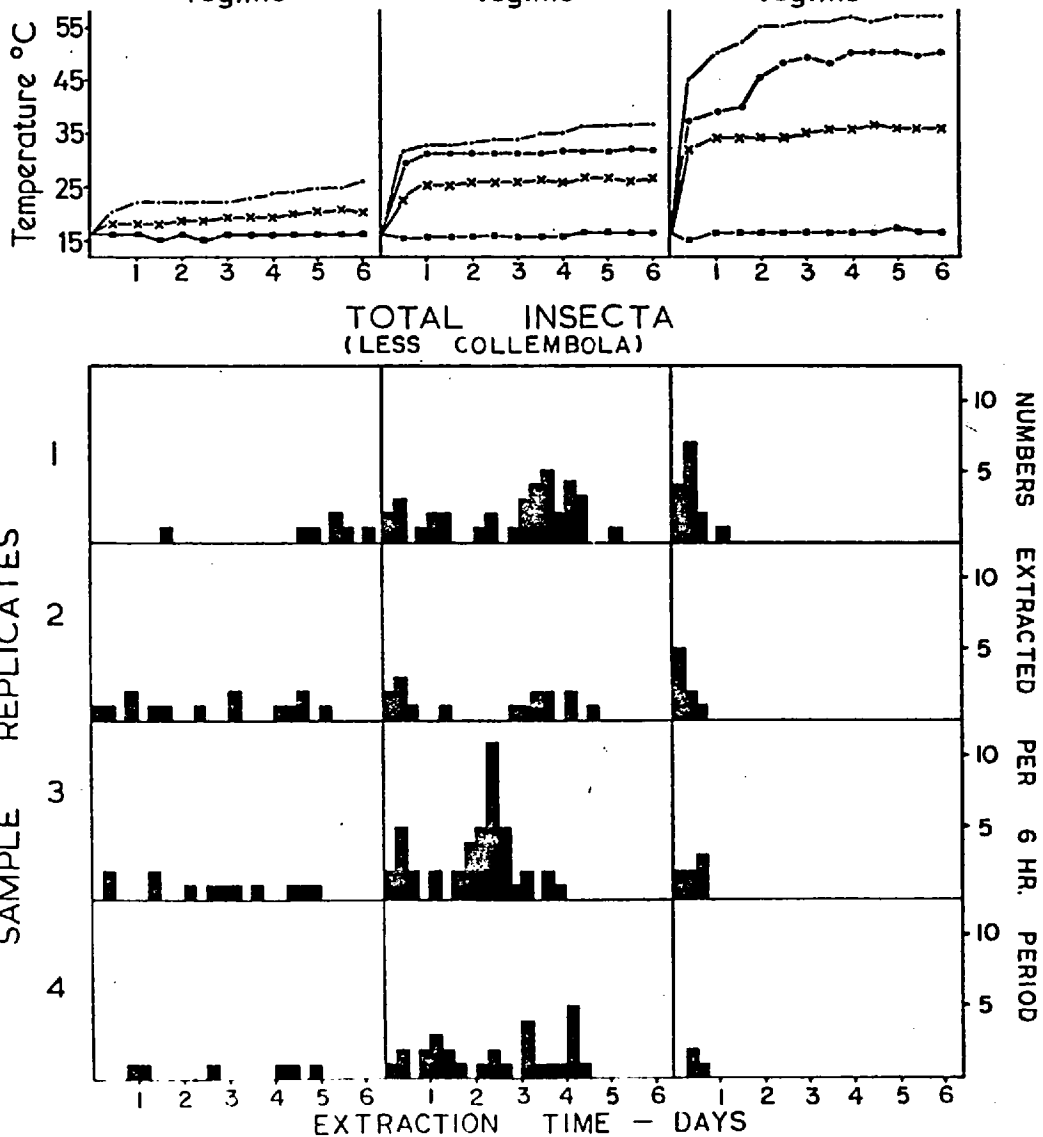


FIG. 57.

THE EXTRACTION PATTERNS OF ARTHROPODS FROM SOIL SAMPLES USING ROTHAMSTED TULLGREN FUNNELS

TEMPERATURES °C recorded at :-

----- Upper soil surface ●●●●● Collecting level
 ●●●●● 2.5 c.m. from upper soil surface ××××× Sieve level
 "Low" temperature regime "Normal" temperature regime "High" temperature regime



this second peak extraction period corresponded to a sudden drop in relative humidity within the soil cores or to the point at which moisture availability became a critical factor to the arthropods remaining in soil samples. Although the second extraction peak always occurred at approximately the same time for different arthropod groups within the same soil core, there was a maximum time lag of 48 hours between different soil cores. This suggested a common factor possibly water content, which varied slightly between samples. Water content expressed as a percentage of oven-dried weight, given in Table 38, showed a difference of over 20% between samples taken side by side from the same site on the same day. Presumably, this reflected the stony nature of the soil.

Not all the arthropod groups emerged in the two peak periods, because the first peak was much less obvious and sometimes absent for the mesostigmatid mites, and occasionally, neither of the peaks were obvious particularly when the results from only one soil core were considered.

In the 'normal' temperature regime, the majority of arthropods were extracted by the end of the fourth day, and usually the majority of arthropods had emerged during two peak periods of the extraction process, the timing of the second peak differing for different cores. With the 'low' temperature regime, extraction of all the arthropods took longer, and was not completed until after six days. Fewer arthropods were usually recovered from soil cores using the 'low' temperature regime than when the 'normal' temperature regime was used (Table 37). Mites, in particular prostigmatid mites, emerged mostly towards the end of the extraction process, and there was little indication of an earlier peak of emergence, as occurred with the 'normal' temperature regime. Most other groups showed no bimodal extraction pattern when 'low'

TABLE 38

THE WATER CONTENT OF SOIL CORES USED IN EXTRACTIONPATTERN INVESTIGATIONS

FRESH WEIGHT (10 cm diameter 5 cm deep)	OVEN-DRIED WEIGHT (80°c FOR 4 DAYS)	WATER CONTENT (AS PERCENTAGE OF DRY WEIGHT)
529.0 g	315.0 g	67.9%
445.0 g	250.0 g	78.0%
402.5 g	221.0 g	81.9%
490.0 g	311.0 g	57.5%
494.6 g	283.4 g	74.5%
504.7 g	307.3 g	64.2%
499.8 g	308.0 g	62.3%
473.8 g	287.9 g	64.6%

temperature regimes were used. When using the 'high' temperature regime, all arthropods that emerged did so during the first 24 hours, the majority being extracted in the first 12 hour period. In comparison with the numbers of arthropods extracted by the 'normal' temperature regime, the 'high' temperature regime recovered very few arthropods. (Table 37).

c) Discussion and Conclusions

Temperature plays an important role in influencing populations of most animals (Andrewartha and Birch, 1954; Andrewartha, 1961). Extensive surveys by Vannier (1970b) show increases in population density of soil microarthropods were correlated with increases in temperature rather than changes in relative humidity, and various workers have demonstrated the importance of temperature and humidity on the survival and distribution of soil arthropods, (Uvarov, 1931; Dowdy, 1944; Gilyarov, 1947; Wallwork, 1960 & 1970; Madge, 1961, 1964a, b, & 1965a, b).

The role of temperature and humidity in the dry funnel extraction process is rather different to that in field conditions, but under extreme climatic conditions, similar principles may apply (Vannier, 1970b). Temperature increases the locomotory activities of soil arthropods as does decreasing moisture content of the environment of most insects, hence the chances of arthropods falling into the collecting device are increased. There is, however, no consistent pattern of temperature or humidity requirements for soil arthropods in different environments, e.g. the optimum temperature range for the extraction of soil arthropods in Calcutta soil ranged from 51°C to 54°C (Deb and Raychaudhuri, 1966). Temperature and humidity regimes differ for every type of dry-funnel apparatus and different soils and climates require the application of different extraction temperatures and humidity changes in order to extract

TABLE 37 TOTAL NUMBERS OF ARTHROPODS RECOVERED FROM SINGLE SOIL CORES IN EXTRACTION PATTERN INVESTIGATIONS

TEMPERATURE REGIME ANIMAL GROUP	LOW TEMPERATURE REGIME				CONTROL				NORMAL TEMPERATURE REGIME				CONTROL				NORMAL TEMPERATURE REGIME				CONTROL				HIGH TEMPERATURE REGIME				CONTROL			
	SAMPLES				SAMPLES				SAMPLES				SAMPLES				SAMPLES				SAMPLES				SAMPLES				SAMPLES			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
ARACHNIDA																																
ACARI																																
PROSTIGMATA	137	290	100	49	120	78	148	99	274	145	139	151	236	179	238	267	265	145	139	136	335	299	321	426	30	45	51	53	74	279	254	224
MESOSTIGMATA	14	34	9	19	37	36	18	83	68	73	62	80	73	57	110	120	48	55	61	62	68	71	73	116	31	24	25	9	108	129	172	87
OTHER ACARINA	12	25	25	19	13	54	28	44									23	74	12	26	27	30	52	73	35	11	7	7	71	17	72	12
INSECTA																																
TOTAL COLLEMBOLA									219	188	293	250	273	321	338	489																
ONYCHIURIDAE)	11	18	5	5	11	7	23	5									38	27	61	52	6	7	14	12	28	112	13	22	25	15	14	5
AND PODURIDAE)																																
ISOTOMIDAE AND)	107	34	18	13	39	52	39	92									80	94	107	76	69	37	126	77	35	75	55	34	112	126	171	40
ENTOMOBRYIDAE)	53	28	41	42	111	39	53	38									96	60	129	113	91	57	55	57	24	18	29	13	153	78	135	84
SMINTHURIDAE																																
TOTAL INSECTA (LESS COLLEMBOLA	7	13	12	6	12	10	27	15	36	16	44	25	41	39	42	57	36	16	44	28	25	12	27	26	10	8	7	3	46	34	31	15
MEAN/SAMPLE	64.1				76.4				128.9				180.0				123.7				161.8				50.9				161.4			

the maximum numbers of arthropods from the soil. Only by careful examination of the reactions of soil arthropods to these changes, can optimum extraction regimes be devised for all conditions.

Comparisons of emergence patterns for major groups of soil arthropod may mask the reactions of individual species or groups of species to the changes in temperature and humidity in the soil sample during the extraction process. The overall impression from the results in the present investigation is that most major groups respond similarly to changes in the temperature of the soil sample if the change in temperature is great enough to elicit such a response. Conversely, too rapid a change in temperature prevents arthropods from leaving the soil sample, either by inducing a form of heat paralysis or by causing the relative humidity within the soil sample to fall to below the lethal limit or by causing the formation of a physical barrier of condensed water on the lower soil surfaces. Vannier (1970b) made no attempt to cool the lower surfaces of the soil samples in his apparatus and found that no further arthropods were recovered from the soil sample when the temperature within the soil sample reached that of the surrounding air temperature. In his apparatus, this point always corresponded to a reduction in relative humidity below the lethal limit. With an extractor employing the principles of Macfadyen's high gradient apparatus, the effects of increasing temperature are more easily distinguishable from those of decreasing humidity. A temperature equilibrium is eventually reached within the sample between the upper and lower surface temperatures and during the period of increasing temperature, increased numbers of arthropods are recovered from the soil sample. Once the temperature, and presumably the evaporation rate, has stabilised, few arthropods are

recovered until all the free water has evaporated from the sample and the relative humidity falls. Vannier (1970b) has shown that isotomid springtails and oribatid mites leave the sample in increasing numbers at specific pF values during the desiccation of a soil sample. It is quite probable that the second peak extraction period which occurred for the majority of soil arthropods groups studied, corresponded to the same critical points on the desiccation curve, although unlike the results obtained by Vannier (1970b) in these experiments the increase in the numbers of all groups extracted, occurred at the same time in each soil sample.

From all these results there can be little doubt that both temperature and humidity are the main factors causing arthropods to leave soil samples during extraction by the dry-funnel process, although it is doubtful to what extent their influence can be manipulated to increase the extraction efficiency. For instance, would a series of temperature increases within a soil sample that was kept moist, increase the numbers of arthropods recovered? Collecting fluids such as ethyl alcohol, light and other factors, shown to affect the numbers of arthropods recovered, probably increase or decrease the amplitude of the emergence patterns rather than determine the times at which the arthropods leave the soil sample. It is clear that although extreme temperatures in a funnel apparatus may speed-up the extraction they do not cause an overall increase in efficiency.

Section VIII.

DISCUSSIONa) Introduction

The aims of the investigations reported in this thesis were:-

- a) To compare the more important of the methods used to assess populations of arthropods in soils, in an attempt to determine which were most efficient for particular groups of arthropods and soil types.
- b) To allow direct comparisons to be made between the results obtained with different extraction methods and to standardise methods.

Dynamic and mechanical methods both have advantages and disadvantages dependent upon the type of investigation being made, the facilities available, the particular groups of arthropods and soil types that are being studied and lastly, and not unimportant, the individual preferences or prejudices of the research worker. Therefore, based on the results of my investigations, it would be impracticable to make rigid recommendations on the methods that should be used for particular groups of arthropods, soil types or climatic areas. Nevertheless, the results of the present studies indicate the broad principles that apply to assessing arthropod populations most accurately, and do not preclude detailed examination of any factors which might limit the effectiveness of any particular extraction method in the circumstances under which the investigations are to be made.

Choice of extraction method

As Macfadyen (1962a) stressed, the type of sampling system used for any ecological investigation must be carefully planned as an integral part of the whole study. In terms of the arthropod fauna of the

soil this means that the extraction method used in each research project must be relevant to the requirements of the investigations. No one method can extract all soil arthropods with equal efficiency from all types of soil and despite recent improvements and innovations, it is most unlikely that any of the extraction methods currently available will extract any group or species of arthropod from soil with complete efficiency.

Previous comparisons between dynamic and mechanical extraction methods have produced contradictory results. The relative efficiencies of the methods compared by Evans, 1951; Macfadyen, 1953; Macklin *et al.*, 1957; El-Kifl, 1957; Müller and Naglitsch, 1957; Satchell and Nelson, 1962; Hale, 1964; Wood, 1965 and Block, 1967, have differed considerably. Much of the confusion is because each comparison was made in different environments using apparatus that differed in detail and on different soil types. It is the practicality of the situation and the requirements of the investigation that usually dictate which type of extraction method is necessary. It is clear from my results that once the aims and objectives of the investigation are known, the most appropriate method should be chosen and the efficiency of that method checked for those particular working conditions, either by attempting to determine the absolute efficiency of the method or by determining its relative efficiency in comparison with any other appropriate method that is available.

In many studies, more than one extraction method may be required, particularly if eggs, pupae or other immobile stages are to be extracted. Furthermore, a dynamic method that is suitable for the extraction of arthropods from wet soil may be quite unsuitable once the soil is dry, or vice versa. Fortunately mechanical methods extract arthropods independent of soil moisture conditions.

The choice of extraction method can also be influenced by the number

and size of the sample units required for the investigation. Most workers agree that a large number of sample units of relatively small area provide a more accurate estimate of populations than a small number of sample units of large area, particularly if the arthropods are small and their distribution is aggregated. However, if a large number of sample units are to be extracted, the experimenter may conclude that the mechanical methods are impractical, because they are extremely time consuming and, as such, are not readily adaptable to the large scale replications required by modern statistical treatments. The size of the sample unit may also be limited by other considerations. Too large a sample unit increases the time taken to process samples and too small a sample unit may result in too many zero counts, especially if arthropods are distributed sparsely or are very aggregated, making statistical analysis difficult. Furthermore, small sample units are more susceptible to errors in sample area accuracy, edge effects increasing as the sample unit area decreases. In modern dynamic extraction apparatus, the size and number of soil sample units are predetermined by the design of the apparatus, even if provision was made to extract different sized sample units, it would be difficult to ensure that they were all extracted with the same efficiency. I found in my comparisons that mechanical methods were much more versatile in these respects and allowed varying numbers and different sized sample units to be treated with equal efficiency in the same apparatus.

Samples for extraction by dynamic methods require to be taken with great care. Macfadyen (1953 & 1962a), Hughes (1954), Murphy (1958a & 1962a) and Lussenhop (1971) demonstrated that sample compression or disturbance caused either by the sampling tool or during the transportation of the soil

samples to the laboratory, may greatly decrease the efficiency with which mites and springtails are extracted from intact soil cores. Rapoport and Oros (1969) showed that the type of container that soil samples were placed in, affected the efficiency of recovery by dynamic methods. However, soil samples for extraction by mechanical methods, can be taken quickly with any type of digging apparatus that will give a standard sized sample; no skill or special care is required. Samples to be extracted by mechanical methods can also be preserved in fixatives such as formalin solution and will transport without deterioration. Nevertheless, if the arthropods that are extracted are required for detailed taxonomic studies, some care is required if mechanical separation methods are used. Raw (1955) described a modification of the Salt and Hollick process, designed to recover micro-arthropods in good physical condition, but his apparatus could only be used with very small sample units of mineral soil. Usually, if arthropods are required undamaged for taxonomic purposes, most authors agree that dynamic extraction methods should be used, and my results confirm this.

The relative efficiency of dynamic methods compared with mechanical methods

There is little information available as to the absolute efficiency of extraction methods, but it is usually agreed that the relative efficiency of mechanical methods as opposed to dynamic methods has been poor on soils with much undecomposed vegetation, because this vegetation floats and interferes with the interface between the organic liquid and the water in the oil-water separation stage that is commonly used; also arthropods become tangled in the vegetation. Apart from these soils, the relative efficiency of mechanical methods has been considered to be good, particularly when animals were to be extracted from heavy clay soils. However, Satchell and Nelson (1962) suggested that the efficiency

of flotation methods may vary according to the physical properties of the arthropods independently of the type of soil being sampled. My work has indicated that the relative efficiency of those mechanical methods used was particularly poor for most micro- and meso-arthropod groups on the soils and habitats studied. Even in arable clay soils, where mechanical methods are usually thought to be superior, the best dynamic methods used in my comparisons extracted more of most species of arthropods. The exceptions of these findings were that the onychiurid springtails and to a lesser degree the podurid springtails together with most of the larger insects, particularly fly larvae, were usually extracted more efficiently by the mechanical methods.

In my studies, the relative efficiencies of dynamic and mechanical methods were usually related to the amounts of undecomposed plant material present in the soil, and to a certain extent, the size of the arthropods being extracted. For example, the relative efficiency of mechanical methods improved and occasionally exceeded that of dynamic methods on fallow arable soil where there was little undecomposed plant litter, but were much less efficient than most dynamic methods on the woodland sites. Conversely, the relative efficiency of mechanical methods increased when the extraction of fly larvae, root aphids, thrips or beetle larvae and adults was considered, but mechanical methods extracted far fewer prostigmatid mites or sminthurid and isotomid springtails than dynamic methods from almost every site. There were many exceptions to these general conclusions; for instance the results of the comparisons made on peat soil, especially the woodland site, showed that the flotation method extracted significantly more of most groups of small-sized arthropods than did the dry-funnel method. These results were thought to have been

influenced both by the nature of the plant material; (the water-logged fen peat did not overtly interfere with the oil-water separation stage), and an unusually large number of intact well-preserved arthropod exoskeletons remaining undecomposed in this acidic and anaerobic soil. The dead bodies of small arthropod animals, preserved in this way, were indistinguishable from those of arthropods that were alive at the time of sampling, when extracted by the flotation method. The larger arthropods, which were more easily identified into those categories by the presence of muscle or other soft tissues, were usually extracted more efficiently by the dry-funnel method from the fen^{peat}. The physical condition of most arthropods, particularly the smaller, weakly-sclerotised specimens, after extraction by the mechanical methods, was always very poor. Counting and identification of these damaged and ~~often~~ dismembered arthropods was extremely tedious. This, added to the longer time spent on the separation processes, made mechanical methods very much more laborious than dynamic methods.

Mechanical methods have been generally considered to be much more suitable for micro-arthropod investigations if small amounts of sample material are extracted with care, (Raw, 1955 and Müller, 1962) or if specialised groups of arthropods are to be extracted from specific soil types (Hale, 1964; Healy and Russel-Smith, 1970). Large-scale washing and flotation programmes should be restricted to the examination of the larger, more robust macro-arthropods or to the immobile stages such as eggs or pupae. Mechanical methods involving flotation processes should not be used for those arthropods that carry mineral particles on their outer surfaces as do some oribatid mites and those processes involving oil-water separation stages are unsuitable for arthropod groups, such as

some myriapods and isopods, whose cuticles are not thoroughly wetted by the organic solvent.

The relative efficiencies of dynamic methods

The most efficient method used in my investigations was the air-conditioned funnel apparatus designed by Macfadyen (1961). In this apparatus, special provision was made for the production of steep, controlled gradients of temperature and humidity, by heating and drying the upper surface of the soil sample and cooling and moistening its lower surface. Prior to my investigations, I had assumed that the complexity of design, caused by incorporating these special features, was probably unjustified. However, the complexity was amply justified by the greatly increased numbers of most arthropod groups that the apparatus recovered. The relatively poor and somewhat inexplicable results obtained with the high gradient canister apparatus, which was based on the same principles of steep controlled gradients of temperature and humidity, were probably caused more by the inexperience of the operator and modifications made to the original design of the apparatus (Macfadyen, 1961) than by a failure of the principles of controlled gradients of temperature and humidity outlined by Macfadyen (1953, 1955, 1961 & 1962b). However, it must be emphasised that, by introducing controlled temperature and humidity gradients and the accompanying complexities in design, more care and expertise on the part of the operator is required. The increased efficiency of controlled gradient apparatus may be drastically reduced if, for example, the air-circulation across the base of the soil core is not sufficient to prevent condensation of water droplets which may hinder the escape of arthropods from the sample.

The relative efficiencies of the other dynamic methods that were

compared, were seldom comparable for similar arthropod groups extracted from soils in different habitats. However, the Oxford infra-red extractor and the Rothamsted Berlese/Tullgren funnels extracted many arthropod groups with comparable efficiency to that of the Macfadyen air-conditioned funnel apparatus on the woodland and pasture sites, and the Murphy split-funnel apparatus was much more efficient than other methods in extracting some groups of mites on the fallow arable site.

In most of my investigations, the relative efficiency with which various groups of arthropods were extracted from soil, was increased for those methods which incorporated increased control of temperature and humidity gradients. The simple plastic funnel and the Rothamsted Berlese-Tullgren funnel apparatus with no heat, tended to extract fewest arthropods. However, particularly on fallow soils, those methods in which no provision was made for establishing a temperature gradient were occasionally as efficient as the more sophisticated methods for a few arthropod groups. The numbers of arthropods recovered by these less complex methods were seldom greater than the numbers recovered by the Macfadyen air-conditioned funnels and the few exceptions are not considered to invalidate the principles of applying controlled temperature and humidity gradients across soil samples to increase the efficiency of the extraction process.

Although it is impossible to separate the effects of temperature and relative humidity in relation to their influence on the extraction process, emergence patterns of arthropods under carefully controlled temperature conditions showed two peak periods of emergence. These were comparable with those found by Haarløv (1947 & 1955), and suggested that arthropod behaviour during the extraction process was stimulated by increases in temperature and also at some critical point of moisture-loss

in the soil sample, possibly at the point when the relative humidity of the soil air begins to fall below 100%. Support for this supposition was provided by Vannier (1970a) who found that at constant temperatures between 10°C and 30°C the emergence of isotomid springtails and oribatid mites from soil increased when specific pF values were reached. Soil suction measurements (pF values) are a particularly useful method of expressing the moisture content of soils in this respect. These measurements not only record moisture measured in terms of its availability to soil animals, but also allow direct comparisons of moisture availability to be made between different soil types.

Other investigations of emergence patterns of arthropods from soil during the extraction process have shown different species of arthropods to leave the soil at different times during the extraction process (Haarlov, 1947; Macfadyen, 1953 & 1961; Block, 1966; Brady, 1969; and Lasebikan, 1971 a & b). My investigations, carried out under carefully controlled temperature conditions, produced emergence patterns that showed that all the major groups of soil arthropods behaved similarly. When the 'normal' temperature gradients were used no more arthropods emerged from soil cores after the second peak period, suggesting that moisture availability was the critical factor terminating the extraction process. When very steep temperature gradients were applied, the emergence of arthropods from soil was restricted to a single peak extraction period, suggesting that a lethal temperature level was reached before moisture availability could become a limiting factor in the extraction process. The greater efficiency of the air-conditioned funnel apparatus may well derive from the production of relative humidity or moisture availability gradients through the soil core, resulting from spraying a fine mist of

water into the air circulating across the base of the soil cores.

Thus, temperature and humidity gradients in soil samples play an important role in the efficient extraction of arthropods. My studies indicate that the development of such gradients during the extraction process must not be left to chance and only by careful monitoring of the extraction process, will optimum gradients for recovering maximum numbers of arthropods be established. If and when these can be determined for different groups of arthropods in different soil types under various climatic conditions it may be possible to standardise methods and allow direct comparisons between the results of various workers to be made.

However, it must also be remembered that other factors also affect the efficiency of dynamic extraction methods. My investigations into the effects of the way in which soil cores are placed on the funnel sieves showed that the orientation of the intact soil cores was even more important than had been previously concluded by Jacot (1936); Hammer (1944) and Murphy (1958a). Significantly more arthropods were extracted from intact, inverted soil cores than from intact samples placed upright on the funnel sieve or from soil cores that were broken into pieces and spread evenly on the sieve.

My work also showed that the volume of soil placed in the sample container of the Rothamsted Berlese-Tullgren funnel apparatus, was less important than had been previously suggested (Murphy, 1958a), although some deeper dwelling soil arthropods such as rhodacarid mites, onychiurid springtails and Diptera larvae, were extracted in greater numbers from the shallower depths of soil on the sieves.

My investigations showed clearly that different collecting fluids affected the efficiency of dynamic methods very much. Previously, emphasis

had been directed towards finding a collecting fluid that would not repel the arthropods during the extraction process (Mafadyen, 1961); for instance in the high-gradient canister apparatus, ethyl alcohol instead of distilled water was shown to decrease the efficiency of the extraction. However, the efficiency of the Rothamsted Berlese-Tullgren funnel apparatus was significantly increased by using ethyl alcohol or picric acid solution rather than distilled water. Most groups of arthropods were extracted more efficiently when ethyl alcohol or picric acid solution was used as a collecting fluid than when distilled water was used (except for dipterous larvae, which were always collected in greater numbers into distilled water or picric acid solution than into ethyl alcohol). Further tests to discover why these collecting fluids recovered different numbers of arthropods from soil samples were inconclusive.

The relative efficiency of mechanical methods

The comparative efficiency of mechanical methods for extracting soil arthropods has received even less attention than the efficiency of dynamic methods. Most authors measured the relative efficiency of their mechanical apparatus either by comparing it with a dynamic method or by introducing known numbers, or marked arthropods into the apparatus and expressing the fraction recovered as percentage efficiency. Others such as Heath (1965) and Feeny (1967) compared modifications of the Salt and Hollick process with the original technique as described by Salt & Hollick (1944).

Of the four mechanical methods compared in the present studies, no single method was outstanding or could be considered more efficient than the rest. As with the dynamic methods tested, the relative efficiencies

of the four methods were not the same for similar arthropod groups when extracted from soils of different habitats. The range of the variability in respect of the relative efficiencies of mechanical methods was similar to that of the majority of dynamic methods.

The grease film method, developed by Aucamp and Ryke (1964, 1965), was especially efficient in extracting most groups of arthropods, except myriapods and woodlice, from the clay soil of the woodland site. Onychiurid springtails and spiders were extracted in greater numbers by the grease film method than by any other extraction method tested on the woodland site. Unfortunately, as with other mechanical methods, the arthropods recovered by the grease film method were often badly damaged and difficult to identify. The freezing of soil samples before processing was thought to have contributed to the damaged nature of the specimens recovered.

The storage of soil samples before extraction

Storage of soil samples prior to the extraction of arthropods by mechanical methods, would appear to present few problems. However, freezing and thawing of soil samples during the storage period (Raw, 1955), which is helpful in breaking down the structure of dense clay soils, may well increase the incidence of damaged specimens recovered and could decrease the efficiency with which weakly sclerotised species are extracted.

Sample storage was considered to have much greater implications for the extraction of arthropods by dynamic methods. Before my investigations most workers assumed that samples must not be kept long or transported far, before extracting the arthropods by dynamic methods. Murphy (1958a) found the numbers of mites recovered by his funnel method decreased after

storage at ca. 4°C for 12 days. Hughes (1954) found that springtail numbers were unaffected by storage periods of 1-9 days at unspecified temperatures. My work indicated that the storage of cores of grassland soil at a suitable temperature, in this case 5°C, for a period of four weeks, had little effect upon the numbers of most arthropods recovered by the Rothamsted Berlese/Tullgren funnel apparatus. Storage for a longer period or at a higher temperature increased the numbers of some groups of arthropods extracted by the funnel apparatus and decreased others.

After reporting my findings on the effects of storage of soil samples in Paris in 1967, the effects of transport and the types of containers used to store soil samples before extracting them on a funnel apparatus, was further investigated by Rapoport and Oros (1969). Their results confirmed mine and showed that if soil samples are to be extracted by dynamic methods, the temperature of the samples before extraction should not be allowed to go above the normal soil temperatures. Very high or low temperatures can kill arthropods and relatively small increases in temperature may induce changes in arthropod numbers due to increased rates of development, hatching of eggs or emergence from pupae, particularly if long journeys are considered.

Optimum storage temperatures for soils from different climates and the effects of seasonal changes (the samples for the present study were taken in mid-May), require further investigation. The results of my investigations showed that it is feasible to store samples of soil prior to extraction by dynamic methods, as long as the optimum conditions are determined and suitable storage facilities are available.

Methods for specific groups of soil arthropods

Murphy (1962a) and Macfadyen (1962a) suggested the most suitable extraction methods for various groups of soil arthropods from different soil types and habitats. Although the best all-round extraction method

used in my studies was the Macfadyen air-conditioned funnel apparatus, specific groups of mites, springtails and other arthropod fauna were extracted more efficiently by different extraction methods from different soils. It is possible that these differences reflect changes in the species composition of the arthropod groups in the sites studied or the age structure of the different populations of soil arthropods examined. This is thought to be unlikely in the case of dynamic methods, because, as the emergence pattern data showed, all the arthropod groups tended to be affected by the same changes of physical conditions within the soil core during the extraction process. If taxonomically distinct groups of arthropods such as mites and springtails show similar behavioural responses to the changes in temperature and humidity during the extraction process, presumably, different species within the same taxonomic group would also tend to respond in the same way. Even so, it is dangerous to generalise and the following recommendations must be considered in respect of the limited number of groups and species living in those soil types examined in this study.

Acarina

The prostigmatid mites, including the Heterostigmata, were extracted much more efficiently by dynamic methods than by mechanical methods on all but the fallow arable sites on clay soils. Evans (1951) suspected that these smaller arthropods were being lost through the final sieve of the Tadel can, this would seem an unlikely explanation for these comparisons as the aperture size of the final sieve was 0.12 mm. My comparisons showed that the mechanical extraction methods so seriously underestimated the numbers of prostigmatid mites that they could not be recommended for the estimation of populations of this group of arthropods

in most situations.

Gamasid mites were often extracted equally efficiently by both mechanical and dynamic methods, but most of the significant differences that were observed, showed dynamic methods to be more efficient, presumably because these animals are very active and have no problems in escaping from soil samples. The Oxford infra-red extractor was particularly efficient for extracting rhodacarid mites from the woodland and pasture sites on silt clay loam soil. Uropodid mites tended to be extracted equally well by both dynamic and mechanical methods.

The astigmatid and cryptostigmatid mites were usually recovered in greater numbers by the dynamic methods; only on the fallow clay soils did mechanical methods occasionally extract more of these invertebrates. The increased numbers of many species of mites recovered by the flotation method from the woodland site on fen-peat soil are probably anomalous, due to the difficulties of distinguishing live from dead mites, at the time of sampling, in those mites recovered by the flotation method.

Collembola

There is little information on the most suitable extraction methods for these arthropods (Murphy 1962a). Poor recovery of Collembola from soil samples by dynamic methods was reported by Forsslund (1949) and Macfadyen (1953 and 1961). These authors compared funnel extraction with hand-sorting of soil samples. My studies showed that most Collembola are more efficiently extracted by the dynamic methods used than by the mechanical methods. Sminthurid and isotomid springtails were almost always extracted in greater numbers by dynamic methods. Of the few significant differences observed for the extraction of entomobryid springtails, most favoured the dynamic methods used. However onychiurid springtails were almost always extracted in greater numbers by the

mechanical methods and there was a tendency for podurid springtails to be extracted better by mechanical methods. Onychiurid springtails appeared to be the most difficult group of microarthropods to extract efficiently by dynamic methods.

Myriapoda

Myriapod populations have been estimated by a variety of methods. Wignarajah (1968) and Blower (1970) have used Tullgren funnel methods for estimating populations of Chilopoda and Diplopoda respectively. Michelbacher (1939), Edwards (1955) and Edwards and Dennis (1962) recommended the use of flotation methods rather than funnel methods for the extraction of Symphyla from all but forest litter. Little is known about the most suitable methods for extracting Pauropoda from soil.

The Macfadyen air-conditioned funnel apparatus was the most efficient extraction method for myriapods in these studies, but very few of the comparisons between the different methods of extraction were significant at the 5% level of probability. This was because so few individuals were recovered from most of the soils studied. Larger soil cores, 10 cm in diameter or greater, were required to estimate populations of these less abundant species accurately in most of the situations studied. Pauropods were always extracted in greater numbers by the dynamic methods in my studies, but none of the differences were significant ($p < 0.05$). Symphylids, centipedes and millipedes were extracted equally well by funnel and flotation methods from most soils, although greater numbers of centipedes and millipedes were recovered by flotation methods from most woodland soils.

Despite the fact that most myriapod exoskeletons are not completely wetted by the organic solvents used in the oil-water separation stage of some mechanical methods (Macfadyen, 1962a), my studies show they can be extracted relatively efficiently by flotation methods particularly if a

clean xylene-water interface is obtained (Raw, 1955). However, most myriapods extracted by these mechanical methods were badly damaged during the separation process.

Other arthropod groups

There are many different arthropod groups closely associated with soil for at least part of their life-cycle and these arthropods differ in size, shape, physiology and behaviour (Kuhnelt, 1961; Kevan, 1962; Wallwork, 1970; and Phillipson, 1971). Estimates of the populations of each group of arthropods have been made using a wide variety of methods by numerous authors, and many groups require specialised techniques. Raw (1956b) recommended his modification of the Salt and Hollick method for the extraction of Protura from grassland soil. Duffey (1962), developed a specialised extractor for spiders, Lewis (1960) used turpentine vapour to drive thrips from soil samples, and tipulid larvae may well be more efficiently extracted by the hot water extractor developed by Milne et al. (1958), although Healy et al. (1970) found glycerol-water flotation was the most efficient method for extracting fly larvae from woodland soils.

The mechanical and dynamic methods used in my studies, tended to extract these arthropod groups with equal efficiency, although for most groups the dry-funnel methods tended to be more efficient on the sand and peat soil types while the flotation methods were more efficient on clay soils. The comparisons showed that woodlice were always extracted in greater numbers by dynamic methods than by mechanical methods, and flotation methods should not be used to estimate populations of these arthropods (Sutton, 1968). On all soil types fly larvae and occasionally thrips, were extracted in greater numbers by the flotation method than by the dry-funnel method, but, as further studies showed, fly larvae were less efficiently

extracted in this type of dry-funnel method when alcohol, instead of water, was used as a collecting fluid. Even so, the Macfadyen air-conditioned funnel apparatus extracted more Coleoptera, Diptera larvae, Hemiptera, Thysanoptera, Psocoptera, Protura, Diplura, Araneida, Pseudoscorpionidae (Chelonethi) and Isopoda, than most mechanical methods, although the numbers recovered were usually few and seldom were significant differences observed.

The effects of soil type and vegetation upon the relative efficiency
of extraction methods

Most authors consider that dynamic methods for extracting arthropods from soil are more efficient on loose-textured soils with large air spaces that contain appreciable amounts of decaying plant material. Conversely, mechanical methods are thought to work best with compact clay soils with little organic matter content. Between these two extremes of soil type, a wide range of soil types occur (Simonson, 1957), and the problems of separating the arthropod fauna from them differ according to the physical characteristics of each soil type. Investigations of the arthropod fauna of tropical soils have been carried out using flotation methods by Strickland (1947), Salt (1952, 1955), Belfield (1956) and Block (1970), and Aucamp (1967) used his grease-film extractor to extract arthropods from South African soils. Presumably the characteristics of these soils made them more suitable for extraction by mechanical methods; for instance, their structure leads to a great deal of compaction when samples are taken. Mineral soil and the overlying plant litter were extracted separately by Murphy (1958a), Nef (1960) and Milne (1962) using dry-funnel extraction methods, because these two very different materials were considered to have different extraction characteristics. Kempson et al. (1963) developed the infra-red extractor specifically for extracting

arthropods from woodland litter, while Raw's (1955) modification of the Salt and Hollick apparatus was designed to extract arthropods from mineral agricultural soils characterised by their compact nature, fine texture and lack of undecomposed plant material.

My comparisons of the extraction efficiency of various methods on the different temperate soil-types studied, indicated that the more recently developed dynamic methods for extracting arthropods are much more efficient on clay soils than was previously believed. Although mechanical methods were best on clay soils, they seldom extracted more arthropods than the improved dynamic methods, even on clay soils with little organic matter content, except for a few specific groups of arthropods such as *onychiurid* springtails. The relative efficiency of mechanical methods compared with dynamic methods tended to decrease with increasing organic matter content on clay soils, but the comparison of methods on fen-peat showed that mechanical methods are not necessarily always less efficient than dynamic methods on organic soils. The nature and state of decomposition of the plant material appeared to be the most important factors affecting the efficiency of mechanical methods. Plant material that floated, or with a wax cuticle, that caused interference with the benzene-water interface or stuck to the greased plates of the grease-film extractor, decreased the efficiency of the mechanical methods.

The efficiency of dynamic methods on different soil types is affected more by changes in the internal structure of the soil core, caused by shrinkage and cracking of the soil during the drying process and the rates of evaporation of soil water, which may or may not be dependant upon the organic matter content of the soil. Therefore, different soil types require different extraction temperatures and humidity regimes in order to achieve maximum extraction efficiency. My results show that dynamic

methods of extraction were to be preferred for extracting most soil arthropods on all but some heavy, compact or sticky clay soils, but only by comparing different extraction methods on each soil-type, can the precise effects of soil-type on extraction efficiency be known.

Recommendations for improved extraction efficiency based on the
results of this work

These comparisons of dynamic and mechanical extraction methods for soil arthropods have shown that, except for the immobile stages and some specific groups of arthropods and soil-types, the best dynamic methods were much more efficient than the best mechanical methods on all the soil-types tested. The dynamic methods also had the advantage of being very much less laborious and quicker and recovered most arthropods in an undamaged condition. Theoretically, mechanical methods should be more efficient than dynamic methods, because the technical problems of separating arthropods from soils should be less difficult to solve than the behavioural or physiological problems associated with dynamic methods. However, the mechanical methods used in these studies were seldom more efficient than dynamic methods, and none of them could be used to collect arthropods alive. The future development of mechanical extraction processes must concentrate on a much finer separation of animals from soil particles without damaging the specimens, and the process should preferably be automated to reduce the number of man-hours involved (Bel field, 1976). Although freezing and thawing of the heavier clay soils may ensure the complete break up of soil aggregates, the freezing process can also damage animals or render them more prone to subsequent damage in the separation process. Chemical dispersal agents such as "Calgon" (Raw, 1955) are to be preferred.

Until new or improved mechanical methods are developed, there seems little point in advocating their use for extracting the micro-arthropod fauna for general study purposes, and their use should be restricted to specific situations where it is known that behavioural or dynamic methods are unsuitable. This does not imply that dynamic methods are an easy alternative to mechanical methods for extracting arthropods from soil; dynamic methods are particularly subject to misuse and only by strict adherence to the principles underlying the success of modern dry-funnel extractors can efficient extraction of arthropods be obtained. The introduction of controlled temperature and humidity gradients within the soil cores requires a much more detailed approach to the design of apparatus, and ideally such apparatus should incorporate continuous temperature and humidity measuring devices to ensure that optimum conditions are maintained throughout the extraction period. Further improvements may be possible with the introduction of controlled humidity systems, but care must be taken to ensure that sufficient air-circulation is maintained to prevent condensation of water droplets from decreasing the efficiency of the apparatus. With dynamic methods, the steep gradients of temperature and humidity, produced by heating and drying the upper surface of the sample and actively cooling and moistening the lower surface, as advocated by Macfadyen, were amply justified by the large increases in the number of arthropods extracted from the soil samples. The manipulation of these gradients and the timing of their application seems to be the most promising area for the development of more efficient dynamic extraction methods. The optimum gradients of temperature and moisture differ with site, soil type, climate and the particular arthropods being studied. Macfadyen (1968) has shown that the temperature gradients that can be produced, depend to a

considerable extent upon the thermal properties of a particular type of soil, so this may be an important factor limiting the efficiency of extraction methods that utilise the behavioural reactions of arthropods to extract them from soil.

Many factors affect the efficiency of dynamic extraction methods, and each stage in the process, from the time the soil samples are taken in the field, to the counting of the numbers of arthropods extracted can affect the results of any investigation of soil arthropod populations. Singly, these effects may be more or less important, but the combined effects of such factors as compression of the sample material, soil core orientation on the funnel sieve and the type of collecting fluid used, together with the application of different temperature and humidity regimes, produce large differences in the numbers of arthropods extracted.

GENERAL CONCLUSIONS

- 1) From a postal survey by questionnaire, of one hundred and fifty soil biologists, seventy percent used some form of Berlese-Tullgren funnel apparatus to estimate populations of soil arthropods and twenty six percent used some form of flotation method.
- 2) Of the eleven methods for extracting arthropods from soil compared in this study, the best was the Macfadyen air-conditioned funnel apparatus.
- 3) A typical Berlese-Tullgren funnel apparatus extracted more of most species of arthropods from soil than the Salt and Hollick wet-sieving and flotation apparatus for nearly all types of soil tested.
- 4) Mechanical methods for extracting arthropods from soil, seriously underestimated populations of prostigmatid mites and isotomid and sminthurid springtails in woodland and grassland soils and occasionally underestimated populations of these arthropods in fallow arable soils.
- 5) The relative efficiency of mechanical methods was occasionally greater than that of dynamic or behavioural methods when some species of arthropods were extracted from soils containing little or no undecomposed plant material, particularly clay soils under fallow or arable crops.
- 6) Mechanical methods usually extracted greater numbers of onychiurid springtails than dynamic methods, occasionally, mechanical methods also extracted more podurid and entomobryid springtails and larger insects such as fly larvae, beetles, root aphids and thrips.
- 7) Mechanical methods for extracting arthropods from soil were more laborious and time-consuming than dynamic methods and often recovered

arthropods in a damaged condition; freezing soil cores prior to extraction by mechanical methods contributed to this damage.

- 8) It was difficult to distinguish arthropods that were alive at the time of sampling from those that were dead when arthropods were extracted by mechanical methods.
- 9) The efficiency of dynamic methods for extracting arthropods from soil increased with the introduction of controlled temperature and humidity gradients.
- 10) The efficiency of dynamic methods increased when soil samples were placed intact and in an inverted position on the funnel sieve, compared with similar samples placed in an upright position or fragmented.
- 11) Onychiurid springtails and fly larvae were usually extracted more efficiently by dynamic methods from fragmented or intact layers of soil, 1 - 2 cm deep in the sieve container, than from 5 cm or deeper layers of intact or fragmented soil. The depth of sample material either did not affect the efficiency of extraction of other arthropods or greater numbers were extracted from the deeper layers of soil.
- 12) The relative efficiency of dynamic methods was not significantly different for soil cores of 5 cm, 10 cm and 12.5 cm diameters.
- 13) Heat without light extracted fewer soil arthropods than heat and light combined in a modified air-conditioned funnel apparatus.
- 14) The efficiency of Rothamsted Berlese-Tullgren funnels was adversely affected when distilled water was used as a collecting fluid rather than alcohol or picric acid solutions.
- 15) Diptera larvae were extracted in significantly greater numbers from soil cores when distilled water was used as the collecting fluid in the Rothamsted Berlese-Tullgren apparatus rather than alcohol.

- 16) The efficiency of the Macfadyen high-gradient canister apparatus markedly decreased when alcohol was used as the collecting fluid instead of water.
- 17) Greater extraction efficiency was not achieved for most soil-arthropods if soil cores extracted by a dry-funnel method were subsequently processed with a flotation method.
- 18) An automatic, continuous-collecting method was devised to record the emergence patterns of arthropods from soil cores in a Berlese-Tullgren funnel apparatus.
- 19) Most species of soil arthropods emerged from soil cores in two peak periods, probably associated with critical increases in soil temperatures and decreases in moisture availability.
- 20) Temperature gradients within soil cores affected the patterns of emergence of most species of arthropods and different species of arthropods had similar patterns of emergence under the same temperature regimes.
- 21) Optimum temperature and humidity gradients for extracting soil-arthropods varied with different soil types and climates.
- 22) Manipulation of temperature and humidity gradients during the extraction process should increase the efficiency of dynamic or behavioural methods for extracting arthropods from soil.
- 23) Soil cores from grassland could be stored at 5°C for up to four weeks before extraction in Berlese-Tullgren funnels without significantly affecting the numbers of arthropods extracted. After this time or when stored at higher temperatures, the numbers of some species were considerably increased, whereas those of others decreased, probably due to predation.

- 24) For soil-arthropod investigations that require accurate estimations of populations of many different species of arthropods, the most broadly applicable extraction method is one incorporating the design features of the Macfadyen air-conditioned funnel apparatus.

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