THE INFLUENCE OF DIFFERENT CULTIVATION TECHNIQUES ON CHANGES IN SOIL PROPERTIES AND SOIL MESOFAUNA

BY

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SUMMARY

A review of the effect of different seedbed preparation techniques on soil physical properties and soil fauna is presented. Field work on the subject was carried out at 3 sites in South Australia; Avon, Tarlee and the Waite Institute.

At Avon, the effect of direct drilling and conventional cultivation on the distribution of soil pores >40 µm was considered to be an appropriate study. Pores >40 µm are considered to drain the soil of excessive water, and the larger pores serve as a habitat for the mesofauna which are 200-600 µm in diameter or about the same diameter as roots of cereal plants. Measurement of pore size distribution was made using an image analysis computer directly on thin sections. Total porosity was calculated from the bulk density of the soil.

The results indicate that conventional cultivation produced more pores in the 0-4 cm soil layer compared with direct drilling, but the pores were unstable. Also, conventional cultivation caused a compacted layer to develop in the 4-8 cm layer (and deeper) with about 50% of the pores >40 µm in diameter. Results from direct drilling, however, indicate a stable continuous porosity throughout the 0-8 cm layer.

Macro-organic matter was extracted from soil by a flotation method using $ZnBr_2$. The results indicate that much of the leaf material remained on the soil surface after direct drilling but not after conventional cultivation. However, the total macro-organic matter content to a depth of 8 cm did not differ between the two treatments.

The effects of different implements were compared at the Waite Institute. As expected the Mouldboard plough buried plant residues whilst other treatments distributed them in and over the soil surface.

Soil which was direct drilled had a higher water content than conventional cultivated soils, especially during drier periods. This may have been influenced by the differences in porosity and distribution of organic matter in the two soils. Determination of the effects of 4 treatments on both water content and soil temperature were made at the Waite Institute. Soils which were disc ploughed and soils treated with herbicide had lower water contents and temperatures than soils tilled with tined implements and a Mouldboard plough.

The effect of direct drilling, conventional cultivation and single runs with different implements on soil structure and macro-organic matter was related to the populations and distribution of soil animals. The deleterious effect of conventional cultivation on soil fauna was probably a result of changed soil structure and macro-organic matter (quality and distribution). The effect was greater than that of direct drilling which included the toxicity of the herbicides used.

Crop rotation may or may not be suitable for the restoration of large populations of soil animals. Permanent and annual pastures were found to favour soil animals, probably due to the availability of plant litter and a favourable micro-environment. A rotation including a fallow period showed the most deleterious effect on both soil animals and macro-organic matter.

The disposal of trash by different methods after harvesting a crop, i.e. rotary hoe (incorporation), burning or retention on the soil surface, was investigated at Tarlee. The results indicate that trash retention

favoured soil animals since significantly more animals were found after trash retention than other treatments.

The movement of soil animals in beds of soil aggregates and the ability of mites and Collembola to degrade leaves was also examined. Poduridae (Collembola) were used to investigate movements of animals in aggregates because they move faster than mites. The results indicate that fewer animals found their way through beds of smaller aggregates. Increasing temperatures and the drying of soil aggregates from top to bottom, and the resultant low humidity created in the aggregates, also affected the animal movements.

To test the effect of the soil mesofauna on the degradation of plant materials, leaves from common Lantana were observed in culture tubes, together with selected animals. The leaf area consumed in unit time by Astigmata (mites) and Poduridae (Collembola) was measured: Astigmata were found to consume more than Poduridae.

It is concluded that in the South Australian environment mites and Collembola may be as beneficial to agricultural soils as earthworms and termites.

S T A T E M E N T

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University or College, and this thesis contains no material published previously or written by any other person, except where due reference is made in the text of the thesis.

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CHAPTER 1

GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL INTRODUCTION

Different techniques for the preparation of seedbeds include conventional cultivation (CC), direct drilling (DD) and minimum tillage (MT). The scale at which they are used depends on soil type and condition and differs from country to country.

Conventional cultivation is the technique normally used for preparing seedbeds in a particular area using machinery and implements of all designs, types and sizes. The method may include primary and secondary operations depending on soil condition, soil type and the crop to be grown.

More recently direct drilling of seeds into unprepared soil has been practiced. The technique limits the use of agricultural machinery and implements to the spraying of herbicides and crop seeding.

For several reasons DD and CC methods have been integrated to produce an intermediate system called "Minimum tillage". My definition of MT would be any seedbed preparation method using operations between the extremes of DD and CC. The operations in MT would be controlled by the availability of machinery and implements, soil condition and crop to be grown.

Soil animals are known to be important in the initial degradation of plant debris and its incorporation into the soil where fungi, bacteria and microflora take up the secondary step of decomposition (Kononova, 1966). Some soil animals help maintain soil structure by moving in the existing pores and thereby helping to stabilize the pores. Therefore we could propose that soil animals are important in an agricultural ecosystem where the crop needs optimum conditions to grow.

The aim of this study was, therefore, to determine the individual effects of different seedbed preparation techniques on soil physical properties and soil animal populations, and the relationships between them. The first aspect considered was the change in soil physical properties as a result of CC or DD and how these changes affect the soil animals. The second aspect was to determine the importance of these animals in agricultural soils especially where DD techniques are utilized.

Many methods have been developed for studying soil animals and their environment (see Edwards & Fletcher, 1977); extraction from the soil for counting and identification (Murphy, 1958a,b); soil organic matter (Oades and Ladd, 1977; Ford, 1968); soil structure (Lawrence, 1977; Ismael, 1975; and Dexter, 1976) and soil water (Hajduković *et al.*, 1967 and Greacen, 1981).

Many of the mesofauna (see Table 2) feed on plant remnants and associated fungi (Allison, 1973) it was considered that a measure of macroorganic matter or a light fraction (LF) would be the most meaningful measure of organic matter acting as substrate for the organisms. The LF was determined gravimetrically and the results were then related to the numbers of soil animals present with a view to evaluating the dependence of the soil fauna on the LF.

Soil structure was studied by a thin sectioning method followed by descriptions of structure using a Quantimet image analysing computer directly on the sections. Pore size distributions were measured which were then related to the activities of soil animals in the soil. The pore stability was of particular interest because it was considered to be a major factor in determining the vertical distribution of the animals.

The water content was mainly assessed by gravimetric method since it can be used for all water contents (Hajduković *et al.*, 1967). The gypsum-block electrical resistance method was used only in the Waite Institute grounds and the data obtained were compared with the former method.

1.2 REVIEW OF THE LITERATURE

1.2.1 Definition of soil structure

Soil structure is the arrangement of all soil particles and the pores around them. It includes size, shape and arrangement of the aggregates formed when primary particles are clustered together into large separable units (Marshall, 1962).

It is proposed that the best soil structure for most soil animals would be that where pores are stable and continuous and where exchange of gasses takes place freely.

1.2.2 Development and use of tillage

1.2.2.1 Conventional Cultivation

According to the Websters Dictionary "Tillage" means "turning" or "stirring" (as by plough, harrow or hoeing) to prepare a seedbed; to sow, dress and raise crop from the soil and cultivate. By this definition; till, plough, cultivate and even seed are nearly synonymous.

The term "cultivation", as used in this thesis will therefore include all operations involving manipulation of soil during seedbed preparation and subsequent growth of crop. Where the term "ploughing" is used, it will refer to preseeding operations or "primary cultivation".

Reviews on machinery use and cultivation methods can be found in Slicher Van Bath (1960); Anderson (1936); Agricultural Engineers Handbook (1961); Allison (1973) and elsewhere.

From these reviews, it is obvious that a variety of agricultural implements and tools exist for both shallow and deep cultivation and their use depends on soil, soil condition and climate.

The machinery used for shallow cultivation may include disc plough (DP), mouldboard plough (MB), tine cultivation (TC), sweep cultivation (SC) and rotary hoes (Fig. 10 and Plate 2). For deep cultivation, deep and heavy ploughs, chisels and subsoilers are used.

1.2.2.1.1 Shallow Cultivation

In most cases a MB would be used where soil scours very well, the DP would be used in a soil with the opposite quality and rotary hoes are used to prepare a fine tilth for small seeds which have a low sprout energy (Agricultural Engineering Handbook, 1961).

The basic purpose of shallow cultivation is to provide a favourable soil environment for the germination and growth of the crop i.e. provide sufficient air, warmth, and ease of emergence to plant shoots, also to eliminate and incorporate weeds and green plants as manure.

Sufficient stable pore space is very necessary for respiration of plant roots, animals and also bacteria which transform organic nitrogen into nitrates available to plants. This soil condition is defined by Slipher (1956) as "the optimum degree of aggregation of the soil into crumblike particles that allow free access of air and water" and it is therefore very important to achieve.

1.2.2.1.2 Time of tillage

Time of tillage can be independent of the soil and season i.e. sandy soil can be cultivated any time whether wet or dry but heavy soils maybe excessively damaged when these operations are undertaken in wet weather. Dry ploughing especially in heavy soils does not provide a good seedbed and may smash aggregates.

1.2.2.1.3 Amount and depth of cultivation

Cultivation is often repeated unnecessarily even when the soil is clean. A total of about 6 operations is not rare (Ellington, personal communication).

The necessary amount of cultivation is that which provides for freedom of root development and penetration, maximum water storage capacity, maximum air circulation and resistance to compaction by wheels of machinery and implements. The control of weeds has long been the most important reason for cultivation because weeds compete with a crop for nutrients, water and light. If weeds are controlled by means of a herbicide, then cultivation can be dispensed with or reduced to a minimum without serious effects on yield (Blake and Aldrich, 1955).

Water-stable soil aggregates are normally secured by the binding action of roots and soil organic matter (Tisdall and Oades, 1982), thus the exhaustion of OM by poor farming practices or excessive cultivation is accompanied by a deterioration in soil structure accelerating the decrease in soil productivity (Slipher, 1956).

1.2.2.1.4 Deep cultivation

Deep cultivation can result in a deeper root system taking up more water and plant nutrients resulting in a higher yield (Russell, 1956; Larson *et al.*, 1960; Brill *et al.*, 1965; Ellington and Reeves, 1978). This exercise is effective when it shatters hard pans or plough soles. Better drainage is one of the few benefits that may be realised if this operation breaks a hard impervious layer.

Cultivation has been undergoing a period of re-evaluation during recent years primarily because it encourages soil erosion, depletion of OM and is accompanied by loss of aggregates resulting in undesirable compaction, and also because of the extra energy used in the tillage operations. For the above reasons, minimum tillage was developed i.e. a mulch planter was developed to also kill plants and fertilize in one-operation (Paynor, 1950) and cultivating operations are being replaced by DD.

1.2.2.2 Direct drilling

The characteristic of DD, as commonly practiced, is that none of the land is tilled to prepare a seedbed but seed is dropped into the bottom of a slit made by the coulter of the drill.

The earliest I.C.I. plant protection experiments were aimed, therefore, at exploring the possibilities of planting cereals into soil uncultivated but with vegetation killed by spraying (Hood *et al.*, 1963). This technique started around 1960 (Allen, 1975) and has progressed markedly (Lal, 1974, 1976; Hayward *et al.*, 1980). In the U.K., from 1969 to 1974, the area of direct drilled land rose from 0 to 137 x 10^3 hectares (Allen, 1975).

1.2.2.2.1 Development of the technique

Research in Australia has shown that the technique of DD has given yields of winter wheat equal to that of CC (Ellington *et al.*, 1979). In England it also has given yields of winter wheat and spring barley equal or better than the traditional system of cultivation (Davies and Cannell, 1975; Russell, 1975) and this itself is a big breakthrough.

The technique also has been shown to result in an improvement of soil structure, and an accumulation of OM and more water down the profile.

1.2.2.2.2 Problems associated with the technique

Surface trash and straw appear to cause considerable problems for commercial direct drilling, particularly in wet seasons. Burning has been practiced as a successful commercial operation. It therefore appears that a major problem needing greater research and development is the design of a suitable light multipurpose drill which drops the seed at an even depth below the soil surface and in heavy soil it should have little smearing effect on the walls and bottom of the slit in which the seed is dropped.

For small subsistent farmers, a quick solution to seeding on trash has been found at the International Institute of Tropical Agriculture (IITA) (Wijewardene, 1978). Evaluation and tests of this prototype rolling injection planter have been undertaken in different countries including The Kenya Agricultural Machinery Testing Unit (KAMTU).

Wijewardene's concept of a complete machinery package to take improved production systems to the small farmer, has centred on the development of a single traction unit which can be equipped with sprayer units mounted on a boom and small matched rolling planter attachments.

In 1979, commercial machines based on the IITA prototype were developed by Geest Industrial Group Limited of Spalding, U.K. and a complete unit including planters and sprayers is now being tested in the tropics.

Weeds are not a barrier to the technique but an economical and managerial problem (Cussan, 1975). Repeated spraying is at the moment necessary. The effects of those chemicals on the soil and soil ecology have not yet been suitably investigated.

1.2.3 Effect of tillage practices on soil properties

1.2.3.1 Effect on soil structure

The main effects on soil structure are compaction and blocking thus modifying the pore volume and pore structure and resulting in a change in both the numbers of meso- and macro-pores (>50μm) and their shape and continuity. The degree of compaction may depend on water content, organic matter and texture (Harris *et al.*, 1966; Soane, 1973), the type of primary tillage employed and the state of compaction before tillage (Soane, 1970; Soane and Pidgeon, 1975). Soane found that the greater the OM content of soil the smaller the ultimate compaction and the greater the water content.

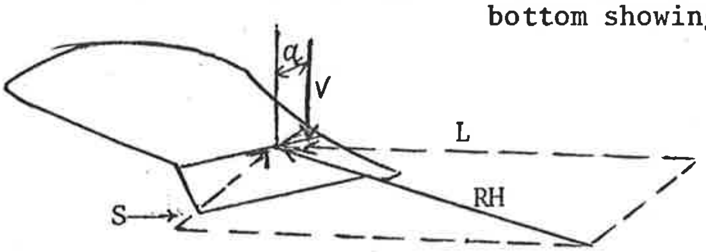
Compaction of cultivated soil may occur through two processes. Firstly by the weight of agricultural machinery and implements and secondly by natural means i.e. rain drops on bare clear soil surface (Sloane *et al.*, 1981). Compaction may be time dependent or result immediately.

1.2.3.1.1 Immediate compaction

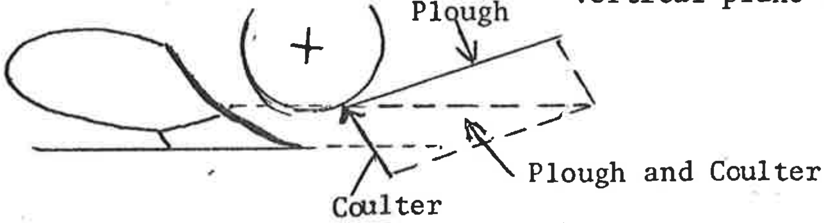
The main functions and purposes of design of most tillage implements i.e. MB, DP, and TC and the operations and influence of the implement and its tool shape have been studied and discussed (Agricultural Engineers Handbook, 1961; Soane, 1973; Gill and McCreery, 1960; Bushan and Ghildyal, 1971; Spoor and Gordwin, 1978 and Ojeniji, 1978). It has been found that a MB produces larger clods than a disc plough (Gill and McCreery, 1960) and than a cultivator (Bushan and Ghildyal, 1972). The mechanical function of a MB on soil consists of cutting, loosening, granulation and inversion. The granulation occurs through the centre of the MB and the inversion of the furrow slice takes place at the edge of the shin of the plough share.

Where a tool is pressed or driven into a soil, cutting or separation, shear failure, compression or any combination of these may occur depending on the shape of the tool used. According to Mulqueen, Stafford and Tanner (1977) the resistance offered by a soil to a penetrometer is a compound parameter involving components of shear, compression and tensile strength and soil metal friction. This theory may help us to understand more of the change of soil structure as a result of implement usage. For example, during tillage with a MB soil compaction may occur as a result of horizontal force produced by thrust or vertical force due to load (Agrictural Engineering Handbook, 1961) (Fig. 1). Wheel slip is also more effective than load increase in causing compaction (Soane, 1973).

(a) Forces exerted by the furrow slice on the face of a plough bottom showing couple Va.



(b) Division of the resultant forces on plough and coulter in the vertical plane for moist soil.



(c) Typical resultants for a wide range of conditions showing that in hard ground the increased coulter force causes an upward resultant.

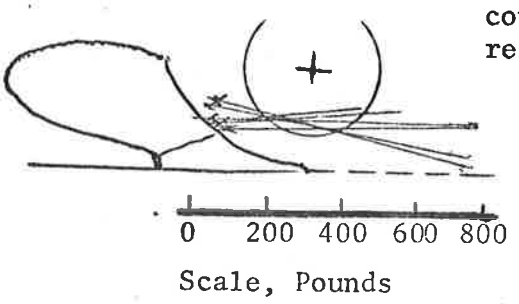


Fig.1: Forces resulting from the movement of a Mouldboard plough in soil. L= longitudinal force, S = side force (Wayne, 1952).

During this operation, measurement have indicated that side force (S) is less affected by soil variation than longitutional force (L) and may range from 25 to 50% of the force L. The third force (V) is usually offset to the land introducing a couple as seen in Fig. 1. Balancing the side force (S) is usually accompanied by furrow wall pressure against the land slide which of course introduces a parasitic drag which has been calculated to be 7.5 to 15% of L (Wayne, 1952). The parasitic upward force on the cutting edge will vary greatly with sharpness of the share.

The effect of water content, at time of tillage, on soil structure has been extensively studied (Bushan and Ghyldyal, 1972; Ojeniji and Dexter, 1979a). It has been shown that the optimum water content for tillage is around the plastic limit (Ojeniji and Dexter, 1979a) and this is influenced by the tillage implements and the speed of tillage (Vershinin, 1959). Ljungars (1977) showed that maximum compaction occurs between water content of 24 to 26 (% w/w) and this is well illustrated in Fig. 2.

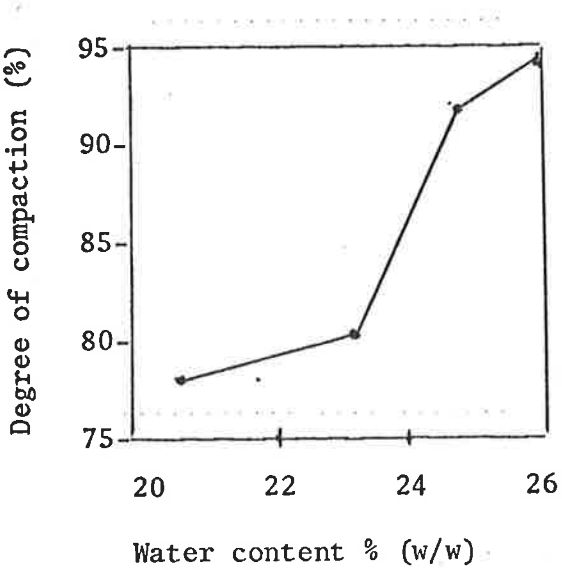


Fig. 2: The influence of soil water content on the degree of compactness after a single pass of a 46 kw tractor (mass 4.03t) at 71 cm/hr. over soil of 38% clay content.
(After Ljungars, 1977).

Data in Agr. Eng. Handbook (1961) show that the net reaction of a plough bottom and coulter produce a vertical force ranging from 59 kg downward in moist sod to 90.7 kg upward in dry hard soil. Thus it is obvious that the plough must be kept in the ground by weight when the later condition is encountered. Therefore compaction will depend on load in addition to water content, elasticity of soil and organic matter content.

Spoor and Gordwin (1978) examined and compared a number of rigid tines both in the field and laboratory under a range of different soil textures, densities and moisture content. Two methods were used for measuring tine force. The horizontal and vertical forces acting on single tines were measuredsimultaneously using extended octanol ring transducers, the tine being mounted directly on the transducer. For horizontal force alone, a tractor/toolbar combination carrying the tine was towed and the tension in the towing chain was monitored using a strain gauge tension dynamometer. The tractor rolling resistance was subtracted from the dynamometer reading to give the horizontal implement force. Soil disturbance at depth was monitored by digging a trench across the disturbed area immediately after a run. The disturbed soil was removed by hand and the undisturbed soil profile so exposed was measured using a profile meter. In the laboratory, glass sided tanks were used to observe the soil disturbance ahead of the tines. After these experiments they arrived at a conclusion that there is a critical depth for all rigid tines below which compaction, rather than effective loosening, occurs. This could be better understood by examining the critical depth function (Spoor and Gordwin, 1978).

With the use of this equation, Gordwin and Spoor were able to find the critical depth for different soils. They came to a conclusion that this critical depth is dependent upon the width, inclination and lift height of the tine foot, also the moisture content of the soil. They also indicated that this critical depth is much closer to the soil surface in uncompacted than in compacted soil.

On the other hand Hettiarachi and O'Callaghan (1980) discussed the mechanical properties of agricultural soil upon tillage. They associated compaction with soil failure and the changes of soil pores. Swanson, Hanna and De Roo (1955) found that excessive tillage at high soil water content broke down the aggregates larger than 2 mm diameter and decreased aggregate water stability.

Sorochkin and Sheptukhov (1979) tried to explain compaction further and associated the compaction in the subsoil to stresses caused by heavy machinery while that of the ploughed layers may be influenced by light machinery. What he meant here was probably the compaction caused by machinery tyres (Soane *et al.*, 1981) as illustrated in Fig. 3.

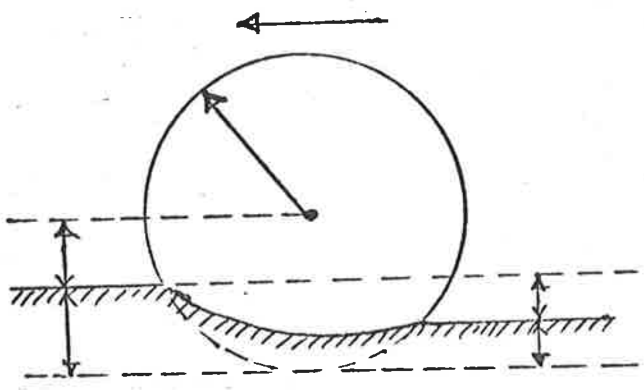


Fig. 3: The effect of tyre deformation on contact area.

A number of empirical relationships have been suggested for estimating contact area, on hard surface, from data on tyre geometry (Inns and Kilgour, 1978).

Since during tillage tyres are not standing on flat surface the contact area will increase when the tyre is deformed or underinflated (Fig. 3). This was realised by Christov (1969) who proposed different relationship than that proposed by Inns and Kilgour *(Loc. cit.)*.

From this theory we understand that the area of coverage by tractor wheels will depend on the numbers of separate agricultural operations peformed. To support this hypothesis, Soane (1970) showed that fertilizer distribution, twice harrowing, sowing and rolling gives about 90% field coverage with a medium sized tractor. Within this coverage soil compresses (contract). Since the contraction during compression exceeds the expansion during unloading (removal of the tractor from the field) continuous compression of soil will cause a continuous decrease in its volume until a point of maximum compaction is reached. Soane *et al.* (1981) showed that 8 passes with a light vehicle resulted in a bulk density increase from 680 to 800 kg/m^3 where as infiltration decreased from 323 to 2 mm/h. This decrease in infiltration and increase in bulk density could be ascribed to the formation of a compacted layer or pan (Baver *et al.*, 1972).

1.2.3.1.2 Time dependent compaction

Barley and Davies (1971) showed that during the growing period, plant roots exert pressure to the soil causing compaction. Dexter and Tanner (1974) tried to explain time dependent compaction of tilled soil by remoulding soil and concluded that tilled soil compresses quicker than non-tilled soil. More information on time dependent compaction can be obtained from rain drop theory.

Rain drops contain kinetic energy and the exact magnitude of this energy will depend on the drop size and velocity of fall which is determined by the height. For any given rainfall intensity (Rose, 1961), the relative aggregate breakdown increases as the size of aggregates decreases. Therefore if the rain continues for some time, a crust seal may develop at the surface soil as a result of slaking of soil aggregates (McIntyre, 1958a, b). The slaking results from the great forces and pressures which are likely to arise upon the impact of the rain drops especially on tilled, bare soil surface. This follows the Newton Law on the basis for which formulae have been derived for computing the impact force of drops on an ideal solid surface (Slastikhin, 1971; Gadzheve, 1968). The drop theory of Slastikhin and Gadzheve (Loc. cit.) may lead to the conclusion that serious compaction of the soil surface in cultivated soil will occur. This phenomenon may be more pronounced in the tropics where heavy storms continue for a long time.

Such a compaction has been found to influence porosity in the top 9-50 mm of arable soil although the effect is more pronounced in the top 2 mm of a fresh tilth (Bulfin and Gleeson, 1967). This crust formation can be minimised in soil with a high OM content (Ahmed and Rublin, 1971). Tackett and Pearson (1965) tried to show the magnitude of the effects of rain drops on tilled soil. They showed a dense layer 1-3 mm thick with a surface thin skin coat of well oriented clay and this dense layer reduced water permeability of the 0-5 mm layer to 1/5 that of the soil underneath.

The information given in this section will also help to explain why many workers (Bulfin and Gleeson, 1967; Free *et al.*, 1963;

Van Ouwerkerk and Boone, 1970; Soane *et al.*, 1970; Finney and Knight, 1973) comparing tilled with untilled soil found great differences of soil structure between treatments both within and between soil types.

1.2.3.1.3 Conclusion

Until we have more information on the processes determining changes in soil porosity it is difficult to be certain how far loss of porosity due to compaction will be reversed by natural processes.

Loss of macropores on the soil surface can normally be reversed by cultivation which may also reduce the continuity of those pores.

Biological action, particularly over a long period, can also restore porosity of the transmission and storage pores (see Table 2).

Seedbed preparation techniques alternative to conventional cultivation that will cause minimal disturbance to soil structure and OM of the soil seem to be the best answer to improve soil structure.

1.2.3.2 Effect on Organic Matter

1.2.3.2.1 Introduction

Organic matter plays a major role in the stabilization of soil structure and control of biological and chemical properties of soils. Under a given land system, the organic matter content of the soil will ultimately attain an equilibrium level where the rate of accretion to the soil from plants and animals balances the rate of mineralization. However this equilibrium may be changed following a change in management.

There is considerable information on the general nature, chemical composition and fractionation techniques of soil OM (Bremner, 1965; Dubach and Mehta, 1963; Hurst and Burges, 1967 and lately Oades and Ladd, 1977).

1.2.3.2.2 Accretion of OM in soil

Phytomass production differs between soils, regions and even continents (Allison, 1973). From the information available regarding soil organic matter levels, no general statements can be made that apply to all soils but it is possible to generalise in many soils. Oades and Ladd (1977) suggested that phytomass production varies from .3 to 50 kg/m^2 yr^{-1} from the extremes of tropical deserts to humid tropical forests and that total phytomass for cereal crops varies from .1 to 1 kg/m^2/annum, whilst the production for leys is 1.2 kg/m^2/annum. They also indicated that up to 80% of the phytomass production ma be in the root depending on the plant community.

1.2.3.2.3 Fractionation of organic matter

Organic matter of the soil consists of several components; (a) partly decomposed plant and animal residues; (b) humus which can be divided into humic acids, fulvic acids and humins; and (c) a range of non-humic components e.g., protein-like substances, carbohydrates, waxes tannins etc. (Kononova, 1966; Ford, 1968; Oades and Ladd, 1977 and Oades, 1981).

Soil OM is important as a source of food and energy for heterotrophic microorganisms and soil fauna. Organic matter is also important in the stabilization of soil aggregates (Tisdall and Oades, 1982; Cockroft and Tisdall, 1978 and Oades, 1981).

Attempts have been made to fractionate soils into its various particle sizes using ultrasonic energy for dispersion (Edwards and Bremner, 1967; Greenland and Ford, 1964). After that, heavy liquids were used to float the light fraction (LF) from the heavier soil material. Heavy liquids used have been bromoform-petroleum spirit mixtures, Nemagon and aqueous zinc bromide. The choice of an appropriate density depends on the soil, and on the reason for which the LF is being separated. Generally a density of 1.6 to 2.0g cm^{-2} has been used, but different densities have been found to yield different amounts (by weight) of LF (Oades, 1981).

The lowest size limit of this descrete material separated in this way has been placed at 0.25 mm (Barley, 1955) and has been found to contain about 10% humic material, organomineral complexes and fungal hyphae and spores (Oades, 1981; Oades and Ladd, 1977).

1.2.3.2.4 Organic matter and soil aggregation

Attempts have been made to determine the size of soil aggregates which contain most of the organic matter; and also to identify the binding agents for these aggregates. Tisdall and Oades (1982) defined the stages of aggregation as follows:

$<0.2\ \mu m \rightarrow 0.2 \rightarrow 2\ \mu m \rightarrow 2\text{-}20\ \mu m \rightarrow 20\text{-}250\ \mu m \rightarrow 2000\ \mu m$

with the aggregates >250 μm being termed macroaggregates and those <250 termed microaggregates (Oades, 1981).

The macroaggregates have been found to be stabilized mainly by plant roots and fungal hyphae. Aggregates <250 μm have been found to contain particles 2-20 μm bound together by organic matter, crystalline oxides and aluminoscilicates (Tisdall and Oades, 1982). The 2-20 μm aggregates have been found to be enriched in organic matter (Oades and Ladd, 1977). The binding agents of aggregates have been classified into two groups: firstly polysaccharides, including microbial polysaccharides and polysacharides associated with the microbial biomass in the rhizosphere (Oades, 1978) and roots and fungal hyphae (Tisdall, 1980); secondly resistant aromatic compounds associated with metal cations and strongly sorbed polymers (Oades, 1981; Tisdall and Oades, 1982) which form the largest organomineral fraction of the soil and which consists of 52-98% total OM in the soil (Greenland, 1965; Tuchenek and Oades, 1978).

1.2.3.2.5 Effect of cultivation on soil OM

Where soil is cultivated frequently aggregates are exposed to physical disruption by rapid wetting, rain drop impact as well as shearing by implements. Therefore if we consider the model of aggregation mentioned earlier in section 1.2.3.2.4, we can expect after cultivation the once hidden OM to be exposed to soil animals and microorganisms resulting in eventual loss of OM (Rovira and Greacen, 1957; Adu and Oades, 1978). This may explain why the rate of loss of OM has been found to be greater following cultivation (Saunder and Grant, 1962; Greenland, 1962; Abbott *et al.*, 1979). Cultivation has been associated with enormous losses of OM by many workers including Kononova (1966); Allison (1973); Moschler *et al.* (1972); Juo and Lal (1977) and Oades (1981). Among the implements and the processes contributing greatly to the loss of soil OM are the MB and the various systems of cultivation that keep the soil bare for a considerable portion of the year.

If the best farm practices are used, it is hoped that this loss of OM can be partially prevented.

1.2.3.3 Effect on soil water

The aspects of water of most relevance to crop production are: storage capacity, infiltration capacity and internal drainage (Greacen, 1981).

1.2.3.3.1 Infiltration

Before water is available to plants and animals and if the water has to be distributed and redistributed in the profile, it has to infiltrate into the soil and this may proceed in three dimension as shown by the equation (Marshall & Holmes, 1979):

$$\frac{d}{dx}\left(K\frac{4\psi}{dx}\right) + \frac{d}{dy}\left(K\frac{d\psi}{dy}\right) + \frac{d}{dz}\left(K\frac{d\psi}{dz}\right) + \frac{dk}{z} = \frac{d\theta}{dt} \qquad (1)$$

where the 3K's represents the three directions xy and z, z when expressed in the unit of hydraulic head equals ψg.

Sometimes runoff occurs before the profile is full of water and this could be due to low hydraulic conductivity in the B horizon or the plough sole or a surface crust. McIntyre (1958a) found that the permeability of a surface crust was 5×10^{-7} cm. Sec^{-2} compared with 10^{-3} cm Sec^{-1} recorded for an uncrusted soil. Also Ojeniji (1973), found that hydraulic conductivity of a crust was 30 to 40 times less than that of uncrusted soil. Similar results were reported by Oades. (1976) where smaller infiltration rates due to the presence of a crust led to increased surface runoff.

If the porosity is adequate down the profile, then water continues to infiltrate and eventually the soil becomes saturated (where potential equals zero). At this time the profile is fully charged with water. If the transmission properties are poor, ponding may occur which is detrimental to soil animals and plant communities. Infiltration depends on pore size distribution. Compaction of soil by traffic may cause a reduction in infiltration thus causing less water storage in the profile. The saturated hydraulic conductivity of the pan in a silt loam soil in Germany was determined as 8×10^{-4} cm Sec^{-1} whereas that of the uncompacted tilled soil was 5×10^{-3} cm Sec^{-1} (Ehlers, 1975).

1.2.3.3.2 Water store

Different soils have different capacities to store water. This is due to varied textures, soil structure and soil OM content (McGowan and Williams, 1980). The amount of stored water has been measured in the field both two days after complete wetting and in the driest condition (Greacen, 1981). This water is within 0 to -15 atm. and could be measured in different ways. For example gravitational potential is simply measured with a ruler between the reference level and the level in question while matric potential is measured by tensiometers. Some of the tensiometers can operate in the range of ψm = 0 to -15 bars.

In the field, this stored water can be determined by measuring the water at field capacity W_f (-0.1 to -0.33 atm) and the driest condition W_w (wilting point = 15 atm) then the available water is obtained by

$$Wa = \frac{P}{1000} \left(\frac{W_f - W_w}{100}\right) \text{ mm/mm} \qquad (2)$$

Total soil water will depend on soil structure and soil texture (Table 1).

TABLE 1: Total soil water store (0 to 1m) and grain yield for Red-brown earths and associated soils in south-eastern Australia. (After Greacen, 1981).

Factual key[1]	District	Depth A(cm)	AWSC (mm m^{-1}) Horizon A	B	Soil store 0 to 1m (mm)	Grain yield (kg ha^{-1})
Gn2.13	Condobolin	10	120	100	102	2241
Gn2.13	"	8	120	80	88	1350
Dr2.13	"	25	120	130	128	2536
Dr2.13	"	20	170	120	130	3387
Dr2.13	"	14	160	70	83	1591
Dr2.13	"	23	130	100	107	1801
Dr2.13	"	35	130	110	117	2321
Dr2.33	Jamestown	17	200	130	142	1750
Dr2.33	"	26	220	170	183	4000
Dr2.33	"	28	190	160	168	4250
Dr2.33	"	21	220	120	141	4550
Dr2.33	"	27	240	180	196	2020
Dr2.43	Roseworthy	14	140	110	114	860
Dr2.43	"	19	140	150	148	490
Dr2.43	"	23	130	230	207	440
Gc1.11	"	17	120	80	91	2500
Dr2.53	"	13	160	110	117	1610
Gc1.11	"	18	120	170	161	2100

[1] Northcote (1979).

[2] First 7 sites were for 1978 season; others 1979.

It has also been reported that the soil organic matter plays a leading role in soil water storage of many soils (Greacen, 1981).

1.2.4 Determination of soil structure

Soil structure has always been directly related to water content and its measurements based largely on physical parameters.

To compare one soil with another measurements of bulk density, infiltration, water permeability, water stability, pore size distribution etc. are important.

Reviews are available of the methods used so far for measuring soil structure (Lawrence, 1977) and some work shows a clear relationship between parameters (Greacen, 1981). A lot of this work is only possible in laboratory, but some has been conducted *in situ* to find the pore size distribution. Dexter (1976) used epoxy resin to measure pore size distribution in the field, but this method can only produce reliable results in freshly cultivated soil. Other workers such as Douglas *et al.* (1980/81) have used a radioactive tracer solution (^{144}Ce) to study the continuity of transmission pores. They used this to compare two treatments i.e. DD and CC, and concluded that pores >50 μm were more abundant in the upper layer of CC than DD soils and that in the subsoil, values converged. They also pointed out that transmission pores (>50 μm) were more numerous in DD than in CC soil. They linked this difference with the presence of soil animals in DD soil and suggested that this improvement of porosity will improve aeration status and encourage more rapid root growth.

In existing reviews and papers, measurements of soil structure have been reported under broad headings such as:

1. Measurements of soil structure by scanning of photographic films of small sections of soil.
2. Measurement of soil stability and aggregate size distribution.
3. Measurement of physical properties that are a function of pore size distribution.
4. Description and microscopic assessment of impregnated soil structure.

Many workers have reported that the methods used are either good, or exceedingly expensive, time consuming and unreliable due to variability of sampling measurements. For example, pore size distribution of soil has generally been obtained by observing the relationship between moisture content and suction and the pore size related to suction by assuming cylindrical pores and applying the equation:

$$Pgh = 2 \gamma \operatorname{Cos} \frac{\Theta}{r} \qquad (3)$$

Where P = density of water (1000 kg m^{-2}) g = gravity force (9.81 m S^{-2}) h = applied potential (m), γ = surface tension of water (73 mNm^{-1}), Θ = angle of contact between water and the soil particles (usually assumed zero) and r = radius of capillary pore (m) which indicates the largest of capillary pore retaining water at the applied potential.

Because of the range of pore diameters to be analysed in soil, people have used different fluids including non-polar liquids i.e. mercury has been used to measure very small pores (10^5 nm to 10 nm) (Lawrence, 1977). In this case pressure was required to force mercury into the pore where equation 3 takes form:

$$P = 2\ \gamma \text{Cos}\ \frac{\Theta}{r} \qquad (4)$$

Where P = applied pressure

Equations 3 and 4 above were not found to be appropriate for many soil materials (Sills *et al.*, 1973) e.g. clay where the pores are slit-like due to the shape of the clay plates (Aylmore and Quirk, 1967). Therefore formula 4 was rewritten:

$$P = -2\ \gamma \text{Cos} \frac{\Theta}{d} \qquad (5)$$

Where d = the plate separation

However, there is much literature describing how incorrect pore size distribution estimates may be arrived at due to some of the intruded volume of polar-liquids being attributed to pore sizes that are too small i.e. pores having a restricted entrance (Dullien and Mehta, 1972) and water characteristic curves attributed to hysteresis (Marshall, 1962; Childs, 1969).

Although pore size distribution results obtained from thin sectioning methods have been shown to compare favourably with those derived from water and non-polar liquids desorption (Swanson and Peterson, 1943; Panabokke, 1956), the thin section method probably remains acceptable as the only method that will give considerable information on soil structure (Brewer, 1964; Ismael, 1975; Dexter, 1976). Measurements of pores by most other methods yield information relating almost exclusively to pore neck size.

In conclusion, it should be pointed out that in order to prevent more confusion and unreliability in measurements relating to soil structure, methods should be standardized.

1.2.5 Ecology of soil animals

1.2.5.1 Geographical distribution

Maximum densities of soil animals are found in tropical climates but a large number may live comfortably in a temperate climate (Murphy, 1958d). Their distribution, however, depends on microenvironmental parameters such as water, organic matter, soil pH status etc.

1.2.5.2 Space distribution

Soil animals are generally aggregated rather than randomly distributed (Satchell, 1967). Although the depth of sampling for soil animals will depend on the purpose of the individual investigation, both shallow and deep sampling have been found to provide a useful source of information. In the previous section, we have seen that most animals live in the top few cm of soil. For example Anderson (1976) found most Cryptostigmata (Acari) to occur just above the mineral soil where temperatures are buffered by surface litter; but other animals, e.g. earthworms have been reported to occur at a depth of 20 cm (Zicsi, 1962). The percentages of earthworms and other animals living within 20 cm of the surface have been reported to be 80-90% but this value may also depend on the species (Russell, 1961). Most large animals reach these depths by burrowing while the smaller fauna can use these burrows to migrate up and down. Also they follow the cavities left by decaying roots. A positive correlation between vertical distribution of soil animals and soil structure has been reported by Griffiths (1965).

Distribution of soil animals down the profile is controlled by biotic and abiotic suitability for the animals (Satchell, 1967). These animals may retreat upward or downward in case of unsuitable microenvironment. However, it is proposed that migration of animals may be possible only if the soil contains continuous pores of greater dimensions than the animals body. Meso- and macro-pores (i.e. 50-5000 μm) have been reported to be favoured habitats by soil animals (Forgi, 1948; Macfadyen, 1955; Haarløv, 1955).

1.2.5.3 Activities of soil animals

Soil animals can be grouped into different types in terms of their activities. Some groups spend most of their energy burrowing, building mounds and feeding whilst other groups spend their energy moving around and feeding (Lee and Wood, 1971).

The primary effects of most soil animals on the soil appear to be physical rather than chemical. The chemical function, which is decomposition of degraded plant and animal residues, occurs mainly through the activities of soil fungi and bacteria (Oades and Ladd, 1977).

However, the presence of soil animals is contributory to the establishment of vigorous populations of these microorganisms.

The litter, together with the animal faeces and carcasses, form the energy base on which detritivorous soil animals and microfloral decomposers feed. These animals help in the cycling of plant nutrients but as a general rule, the complexes in which these elements occur (Kononova, 1975; Ahmed, 1981) must be mineralised to yield orthophosphate and sulphate before nutrients can become available to plants again. However, this process is not easy to measure.

The chemical degradation of the energy rich plant debris, which results from the feeding activities of soil organisms, is characterised by the liberation of energy and nutrients. For example, the energy entering soil animals is not cycled but ultimately becomes dispersed as heat due to the metabolic activities of the soil animals. Therefore the metabolic activity in the soil is a good measure of the activities of soil animals in soil (Wallwork, 1970).

The simplest and most convenient way to describe the energy budget of the entire soil population is given by the formular:

$$I = R + Y \qquad (6)$$

Where I represents the energy assimilated with food, R is energy used up in respiration and Y is energy bound up in the animal protoplasm and available to other trophic levels (i.e. the production of the populations under consideration.

The above term could be estimated in the following way. I can beobtained as the difference between the amount of food ingested and that egested per unit time, per unit body weight. This is simply estimated by subtracting the weight of faeces produced from the weight of food offered and consumed. The latter can be measured by using leaf discs of uniform thickness, known surface area and known weight and subsequently assessing the total area of the disc consumed. Y can be estimated by making successive measurements of animal biomass. However direct weights of micro- and meso-fauna are often difficult and subject to large errors. Therefore, a better method could be that of Engelmann (1961) where the relationship between faunal surface area and dry weight is defined. The estimation of R could be by direct or indirect measurement of oxygen uptake by animals. For small animals such as mites and Collembola, the detection of volume changes of considerably less than 1 ml per unit time has to be made. Micro-respirometers may be used for some animals but the respiration of small soil animals such as mites and Collembola is too low to be correctly measured by this method. Thus an indirect method (Engelmann, 1961) for small Cryptostigmata was found to be possible by using the equation:

$$Y = 18.059 + 0.7w - 0.487\ Z \qquad (7)$$

Where Y is the log oxygen consumed / individual / day in $10^{-3}\ mm^3$, W is log body weight in µg, Z is $^1/Tabs\ .\ 10^4$.

As can be seen from the information given above, to measure the metabolic activity of the soil is a complex process, thus the best way to assess the activities of soil communities is to study each group separately.

1.2.5.4 Interactions of soil fauna and microorganisms

A direct interaction between soil fauna and soil microorganisms exists. The large saprophytic soil animals distribute both decaying OM and some of the microbial populations throughout the soil layer in which they are working. They do this by ingesting food in one place, mixing it in their guts and excreting it elsewhere. Russell (1973); Hole (1981) reported that some saprophytic invertebrates carry protozoal populations in their guts to help digest the more resistant plant products such as cellulose on which the animals feed. Some other animals (e.g. Collembola, mites and Protura) have been reported to stimulate microbial life in the soil and accelerate the decomposition of OM (Nosek, 1975).

1.2.6 Effect of soil animals on soil

1.2.6.1 Modification and maintenance of soil structure

It appears from the results of many workers (Hole, 1981) that the large animals (macro) are effectively modifying the soil both physically and chemically, whereas the smaller ones (meso and micro) maintain the changed soil structure.

A lot of work has been done on earthworms for the last 150 years (Karkham, 1980) and in most cases the effects of earthworms has been associated with stable crumb structure of soil (Van Rhee, 1970; Guild, 1955). Smaller animals within the macrofaunal group have also been regarded as important to the formation of stable aggregates and include termites and ants (Lee and Wood, 1971).

Physical modification of soil has been reported as a result of burrowing and mixing the soil with organic and inorganic matter. A study by Rogaar and Boswinkle (1977) has shown well defined channels made by large animals and this topic is reviewed by Hole (1981). The importance of these channels or voids is their function as a drainage system. Rogaar and Boswinkle (1977) also found by a field experiment that intensive mixing of the soil by earthworms, did form an A_1 horizon which otherwise may not have been there.

The existing pores made by large animals and left by decaying plant roots may be maintained in a stable condition by smaller animals. Most agricultural cereal plant roots are between 200-600 µm in thickness (Low, 1972) therefore the maintenance of pores of this range by the vertical and horizontal movements of soil mesofauna would promote the ease of entry into the soil by new plants roots.

1.2.6.2. Effect on OM

Leaf fall is a major contributor of OM to a forest soil while roots are more important in a pasture ecosystem and stubble and straw are important in cultivated land (Allison, 1973). Soil animals have been linked with the physical fragmentation of the organic residues and they are important to future plant growth through the initiation of decomposition process.

Elucidation of the relative importance of the different invertebrate groups in degrading organic residue was first attempted by Edwards and Heath (1963); Heath, Arnold and Edwards (1965). They showed that fragmentation of fallen oak leaves starts immediately large animals come in contact (introduced), and within 4 months 90% of leaves were fragmented and about 45% had completely disappeared.

Although most of the work was done on large animals, Kononova (1966) examined the contribution to decomposition by Collembola: a population of 10^5 m^3 was associated with the formation of 180 m^3 ha^{-1}

of a fine grained humus which would be a great contribution by these animals to an agricultural ecosystem.

Therefore both the meso- and macrofauna are important in fragmentation of organic residues. They also translocate organic matter and spores (Witcamp and Crossley, 1966) thus stimulating microbial growth and changing the rate of mineralization. During this process, various acids (Oades and Ladd, 1977) are formed which act on soil mineral matter releasing plant nutrients which may otherwise not become available (Jacks, 1963).

Thus it can be concluded that the soil animals play a primary part in the decomposition of OM by their contribution to its physical degradation and incorporation into the soil. The secondary stage of decomposition involves 6 main categories of chemical constituents which are decomposed further by fungi, bacteria and microflora.

1.2.7 Effect of tillage practices on soil fauna

Soil animals have been classified in terms of their size, e.g. micro-, meso- and macrofauna (20μ-200μ, 200μ- 1cm and >1cm respectively (Wallwork, 1970). Each of these groups of animals are important in their own way in the agricultural ecosystem. Therefore I am going to classify the animals using the same terminology but based on the sizes of soil pores in which they could move and live freely (i.e. their diameter) (Table 2).

Within one soil type (Aleinikova and Utrobina, 1969) the population density, the proportion of different types and the trophic structure of the soil fauna, depends on the type of farm crops sown and in particular the method of soil disturbance (tillage used).

TABLE 2: Classification of soil pores (Greenland, 1977) used as a basis for classifying soil animals.

	SOIL PORES							Soil animal
E.c.d* μm	Manegold quoted by Cherdegger 1957	Jouger 1957	Brewer 1964	IUPAC	McIntyre 1974	Smart 1975	Green-land 1977	Malinda
5000			Course macro voids				Fissures	Macro fauna
500	Voids	Macro pores	Macro voids		Super pores	Mini pores		
100								
75							Transmission pores	Mesofauna
50	Capillary	Meso pores	Meso voids	Macro pores	Macro pores			
30						Macro pores		
5	Force space		Micro voids		Mini pores			
2							Storage pores	Micro fauna
.5		Micro pores				Micro pores		
.1			Ultra micro voids		Micro pores			
.05			Crypto voids	Meso pores			Residual pores	
.02								
.005								
.002				Micro pores			Bending pores	

*Equivalent cylindrical diameter

Tillage has both direct and indirect effects on soil animals. Among the direct effects (Ghilarøv, 1969) are the pressing and cutting of the animals by implements and machinery wheels. The indirect effects occur as a result of reducing soil pore sizes and blocking the pores with small soil particles. These changes may have a serious effect on the soil animals of a particular size as indicated by a reduction in population numbers. Aritajat *et al.* (1976) found not only a reduction in population numbers but also a change in average body weight after compaction. This could probably be attributed to an indirect effect in that a change in soil pores and their continuity may have increased the energy required by animals to move around in search of a suitable microenvironment as well as food.

However, soil animals living on the soil surface may not suffer as much. Edwards (1975) found that tillage favoured some soil pests e.g. shoot borers.

Most of the fauna are concentrated in the top few centimeters of soil (Furstenberg and Heyns, 1978). This is the layer most influenced by cultivation therefore cultivation is liable to contribute a lot in the reduction of animal populations.

Unlike the mesofauna, some macrofauna live deeper than the depth of cultivation. The number of animals below this depth are very few, however, and a decrease in population due to cultivation is inevitable (Abbott, Parker and Sills, 1969; Evans, 1949; Low, 1972). Also Russell (1973) found that the difference in population density of mesofauna between DD and CC may depend on the soil type and that the rate at which the population decreases may be determined by the period of cultivation (Ghilarøv, 1969).

1.2.8 Extraction of animals from soil

Studies of soil animals include (a) the determination of the sampling programme required; (b) collection of the samples in the field; (c) separation of the animals from soil; (d) counting and identifying the animals, and (e) assessing the population size.

Murphy (1958b) attempted to classify the principal methods of extraction (1) Direct examination; (2) Funnel extraction; (3) Floatation; (4) Sieving; (5) Suction, and (6) Sedimentation.

Direct examination entails systematic hand-sorting of soil. The very early workers e.g. Thompson (1924) found this method to be simple but laborious and also unsuitable for studying small animals (i.e. mesofauna). Ford (1935) attempted to break the soil under water and collect the floating animals. This technique was later used by Salt and Hollic (1944), and further developed by Raw (1955). Since then several washing and floating methods have been used (Hale, 1964; Heath, 1965) but they did not work well with soil containing large amounts of OM.

A funnel extraction system is based on the repellent effect of desiccation and high temperatures used to drive the animals out of the soil. The condition of the soil and treatment it receives has an important bearing on the extraction efficiency. This method was first used by Berlese (1905) and Tullgren (1918). They used an electrical bulb to provide heat and light. Further improvements included the maintenance of the sample in an undisturbed condition (Hammer, 1944 and Murphy, 1958c,d). Methods of ventilating the funnels to prevent the trapping of animals by moisture condensation and the controlling temperatures within the apparatus were also developed (Macfadyen, 1961). Kempson *et al.* (1963) used picric acid in the bottles used to collect the animals, but he noticed a repellent reaction on the animals.

The wet and dry sieving methods were also commonly used. Among the first workers were Cobb (1918); Morris (1922-3); Faust *et al.* (1938) but they found a lot of problems associated with the methods.

A suction method has been used to collect insects and animals from trees and the soil surface. A power source and fan to provide the suction force, and a collecting head containing one or two fabric sieves to filter the animals are the main components needed. The method was first used by Hills (1933) and Johnson, Southwood and Entwistle (1957).

Though each of the above methods has both advantages and disadvantages, the Tulgren funnel method has been found to be superior to most other techniques. It is relatively simple, requires very little maintenance and labour and animals can be collected in a good condition. It is certainly the only successful method of extracting animals from soil having a high OM content and is the most suitable method for obtaining live animal specimens for culturing.

CHAPTER 2

METHODS OF STUDY FOR FIELD EXPERIMENTS

2.1 DESCRIPTION OF SITES AND SOILS

2.1.1 Avon

This experimental site is located on latitude 30^{o} 17'S and longitude 138^{o} 20'E. It has a gradual slope to the S.W. The main soil of this site, which represents the soil of a large wheat growing area of South Australia, is a dark brown (7.5 YR 3/3m) fine sandy loam (C.S.I.R.O. Australia, Division of Soils Technical Memorandum 1, 1977) formed largely in sandy calcareous strata underlain by clayey strata. The $CaCO_3$ is not readily visible.

The soil physical properties (June, 1980), pH (1:4 soil : water) and organic carbon content are given below (Table 3).

TABLE 3: Physical properties and organic carbon content of Avon soil

		Particle Size µm)					
Site and Soil	Treatment and depth (cm)	Rest >200	Fine Sand <200	Silt <20	Clay <2	pH (H_2O)	Organic Carbon (%)
	0-4						
Avon	DD	54	28	9	9	7.5	1.71
Gc 1.12*	CC	62	18	8	12		1.20
	4-8						
	DD	60	12	13	11	6.5	1.40
	CC	58	22	11	10		1.29

*Gradational Calcareous soil (Northcote, 1960)

Particle size was measured by the method described by Kachinskii(1958) and Loveday (1974). Samples for analysis were taken in June 1980, while sampling for plant debris and soil animals continued throughout the experimenta period. Light fraction was determined by the method used by Barley (1955) and the method described by Ford (1968) but with some modifications. The study was concentrated at two soil depths (0-4 and 4-8cm).

2.1.2 Tarlee

This site is on latitude 34° 17'S and longitude 138° 46'E. The experimental site is gently sloping (5%) to the west. The soil is a brown to red fine sandy loam, poor in structure with no lime. Below 10 cm it is a dark red-brown gritty clay with friable structure and also contains no lime. Measurements of soil animal numbers, L.F., water content, physical properties and pH (1:4 soil : water) started in May 1980.

The soil physical properties, pH and organic carbon are given below (Table 4).

TABLE 4: Physical properties and organic carbon content of Tarlee soil

Site and soil	Treatment and depth (cm)	Particle Sizes (μm)			$pH(H_2O)$	Organic* Carbon %
		Sand >20	Silt <20	Clay <2		
Tarlee Gn 3.12**	0-8 Overall field sampling	78	8	14	6.8	1) .71 2) .88 3) .90 4) .75 5) .95 6) .94

* After Dept. Agric. South Australia (April 1980)

** Neutral non-calcareous gradational soil (Northcote 1960)

[1) Fallow x burn; 2) Pasture x rotary hoe; 3) Pasture x stubble retention; 4) Fallow x rotary hoe; 5) Fallow x stubble retention; 6) Pasture x burn].

2.1.3 Waite Institute

This site is located on latitude 35° 57'S, and longitude 138° 38'E, 120 m above sea level and has a gradual slope (5%) to the west. The 0-15 cm depth of most of the site is Urrbrae dark reddish-brown (5 YR 3/3 m) fine sandy loam (Chittleborough and Oades, 1979). It is not friable and it is free from $CaCO_3$. Table 5 shows the physical properties, pH (1:4 soil : water) and organic carbon content.

TABLE 5: Physical properties and organic carbon content of Waite soil

Site and soil	Treatment and depth	Particle Size (μm)				$pH(H_2O)$	Organic carbon(%)
		Rest >200	True sand <200	Silt <20	Clay <2		
Waite* Dr 2.23	0-10	23	36	28	16	0-4 / 4.75	1.91
						4-8 / 4.16	1.60

* Alkaline Duplex soil (Northcote, 1960)

2.2 DESCRIPTION OF SITE TREATMENTS

2.2.1 Avon

The crop rotation was pasture x wheat with DD plots used as a control to CC plots. Sampling started in the wheat phase. Each of the two treatments was replicated 3 times and samples at 2 depths (0-4 cm and 4-8 cm soil layer). The plots were sown at Avon on 5/6/80 with 153 mm between rows. Samples were taken from between the rows. Emergence occurred after 7-10 days and plants were harvested on 11/12/80 (yield 0.86 t ha^{-1} DD, 0.93 t ha^{-1} CC). Herbicide treatment was not initially included as part of the experiment on soil animals but was applied by the CSIRO Division of Soils as part of their trial to study direct drilling.

2.2.2 Tarlee

There were eight crop rotations, each consisting of a crop alternating with wheat and two replicates with two phases (i.e. each crop was grown each year). There were also 3 crop residue (tillage) treatments i.e. residue was (a) removed by burning and scarifying; (b) left on the soil surface or trash worked, and (c) incorporated into the soil by rotary hoeing.

This experiment was complex and big because the original purpose (South Australian Department of Agriculture) was to investigate a number of agricultural factors. The experiment, like Avon, had been established for 3 years before sampling for soil animals started. Two crop (fallow and pasture sown) and 3 tillage (crop residue disposal) treatments were chosen for study.

The aim of this experiment was to determine the effect of alternative methods of handling a crop residue and of different crop rotations on soil OM (LF) and the soil fauna. This was achieved by determining the changes of the LF content and populations of soil animals with the different tillage treatments.

2.2.3 Waite Institute

This site accommodated 3 experiments. The first experiment (September to December 1980) consisted of two treatments (i.e. Herbicide treated and control) each of which was replicated 6 times. The plots had previously grown pasture for one year. Six plots were treated with a mixture of Buctril and Hoegrass (chemical names appended) at a concentration of 1.4l and 1l ha^{-1} respectively. Soil animals were then extracted from the 0-4 cm soil layer only (on 3.10.80, 24.10.80 and 5.12.80).

A second experiment commenced on 23.3.1981 on a different site. The first samples for soil animals at this site were taken in May. The experiment consisted of 6 treatments: 2 concerned with DD (i.e. individual herbicides - Hoegrass and Buctril - 1l ha^{-1} and 1.4l ha^{-1} respectively), and three concerned with CC (i.e. the tillage implements - Mouldboard plough, disc plough and tine cultivator). The sixth treatment was a control site with natural regenerated pasture. The history of the entire site was: 1979 - cultivated in strips and in October of the same year rotary hoed and rolled; 1980 - sheep grazed only, no spray (herbicide) used.

Each of the above treatments was replicated twice. Observations were made at the two depths and wheat was grown on all plots other than the control plots. The soil animal populations and LF content were assessed. Temperature and rainfall measurements were recorded.

The third experiment at the Waite Institute consisted of a comparison of seven agricultural rotations (i.e. (a) virgin soil (VS); (b) permanent pasture (PP); (c) 4 year pasture x 2 year wheat (PPPP x WW); (d) 2 year pasture x 1 year wheat (PP x W); (e) continuous wheat (WW); (f) fallow x wheat (FW) and (g) wheat x pasture x fallow (WPF).

The aim of the investigation was to determine the effect of various rotations on soil animal populations and LF content.

2.3 ESTIMATION OF SOIL ANIMAL NUMBERS AT ALL SITES

2.3.1 Plot size and sampling intensity

The corers used for sampling soil animals were 5 cm internal diameter and 4 cm deep. Plot size and animal sampling intensity are given in Table 6.

TABLE 6: Plot size and animal sampling intensity for Avon, Tarlee and Waite Institute

Site	Plot size (m)	Numbers of sub samples taken per treatment Depths (cm)		Period of sampling (months)
		0-4	4-8	12
Tarlee	3 x 50	5	5	13
Avon	6 x 90	15	15	3
Waite 1)	5 x 8	24	-	5
2)	10x25	12	12	1
3)	5x80 to 15x80	16	-	

The period of sampling and numbers of subsamples taken (see Table 6) was determined by the importance of treatment, size of the plots and the aim of the investigation.

Due to large variability of numbers of individual groups of animals within a sample, a large series of subsamples need to be obtained for accurate estimation of the mean population density. However the large numbers of samples required poses the problem of handling the samples and identifying and counting the animals.

A compromise was, therefore, undertaken to obtain reasonable sample at each sampling period and to identify the animals (mites and Collembola only). The lower the taxa the greater the variability in numbers.

2.3.2 Handling of soil samples

Proper and careful handling of soil samples for the extraction of soil animals is vital. Careful handling determined the ease with which the soil animals were isolated from the soil and the numbers obtained. It also made identification and counting easier because of the clarity (lack of soil) of the alcohol in which the animals are collected. Maintaining cores undisturbed was essential for extraction. Hence after taking the cores by pressing them into the soil and lifting out the core unit, it was necessary to close each side of the corer with a lid, secure the lids with rubber bands and carefully pack the samples in appropriate boxes for transportation to laboratory.

2.3.3 Extraction of soil animals

Tullgren funnels similar to those developed by Berlese (1905) and modified by Murphy (1958c) and Macfadyen (1961) were used to extract the soil animals from the cores.

After core samples were taken in the field and brought to the laboratory, they were loaded into the funnels with the top side of the soil surface facing down. McCartney bottles containing 75% alcohol were pressed firmly up against the base of the funnels with the support of a foam rubber base. Each of four extraction systems consisted of 20 funnels with aeration tubes joined from a central tube to the side of each funnel level with the base of each core. Air was fed from the main pipe to the central distribution tube and in this way the system was kept free from condensation. Temperature was thermostatically controlled from filaments on the top cover of each extraction system. Introduction of heat was started at 20°C on the second day after soil cores were loaded into the funnels. Thereafter, temperature was raised every day by 5°C. The room temperature was kept between 20 and 22°C throughout the extraction period of 7 days. The aim of raising the temperature every day was to create a temperature gradient throughout the sample thus drying out the soil from above and driving out the animals into the funnels below.

2.3.4 Mounting of soil animals

The first group of animals which had been preserved in alcohol were transferred into a dish containing lactic acid. The acid was used to clear the animals for about 3 to 5 minutes making them easy to identify after mounting in Berleses fluid on microscope slides with a cover slip.

2.3.5 Identification of soil animals

With the help of identification keys (e.g. Fjellberg, 1980; Womersley, 1939 and others) it was possible to identify most of the animals (mites to Suborders and Collembola to families). Identification of immature animals, however, was difficult and help was sought from the South Australian Museum (Entomology section).

At each sampling period animals were examined under an Olympus Zoom Stereo microscope (model SZ-Tr with a magnification range of 7x to 80x) and were counted and grouped appropriately.

2.4 EXAMINATION OF SOIL STRUCTURE

2.4.1 Measurement of pore size distribution at Avon

2.4.1.1 Sampling

Sampling was started at the end of pasture and beginning of wheat phase. Soil cores (15) of 5 cm diameter were taken from 0-4 cm and 4-8 cm depth at random in DD and CC plots at Avon on 18.7.1980 for determination of soil structure. The 3 replicates of both the DD and CC plots had been sown with a wheat x pasture rotation for 3 years.

2.4.1.2 Thin section preparation technique

Samples were dried at 20-40°C for seven days to simulate slow drying in the field, then impregnated with araldite epoxy resin under vacuum (C.S.I.R.O. Division of Soils Tech. Memo 52/1973). Impregnation of soil was done on intact cores. This was necessary to prevent dislocation of particles or aggregates or collapse of pores.

Due to the sensitivity of the Quantimet, high technical quality is necessary for thin sectioning (i.e. the thin sections must be of equal thickness over the whole surface and should be cleaned and dusted to remove attached particles). Handling of the thin sections was done with care to avoid breaking or splitting the samples.

The impregnated cores were sawn into 300 μm thick sections with a diamond saw. The chosen thickness was of importance in assessing the living space of the soil animals whose dimensions ranged from 300 μm in diameter to 2500 to 3000 μm in length. Also it was important in studying the pedogenic process affecting pore space and pore geometry (i.e. translocation of particles and clay and organic matter) by partial or complete filling of pore thus decreasing pore space.

To avoid overheating of the saw, it was cooled by kerosene oil instead of water.

2.4.1.3 Measurements and characterization of thin sections

It is known that soil pores are non-cylindrically uniform. Therefore in this thesis Quantimet measurements refer to an equivalent size distribution which is an estimate of the diameter of a spherical aggregate or cylindrical pore equal in magnitude to the actual non-spherical or cylindrical aggregates and pores respectively.

The thin sections were examined directly using a Quantimet 720 (Fig. 4). The principles of this image analyser and its use on soil sections have been described by several authors (Cole, 1971; Ismael, 1975; Bullock and Murphy, 1980). Basically, an image formed by a thin section under the microscope or epidiascope is transmitted into the module and scanned by a Plumbicon television camera. The signal from the scanner is passed to a detector module where 500,000 picture points (PP) on the image, each one square and adjoining neighbouring points in vertical and horizontal direction, are individually analysed for their grey value (level). By using this technique size numbers were determined by applying the sizer and counting features of a particular size range. Sizes were measured in seven size ranges at a time.

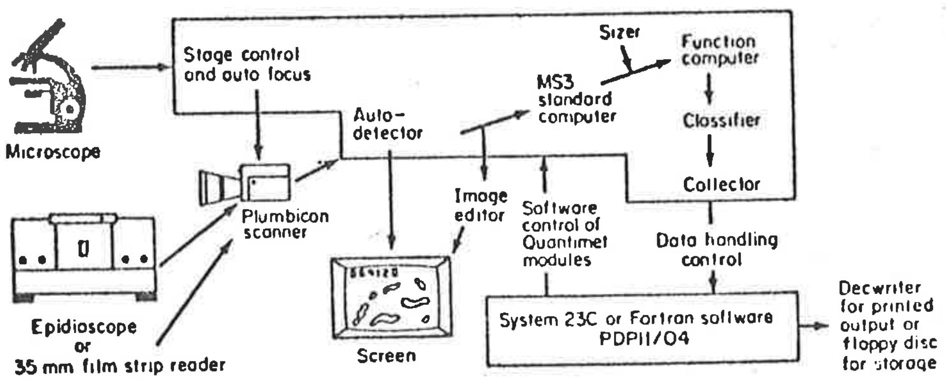


Fig.4: The Quantimet 720 (after Bullock and Murphy, 1980).

The quantity of numbers was interpreted as the size distribution of the pores and particles present in this particular soil. It will be seen in the results, however, that the sum of the % of pores and aggregates does not total 100%. The reason is that any aggregates and pores <40μm maximum diameter were not included in the analysis and also only pores equal to 300 μm or near enough in length were analysed. The rest (shorter in length) might have been discriminated because of differences in grey value.

2.4.2 Measurements of total porosity at Avon

It was of interest to find how much the total porosity differed from the value obtained from pores of diameter 40 μm to 2500 μm (Quantimet porosity).

The total porosity was calculated from the measured bulk density of the soil. Undisturbed soil cores were taken using metal rings with a volume of 209 cm^3 each. Bulk density was calculated by the formular:

$$\text{Bulk density (g/ml)} = \frac{\text{Dry weight of soil (g)}}{\text{volume of ring (cm}^3\text{)}} \qquad (8)$$

then the total porosity was calculated by:

$$\text{Total porosity} = \frac{\text{Particle density - Bulk density}}{\text{Particle density}} \times 100 \qquad (9)$$

Here the particle density was taken as 2.65 (g cm^3).

2.4.3 Measurement of soil strength at Avon

Simple (Soane *et al.*, 1971) and complex (Brown and Anderson, 1975) penetrometers have been described and correlations between penetration resistance and plant emergence have been carried out (Barley and Greacen, 1967; Taylor and Ratcliff, 1969; Gooderham, 1973; Bowen, 1976). Also penetrometers have been used to find the change in soil strength following different tillage treatments (Dumas *et al.*, 1975 and Soane *et al.*, 1976). Comparative results between simple and complex penetrometers have been obtained (Anderson *et al.*, 1980).

A penetrometer was used in this work at Avon to confirm the Quantimet results of porosity values >40µm in the 4-8 cm deep soil layer of CC. The penetrometer used here was based on the root simulation penetrometer probe of Barley *et al.* (1965) but instead of measuring force with a millivolt meter this one measured force by an electronic digital balance with digital output and data storage, and also had the ability to carry out simple statistical calculations within the instrument.

The penetrometer was equipped with a programmable calculator which enabled the accumulation of up to 20 strokes per plot. The data obtained were stored and processed within the instrument *in situ*. Output of the mean cone index, standard deviation and numbers of strokes recorded at that depth were produced on paper by the calculator.

The force as measured by a strain gauge transducer, ranged from 0-500 ± 5N and the depth was measured by an accurate optical system at intervals of 1 cm or more, an accuracy of ± 1 mm.

In this experiment, penetration resistance

$$Rp = \frac{4F}{\Pi d^2} \qquad (10)$$

Where F is the force required to push the probe and d is the probe diameter.

was calculated and plotted as a function of depth.

2.4.4 Measurement of soil water content

2.4.4.1 Introduction

Several methods for measuring soil water content exist (Hajduković *et al.*, 1967). The evaluated methods include volumetric water content, gravimetric water content, gypsum block electrical resistance, Neutron scattering fibre glass electrical resistance (thermistor method).

Some of these methods are better than others. The method using gypsum blocks is quick, cheap and stable but it is sensitive to salts in the soil solution and can only be used over a limited range of water contents (field capacity to wilting point). The neutron probe method is accurate and enables measurements of water from full water content (saturation) up to an absolutely dry condition and only permits one calibration for all soils. Also it is independent of the mineral composition of soil. Though the results are similar to the gravimetric water content, the equipment is expensive. The gravimetric method is easy, very accurate and can be used for all soils at all water levels and does not need expertise. The volumetric method also has been found reliable and is used extensively.

2.4.4.2 Avon - Gravimetric method

Soil samples were taken at random from two depths (0-4 and 4-8 cm) and carried in tins to the laboratory.

Analyses were expressed on an oven-dry basis. Water in the samples was determined by oven-drying a weight (A) for 24 hours at $105^{\circ}C$. Then the sample was cooled in a desiccator and the oven dry weight recorded (B). Water content was then calculated as follows:

$$\text{Percentage } H_2O = \frac{A - B}{B} \times 100 \qquad (11)$$

2.4.4.3 Waite Institute - Gravimetric method and Gypsum blocks

Soil water was measured by both gravimetric and gypsum block resistance in conjunction with a soil temperature meter (Marcon Digital Multimeter model TF 2670).

Soil from each depth (0-4 and 4-8 cm) was used initially to calibrate the blocks planted at that particular depth because of their sensitivity to pH change. Calibration was done in a temperature controlled room (20°C) with soil at different water contents (days after saturation).

At any time resistance measurements were taken (OHMS), that gravimetric water content was assessed. A general calibration curve for all the 32 gypsum blocks was drawn (Fig. 5) because of the small variability which is indicated in the more or less linear response of the curve.

2.5 MEASUREMENTS OF SOIL TEMPERATURE AT THE WAITE INSTITUTE

Soil temperature was only recorded at the Waite Institute experiment 2 in order to detect any change in temperature as a result of the 6 treatments.

Thermistors have a large temperature coefficient of resistance (R) which varies with absolute temperature (T); thus

$$R = A_e \frac{B}{T} \qquad (12)$$

Where A and B are adjustable parameters.

Values A and B in the formula 12 were obtained by calibrating the thermistors in a water bath using temperatures from 0-60° at 10°C increments.

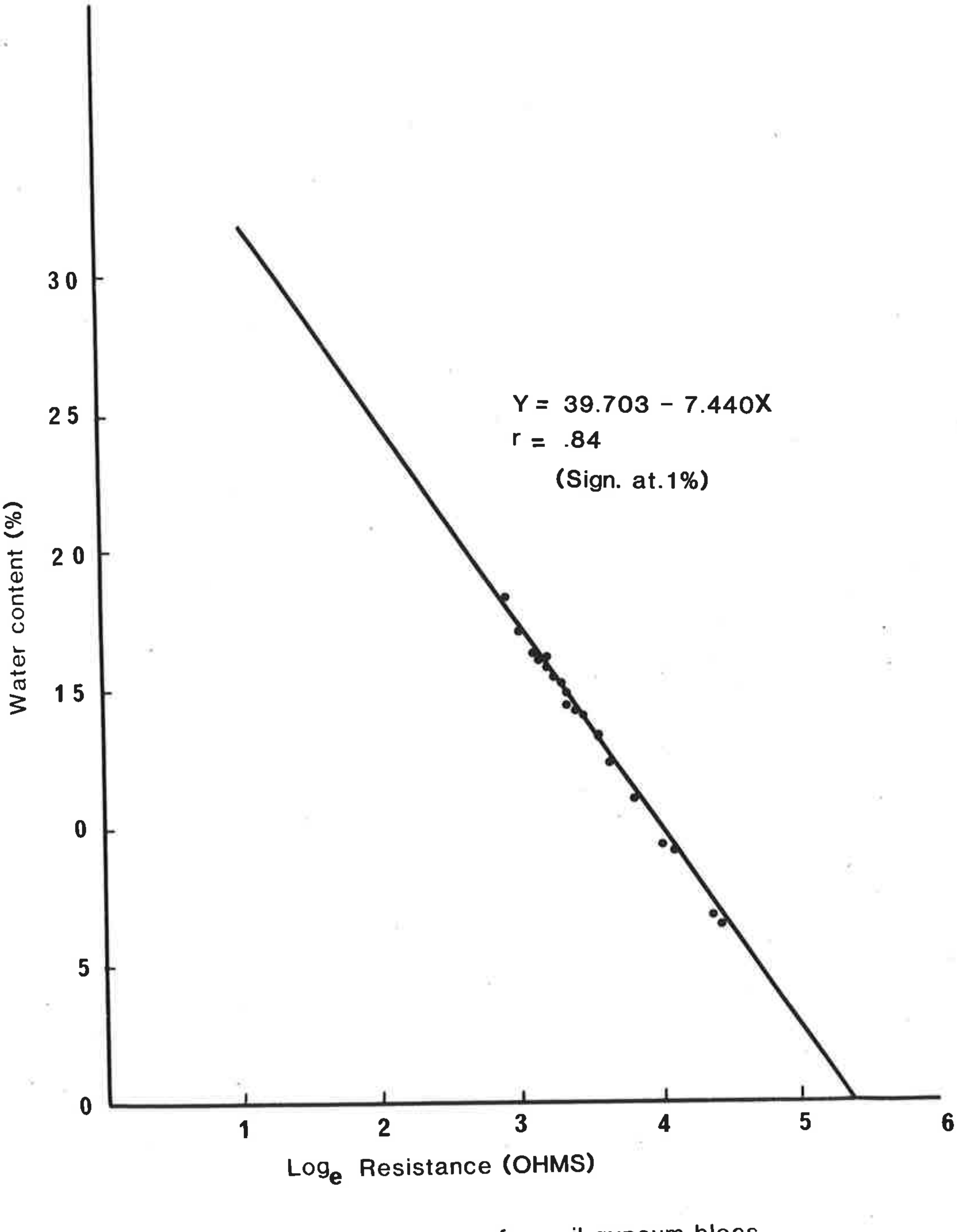


FIGURE 5. Calibration curve for soil gypsum blocs.

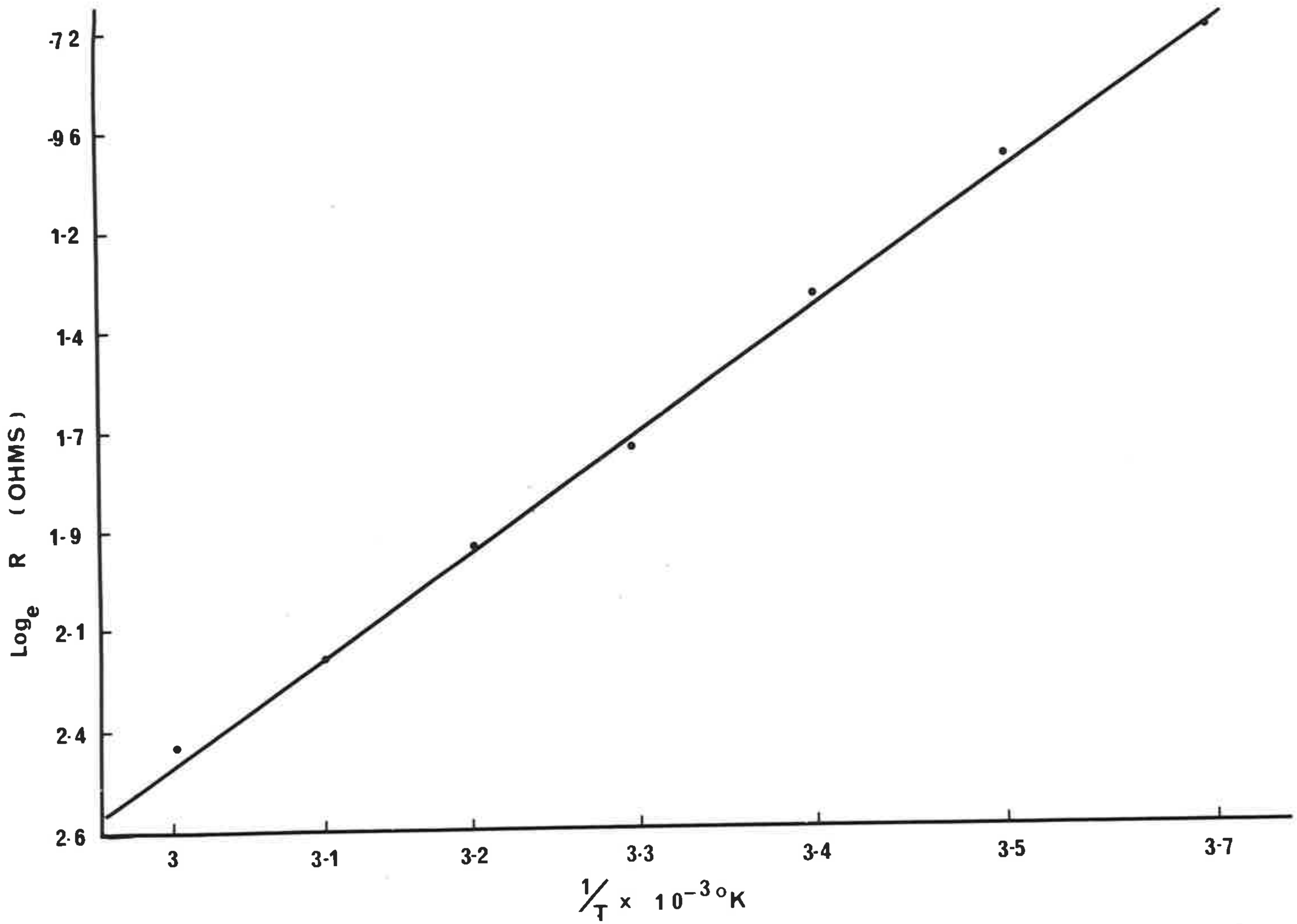


FIGURE 6. Typical thermistor calibration curve for the determination of parameters in equation 12

The previously calibrated thermistors were then used in conjunction with a digital multimeter (Marconi Instrument Model TF 2670) to obtain readings of R in the field.

A computer programme was written to calculate values of A and B for each thermistor in the field. Formula 13:

$$T = \frac{B}{\text{Loge } (R/A)} - 273.2 \qquad (13)$$

Where B is slope when Loge R is plotted against 1/T and Loge A is the intercept (Fig. 6).

was integrated in the programme to calculate temperature T(^{o}C).

2.6 EXTRACTION OF LIGHT FRACTION FROM SOIL

2.6.1 Introduction

Light fraction (Ford *et al.*, 1969), or macro organic matter (Holt, 1980), is the partly decomposed plant and animal remains larger than 0.25 mm diameter (Barley, 1955) which are an important component of the environment for soil animals.

An attempt was made to separate this material from the soil based on its low density. Fifteen soil samples (each 30 g) were examined from each of the two depths and two treatments examined and at each sampling period.

2.6.2 Separation of L.F. from soil

A solution of $ZnBr_2$ of density 1.8g cm^3 was made up. Two hundred cubic centimetres of this solution was put in centrifuge tubes then soil samples were introduced. The tubes were shaken by hand for about 3 min. then further shaken by a Spex mixer for 3 min. and left overnight. The following day the suspension and solids were transferred into 400 ml centrifuge tubes and further $ZnBr_2$ was added to make up the solution to 300 ml. The tubes were balanced by adding $ZnBr_2$ as required then shaken by hand for one minute and on the Spex mixer for 3 min. The tubes and solution were spun at 2000 r.p.m. for 30 min. The supernatant and LF were carefully decanted into a beaker and the walls of the centrifuge tubes were washed down with a fine jet of $ZnBr_2$. The supernatant and washings were filtered through 5 μm "millipore" prefilters under water suction. Each filter was used once only. The filtered LF was washed with a small volume of acetone and collected in preweighed containers. The LF was dried for 30 min. at 80^{o}C and then cooled in a desiccator and weighed to the nearest 0.5 g. The LF weight was calculated as a percentage of the soil weight. The LF was later examined under the microscope.

CHAPTER 3

EFFECTS OF TILLAGE ON ENVIRONMENTAL FACTORS INFLUENCING SOIL FAUNA - RESULTS AND DISCUSSION

3.1 INTRODUCTION

Factors influencing the behaviour and growth of soil animals, and therefore, their population size, are similar to those influencing emergence, germination and growth of agricultural crops. Thus soil structure is included, particularly the pores in which the animals live and which conduct gases and water and also influence the thermal conductivity of soils. Organic matter is the source of food. All the above factors are to some extent affected by crop production (i.e. cultivation).

Description of sites and methods of sampling and measurement of soil factors are given in Chapter 2.

3.2 EFFECT ON SOIL STRUCTURE

3.2.1 Porosity at Avon

Conventional cultivation increased the porosity particularly by increasing the number of pores >1500 μm but decreased the number of pores 600-1000 μm in the 0-4 cm soil layer (Fig. 7).

Little difference was found between the pore size distribution of the 0-4 and 4-8 cm layers of DD plots compared with the highly significant difference detected at CC plots. This may indicate a soil pore continuity in DD plots and a discontinuity of pores in the CC plots.

Although total porosity values were similar in the 4-8 cm layer of DD and CC plots, the proportion of pores <40 μm increased in CC plots.

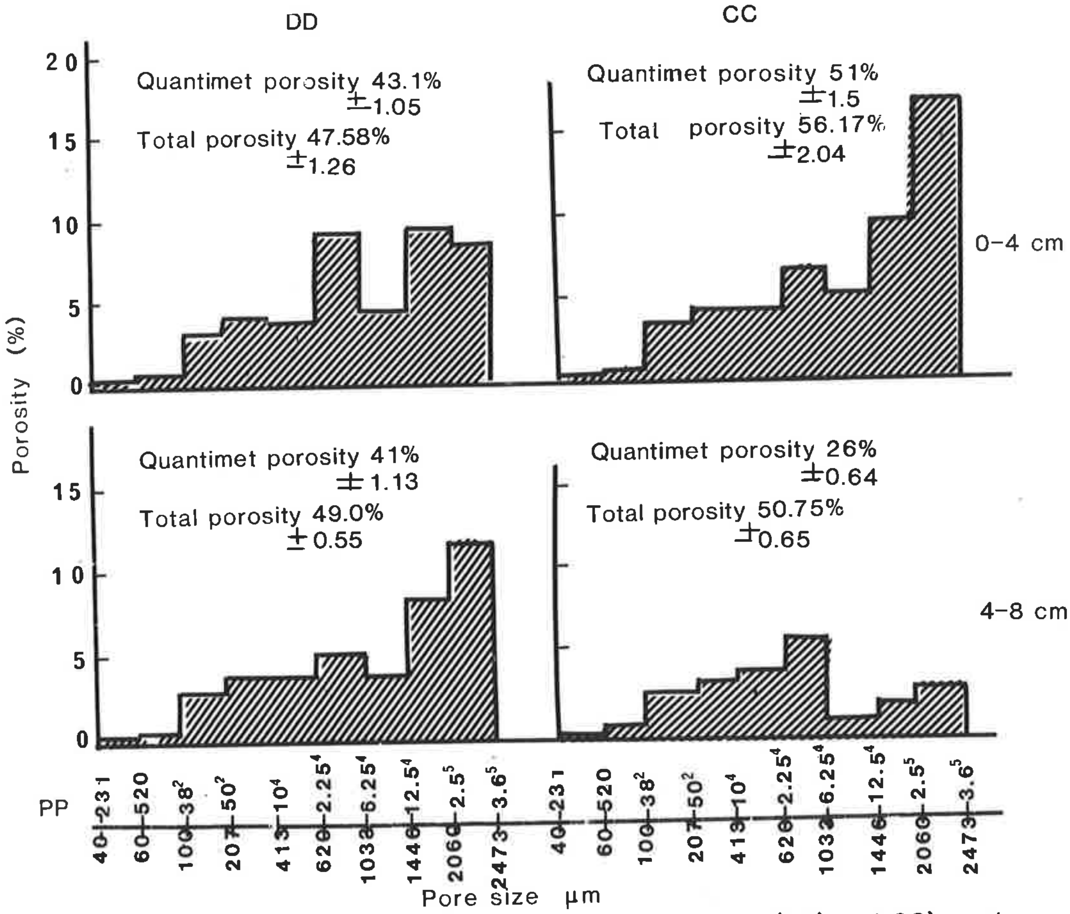


FIGURE 7. Effect of two seedbed preparation techniques (DD) and CC) on the pore size distribution in two soil layers as measured by QTM 720 (▨). Total porosity calculated from bulk density (PP= Picture points)

This is indicated by low macro porosity in the 4-8 cm layer of CC plots which is also confirmed by the penetrometer results (Fig. 8). These results indicate the presence of a compacted layer at this depth which could be attributed to the weight of a tractor and implement, and also to the dislocation of clay and small particles during cultivation thus filling larger pores. Also wetting and drying may have contributed in reducing aggregate sizes thus resulting in the filling of large pores. Fox (1964) showed that clods with diameter of 12-40 mm were prevalent when soil was moist but as it dried to a matric water potential of about -3.2 mPa, they spontaneously broke into uniform aggregates with diameter of 2.0-4.0 mm.

The results produced by both the Quantimet screen photographs and disc photographs (Plate 1) revealed a change in the shape of pores in CC plots. The pores in CC were mainly cracks or voids joined by cracks.

The strongest evidence of the change in pore shape can be seen in the voids of CC as compared to the channels in DD soil. These round and vertical pores in DD soil were probably left after roots decayed and also were the channels dug by large animals.

The stability of vertical pores in the DD plots was important for soil animals enabling their movement up and down the profile in search of food and an optimum microclimate. It was, in a simulated laboratory experiment, related positively to the mesofaunal populations (see Chapter 6). The stable pores were of similar dimensions to the dimensions of mesofauna studied. Therefore it is suggested that lack of these pores in the CC plots made the soil a poor habitat for the mesofauna.

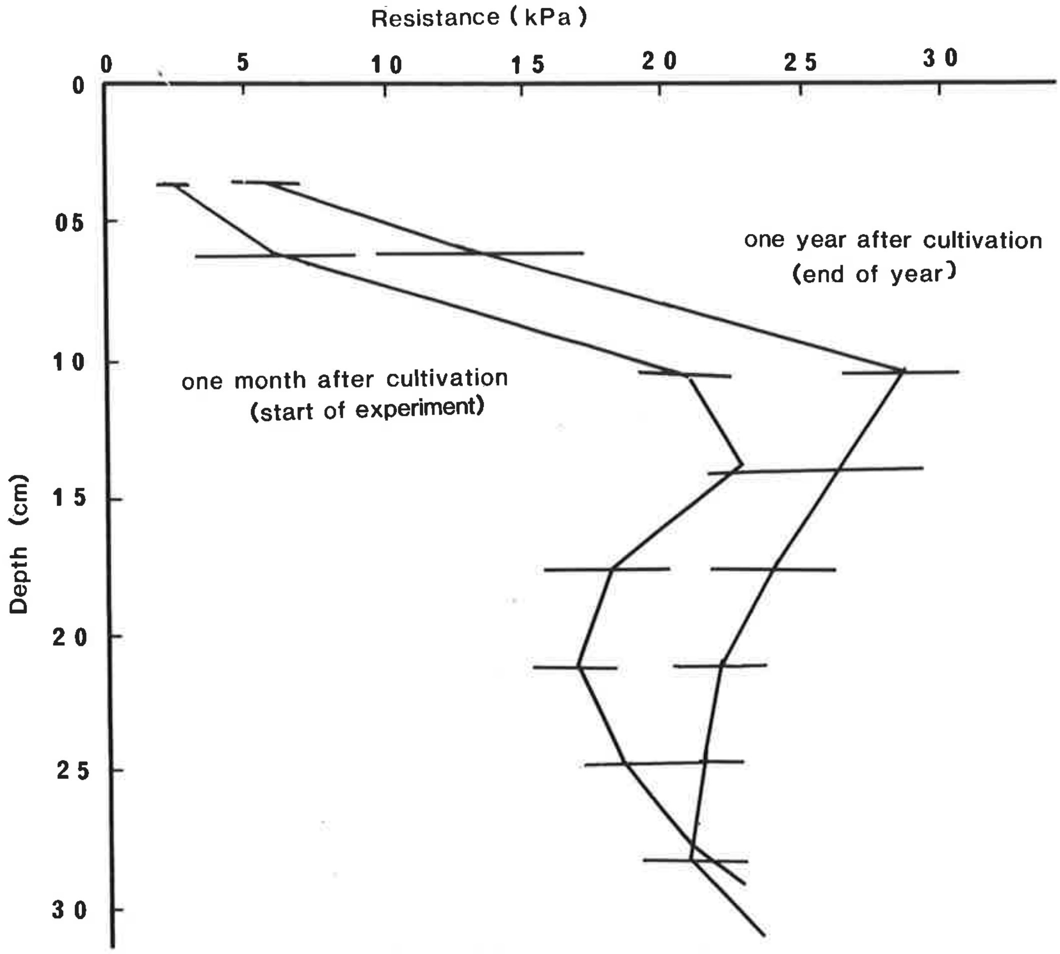
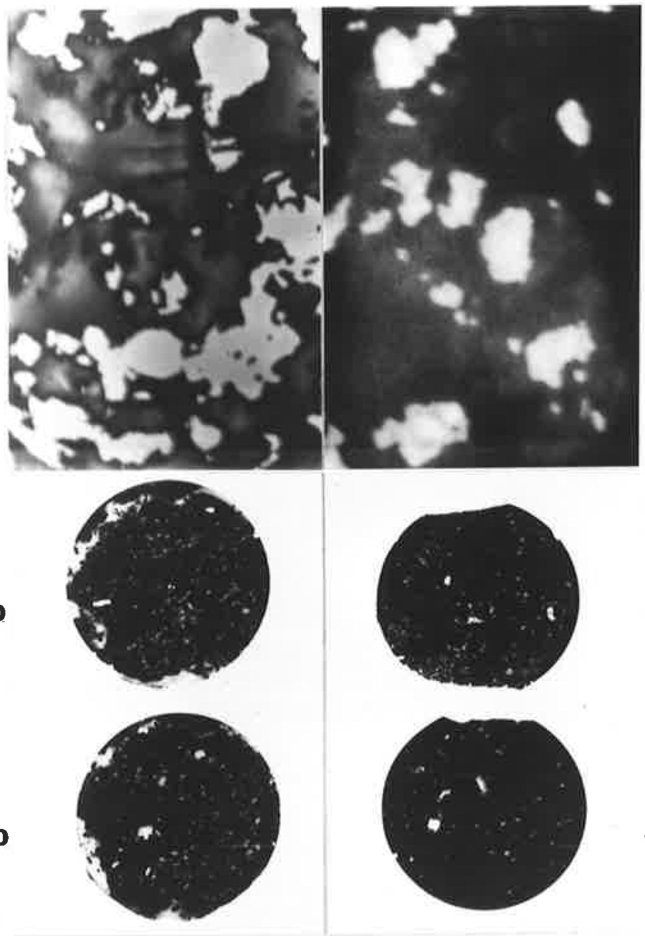


FIGURE 8 Cone penetrometer resistance for a 30° 12.83mm diameter cone for CC treated sandy loam soil for 3 years (⊢ = SE, n=6)

Quantimet Screen Photographs (40X)

C.C. 5 cm deep — D.D. 5 cm deep



C.C. 1cm deep — C.C. 5cm deep

D.D. 1cm deep — D.D. 5cm deep

Disc Camera Photographs (1X)

PLATE 1 Comparison between pores (voids) produced by DD and CC at Avon (July 1980 samples)

3.2.2 Effect on soil water content

3.2.2.1 Introduction

In agricultural research, soil physicists are mainly concerned with the effects of moisture tension on plant growth and neither the influence of soil animals on water tension, nor the effect of moisture tension on soil animals have been considered of any practical importance.

For all practical purposes water is vital. Gravitational water is important in drainage. Under conditions of impeded drainage by compaction, it will interfere with oxidation process (Wallwork, 1976). Capillary water is important from a biological point of view because it remains for a relatively longer period than gravitational water in soil and its presence also ensures that the soil atmosphere is saturated with water vapour. In agricultural soil the amounts of these two types of water will be determined by the soil type and agricultural operations on the soil.

3.2.2.2 Avon

The winter results suggest that the water content of the CC and DD plots did not differ in the 0-4 cm soil layer but was greater in the 4-8 cm layer from DD than CC plots. Towards the end of winter (October) faster drying of the cultivated layer, which did not possess any cover of plant residue and the looseness and cracking of soil probably contributed to rapid drying, resulted in less water in CC than in DD plots at both levels (Fig. 9).

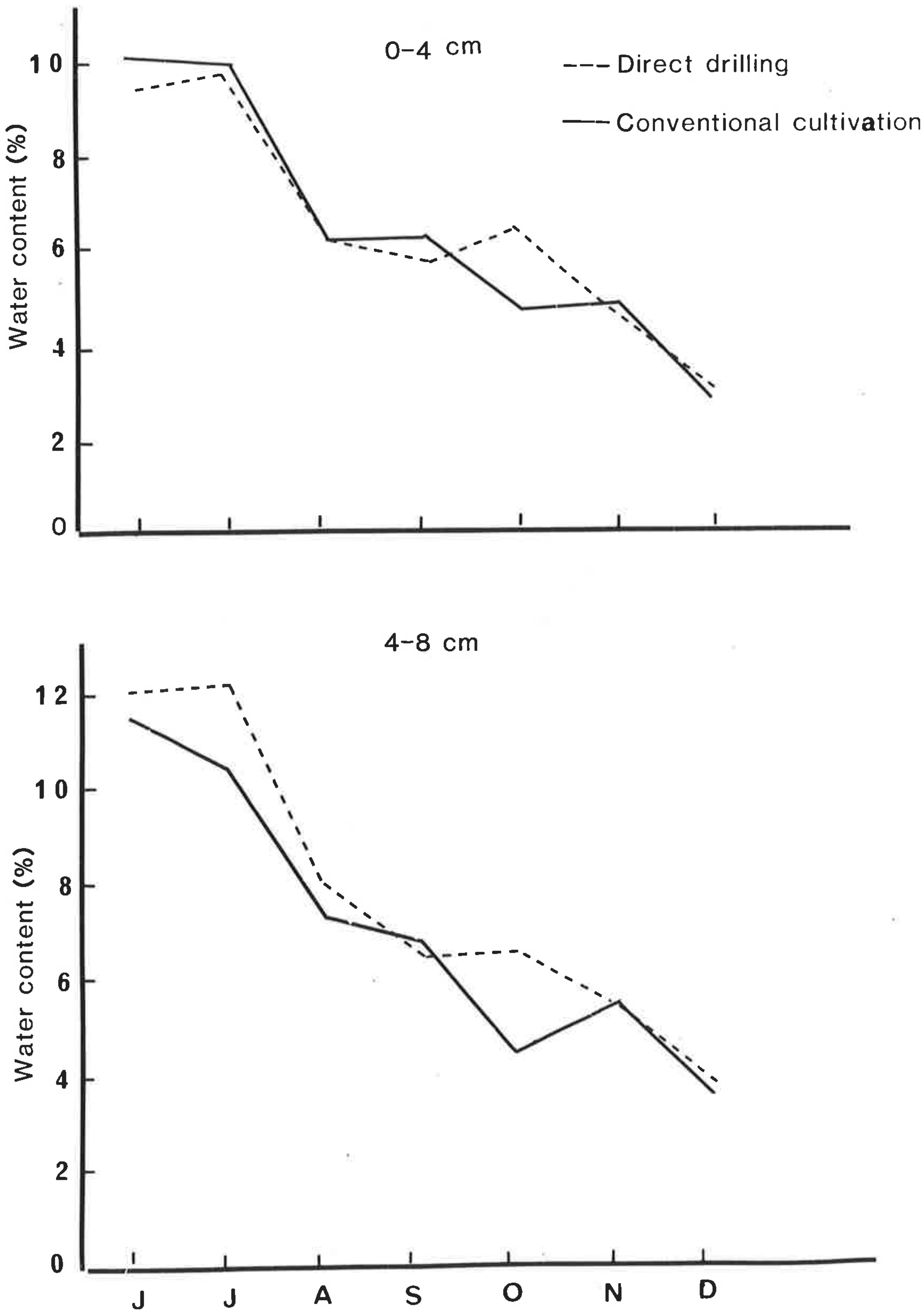


FIGURE 9 Water content of two layers of DD and CC soils at Avon from June to December 1980

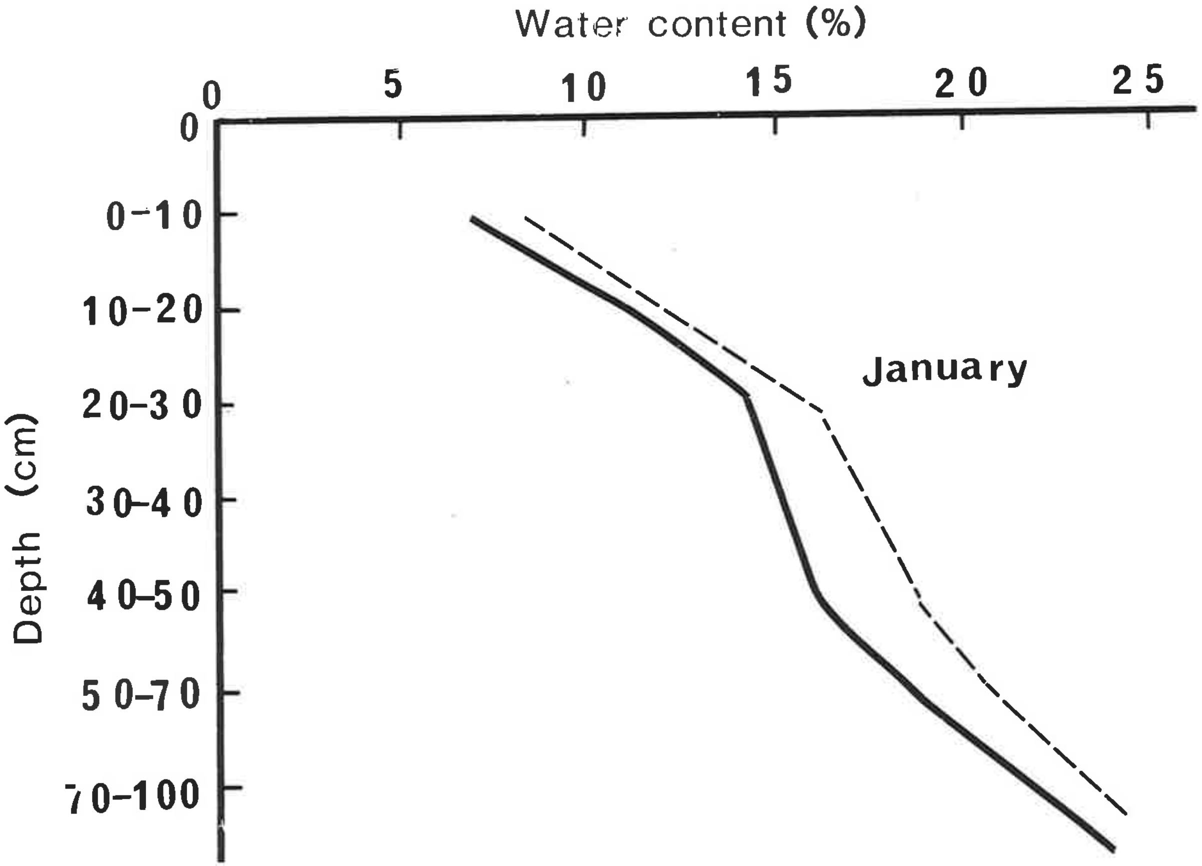


FIGURE 10 Water content depth curves for the driest month-December to January 18 1980 at Avon (---DD,—CC).

The surface layers in both DD and CC plots were very dry in December and January (Fig. 10). However, the observed water content-depth curves showed a greater water content at greater depth in non-tilled (DD) than tilled (CC) plots. Thus the influence of cultivation on soil water content must be considered from both its effect on water transport phenomena as well as on the actual storage factor.

The results presented here agree well with other published results. For example Lal (1978) found an improvement with time of the cumulative infiltration rate and soil structure of plots direct drilled for 3 years and plots with plant debris lying on the soil surface.

Russell *et al.* (1975) showed greater rates of infiltration in DD than in CC plots (Fig. 11). Also equilibrium infiltration rates for Zaria (Nigeria) (Table 7) was shown to be greater in DD than in CC plots (Aremu, 1979).

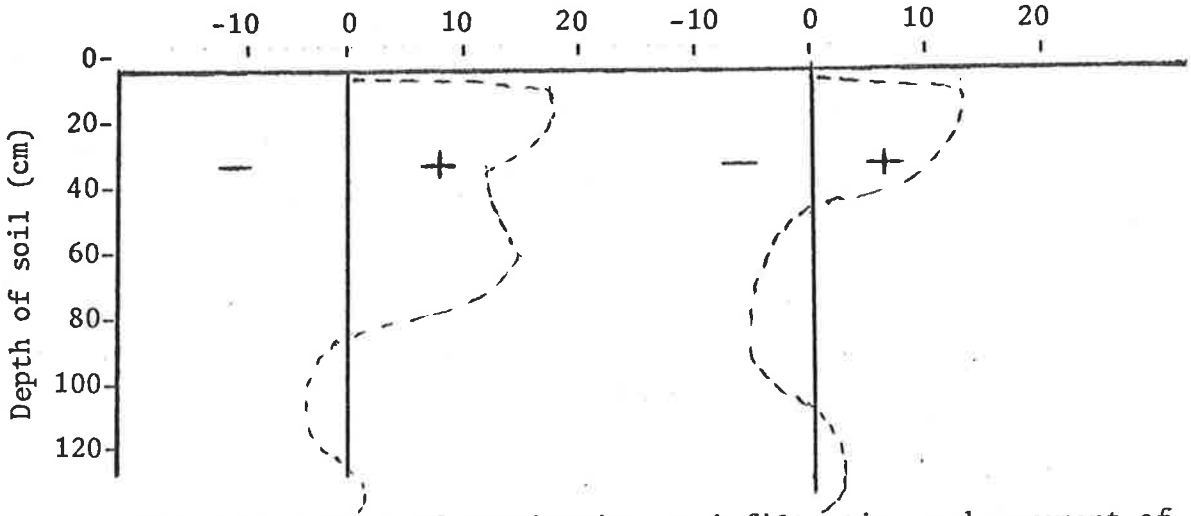


Fig. 11: Effect of cultivation on infiltration and movement of water in silt loam soil four days after 49 mm rain fall (% v/v) (Based on Baeumer, 1970).

TABLE 7: Equilibrium infiltration rate mm/hr (measured in the 4th hour after the start of infiltration. (After Aremu, 1979)

Cultivation system	1st set of measurements (8 weeks after planting)	2nd set of measurements (14 weeks after planting)
Zero tillage	30	67
CC	8	30

3.2.2.3 Waite Institute

Table 8 gives the soil water data from 4 treatments which were pooled together for analysis of variance. The raw data reflected the prevailing weather.

The results suggest an effect of different tillage treatments on the water content of the soil. Mouldboard ploughing and tine cultivation seem to have had a greater effect on water content of the soil than the other treatments. The MB plough was the only implement capable of providing a complete inversion of crop residue, weeds and the more porous top soil thus providing a layer of high retentive power for water in the 4-8 cm. The tine cultivator, by its action of opening new cracks and voids increased the porosity until secondary tillage occurred. Since there was no secondary tillage involved, higher accumulation of water resulted.

The non-tilled plots (herbicide treated) had the lowest water content in the 0-8 cm layer compared with others. Disc ploughed plots showed water contents of medium value.

TABLE 8: Effect of primary tillage on water content of Urrbrae fine sandy loam.

Depth (cm)	Water Content %				Probability levels	
	Tine	Disc	MB	Buctril	*	**
0-4	15.525	15.032	15.579	15.068	.362	.429
4-8	15.604	15.446	15.714	15.375	.375	.475

3.3 EFFECT ON SOIL TEMPERATURES AT THE WAITE INSTITUTE

3.3.1 Introduction, Results and Discussion

The albedo of the soil is changed by altering the appearance of the surface. In this experiment, different tillage treatments changed the appearance of the soil surface differently (Plates 2a,b,d) and as reported by Watts (1976), such treatments alter the energy input into and out from the soil surface. Also in this work tillage has been shown to change bulk density, pore size distribution and water content. By changing such parameters (Feddes, 1973) the transmission of absorbed heat into and out of bulk soil was affected.

During the experimental period at the Waite Institute minimum temperatures were recorded between hours 3.00-8.00 while maximum temperates were recorded between 13.00-16.00 hours (Dexter and Radke, personal communication). Table 9 shows the temperature means recorded at 8.00 on the days shown obtained from the computer sheets for ANOVA.

The highest temperatures occurred in plots treated with a MB plough or tined implements and the lowest in plots with no tillage but herbicide added. Though significant interactions (treatment x depth) were obtained,

Plate 2: IMPLEMENTS USED IN DIFFERENT SEEDBED PREPARATIONS (A, B, C, D) AND COMPARISONS OF DIRECT DRILLING AND CONVENTIONAL CULTIVATION (E, F).

A. TINE CULTIVATION

B. DISC PLOUGHED

C. DIRECT DRILLED

D. MOULD BOARD PLOUGHED

E. DIRECT DRILLED (I) AND CONVENTIONAL CULTIVATION (II) ON PASTURE SOWN THE PREVIOUS YEAR

F. CLOSE-UP OF DIRECT DRILLED PLOT, E_I

TABLE 9: Comparison of variation in soil temperature at 2 depths at the Waite Institute after implements were used for primary cultivation and after the use of a herbicide to kill broad leaved weeds

Date	21.6.82		29.6.81		6.7.81		11.7.81		20.7.81		31.7.81		17.8.81		25.8.81		9.9.81	
	Depth (cm)																	
	0-4	4-8	0-4	4-8	0-4	4-8	0-4	4-8	0-4	4-8	0-4	4-8	0-4	4-8	0-4	4-8	0-4	4-8
Mould-board plough	10.39	8.54	9.90	1.10	11.34	10.95	7.44	7.90	14.76	12.61	9.99	10.73	10.66	11.12	12.29	11.92	13.16	12.06
Disc plough	8.38	7.88	9.96	8.93	11.19	10.87	7.46	6.90	13.35	12.15	8.53	8.66	9.08	9.23	10.62	9.90	11.42	10.33
Tine Culti-vator	8.41	10.04	10.69	10.94	11.70	11.42	13.43	8.65	15.63	12.44	9.76	10.10	10.79	10.66	12.41	12.32	14.26	12.75
Buctril	7.82	8.80	9.55	10.28	10.99	10.88	7.00	8.26	13.98	12.01	9.16	9.46	9.86	9.56	11.45	10.56	13.11	12.16
	N.S.		VR = 7.085 >F.5(3,7)		N.S.		VR = 30.97 >F.001(3,7)		VR = 10.60 >F.05(1,7)		N.S.		N.S.		VR = 10.09 >F.01(3,7)		VR = 18.614 >F.001(3,7)	

(n = 4); (NS = not significant, VR = variance ratio) the differences in temperatures were small and in such a range that a significant effect on soil animals would not be expected.

3.4 EFFECT ON ORGANIC MATTER

3.4.1 Avon

Moshler *et al.* (1972) suggested that DD increases the total organic matter content of the soil but this requires further confirmation.

In this experiment LF content and the decomposition trend throughout the sampling period was investigated. The results indicate that the amount of plant debris in the 0-4 cm layer of soil was significantly greater in DD than in CC plots throughout the year (Fig. 12). In the 4-8 cm layer, however, the opposite occurred and the amount of LF was found to be significantly greater in CC than in DD plots particularly in the early stages of crop growth. At this time (June) population densities of soil animals were approaching their maximum. A low content of plant debris was recorded in July, presumably due to degradation by soil animals and other microorganisms. During the investigation period changes of soil animal numbers were shown to correlate very well with macro-organic matter changes (Table 10) probably because of their dependence on OM as a source of food.

Plant roots contributed significantly to the plant debris in both CC and DD plots, especially in the latter part of the year. This was established by examining the composition of LF under the microscope.

3.4.2 Waite Institute

In general plant debris was found to be concentrated in the upper layer of soil (0-4 cm) before tillage operations. After primary tillage, the distribution within the tilled depth differed with different treatments.

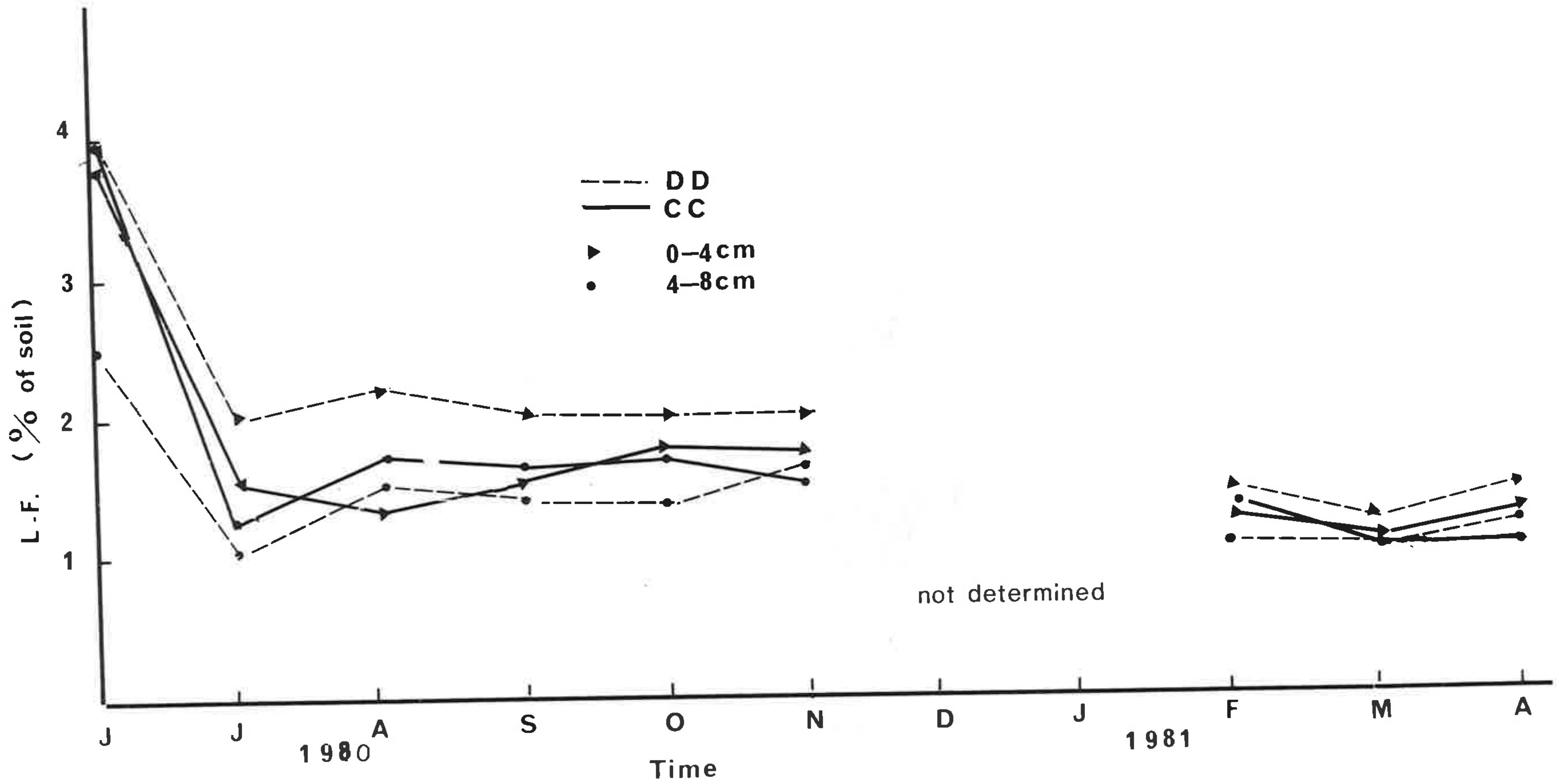


FIGURE 12 Effect of two seedbed preparation techniques on LF content at Avon
(June values after pasture phase)

TABLE 10: Correlation between soil animal population and light fraction† (OM) changes at Avon

	Degrees of Freedom	Direct drilling correlation coefficient	Direct drilling probability	Conventional cultivation correlation coefficient	Conventional cultivation probability
0-4cm					
Mites	7	.90	**	.97	***
Collembola	7	.89	**	.71	**
4-8cm					
Mites	7	.90	**	.95	***
Collembola	7	.91	**	.99	***

† Population density of soil fauna was found by multiplying the mean number of animals per core by a factor 500. Light fraction was calculated as % of soil.

** = P<1%

*** = P<0.1%

TABLE 11: Effect of 3 different tillage implements and 2 herbicides on light fraction content at the Waite Institute (n = 8).

Treatment	May 0-4	May 4-8	June 0-4	June 4-8	July† 0-4	July† 4-8	August 0-4	August 4-8
	LF content (%), Depth (cm)							
Control	2.16	.875	2.471	1.257	2.567	Not determined	not determined	
Tine cultivator	1.893	1.379	1.885	1.109	2.579		2.390	1.059
Disc plough	1.293	1.233	2.327	1.209	2.867		2.405	1.359
Mouldboard plough	1.993	1.634	2.942	2.194	1.860		1.682	1.569
Buctril	1.829	.998	2.137	.889	2.151		2.977	.974
Hoegrass	1.833	.899	2.886	1.072	2.582		3.271	1.064
Sig. level	*		*		**		**	
L.S.D. interaction	.37		.36		.6		.95	

The MB plough contributed greatly to the observed significant interactions between treatments and depth (Table 11). The action of slicing and inversion of soil and microbially decomposable plant debris led to more or less equal distribution of the LF between the two depths. A short lived slow down of transformation of this decomposable material at this time could possibly be ascribed to the disturbance to the soil communities subjecting them to shock and an unfamiliar and an unfavourable habitat.

A slow decomposition rate in the herbicide treated plots U_4 and U_5 (Table 11) could be attributed to the unpalatable plant debris or the low population of soil animals found in these plots (see Chapter 4).

3.5 CONCLUSION

Tillage treatments affected physical factors differently. Pore space is one of the most affected parameters which controls many others i.e. water and temperature. Thus by increasing porosity an increased rate of decomposition of OM may result.

Organic matter (LF) was affected in different ways e.g. by distribution of LF in the ploughed zone, burying and subjecting it to immediate decomposition by the soil communities which firstly degrade the energy rich and easily decomposable material.

Tillage however does not seem to change the amount of plant material as compared to non-tilled agricultural soils. With reduced cultivation (single operation) the effect and distribution of plant debris in the soil profile depends on the implement used.

Creating a compacted layer below the depth of cultivation causes less infiltration capability of rain water in CC than DD soils.

Small but statistically significant differences in soil temperature associated with different tillage systems were observed but their effects on the biology of the soil may not be significant.

CHAPTER 4

EFFECTS OF DIFFERENT SEEDBED PREPARATION TECHNIQUES ON SOIL FAUNA - RESULTS AND DISCUSSION

4.1 INTRODUCTION

Changes in the populations of soil fauna accompanying different cultivation treatments have been demonstrated (e.g. Ghilarøv, 1978; Ellis and Barness, 1977; Abbott, Parkes and Sills, 1979). Assumptions that cultivation decreases the numbers and diversity of soil animals have been based on relatively sparse data from surveys of the fauna of different habitats, and may be unjustified because most have taken no account of changes with time.

This chapter reports on the responses of the soil fauna to the processes of different seedbed preparation techniques over a period of up to 13 months (see Chapter 2).

The overall effects of seedbed preparation techniques on soil fauna were assessed by comparing the numbers of soil animals present at different sites throughout the sampling period; the effect of herbicides was assessed by comparing the numbers of animals at the same site before and after application of the herbicides. Long term effects of the herbicides were assessed by looking at the recovery of the population over one year.

4.2 ANIMAL POPULATION AT AVON

4.2.1 The effect of DD and CC

The overall results from both treatments showed that a large number of the soil animals were concentrated in the 0-4 cm soil layer.

TABLE 12a: Total numbers of groups of soil animals extracted from DD plots at Avon during the period 1980-1981 (data given as totals from 15 subsamples) to get population density = $\frac{N}{15} \times 500.m^{-2}$

	1980							1981						
Fauna Group	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
MITES - 0-4 cm														
Prostigmata	12	13	1	1	0	2	2	-	3	4	6	1	6	0
Mesostigmata	143	118	14	29	3	1	0	-	5	1	12	9	11	6
Cryptostigmata	0	26	0	1	0	0	0	-	0	0	14	1	0	0
Astigmata	1245	209	6	4	1	0	2	-	1	0	31	8	79	23
COLLEMBOLA														
Poduridae	553	140	3	33	2	1	4	-	0	1	0	1	0	2
Onychiuridae	2	20	0	1	0	0	0	-	0	0	0	0	3	0
Isotomidae	3	55	15	0	0	1	0	-	0	0	0	2	8	14
Entomobryidae	198	27	0	0	0	0	0	-	0	0	0	0	0	0
MITES - 4-8cm														
Prostigmata	0	2	2	2	2	0	1	-	0	6	4	1	7	0
Mesostigmata	36	29	29	11	2	2	1	-	2	1	13	7	5	0
Cryptostigmata	1	4	3	4	0	1	0	-	0	1	20	0	0	0
Astigmata	286	60	6	0	0	2	2	-	0	0	12	5	12	3
COLLEMBOLA														
Poduridae	182	12	22	7	0	3	0	-	0	0	0	0	0	0
Onychiuridae	1	3	0	0	0	2	0	-	0	0	0	0	0	0
Isotomidae	3	16	3	0	2	2	0	-	0	0	0	4	4	0
Entomobryidae	55	7	0	0	0	1	0	-	0	0	0	0	0	0

TABLE 12b: Total numbers of groups of soil animals extracted from CC plots at Avon during the period 1980-1981 (data given as totals from 15 subsamples), to get population density = $\frac{N}{15} \times 500\ m^{-2}$

Fauna Group	June 1980	July 1980	Aug. 1980	Sept. 1980	Oct. 1980	Nov. 1980	Dec. 1980	Jan. 1981	Feb. 1981	Mar. 1981	Apr. 1981	May 1981	June 1981	July 1981
MITES - 0-4cm														
Prostigmata	0	12	2	1	2	1	0	-	0	0	5	0	0	0
Mesostigmata	36	44	25	9	4	0	1	-	1	1	4	6	4	1
Cryptostigmata	2	4	2	0	0	0	0	-	0	0	6	0	0	0
Astigmata	1002	66	2	0	3	0	0	-	5	0	35	71	20	64
COLLEMBOLA														
Poduridae	192	83	2	0	3	0	0	-	0	0	5	1	1	0
Onychiuridae	1	4	0	1	0	0	0	-	0	0	0	0	0	0
Isotomidae	1	48	22	3	12	1	0	-	0	0	0	6	0	1
Entomobryidae	69	27	3	0	5	0	0	-	0	0	0	0	0	0
MITES - 4-8cm														
Prostigmata	2	1	2	1	2	0	0	-	0	3	6	1	0	0
Mesostigmata	32	14	15	6	1	1	2	-	1	3	9	10	2	1
Cryptostigmata	2	4	0	0	0	1	0	-	0	0	1	0	0	0
Astigmata	613	45	3	1	0	2	0	-	0	0	62	59	7	10
COLLEMBOLA														
Poduridae	185	10	17	0	0	3	1	-	0	0	0	0	0	0
Onychiuridae	0	3	6	1	0	0	0	-	0	0	0	0	0	0
Isotomidae	1	6	13	0	5	1	0	-	0	0	0	13	3	0
Entomobryidae	42	6	4	0	7	2	0	-	0	0	1	0	0	0

Mean population densities of the major groups of mites (M) and Collembola (C) at both sampling depths are shown in Tables 12a,b. The principal effects in the 0-4 cm layers appeared to be a reduction in numbers of individual groups in cultivated (CC) compared with uncultivated (DD) soil.

Taking the groups individually, greater numbers of the Mesostigmata (M) Poduridae (C) and Astigmata (M) were found on most sampling occassions.

The disappearance, or restriction of pores in CC (see Chapter 3), makes the habitat unsuitable for animals such as mites and Collembola. Their immediate habitats are the pores, cracks and tunnels in the soil where they move in search of food, and in response to changes in the hydrothermal regime. As a result numbers diminish in cultivated soil.

In the 4-8 cm soil layer, cultivation for 3 consecutive years produced a compacted layer (Chapter 3). Due to this layer, lack of pores and poor aeration made it difficult for animals to retreat into deeper horizons. There were few animals that survived cutting, pressing and the changed environment of the cultivated soil. It has been shown (see Chapters 3 and 6) that plant debris serves as food for soil animals and that cultivation changes the quantity of this material in the soil surface; quality also appeared to have changed. Therefore the decrease in plant debris in the 0-4 cm soil layer may have led to a reduction of biological activities within this layer.

4.2.2 The effects of seasonal change

During winter (May-August) rain and cool temperatures are optimum conditions for maximum production of soil mites and Collembola (Fig. 13).

TOTAL	Interaction	**	NS	NS	*	NS	NS
	Depth	***	***	NS	*	NS	NS
	Treatment	NS	*	NS	***	NS	*
COLLEMBOLA	Interaction	*	NS	NS	*	NS	NS
	Depth	**	***	NS	**	NS	NS
	Treatment	*	NS	NS	***	*	NS
MITES	Interaction	*	*	NS	NS	NS	NS
	Depth	***	***	NS	NS	NS	NS
	Treatment	NS	**	NS	**	NS	NS

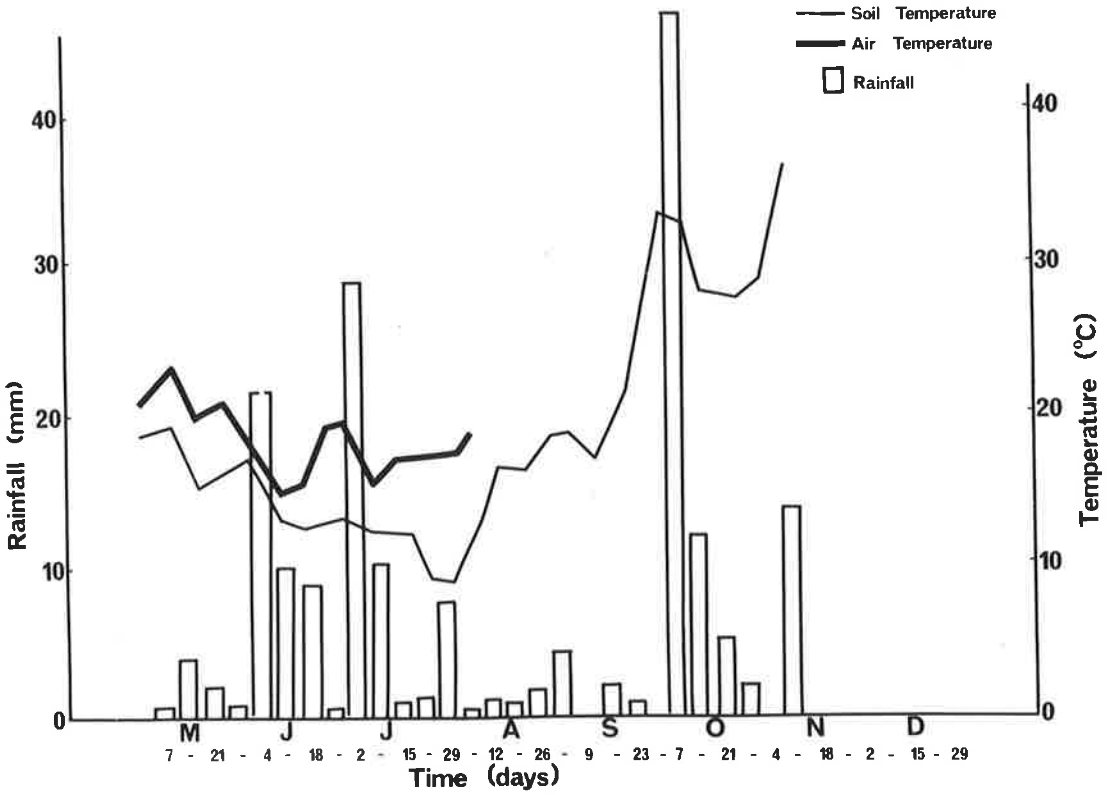


FIG 13. **Significance of the differences between faunal population numbers in two layers ofDD and CC treated soils from May-August at Avon. Climatic data is included.**

TABLE 13: Total numbers of soil fauna other than Collembola and mites recorded at Avon (total from 15 0-4cm plus 15 4-8cm depth cores)

	J	J	A	S	O	N	D	J	F	M	A	M	J
Psocoptera	1		(1)	3	(1)								
Hemiptera			1	1	1								
Isopoda		1											
Hymenoptera	4 (1)	7	(2)	2 (1)	1		3						
Formicidae			2 (1)	1 (2)									
Lepidoptera	1 1	(1)	2 (1)			1	1						
" Larvae	1												
Diptera			3 (1)		(2)								
" Larvae	1	(2)											
Coleoptera		3 (1)	2 (1)	3	(2)						1	(2)	
" Larvae		2 (1)											
Chilopoda													
Isopoda			1										
Oligochaeta					(1)								
Enchytraied			2 (1)		2								3
Others		(1)			(1)								1

CC results in brackets. Others represent DD.

Collembola and mites appeared to exhibit one maximum population density in winter both years (Table 12) which is in agreement with the results of Usher (1970) and the unpublished results of Hutson appended in this thesis. In summer, conditions became increasingly dry and together with high radiation caused elevated temperatures in the upper horizon (0-4 cm) (Fig. 13). The increases in temperature were pronounced in CC plots which had very little cover. A decline in animal numbers occurred in both DD and CC plots at a time when they were expected to rise (see 4.5). The population dropped so low that to detect a significant difference or an interaction between treatments and depth was not possible (Fig. 13). Numbers rose again at the start of the following winter (Table 12).

The numbers of soil animals recorded other than mites and Collembola are summarised (Table 13). Their densities were very low and in CC plots they were virtually eliminated.

4.3 ANIMAL POPULATION AT WAITE INSTITUTE - THE EFFECTS OF DIFFERENT TILLAGE IMPLEMENTS AND TWO HERBICIDES APPLIED SEPARATELY

The most frequently occurring animal groups were the cryptostigmatid mites and the poduridid and isotomidid Collembola. The food of these three groups includes plant debris and decaying organic material and since they are often active in the upper 0-4 cm soil layer are likely to suffer most from the removal of OM. But as the operations examined other than MB plough did not remove the plant debris or the rest of the OM from the soil surface, the short lived decline in numbers after treatment was not caused by lack of food in the cultivated plots (tine and disc) but probably by the disturbance of soil by implements.

The Cryptostigmata accounted for 72% of all mites and the Poduridae and Isotomidae accounted for 70% and 21.4% respectively of all Collembola in all the six treatments.

Although total numbers of animals in the soil from control plots were significantly higher ($P<0.001$) than from the rest of the treatments, at the beginning of the experiment in May (Fig. 14a,b) some groups seem to have been favoured later by lightly disturbed soil.

For all eight animal groups, populations were initially significantly lower with the MB plough, hoegrass and Buctril than disc and tine. However, although the MB plough plots had slightly higher population numbers than the hoegrass and buctril plots in the first month after treatments, only the herbicide treated plots showed signs of recovery later indicating that the overall effect lasted longer in MB ploughed than herbicide treated plots.

The different effects noted in this experiment may be due to the physical action of the implements and the chemical toxicity of the herbicides. The MB plough cuts a slice of soil which is then inverted thus distributing the animals within the tilled depth, burying and killing many of them. The disc plough partly inverts the soil burying some of the soil animals resulting in lower mortality. In contrast the tine cultivator tends only to shatter the soil with non-inversion but creates more cracks which probably form a better microclimate for the animals. This is probably why the latter two treatments seem to have favoured the soil animal somewhat. This is also in agreement with the finding of Critchley *et al.* (1979) and Lasebikan (1975) who found that some animals were favoured by cultivation.

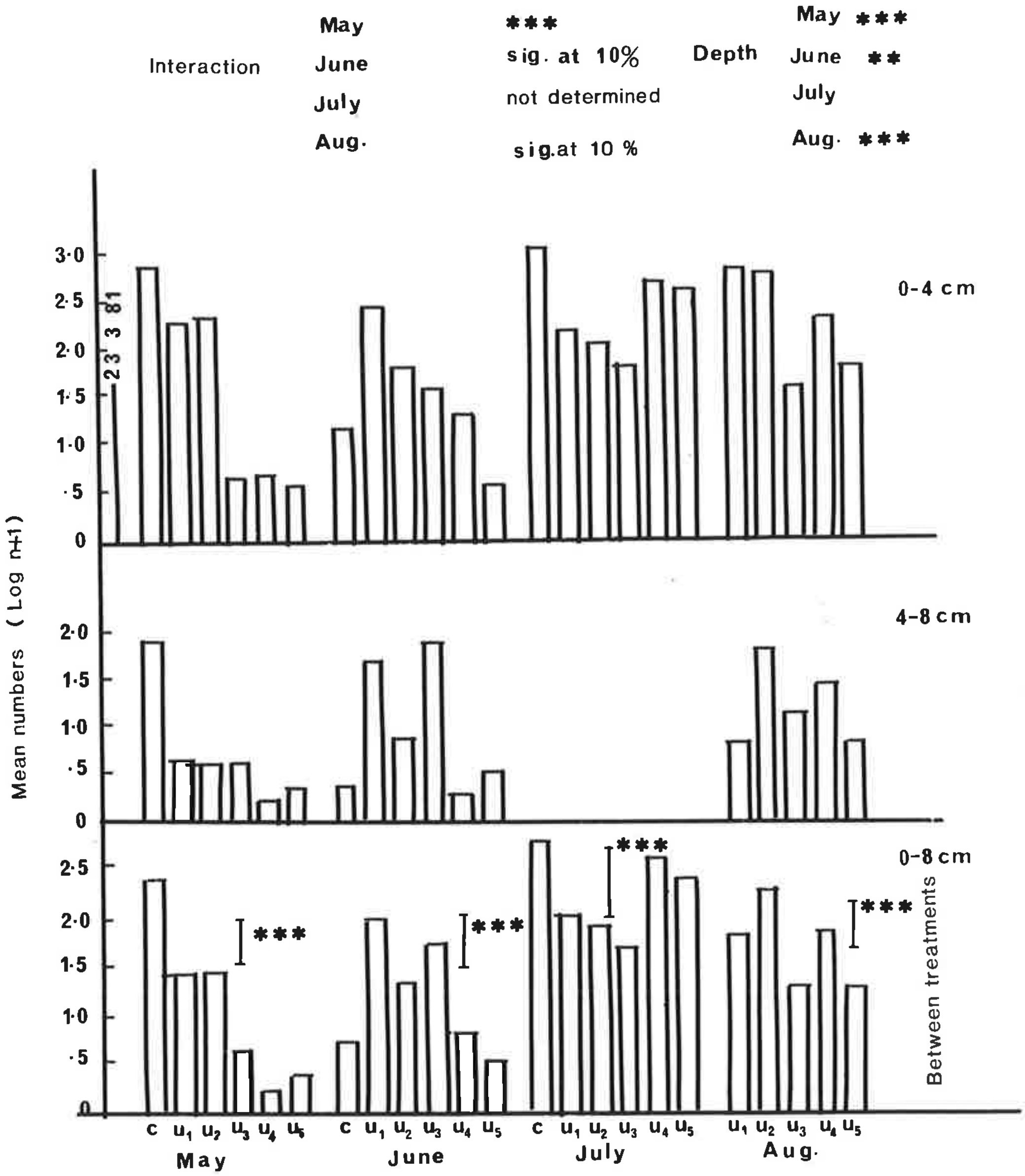


FIGURE 14 a Total numbers of Collembola (each depth 15 samples) in samples taken from two layers of variously treated sites at the Waite Institute between May - August 1981. ├─┤=S E

(C-control U_1-tine cult.- U_2 disk plough - U_3 mouldboard plough U_4-buctril U_5-hoe grass)

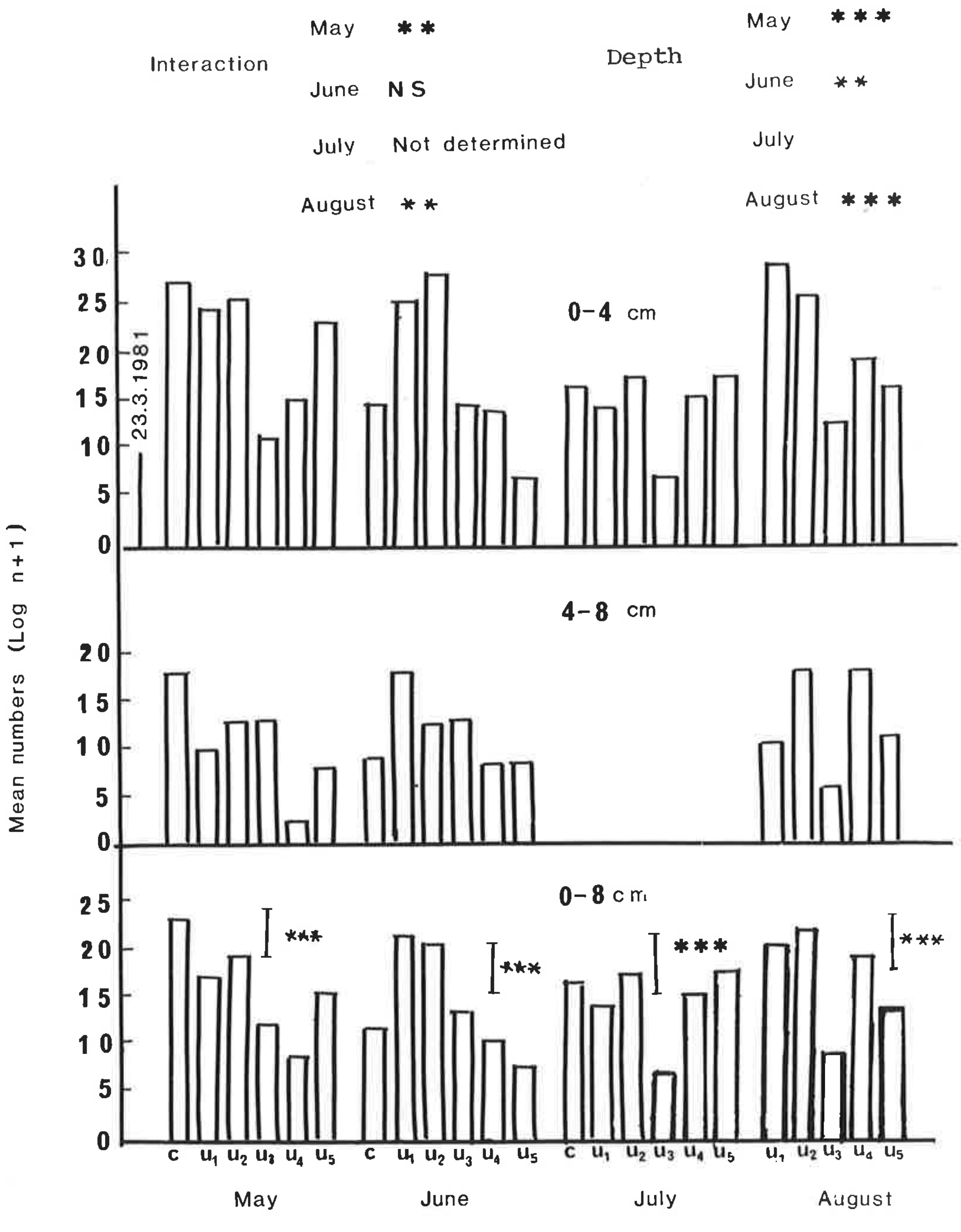


FIGURE 14b Total numbers of mites (each depth 15 samples)in samples taken from two layers of variously treated sites at the Waite Institute between May- August 1981

4.4 DIFFERENCES BETWEEN AVON AND WAITE INSTITUTE

Total numbers of animals were much higher at the Waite Institute than at Avon. At Avon the mites were dominated by Astigmata and some predatory Mesostigmata while the Collembola were dominated by the Poduridae (Table 12). At the Waite Institute, mites were dominated by Cryptostigmata with a few Astigmata while Collembola were dominated by Poduridae and some Isotomidae (Section 4.3).

Amongst the Collembola, Poduridae were dominant at both sites and Isotomidae constituted a much smaller proportion. These results indicate that floral composition and crops may have been determining factors for the faunal composition differences between the two sites (see Chapter 2). Also, these differences may be attributed to the degree and kind of soil disturbance. However, this does not explain the reasons for DD plots at Avon having less animals than at the Waite Institute site. In this case another factor, the residual effect of herbicides may be taken into account.

4.5 EFFECTS OF A MIXTURE OF HOEGRASS AND BUCTRIL HERBICIDES

4.5.1 Avon

Before herbicide application, the numbers of mites in the DD and CC plots were 47000 m^{-2} and 35000 m^{-2} respectively, in the 0-4 cm layer (Fig. 15a). Four hours after herbicide application at the DD plots, numbers of total mites and the dominant Astigmatid order in the 0-4 cm layer were both significantly reduced ($P<0.001$) by 74 and 83% respectively. In the CC plots herbicide application also significantly reduced the numbers of mites ($P<0.05$) by 88 and 94% respectively (Fig. 15c). A similar trend in reduction of numbers of animals after herbicide treatments was observed in 4-8 cm soil

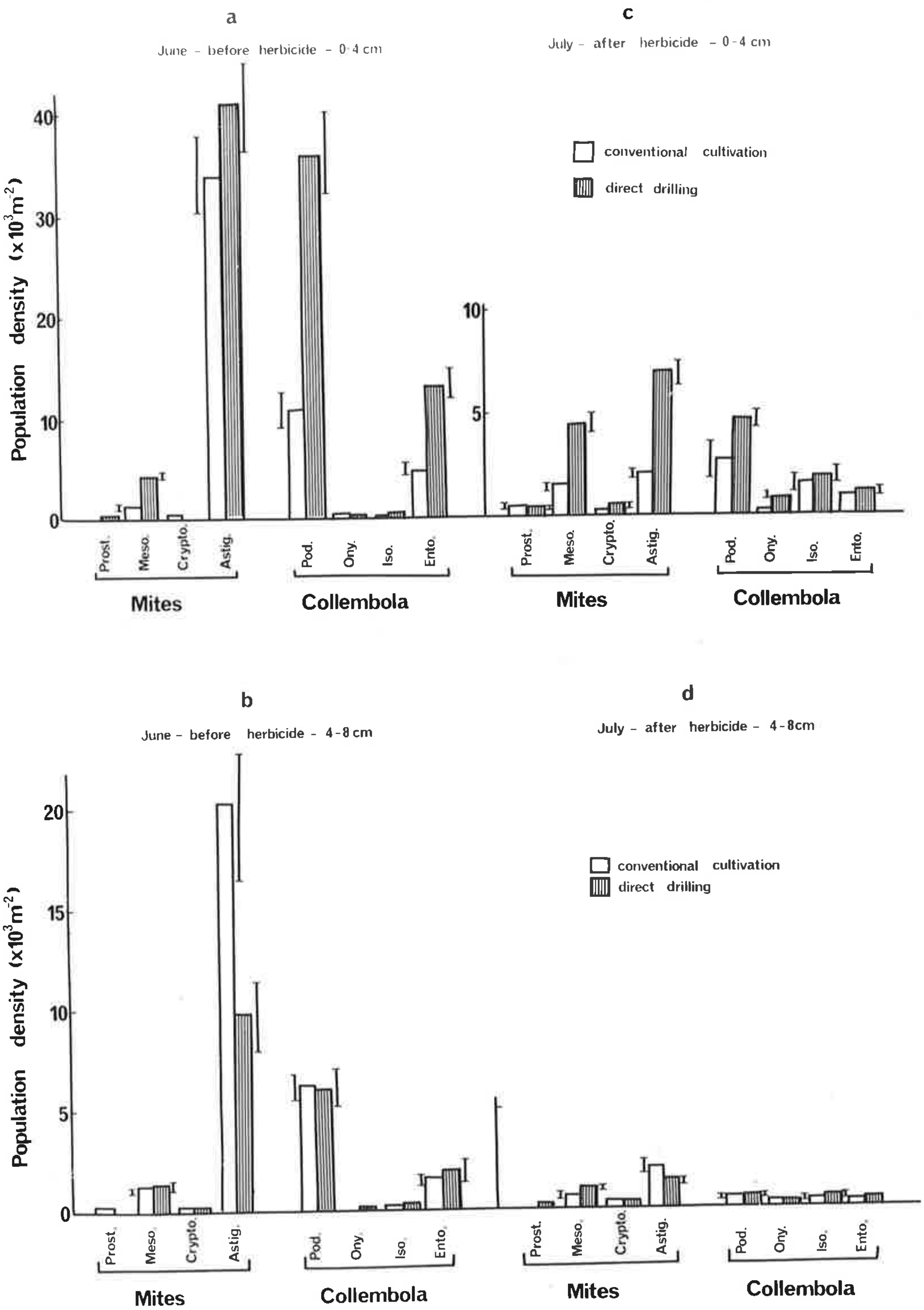


FIGURE 15 Soil animal populations before and after a herbicide mixture (hoegrass and buctril) was applied to DD and CCplots at Avon

layer (Figs. 15b,c). This reduction in both depths could be ascribed to toxicity of the herbicide·mixture used: animals in the 0-4 cm may have been affected directly by the herbicide and fumes while those in 4-8 cm could have been affected by the fumes, especially during transportation to laboratory.

Most Collembola were recorded in the 0-4 cm layer. Numbers in June 1980 were 25000 m^{-2} in DD plots and 8767 m^{-2} in CC plots (Fig. 15a). On July 18, four hours after application of herbicides, numbers of Collembola were significantly reduced ($P<0.05$) by 68% in the DD plots but the reduction of 38% in CC plots was not statistically significant. In the 4-8 cm soil layer reductions were from 8000 to 1250 (84%) in DD plots and 7000 to 750 M^{-2} (89%) in CC plots.

The population density of the dominant family of Collembola (Poduridae) was 18433 m^{-2} and 6400 m^{-2} in the 0-4 cm layer of DD and CC plots respectively (Fig. 15a). Following herbicide application numbers were reduced by 73.8% in DD and 56.8% in CC plots. In the 4-8 cm layer a similar reduction was recorded.

4.5.2 Waite Institute

The experiment at the Waite Institute site was designed subsequent to the experiment at Avon to test the effects of herbicides (mixture) on soil animals without any interactions from tillage treatments.

As a result of herbicide treatments, soil was left almost bare compared with substantial growth of natural regenerated pasture on the surface of the control plots. The similarity between numbers of animals in the 0-4 cm layer of the trial field before herbicide application and the

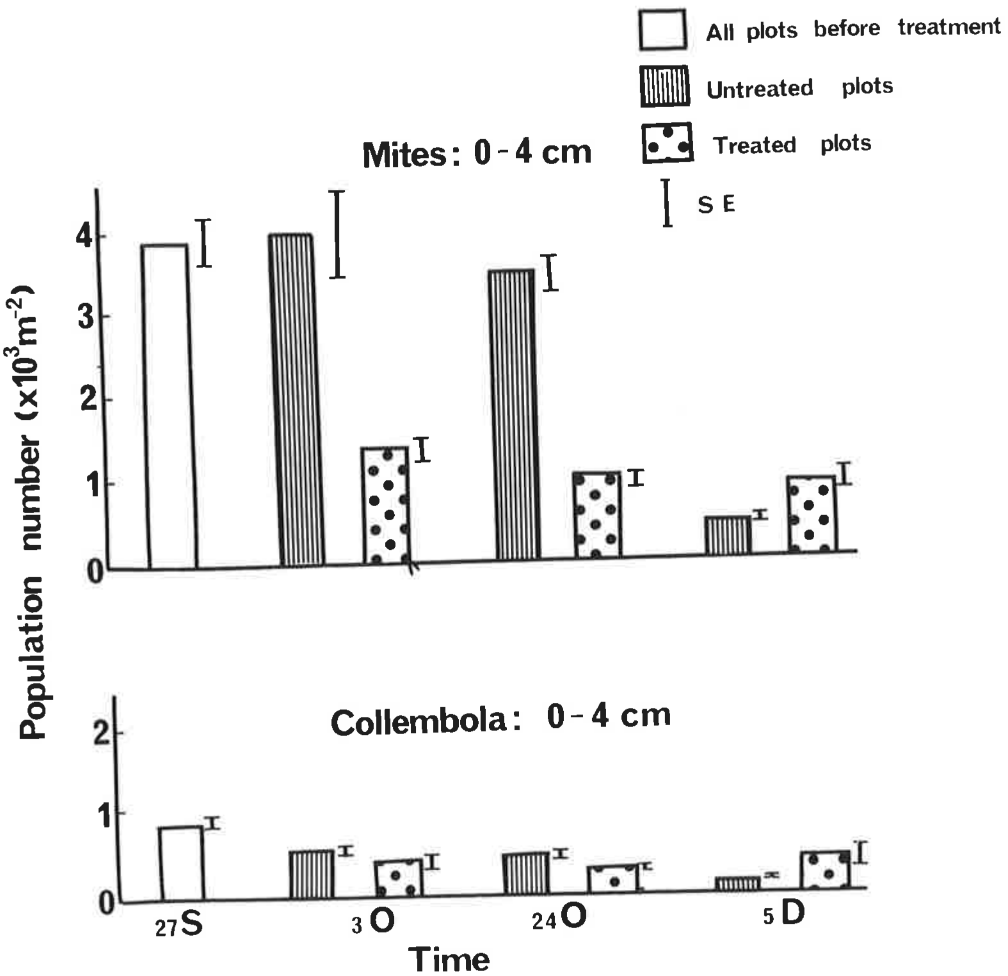


FIGURE 16. Population density of soil animals before and after a mixture of herbicides (hoegrass and buctril) was applied at the Waite Institute.

TABLE 14: Total animals extracted from Urrbrae soil (*The data is given as mean of 24 [0-4cm depth] samples).

Date and Treatment	29.9.80	3.10.80		24.10.80		5.12.80	
	Pretreated	Control	Treated	Control	Treated	Control	Treated
MITES							
Prostigmata	5.25	6.05	2.25	5.04	1.125	.083	0
Mesostigmata	1.96	2.25	.21	.5	.375	.292	.75
Cryptostigmata	1.63	.45	.167	.958	.333	.375	1
Astigmata	.54	.5	.292	.125	0	.042	0
COLLEMBOLA							
Poduridae	1.17	.79	.46	.46	.375	.125	.71
Onychiuridae	0	0	.042	.167	0	.042	0
Isotomidae	.58	.167	0	.167	.125	0	0
Entomobryidae	.042	0	0	0	0	0	0
OTHERS							
Dermaptera	0	0	0	0	.042	0	.042
Hymenoptera	0	.042	0	.083	.83	0	0
Diptera	.042	.083	.042	0	0	.04	0
Lepidoptera	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0
Enchytraied	0	0	.083	0.042	0.042	0	0
Formicidae	.042	.042	0	0	0	0	0
Coleoptera	.042	.042	0	0	0	.042	0
TOTAL	11.29	10.41	3.55	7.54	3.25	1.04	2.5

*To get population numbers (m^{-2}) multiply the mean numbers by a factor of 500.

control plots of the same field after application, and the latter significant difference (P<0.01) between mite numbers in the herbicide treated and control plots (Fig. 16) indicate a direct and immediate effect on the soil fauna.

The mean density for all animals in the plots before and after herbicide application and in the control plots are given in Table 14. Significantly more mites than Collembola (P<0.001) were recorded. The Prostigmata dominated followed by Mesostigmata. After herbicide application their numbers had decreased by 63% and 91% respectively.

Populations of Collembola were generally low with Poduridae dominant and some surface dwelling Isotomidae present. There was some reduction in numbers of Collembola after herbicide application (Fig. 16) but it was not statistically significant except at the 10% level.

The animals on this site were sampled until the beginning of summer when populations were naturally very low, and their recovery could not then be assessed. These results on herbicidal effect are in agreement with the findings of many workers. for example Prasse (1978) reported that simazine significantly reduced the numbers of Cryptostigmatid mite (*Tectocepheus velatus*). The same herbicide, used by Edwards (1964) reduced populations of isotomid Collembola and predatory mites by 13-50%, whereas in the present study the hoegrass-buctril mixture affected all groups of animals examined to some extent. Also Bhattaracharya & Joy (1980) found that nitrofen (2-4 dichlorophenyl-4-nitrophenyl ether) reduced populations of Cryptostigmatid mites (*Schelloribates* spp. and *Oppia* spp.) more drastically than propanil (3-4 dichloropropion analide). However, results from Waite Institute experiment indicate that two herbicides applied individually have similar effects.

Though the application of a greater dosage of simazine (Edwards, 1964) was found to reduce the numbers of soil animals more than a normal dose, Bieringer (1969) in a different experiment found that five months after simazine application, the populations were greater than before application. This may not be the case with the two herbicides used in this study since after one year, the population density at Avon remained less than half that initially reported before the herbicides were applied. The effect could be similar to that reported by Ghabbeaur and Imam (1967) who found that besides causing mortality, Chloroprophen changed the reproductive and feeding habits of the Collembola *Folsomia candida*. Other similar findings were those of Adams and Drew (1965) and Kulash (1947) who observed sluggish behaviour in the Collembola *Orychiurus quadrocellatus*, after application of herbicides. Three hours after application of herbicides, Eijsackers and Drift (1976) found paralysis in Collembola.

4.6 CONCLUSION

A relatively small population of soil fauna was found in cultivated compared with undisturbed soil.

The overall effect of cultivation on the majority of soil animals is a reduction in numbers and possibly in species. At the same time a reduction in the amount of available food and habital space occurs. However some species may survive these changes and even benefit from the new situation. As far as herbicides are concerned hoegrass and Buctril used singly or together are toxic to soil animals. The residual effect of the mixture seems to last longer than the residual effect of the individual herbicides.

With the exception of some information on mites and Collembola (Abbott, Parker and Sills, 1979; and Buckerfield, 1978 unpublished results - appended in this thesis) there is little published work on the fauna of cereal crop lands in Australia with which to compare the results presented here.

CHAPTER 5

EFFECTS OF CROP ROTATION AND TRASH DISPOSAL METHODS ON SOIL FAUNA AND PLANT DEBRIS - RESULTS AND DISCUSSION

5.1 INTRODUCTION

Crop rotation is accepted in agricultural management for many reasons including economics, control of diseases, restoration of soil structure and accumulation of OM in soil.

After crop harvesting the remaining plant debris, which in most cases falls on to the soil surface, adds to the problem of choosing the right implements for seedbed preparation. For this reason farmers choose from many methods of straw disposal.

About 50% of Australian agricultural soil is fallowed as part of a rotational management (Sims, 1977). The evaluation of fallowing in earlier years in Australia was primarily on an agronomic basis and an appreciation of the soil factors involved developed rather slowly.

To find the effect of rotation in this study, the levels of both soil animals and plant debris were recorded at the beginning and end of an experiment at Tarlee and Avon i.e. the end of a pasture phase and the end of a wheat phase. To find the differences, basic statistics were employed. The observed difference was attributed to the rotational treatment. Also the effect of a fallow treatment was compared with that of a pasture.

The effect of trash disposal methods were compared and assessed throughout the sampling period. Also the population density of the soil animals was related to the amount of extracted LF since the distribution of LF was found to be consistent with the numbers of soil animals. The effect of reworking (see later Section 5.4) of earlier seeded plots was related to the immediate sharp decline of the soil animal numbers.

5.2 EFFECT OF ROTATION

The data presented in Table 15 shows both the population dynamics of two groups of animals and the LF content in soils supporting crops in various rotations.

5.2.1 Tarlee

Unlike fallow x wheat rotation, the numbers of soil animals and light fraction from pasture x wheat rotations at the end of the pasture phase (1980) was significantly higher than at the end of the wheat phase (1981).

Soil undergoing fallow alternating with wheat contained significantly fewer animals than pasture alternating with wheat at the end of both pasture and wheat phases. The results indicate that the numbers of soil animals and percentage of light fraction are controlled by the crop rotation in addition to climatic effects.

5.2.2 Avon

The faunal population which followed pasture sown soil was very high compared with that following the wheat phase. Also the content of LF was significantly higher ($P<0.001$) at the end of pasture than at the end of wheat phase. The animal populations did not reach appreciable numbers; which remained comparatively lower than in June 1980, probably due to the late arrival of the 1981 rains and to the residual effects of herbicide applications (Malinda *et al.*, 1981). It should be pointed out that sampling in 1980 followed about 2 years and one year of non-disturbance to the soils of DD and CC plots respectively. That of June 1981, however, followed a year of wheat growth with some soil disturbance at the beginning of the year.

5.2.3 Waite Institute

After any rotation including a fallow phase, the soil was found to contain the least numbers of soil animals and the least amount of LF. The extracted LF consisted mainly of roots and twigs with very little leafy material.

Results from rotations of four year pasture x 2 year wheat, 2 yr Past x 1 yr wheat and also continuous wheat (50 yrs) did not differ significantly either in soil animal populations or in plant debris extracted in LF.

The permanent pasture (30 yrs) supported the higher numbers of soil animals with virgin soil supporting the second highest population.

The virgin soil had a significantly higher LF content than all other rotation soil, but it was comprised of twigs, roots, leaves and other partly decomposed materials. Some humic material with a density lower than 1.8 was also present. The 0-4 cm layer of virgin soil consisted of a litter layer and fermentation layer made up of recently fallen leaves and broken partly decomposed material. A humus layer with decomposed material of uncertain origin was also present above the mineral soil.

The light fraction of the DD consisted mainly of leafy material, easily decomposable plant debris, decaying roots and hyphae some fungus material was also present.

TABLE 15: Mean (±SE) numbers of mites and Collembola/core (to get numbers per m^{-2} multiply by a factor 500) and L.F. content (%) at three sites carrying different crop rotations.

Treatment	1980 Mites	1980 Collembola	1980 L.F.	1981 Mites	1981 Collembola	1981 L.F.
AVON:		June			June	
C.C.	58.03±10.31	15.77±2.32	3.3 ±.51	2.2±	.27±.19	1.21±.09
D.D.	64.47±12.69	33.4 ±7.5	2.89±.44	8.0±	1.0 ±.29	1.35±.16
TARLEE:		June			April	
Psxr	13.6±5.2	31.7±6.7	2.37*±.19	ND	ND	
Psxs	27.7±5.6	23.1±5.8	4.25±.81	5.33±.21	5.08±1.29	
Psxb	16.9±5.1	25.4±8.24	2.65±.17	2.14±.64	0.00±	
Fxr	9.7±3.2	13.9±2.9	2.3 ±.9	ND	ND	
Fxs	15.9±3.4	12.9±2.75	2.32±.15	ND	ND	
Fxb	9.5±1.9	13.8±2.78	1.5 ±.10	ND	ND	
WAITE INSTITUTE:		September 1981				
P.P	15.18±2.47	88.0 ±16.11	1.62±.09			
Virgin	5.69± .97	26.93± 6.17	3.08±.11			
W.W	2.75± .87	5.13± 1.56	0.87±.27			
4P.2W	2.06± .34	4.38± 1.34	1.01±.03			
2P.W	2.13± .49	4.5 ± 1.41	0.98±.04			
F.W	1.18± .37	0.75± .31	0.93±.06			
W.P.F	0.94± .30	2.06± .96	0.37±.03			

(Avon and Tarlee : 1980 end of pasture phase, 1981 end of wheat phase). Phase at Waite Institute in September 1981 indicated.

*determined in May.

CC = Direct drilling; DD = Conventional cultivation; Ps = Pasture sown
F = Fallow; r = rotary hoed; b = burn; s = stubble retention on surface;
1st PP = Permanent pasture; W = Wheat; P = Pasture.

TABLE 16: Effect of rotation on light fraction content and the relationship (R) between LF and soil fauna at the Waite Institute

*Soil and Rotation	Mites			Collembola			LF (%)	
	Numbers per core expressed as							
	Mean ±	SE	Range	Mean ±	SE	Range	Mean ±	SE
PP	3.59	.39	0 - 5.57	8.68	.92	3 - 14.80	.81	.06
Virgin	2.25	.21	1 - 3.61	4.38	.56	0 - 6.95	1.54	.13
W.W.	1.25	.28	0 - 3.16	1.96	.29	0 - 5.10	.44	.073
PP.W	1.25	.195	0 - 2.45	1.72	.34	0 - 4.36	.49	.07
PPPP.WW	1.31	.16	0 - 2.24	1.72	.31	0 - 4.36	.51	.036
W.P.F	.67	.18	0 - 2	.99	.27	0 - 3.87	.19	.01
F.W	.78	.20	0 - 2.24	.51	.18	0 - 2.00	.47	.04

r = .98*** r = .83*

*First PP represents permanent pasture while the rest of the P's indicate a pasture phase. W represents wheat, F represents fallow.

A positive correlation between % LF and numbers of soil animals extracted was found (R^2) from the results of all samples in Table 16, excluding those from virgin soil. From this table it appears that there are factors other than LF influencing numbers of soil animals in this soil which could not be investigated.

5.3 EFFECTS OF TRASH DISPOSAL AT TARLEE

After fallow there was little trash material to dispose of and there were few soil animals (Fig.17). Thus the three methods of trash disposal (Burn, incorporate and retention) did not produce any significant difference in animal numbers and LF content. After pasture a difference of both numbers of soil animals and LF content was observed between disposal methods. Surprisingly a high number of soil animals was found in the pasture sown x burn rotation plots (Fig.17), despite a low content of LF. Many animals have been survived after burning because the temperature of the fire was low and may not have penetrated to the depth where the animals were concentrated. The trash was spread thinly and evenly and a strong wind tended to drive the fire quickly.

5.4 EFFECT OF REWORKING AT TARLEE

Reworking and reseeding was necessary following an outbreak of mice that completely destroyed the emerged wheat seedlings. The operations involved were:

- Shallow cultivation to a depth of 2.5 cm on 16.7.80
- Resown to wheat treated with fungicide on 17.7.80
- Superphosphate fertilizer applied at 120 kg/ha
- Tractor M/F 135 used to pull a Connor shear 3 point linkage seeder.

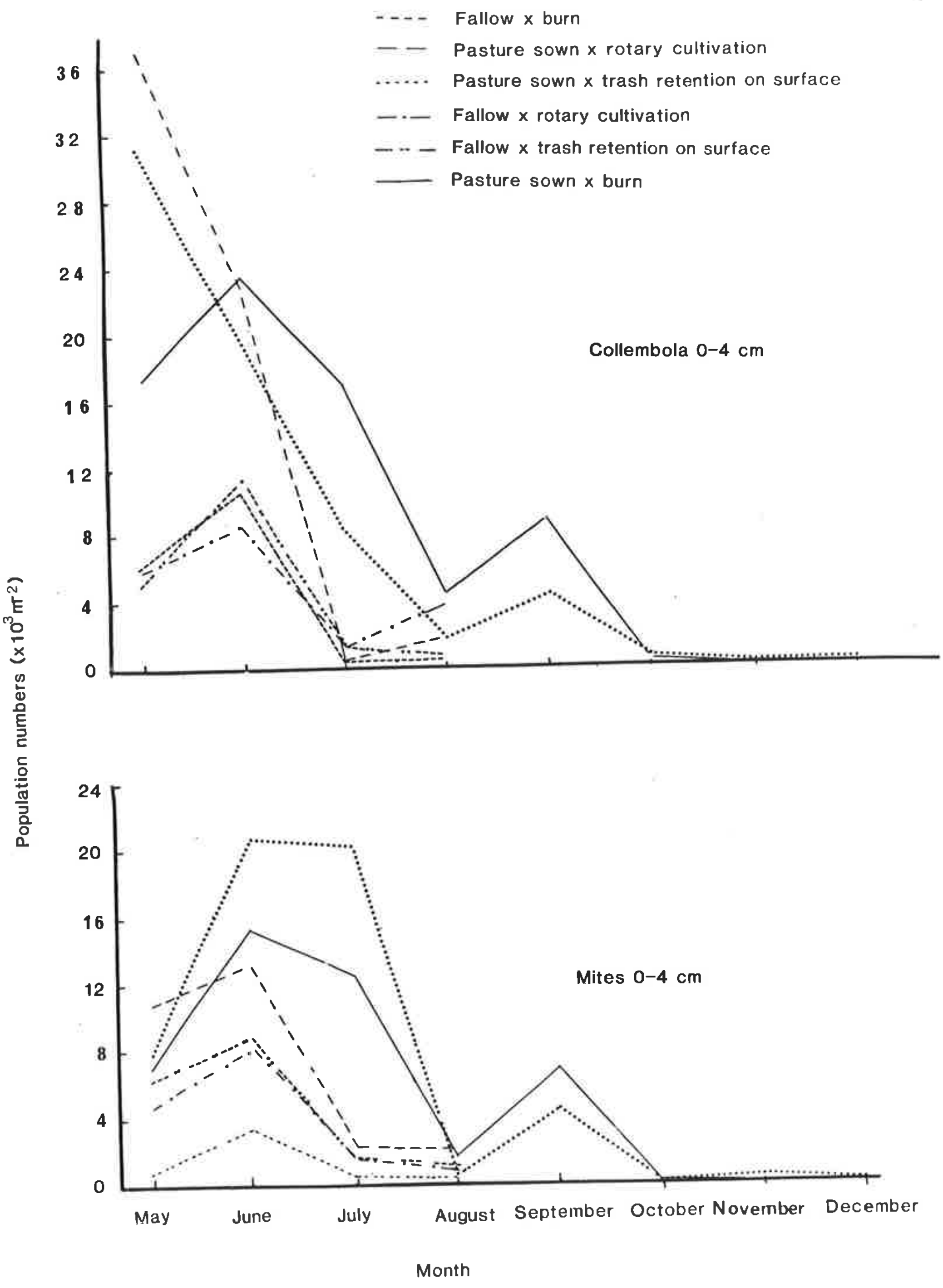


FIGURE 17 (a) Effect of crop rotation, stubble handling methods and extensive use of agricultural tools on soil animals at Tarlee.

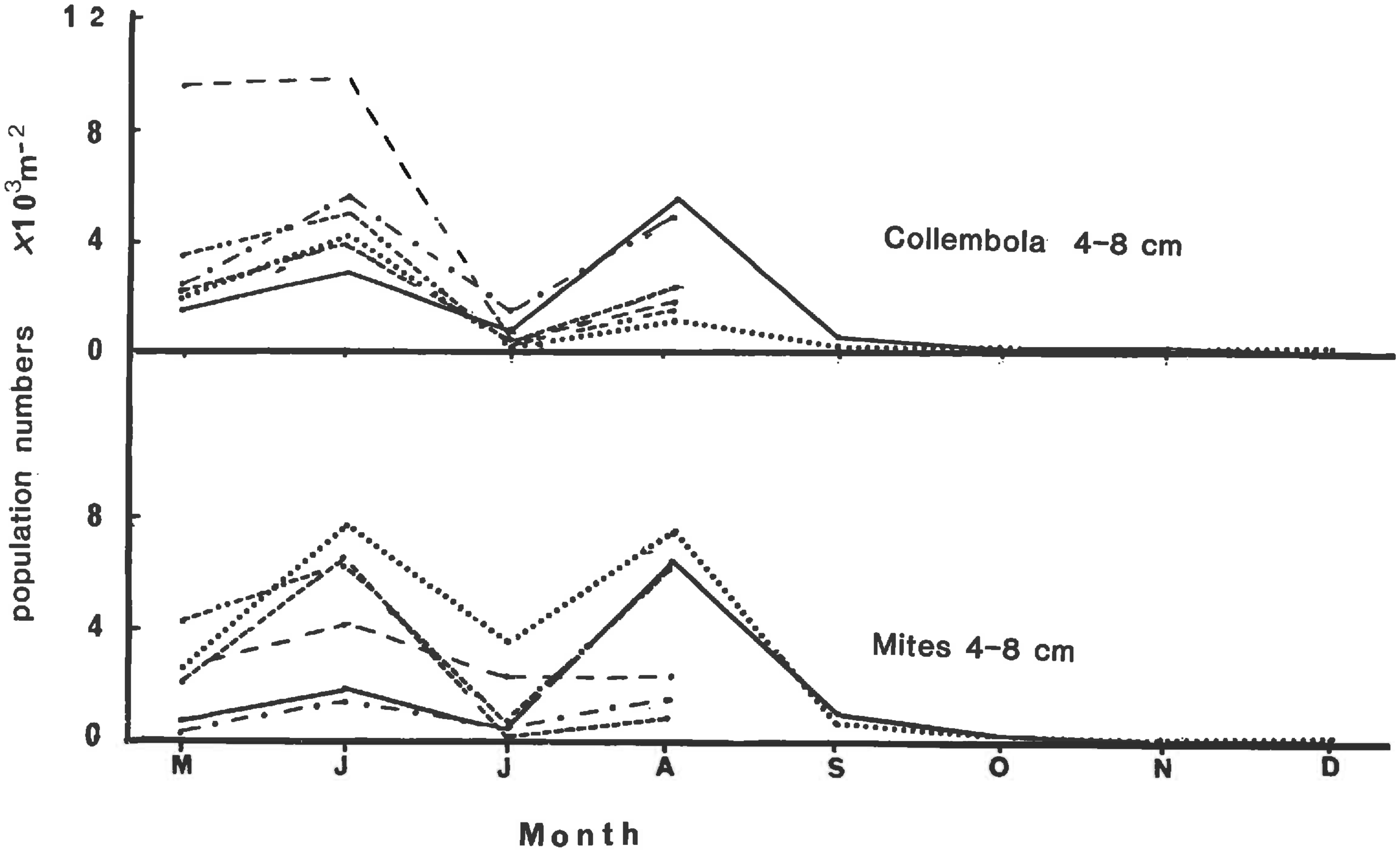

12
8
4
0
8
4
0
population numbers ×10³m⁻²
Collembola 4–8 cm
Mites 4–8 cm
M
J
J
A
S
O
N
D
Month

FIGURE 17

(b)

These operations were undertaken in July when most faunal populations were increasing in numbers, (Fig. 17a,b) and afterwards, the sharp drop in numbers is attributed to the effects of these operations on the animals and their habitats.

The length of time these operations affected faunal density is unknown but may be short term since a recovery was noticed in August-September. However, this apparent recovery was at a time when soil animal population densities are known to be declining due to the natural effect of the dry season.

5.5 CONCLUSION

In all experimental sites, rotations including a fallow period, have the greatest effect on both soil animals and light fraction. The decrease in populations of soil animals was accompanied by a parallel decline of LF content in the soil, however, the quality of the LF is also important (see Waite Institute rotation).

These results indicate that there may be other factors influencing the levels of populations of soil animals which could not be investigated during this project.

CHAPTER 6

LABORATORY INVESTIGATIONS INTO THE INDIVIDUAL AND INTERRELATED EFFECTS OF SOME SOIL ENVIRONMENTAL FACTORS ON SOIL FAUNA AND THEIR FEEDING HABITS

6.1 EFFECTS OF PORE DIAMETER AND TEMPERATURE ON ANIMAL MOBILITY

6.1.1 Introduction

In countries such as Europe, Asia, America, parts of Australia and elsewhere where low ground temperatures occur, the activities of soil animals may be restricted.

Soil temperature depends on the thermal conductivity and volumetric heat capacity of the soil and on the amount of heat that enters or leaves the soil surface. Thus the amount of air, water and cover of the soil are decisive factors for temperature regimes of the soil.

The techniques of funnel extraction of soil animals showed that soil animals live and move in the soil in search of a suitable microenvironment. Therefore it is proposed that the mobility of soil animals will depend mainly on pore size distribution.

6.1.2 Experimental methods

6.1.2.1 Trapping of soil animals

Collembola were pit-fall trapped in water in a plastic tin sunk into the ground. These animals were collected with different body temperatures. Some of them were collected when the air temperature was 7°C after a cold night, others when the temperature was 16°C, also after a cold night. Others were collected at 16°C after a warm night.

Healthy looking representatives of the Collembolan family Poduridae were separated for use in the laboratory.

6.1.2.2 Stabilization of soil aggregates to make pores

In this experiment soil animal movements were studied in relation to known (estimated) pores size obtained from more or less spherical aggregates.

Soil was obtained from the 0-4 cm layer of the Waite Institute fine sandy loam. The dry soil was broken into different size aggregates then sieved into the following size groups: 1-2, 2-4, 4-6.7, 6.7-9.5, 9.5-12.0, >12.0 mm. The aggregates were wetted by immersing them in a beaker containing water and dried at 80^{o}C for 6 hours. The wetting and drying was repeated four times. Then the more spherical aggregates were separated and treated with a 3% solution of poly (vinyl alcohol) to prevent them from breaking during subsequent wetting which was necessary to obtain the required humidity for maximum activities of the animals. The aggregates were dried and finally sieved to remove any detached particles. The remaining aggregates were put in 6 core samplers, each of 5 cm diameter and 4 cm length. The depth of aggregates from the bottom of the cores was 3 cm so as to leave a space in which to introduce the animals. The columns of aggregates of each size group were replicated twice. Circular metal plates with 2 mm mesh openings were put at the bottom of each sampler to retain the aggregates. The aggregates were then vibrated to obtain the minimum porosity possible. Before introducing the animals, the aggregates were wetted in the same manner as before to obtain a humidity acceptable to soil animals (80-100%).

6.1.2.3 Examination of the pores made by different size aggregates

The same aggregates after having been used to study animal movements were used to examine the existing pores. Impregnation, thin sectioning and analysis procedures were similar to those used in Chapter 2.

6.1.2.4 Measurement of animal movement through pores made by aggregates

Forty animals (groups according to 6.1.2.1) were introduced into each cylinder. The top of each cylinder was closed by a cloth netting with 0.05 mm openings to exclude any extraneous animals.

Heat was introduced on top of the soil aggregates. Animals coming out of the bottom of the cylinders were collected in McCartney bottles and preserved in 75% alcohol. They were counted at different time intervals up to 54 hours (see Figs. 18 & 19), and plotted as a function of time. After hour 6 the numbers of animals coming out were grouped together and finally plotted against hour 54.

6.1.2.5 Measurement of animal dimensions

At each given time, animals in the bottles were counted and the diameter and length of the larger animals measured using a microscope.

6.1.3 Results and Discussion

6.1.3.1 Effect of temperature on animal mobility

6.1.3.1.1 Effects of body temperature

Animals kept at 7°C overnight and examined under a microscope appeared sluggish at first but became active

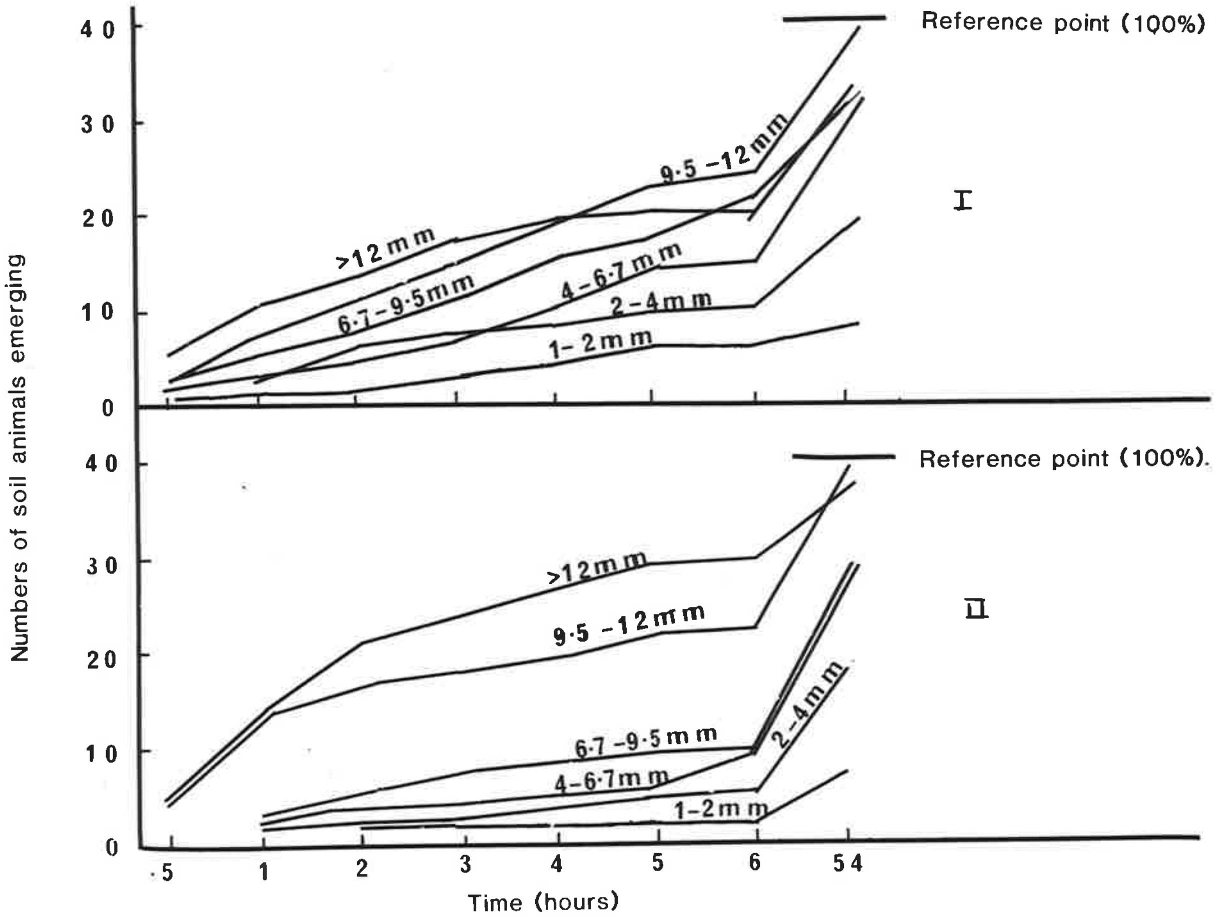


FIGURE 18 Effect of body temperature on the activities of soil animals in various size pore spaces (I-7°C, II-16°C). (size of aggregates given)

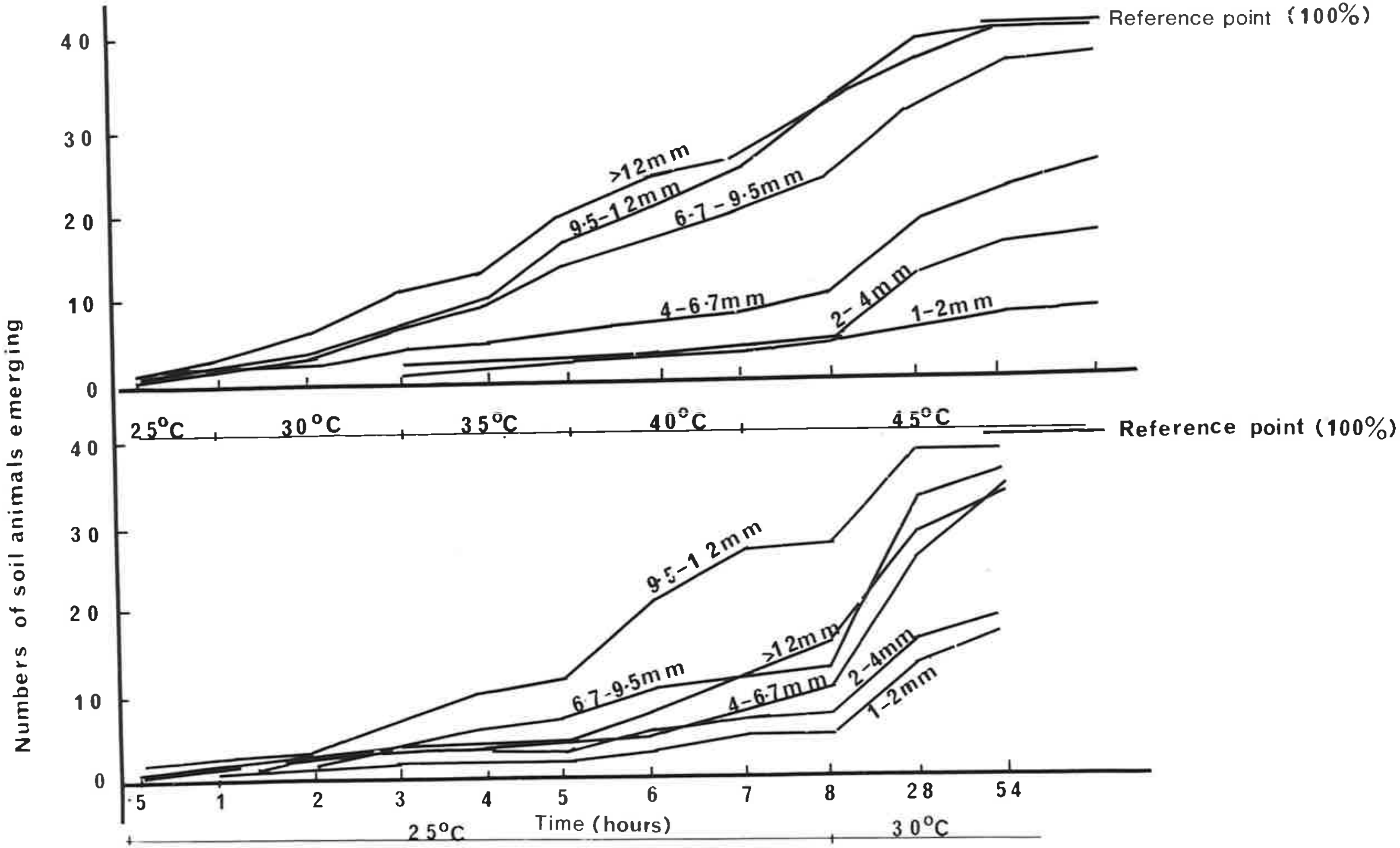


FIGURE 19 Effect of soil temperature on activities of soil animals (size of aggregates given)

under the heat of the microscope light.

When these animals were introduced on to prepared aggregate columns in experimental cylinders, total numbers emerging were less compared with those with warmer body temperatures (Fig. 18).

6.1.3.1.2 Effect of soil temperature

The summation curves (Fig. 19) indicate that soil temperature has some effects on the activities of the soil animals. When the temperature was between 25^{o} to 30^{o}C and soil was moist, there was a tendency for the animals to remain in the aggregates for a longer period, probably until the humidity fell. Upon introducing more heat to aggregates with pores >400 μm diameter, animals moved more quickly from point A to point B at any given time as compared with lower temperatures. However, in pores with diameter <410 μm fewer animals went through with further introduction of heat. Probably increased tortuosity prevented the animals from finding a way through quickly and as a result they may have died.

6.1.3.2 Pore sizes formed between aggregates (results as measured by Quantimet 720)

As shown by the Quantimet 720 results different size aggregates produced pores of different sizes. The information in Table 17 can be extrapolated to the field after aggregates have been reduced in size by cultivation. However, the data (Table 17) can only be used to indicate the direction of change.

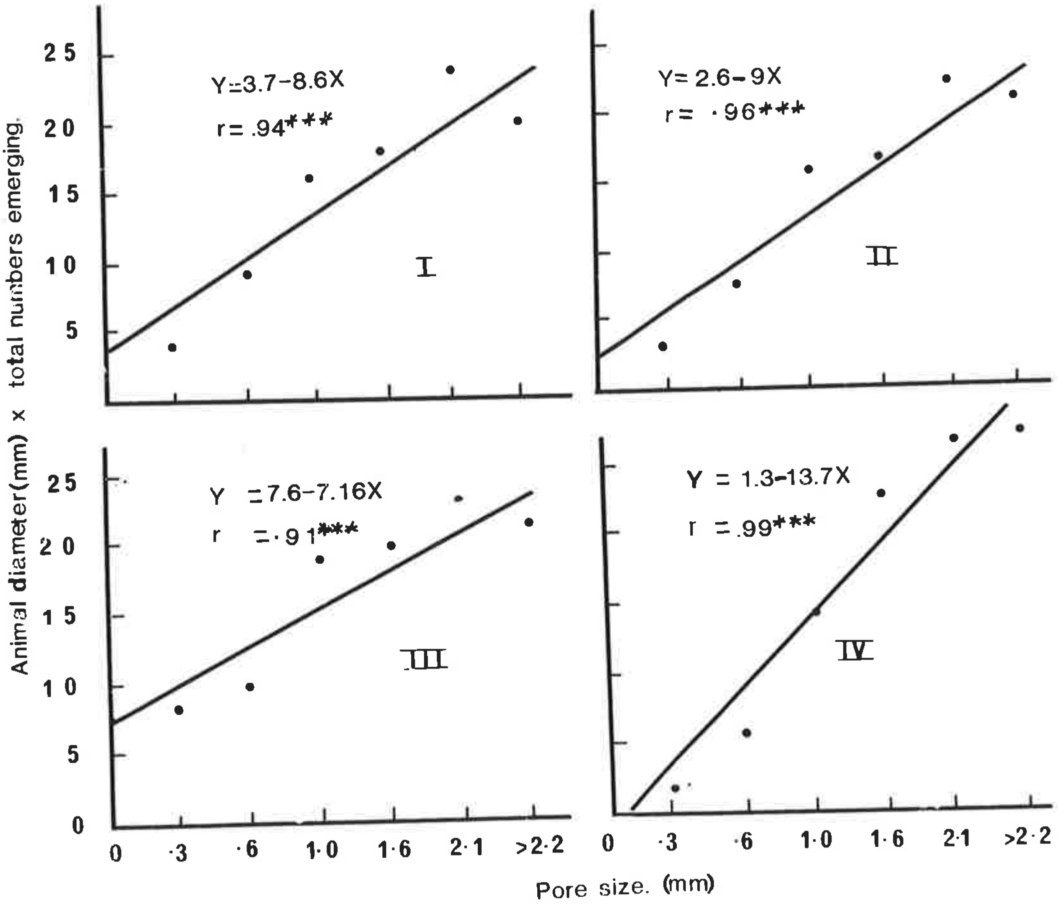


FIGURE 20. Relationship at different temperatures between soil pore size and movement of Poduridae (Collembola) with varied body diameter sizes I= body temperature 7°C, II-body temperature 16°C, III- soil temperature between 25-45°C, IV- soil temperature 25-35

TABLE 17: Pore sizes produced by different size aggregates as shown by Quantimet 720.

Aggregate size by sieving (μm) >	Pore size (by Quantimet) (μm)	% number of pores of that size - by calculation from total pore numbers
1500	100	72
3000	410	89.8
5350	810	88.8
8100	1500	58.0
10750	1790	58.0
12000	1990	-

Measurement of pores formed between aggregates >8100 μm diameter was not reliable probably because of the large pores formed during vibrating the aggregates (i.e. they could not settle well).

6.1.3.3 Effect of pore size

The results show that the numbers of animals moving through the beds of aggregates depend on the diameter of the pores. This is illustrated by the high correlation between pore size distribution and numbers of animals (Fig. 20).

6.2 EFFECT OF COMPLEXITY OF PATHWAY

6.2.1 Introduction

Agricultural practices, especially CC as seen in Chapter 3, produce aggregates of different sizes. A single run in soil with a primary implement will produce clods or large aggregates. Introduction of a secondary operation has been found (Ojeniji and Dexter, 1979b) to result in further reduction of aggregate sizes. If the exercise is repeated many times as in fallow, aggregates may reach the lower size limit (not determined). This condition of clod reduction into small aggregates and particles is part of a seedbed preparation. It is proposed here that the tortuosity of the pathway (pore) will depend on the aggregate size. Therefore in the following section I will show the relationship between the tortuosity of pathway made by different aggregate sizes and the numbers of soil animals able to move from a point A to point B. Also a mathematical model is applied to explain further the effects of pore tortuosity on the animals.

6.2.2 Experimental Methods

6.2.2.1 Measurements of length of pathway

The thin sections from aggregates used in the study of soil animal movements were used to examine the tortuosity of the pathways. This was done using a system consisting of a digitizer tablet (Houston Hipad, Houston Instrument, Houston, Texas) with an active area of 27.94 x 27.94 cm, a video display terminal and an Andromeda system 11/B microcomputer with twin floppy disc drives.

First, the pathway which the animals could follow was traced on scale diagrams similar to those in Fig. 21.

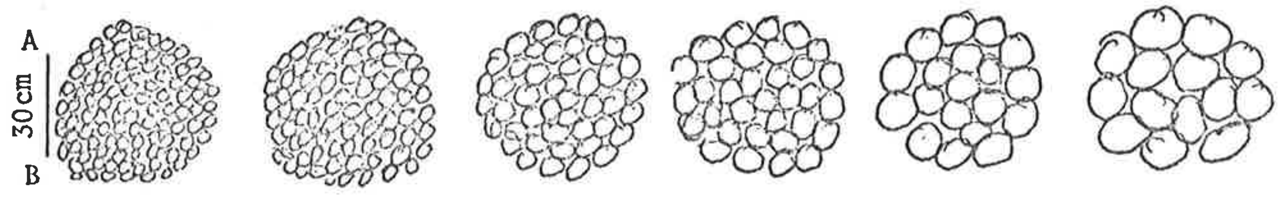


Fig. 21: Aggregate beds showing complexity of pathway from point A to point B.

On average about 7 alternative pathways were traced and the average result for each size group was obtained. When the pathway was traced, coordinate information from the tablet was used to compute the length traced with the digitizer cursor. This particular instrument could also be used to compute area, perimeter etc. as required.

6.2.2.2 Theoretical explanation

Consider a Brownian motion process in a one-dimension that starts at point Y=o and is absorbed at Y=l and at all times t=0 lies between 0 and l. This motion can only be described by use of a series of functions:

Y=o start at t=0

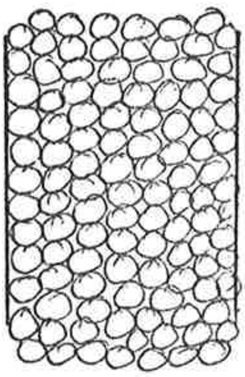


Fig. 22: Diffusion theory-

Y=l absorption or exit from system at t=T

(e.g. see losifescu and Tâutu (1973)).

The dominating term will lead to a probability density for exit time t given by $f(t) = \frac{a}{\sqrt{2\pi t^3}} \exp\left(\frac{-\;^{2}}{2t}\right)$, $t>0$ where a is a parameter involving the "diffusivity" of the system, the length l etc. Hence the fraction of numbers emerging in time T is

$$F(T) = \int_0^T \frac{a}{\sqrt{2\pi t^3}} \exp.\left(\frac{-\;^{2}}{2t}\right) dt. \qquad (14)$$

Note $F(\infty) = 1$

The transformation $\chi = a/\sqrt{t}$ gives

$$F(T) = \frac{2}{\sqrt{2\pi}} \int_{a/\sqrt{T}}^{\infty} e^{-\frac{\chi^2}{2}} d\chi$$

Also it should be noted that this is twice the area under the tail of the normal distribution to the right of $a/\sqrt{T}$

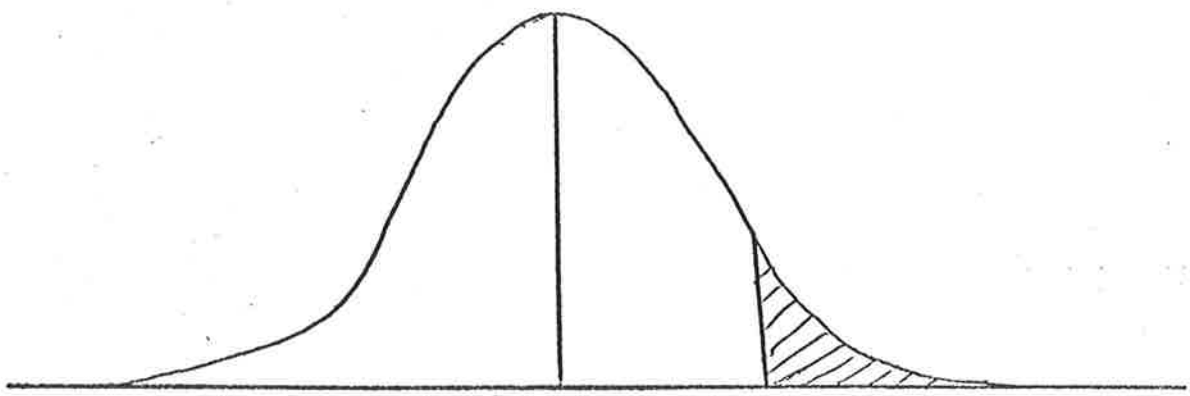


Fig. 23: The normal distribution curve.

Hence from the fractions emerging at time T, the supposed value $a/\sqrt{T}$ was calculated from tables of the normal distribution, and the values $a/\sqrt{T}$ was plotted against $1/\sqrt{T}$. This should be a straight line through the origin slope . Higher values indicate slower diffusion (emergence) rate. The suggestion is that if in a slower diffusion system many animals die the total numbers emerging should be treated as the total original numbers and the fraction at time T can be calculated in this way. Note that at time T final, total fraction = 1. The value ($^1/\sqrt{T}$ final, 0) is on the graph (Fig. 24).

6.2.3 Results and Discussion

The results indicate that the smaller the aggregate sizes the longer and more complicated is the pathway (Table 18). A high correlation was

TABLE 18: Length of pathway from point A to point B (see Fig. 15) formed between aggregates

Size of Aggregates (mm)					
1.0-2.0	2.0-4.0	4.0-6.7	6.7-9.5	9.5-12.00	>12 (mm)
Alternative numbers of Pathway					
8	9	7	7	6	5
Average length of Pathway (mm)					
81.6	77.2	63.0	52.6	54.2	50.5

found when plotting length of pathway and the numbers of animals emerging. It has been found that the longer the pathway the fewer the animals coming out and this could be explained by the theory above where (Fig.24) suggest that there is a high mortality or animals never find their way out in small aggregates. (The greater the slope the less the animals emerging at time T final).

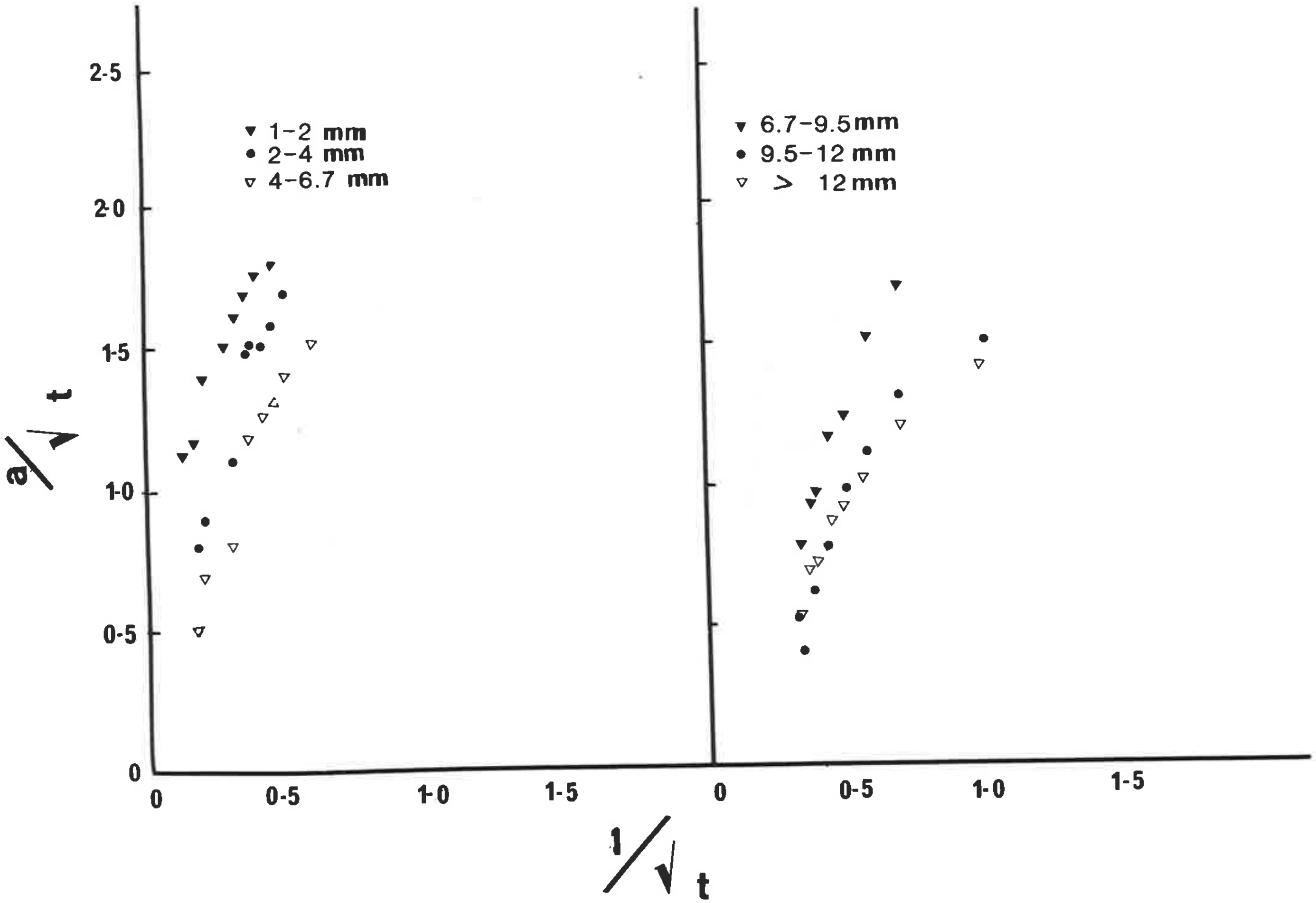


FIGURE 24. Rate of diffusion (emergence) of soil animals through different sized aggregate beds measured at one hour intervals

6.3 CONTRIBUTION OF SOIL ANIMALS TO DEGRADATION OF PLANT DEBRIS

6.3.1 Introduction

Soil animals play a leading role in the degradation and decomposition of plant debris. Thus their importance cannot be overemphasized.

A laboratory experiment was designed to examine the contribution to degradation of plant residue by some soil animals.

6.3.2 Experimental Method

Animals for this experiment were extracted from the soil as in Section 2.3.3 but instead of tubes containing alcohol they contained moist macro-organic matter (MOM). The MOM and the live animals were emptied in a Petrie dish where the Astigmata and Poduridae were separated from the rest of the animals and MOM.

Three treatments i.e. Astigmata, Poduridae and Control were replicated twice, each replicate containing 6 animals. Culture tubes, similar to those used by Vail (1965); Goto (1960) and Hutson (1978) were used but had only plaster of Paris as a base which was kept moist to maintain the required humidity for the experimental period. Leaves from common Lantana *"Verbenaceae"* were cut into pieces of approximately 4 cm^2. Since the leaves were several weeks old, collected from the soil surface, they were wetted and dried at 40^{o}C twice to kill immature animals and eggs. Eight pieces of leaves were put in each rearing tube.

6.3.3 Results and Discussion

The results (Table19a) show that the numbers of mites (Astigmata) and Collembola (Poduridae) increased when supplied with leaves from common Lantana.

In the same table, the area eaten shows that mites contributed more in terms of leaf degradation than Collembola (this is better shown in Plate 3). The difference in area eaten by these animals could be ascribed to their feeding and behavioural differences.

On examination of their movement and activities over the surface of the leaves, it appeared that the Astigmata fed in a group and moved very slowly. This could be supplemented by the uncorrelated relationship between area eaten by the animals and the distance travelled (Table 19b). On the other hand, Collembola were found to feed as individuals and moved faster.

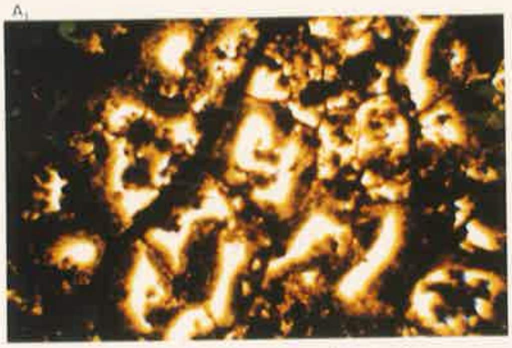
TABLE 19a: Increase in numbers of Astigmata (M) and Poduridae (C) for a period of 9 weeks feeding on common Lantana.

Treatment	Initial number	Final number	*Area of leaf eaten (cm²)
	6	131	1.90
	6	168	1.71
Astigmata (M)	6	129	2.10
	6	60	1.00
	6	165	1.70
Poduridae (C)	6	59	0.60
	6	148	1.00
	6	119	0.95
	0	0	0
	0	0	0
Control	0	0	0
	0	0	0

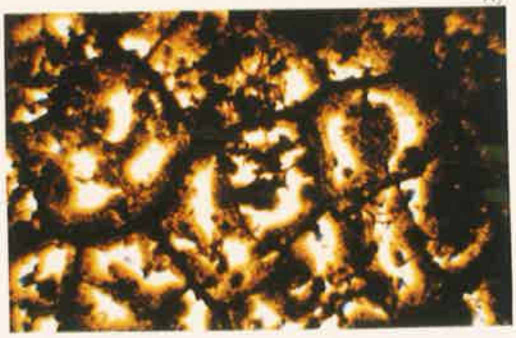
*Area eaten and measured included the unpalatable stalk and leaf veins.

Plate 3: APPEARANCE OF LEAF SECTIONS OF Verbenaceae FED TO SOIL ANIMALS, MAGNIFIED 35X. DARK AREAS REPRESENT LEAF VEINS AND INTACT PARTS OF THE LEAF, LIGHTER AREAS REPRESENT HOLES IN THE LEAF AND AREAS EATEN BY ANIMALS.

A_1

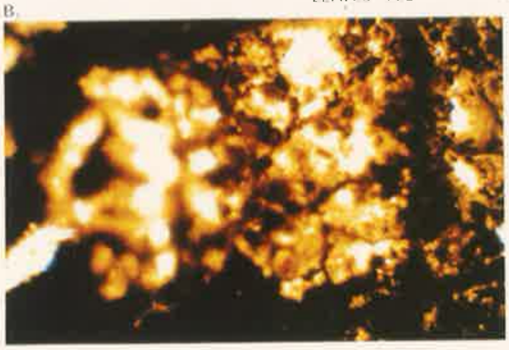


A_2

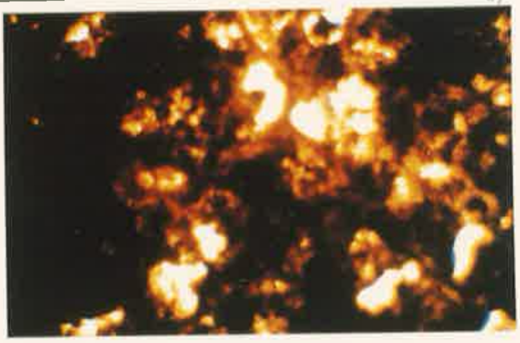


LEAVES FED TO MITES (Astigmata) (A_1 AND A_2 ARE REPLICATES)

B_1

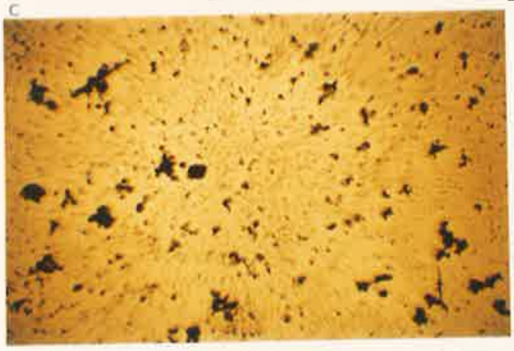


B_2



LEAVES FED TO COLLEMBOLA (Poduridae) (B_1 AND B_2 ARE REPLICATES)

C



PARTICLES NOT ASSIMILATED PLUS FAECES OF BOTH COLLEMBOLA AND MITES (A_1, A_2, B_1, B_2)

D

CONTROL - NO ANIMALS. (LIGHT PATCH REPRESENTS LEAF FRACTURE)

TABLE 19b: Correlation between distance travelled by soil animals during microscopic examination and the amount of leaf consumed during the culture period.

Animal group	Distance travelled (cm)	Area of leaf eaten (cm^2)	Significant level
Astigmata (M)	.5	1.9	N.S.
	.7	1.71	
	.5	2.10	
	1.5	1.0	
Poduridae (C)	2.0	1.7	**
	1.0	0.6	
	1.2	1.0	
	1.2	0.95	

** Significant at 1% level.

From these results it appears that, if the heat and light transmitted on to the animals by the microscope during examination did not cause the observed behavioural difference between the two groups of animals, then there is an indication that the mites (Astigmata) contributed more than the Collembola (Poduridae) in terms of plant residue degradation. Collembola, however, are known to play a leading role in distributing pores which are attached to their bodies and carried in their guts.

6.4 CONCLUSION

To arrive at a workable conclusion on the effects and interrelationship of soil environmental factors and soil fauna, the above factors (size of pores, temperature, water etc.) should be examined very closely in the long term.

Generally it can be concluded that the vertical and horizontal distribution of animals in soil (aggregate beds) will depend on pore size distribution as well as aggregate size distribution, but the overall need to migrate vertically or horizontally will depend on the availability and requirement of water and food. Where the beds are formed by very small aggregates, a lot of energy may be needed to move through complicated pathways, in which case many animals may not be able to meet their requirements and as a result may die. The given theory does not explain whether soil animals actually die or remain in the system. And if they die, it does not explain the factors contributing to their death.

CHAPTER 7

GENERAL DISCUSSION AND CONCLUSIONS

The literature survey and other information at hand show that agriculture is undergoing a revolutionary period, a period when scientists and farmers are working together to produce techniques of crop establishment which are feasible in a time when world population is increasing rapidly and fossil fuel and fertilizer are becoming very expensive. Unfortunately it is a time when soil structure is deteriorating. The structure of soil is very important in an agricultural ecosystem, especially in regions where rain usually falls in heavy showers and topography is hilly (e.g. Kenya).

Very heavy, shallow, or stony soils occur in large areas in the world. These soils are marginal for arable farming, and therefore methods must be developed for arable crop production under such conditions.

Plate 2 shows the two techniques studied in this project and the implements mainly used in CC operations in many parts of the world. The appearance of the soil surface shows a significant difference between each treatment and this indicates a difference in both physical properties of the soil and in the populations of soil fauna.

As shown in this thesis, research has been slow in establishing the relevant importance of soil animals in agricultural ecosystems. Thus little has been published to show the different effects of CC and DD on soil physical properties and on soil animals, especially the reaction of soil animals to DD operations *per se*. There is little work published on the positive contributions of animals in improving and maintaining soil conditions favourable for field crops, water drainage and retention. Based on the literature and the research of this project I have been able to evaluate and discuss the relative effect of CC and DD on the soil physical properties and soil fauna. In previous chapters statements are made case by case because of the complex relations that exist between soil physical properties and soil fauna.

7.1 DIRECT DRILLING

Many workers, most of whom are mentioned in Chapter 1, have shown that DD produces a better soil structure than CC, results in the accumulation of total soil OM and retainment of mulch on the soil surface thus preventing soil erosion by water or by wind. Direct drilling has also been reported to save money and time. But above all this technique has produced crop yields as good as, if not better than, CC.

The results presented in this thesis confirm the findings of many workers in that DD caused lower porosities than CC but produced stable and continuous pores. Direct drilled soils had higher water contents than CC soils which might have been influenced by higher infiltration rates and lower evaporation rates, due to a higher organic matter content on the soil surface.

Fewer occurrences of cereal diseases like take-all (hay-die), and *Rhizoctonia solani*, both of which are fungus diseases, have been reported in plots subjected to DD (Hood, 1965; Schwerdtle, 1971; Brooks and Dawson, 1968; and Ellington and Reeves, 1981). For example Ellington and Reeves (loc. cit.) reported a significant reduction of the occurrence of take-all in DD plots (Table 20).

TABLE 20: Wheat plants which lodged (% of total plants) as a result of Take-all fungus, after different crop rotations and cultivation or DD.

Rotations	% Occurrence	
WxWxWxW	31	15
LxWxLxW	11	4

W = Wheat; L = Lupins.

These reductions may be as a result of the presence of a large number of mites and Collembola (shown in this work to total about 95×10^{3} $^{-2}$ in DD plots during periods of maximum population. Many of these animals feed on decaying plant material and fungi.

This study failed to establish or detect sufficient evidence that DD is in any way directly deleterious to the soil. The main adverse effect is the toxicity to the soil animals of the herbicides used.

Therefore these results and the results of other research workers have shown that the technique is scientifically sound. The major barriers are: firstly, trying to fight the psycho-social problem of trying to introduce a technique which conflicts with the established attitude of the farmer in that a seedbed must be free from trash, thoroughly worked and level. Secondly, the lack of a developed commercial drill to drop seeds in the mineral soil through a layer of trash.

7.2 CONVENTIONAL CULTIVATION

It is evident that the most commonly used implements from earlier days were the Mouldboard plough, Disc plough and Tine cultivator. The rotary hoe was developed very recently for a specific purpose. All or some of these implements may be used in CC operations. The effects on soil, including soil biology, are dependent on the design, numbers of Tines used and on the soil type and surface condition. Also they may, to some extent, depend on the farmers skill because many are unaware of the correct time for operations and do not know the correct amount of cultivation required for a particular soil, area and crop.

The results of this work show that the overall effect of the CC technique is adverse in so far as the soil physical properties are concerned with a concommitant reduction in numbers and types of soil fauna. Prolonged cultivation in the South Australian fine sandy loam led to degradation of macrofeatures in the cultivated layer. A compacted layer developed below the cultivated layer as a result of several factors, particularly compaction by machinery and implements.

Detection of these changes, especially pore shape and continuity, was only possible by the method of thin sectioning and quantifying the pore size distribution using the image analysing computer (Quantimet 720). The infiltration rate of water and water storage capacity may be reduced and run-off increased. This is illustrated by the reduced water content in the Avon soil after CC compared with DD, and also by the run-off for Tarlee soil as illustrated in Plate 4. However, a single run on a field by an implement may not be very destructive.

7.3 EFFECT ON SOIL FAUNA

The effect of these techniques on soil physical properties i.e. soil structure, MOM and water was further related to the population numbers of soil animals and their distribution in the soil.

Plate 4. APPEARANCE OF SOIL SURFACE AFTER DIFFERENT METHODS OF TRASH DISPOSAL (A_1, B_1, C_1) AND THREE WEEKS LATER FOLLOWING RAINFALL (A_2, B_2, C_2).

A_1: TRASH RETAINED ON SURFACE

B_1: ROTARY HOED/ CULTIVATED

C_1: BURNED / CULTIVATED

A_2

B_2

C_2

The adverse change of soil structure (habital area, change of pore continuity) and the change of the MOM (quality and distribution) in soils after CC made the soil less favourable for soil animals. Thus low animal populations resulted. The toxicity of herbicides used in DD was the only deleterious effect recorded.

The build-up of the population of animals in CC plots may be stimulated by a crop rotation which does not include fallow but does include pasture. However, care must be taken where the excess trash remaining after pasture has to be disposed of before necessary following operations can take place, because different methods of disposal can result in different population numbers of soil animals. Some methods, such as incorporating the plant material into soil or competely burying it, may result in an increase in the rate of decomposition of organic matter resulting in not only lack of food for soil animals but also depletion of plant nutrients by leaching, evaporation and also fixation and uptake by growing plants. This may be more important in CC than in DD plots.

7.4 ACTIVITIES AND IMPORTANCE OF SOIL ANIMALS

The method used in this work for extraction of soil animals from soil cores clearly shows that animals do live and move in soil pores. The diameter of most mesofaunal animals is between 200-600 μm which is within the same range as that for most cereal plant roots with an exception of root hairs which may be tens of microns thick (Low, 1972; Russell, 1973). Therefore soils should contain a large proportion of pores of this size range or larger if both soil mesofauna and plant roots are to proliferate and if drainage is to be efficient.

Some information available on soil mesofauna indicates that these small animals do not burrow and thus they use the pre-existing pores and openings made by large soil animals and roots and other phenomena (Kononova, 1966). As indicated by the continuity of pores and their stable nature in Plate 1, this condition is more common in DD than in CC soils. It should be mentioned, however, that animal movement up and down the profile helps to maintain good porosity for both water, root elongation and air circulation.

As seen earlier in this thesis, the mesofauna contribute to plant debris degradation making it easier for micro-organism to complete decomposition. For example, samples of *Quercus* and *Fagus* leaf litter that were undamaged by animals showed no significant decrease in weight per unit area whilst in the soil for a period of 12 months (Edwards and Heath, 1963). The results of feeding trials in this study indicate clearly that soil animals are very dependent on soil OM as a source of energy. It has been shown that plant material would take a long time to decompose in the absence of soil fauna although leaf degradation rate differs with different soil animal groups.

Parker (1962), among others, observed that corn stalk applied to the surface of soil in Iowa in May lost 50% of the initial weight after 20 weeks. This was probably due to animals feeding on the corn stalk. This also agrees with the laboratory results of this work where both mites and Collembola fed on the most palatable parts of leaves leaving the stalk and veins. Apart from maintaining soil structure and helping decomposition processes some soil animals may help control plant diseases. Their presence in agricultural land is, therefore, an indication of soil of good structure and high OM.

In conclusion, the groups of soil mesofauna examined here may be as important as, if not better than, earthworms and termites to agricultural soil. Their breeding activities and numerical abundance are dependent on the factors discussed in previous chapters, i.e. habital areas, food, water and temperature. Therefore it should be pointed out that the deleterious effects of CC on soil physical properties and the resultant effects on soil fauna are greater than those of DD. Thus DD should be recommended as a workable technique in crop production.

Finally, interpretation of the results given in this thesis is complex and difficult. Firstly, because there is no published work with which to compare these results. Secondly, because of the many variables which make it difficult, if not impossible, to generalise.

7.5 PROPOSAL

1. Take-all causes as much as A$30-100 mill. loss per year, depending upon season in Australia (Rovira, 1979). Therefore, if indeed soil mites and Collembola which feed on decaying OM and fungi can be used for biological control of this disease, a substantial saving would result.
2. The use of DD technique can improve poor soil structure and low soil organic matter levels.
3. The invention of a proper drill for all operations would save money in terms of time, labour, implements and crop yield.
4. If the DD system has to succeed CC, a good start would be to engineer a herbicide which would kill the unwanted plant material, but does not significantly affect soil fauna.

APPENDIX A_1:

Active chemical ingredients of the herbicides used in this work:

(i) BUCTRIL - Selective herbicides for broad leafed weeds and plants. its active constituent are 200g/l Bromoxynil present as the n-Octanoyl est (Solvent : 255g/l Hydrocarbon solvent).

(ii) HOEGRASS - for post emergence control of annual ryegrass and wild oats in wheat, linseed, peas and other crops. Its active constituents are 375g/l/2-[4-(2',4' dichlorophenoxy)-phenoxy] methyl proprionate. (Solvent : 389g/l xylene).

APPENDIX A_2:

Aggregate size distribution as determined by QTM 720 and total particle/aggr. as calculated from bulk density:

Treat-ment	Depth of soil cm	QTM 720 Results >40μm		Calculated from Bulk Density	
		*%Porosity	%Aggregate	*%Total porosity	%Total particle/rogates
D.D.	0-4	43.1	15.6	47.58	52.42
	4-8	41.0	23.4	49.00	51.00
C.C.	0-4	51.0	27.0	56.17	43.83
	4-8	26.0	34.1	50.75	49.25

*This appears in Fig.7 in the text.

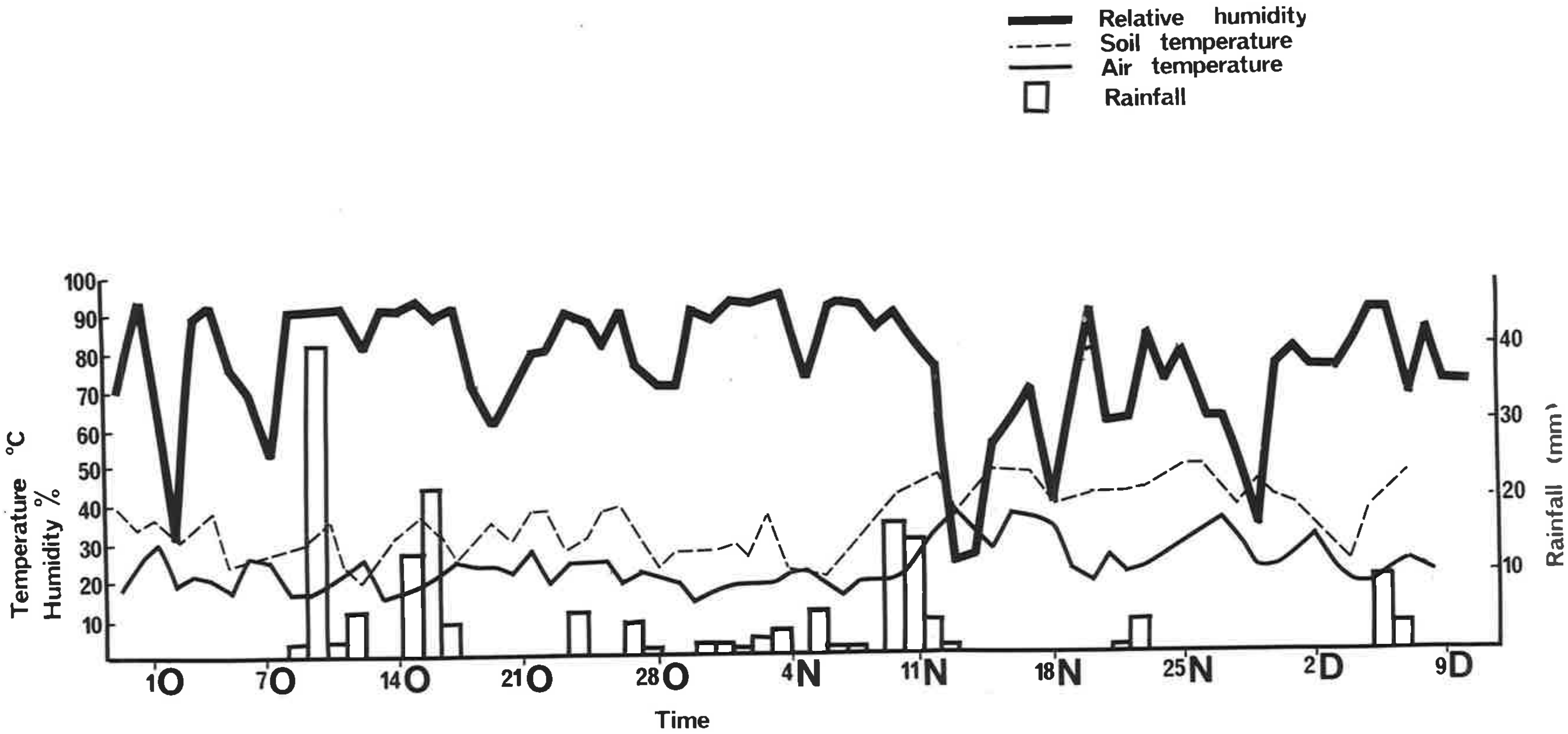


FIGURE 26 Daily maximum temperature, humidity and rainfall during the period Oct. — Dec. 1981 at the Waite Institute

APPENDIX B1: The estimates of soil animal density as shown in Figures 25a, b; obtained from three sites in the Mount Lofty Ranges of South Australia (with permission from B.R. Hutson, C.S.I.R.O. Div. Soils, Adelaide).

(i) South Para Reservoir Reserve ("Dry" site is at an elevation of 220-240m above sea level, 37km northeast of Adelaide, and 4km west of Williamstown Post Office (grid reference 184715 Adelaide 1:256,000 Sheet S1 54-9 Edition 1, Series R502).

(ii) Hale Conservation Park ("Medium" rainfall site) is at an elevation of 320-360m above sea level, 39km northeast of Adelaide and 2km southeast of Williamstown Post Office (grid reference 190715 Adelaide 1:250,000 Sheet S1 5409 Edition 1, Series R502).

(iii) Engelbrook National Trust Reserve ("Wet" site) is at an elevation of 320-380 m above sea level, 25 km southeast of Adelaide, and 1.2 km southeast of Bridgewater Post Office (grid reference 177673 Barker 1:250 000 sheet S1 54-13 Edition 1 Series R502).

The three sites are classified as acid yellow duplex soils (Northcote, 1971). The top 10 cm of all the three sites consist of a loamy sand or sand loam with a weak, fine granular structure.

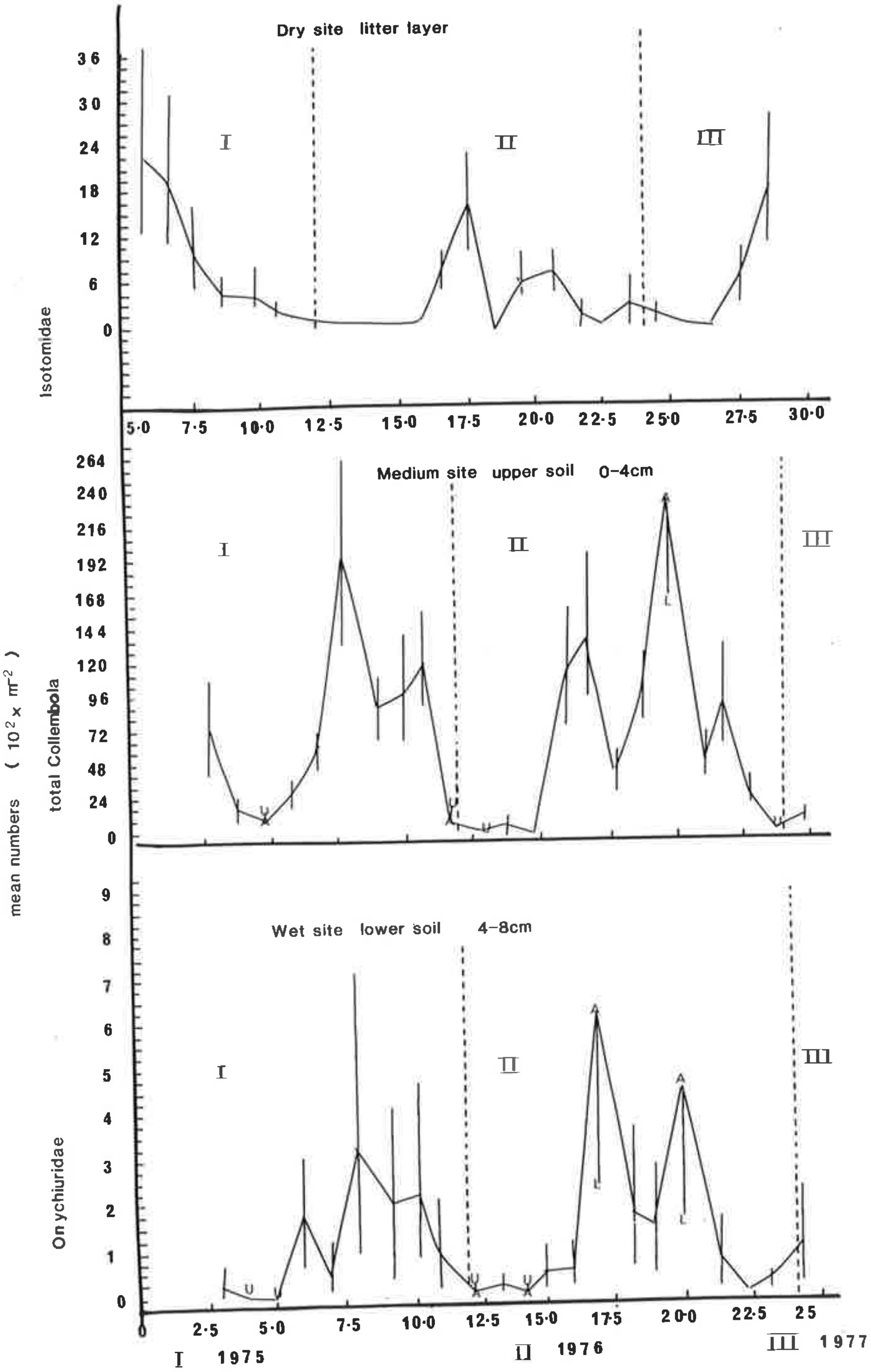


FIGURE 26. Examples of mean (± 95% confidence limits) population density estimates of Collembola and Acari from samples taken at three levels from three forest sites in South Australia over a two year period (statistical analyses based on cube-root transformation) (Hutson, B.R. unpublished data.

A

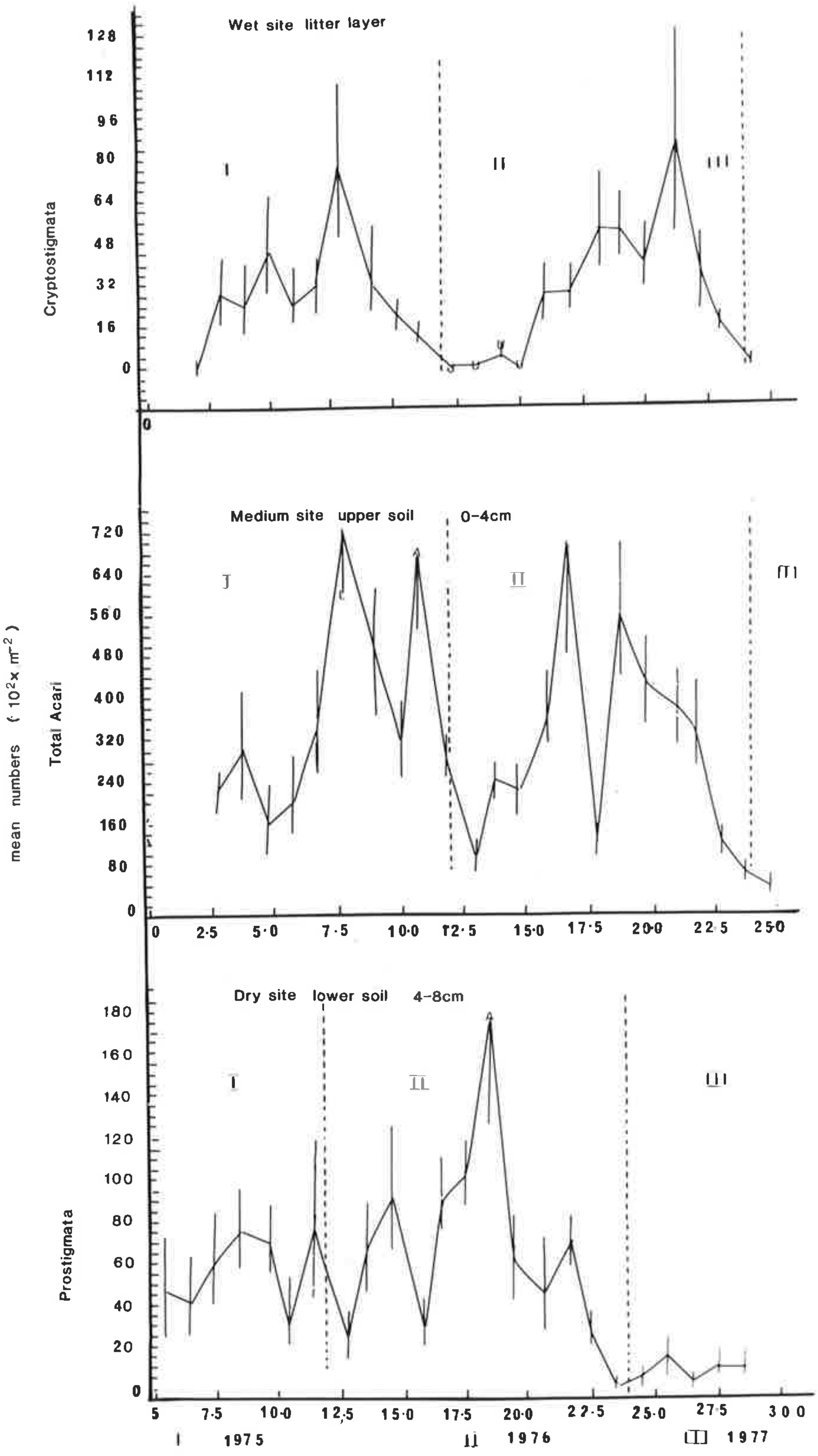

Wet site litter layer
Cryptostigmata
Medium site upper soil 0-4cm
Total Acari
mean numbers (10^2x m^{-2})
Dry site lower soil 4-8cm
Prostigmata
1975
1976
1977

FIGURE 26

(B)

APPENDIX B2: A preliminary result of the soil fauna of crop lands in South Australia. Samples of soil animal populations were taken from experimental plots where studies were in progress on the effects of pesticides on wheat production (with the courtesy of John C. Buckerfield, CSIRO Div. of Soils, South Australia. Technical Memorandum 16/78).

Treatment	Control		Headland		Control				Low aldicarb				High aldicarb			
Soil animal groups \ Depth of core (cm)	0-4	4-8	0-4	4-8	0-4		4-8		0-4		4-8		0-4		4-8	
No. of cores	4 *	4 *	4 **	4 **	8 Row	8 Inter-row	8 Row	8 Inter-row	4 Row	4 Inter-row	4 Row	4 Inter-row	8 Row	8 Inter-row	8 Row	8 Inter-row
ACARI																
Prostigmata	8	20	23	31	45	26	20	25	17	6	10	5	7	25	9	10
Mesostigmata		1			24	35	6	3	16	10	3		15	26		1
Cryptostigmata	2	2		1	12	9	8	6	4	2	1		9	3		1
Astigmata	19	3	2		376	356	113	32	72	9	8	3	104	222	6	12
COLLEMBOLA																
Poduroidae	1			1	76	53	7	8	19	9	3		20	29	3	2
Onychiuridae	1	1			1	6	3						1	2	3	2
Isotomidae				1	23	20	4	6	7	3	7		16	18		1
PSOCOPTERA					2											
HYMENOPTERA																
Formicidae		1		1	1											+
DIPTERA													1			
LEPIDOPTERA					2	2				1			1	1		
COLEOPTERA			1													
Carabidae													1			
Staphylinidae				1	2							1				
other larvae	1				2											
NEMATODA								3								
Total animals	32	28	26	36	566	507	161	83	135	40	32	9	185	326	21	29
Mean(±S.E.)animals/core	8.0±3.3	7.0±2.9	6.5±3.3	9.0±4.7	70.8±10.3	63.4±14.8	20.1±6.2	10.4±2.9	33.8±11.3	10.0±3.4	8.0±3.6	2.3±0.8	23.1±5.0	40.8±14.2	2.6±0.7	3.6±1.4

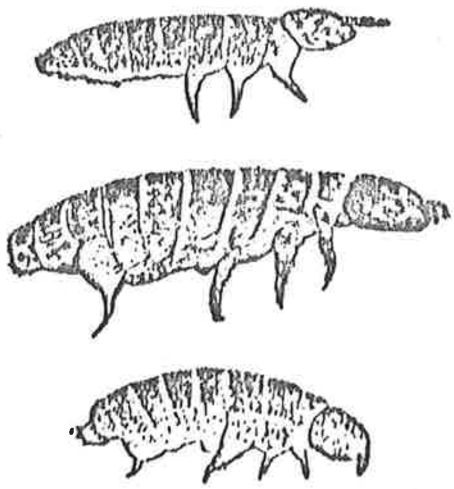
* plot prepared for seeding - not treated with pesticide } - samples collected at seeding time
** undisturbed pasture headland adjacent to above

APPENDIX C1: Simple identification key to Collembola families (Adapted from Gisin 1960 - Adults only).

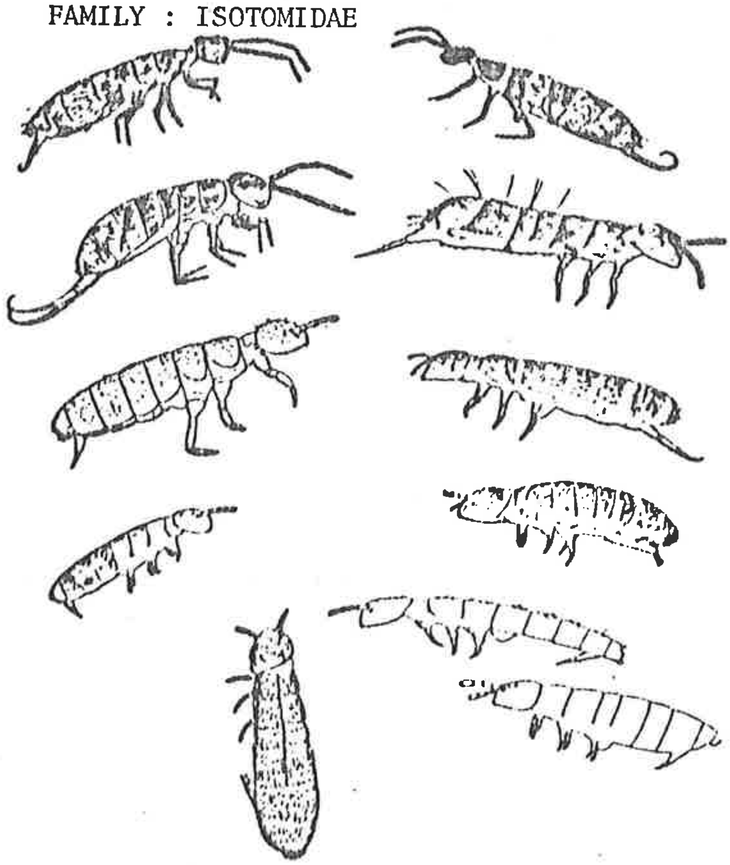
- (body elongate, (segmented, thorax (& abdomen clearly (separate, thorax (3 segments, (abodemn 6 (segments
  - (prothorax (well devel (oped and (with small (setae. 1st (pair of (legs inser (ted ventra (lly on (prothorax
    - (dark ocelli patch (pigmented body, (jumping organ (usually present, (no pseudo-ocelli —— (Neanuridae ((part) (Hypogastruridae
    - (blind, (white, no (jumping (organ, (pseudo- (ocelli (present (or (absent
      - (pseudo-ocelli (present, abd. VI (undivided, ant. (III with large (sense rods —— Onychiuridae
      - (no pseudo- (ocelli, abd. (VI bilobed, (ant. III (with small (sense rods —— Neanuridae (part)
  - (prothorax (reduced & (without (setae. 1st (pair legs (inserted (ventrally (on neck
    - (furca often (reduced, abd. IV (& III approx. (the same length, (body without (scales or clubbed (setae —— Isotomidae
    - (furca well deve- (loped, abd. IV (nearly always (longer than abd. (III, body scaled (or with thick (clubbed setae. —— Entomobryidae
- (body subglobose, (segmentation (obscure, thorax (& abdomen fused —— Sminthuridae

APPENDIX C2: Examples of soil Collembola found in South Australia
(a) (Refer Womersley, 1939).

FAMILY : PODURIDAE*



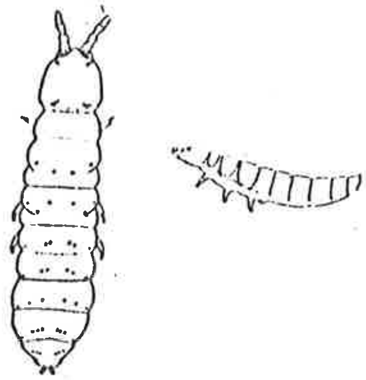
FAMILY : ISOTOMIDAE



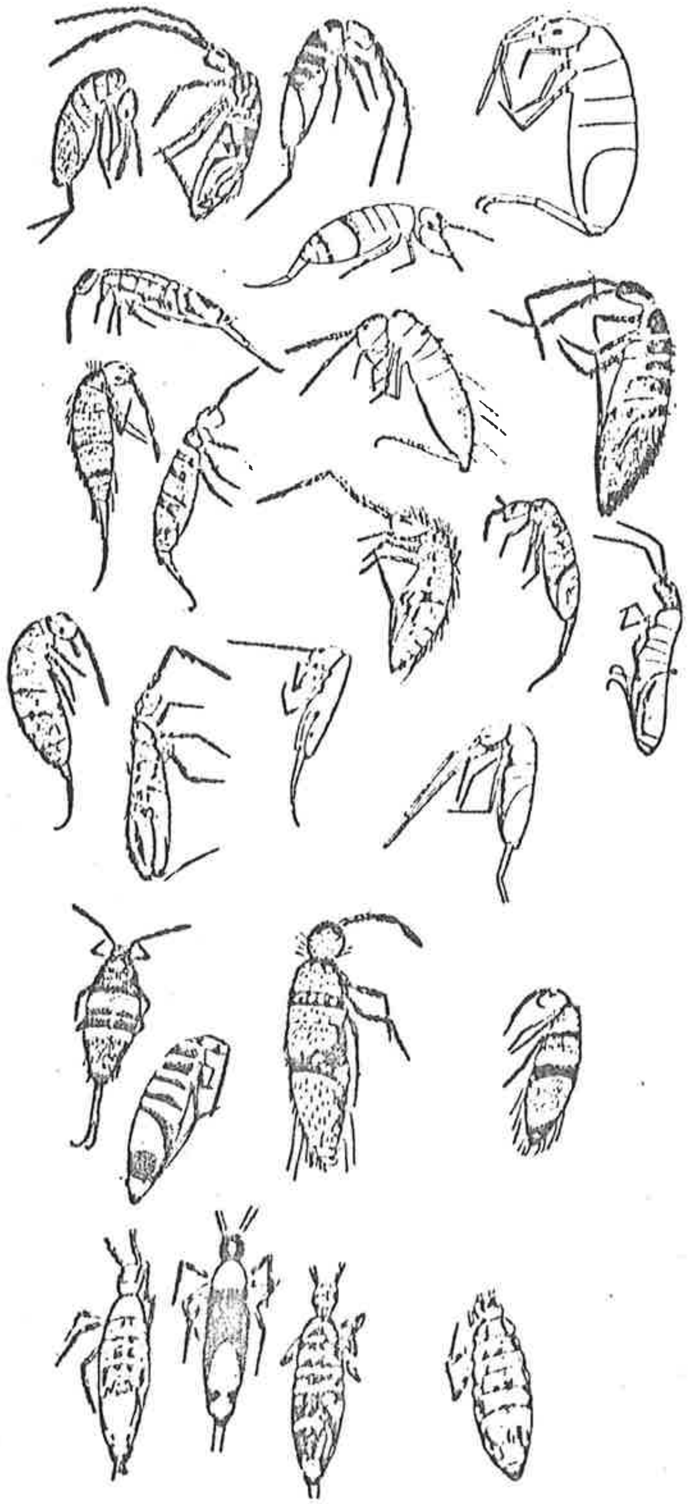
*Classified as Poduridae, Hypogasturidae and
Neanuridae according to (e.g.) Massoud, 1976.

APPENDIX C2(b):

FAMILY : ONYCHIURIDAE

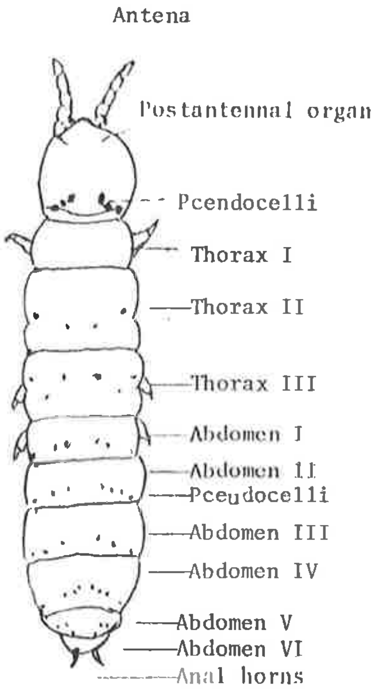


FAMILY : ENTOMOBRYIDAE



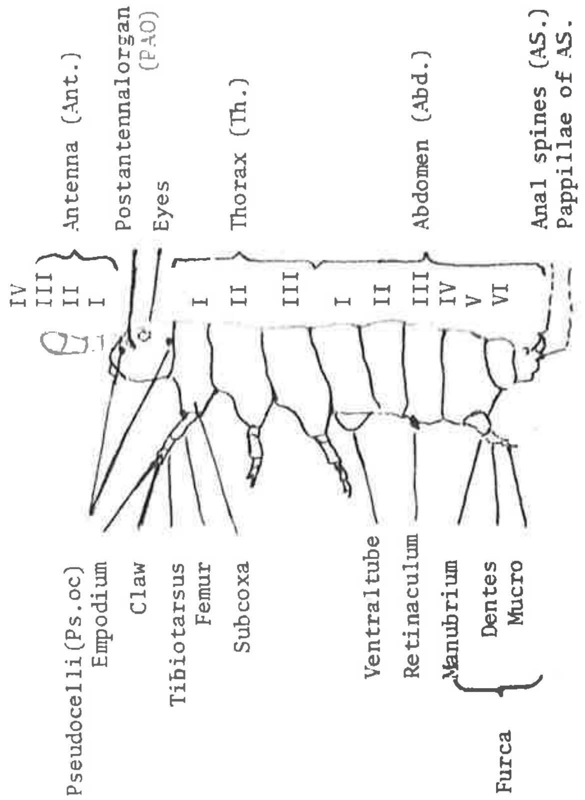
APPENDIX C3: General morphology showing important identification parts of body (a) After Womersley, 1939. (b) After Hutson, 1974).

(a)



(After Womersley, 1939).

(b)



(After Hutson, 1974).

APPENDIX C3: Simple identification of lower taxa of Collembola (P. Greenslade, South Australian Museum).

Cryptopygus thermophilus

grey, 8+8 ocelli, body straight, abdomen V & VI fused.

Isotoma sp. cf *notabilis*

white, slight grey pigment, 4+4 ocelli on square deck pigment patch, body dorsally curved slightly, abdomen V & VI separate.

Brachystomella sp. 1 cf *parvula*

small, plump, pink, rounded tip to abdomen, no clavate tenent hairs to claw.

Brachystomella sp. 2 nr *parvula*

slightly, larger plump, dark reddish or grey speckles on slightly paler background, rounded tip to abdomen, 3 clavate tenent hairs to claw.

Hypogastrura sp. cf *manubrialis*

slender, elongate, dark greyish black, pointed tip to abdomen.

H. (Ceratophysella) sp. cf *gibbosa*

pinkish or greyish speckles on white, body often arched convexly, i.e. tip of abdomen elongate with long curved spines, long setae clearly visible on body.

Onychiurus

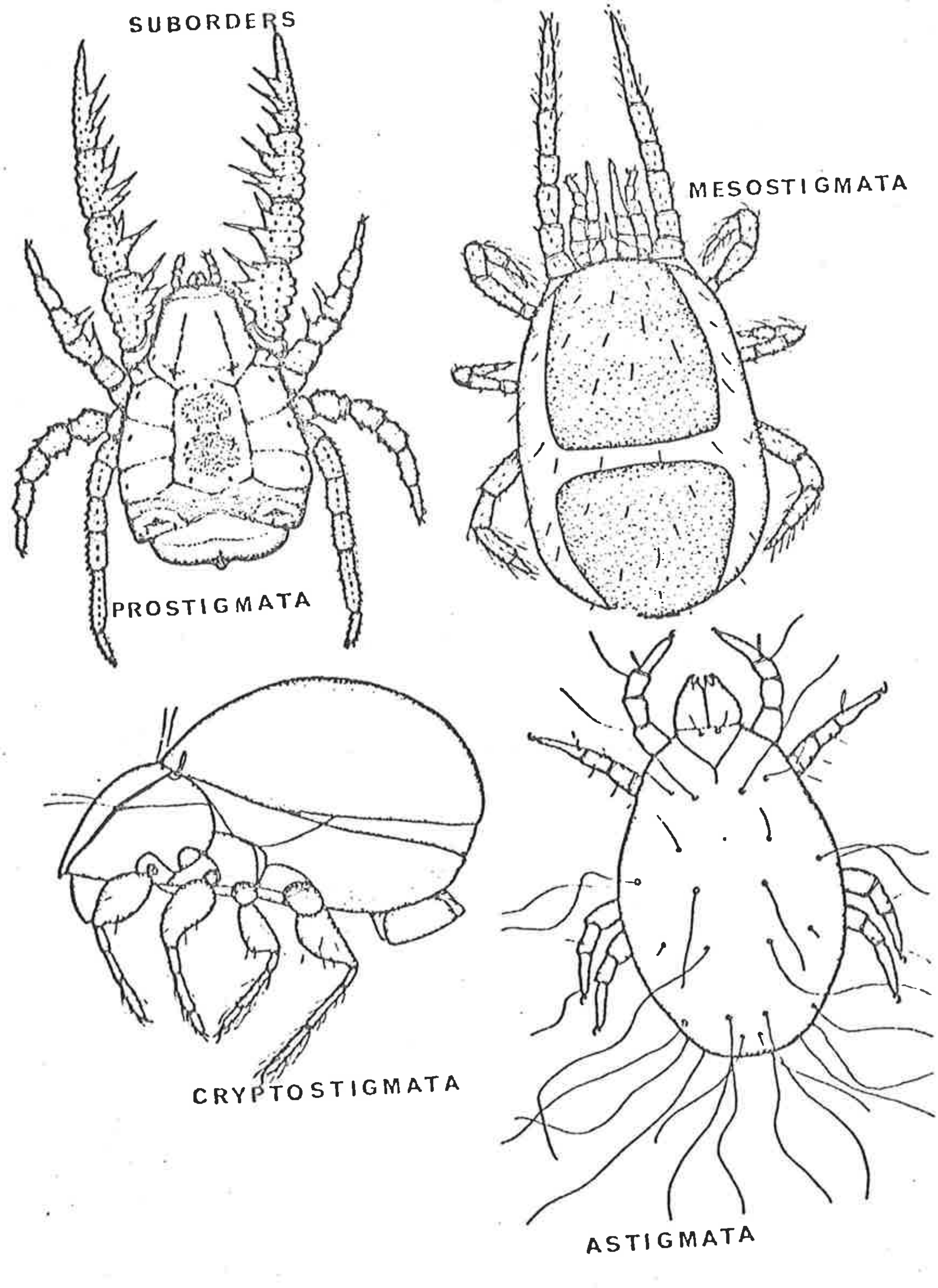
elongate blind white, no jumping organ, tip of abdomen pointed with 2 large hooks.

APPENDIX C4: Identified (to lower taxa) Collembola sampled in May, June, July 1981 at Urrbrae (Refer Exp. 2 Waite Institute) (Identified by P. Greenslade).

		0-4cm Core number	
	1	2	3
Isotomidae			
Cryptopygus thermophilus Axel. Ad.	2	24	31
im.			35
Isotoma sp. cf *notabilis*		1	
Neanuridae			
Brachystomella sp. 1 cf *parvula*			5
Brachystomella sp. 2 nr *parvula*	1	2ad;5im.	
Hypogastruridae			
Hypogastrura manubrialis	2ad.	6	8
H.(Ceratophysella) gibbosa	2	1	2
imm. indet Poduromorph	4	13	50
Onychiuridae			
Onychiurus sp. *armata* group	1	3	
Total	12/5	55/6	131/5

Total sp. 7

APPENDIX D1: Example of suborders of mites (Acari) found in South Autralian cereal growing soil.



APPENDIX D2: Identified (to lower taxa) mites samples in May-June-July 1981 at Urrbrae (Refer 2nd Experiment, Waite Institute). Identified by D. Lee of South Australian Museum.

MESOSTIGMATA

UROPODINA - Fungus-feeders

Uropodidae ? genus 1 deutonymph

The deutonymphal stage often phoretic on insects.

GAMASINA - Predators on small invertebrates (rarely pollen feeders, some families include parasites on vertebrates).

Phytoseiidae *Amblyseius* 1♀

Laelapidae *Ololaelaps* 1♀

PROSTIGMATA

Penthaleidae ? genus 19 larvae

Probably belong to the important pest species *Halotydeus destructor* (Red-legged earth mite)

?Pseudocheylidae ? genus 5 nymphs

Regarded as predators, usually occurring under tree bark.

Stigmaeidae ? genus 1 nymph

Predators.

Bdellidae ? genus 1 larva

Predators.

Tetranychidae ? genus 1 nymph

Plant parasites.

Both following Orders are unusual amongst Arachnids in that they ingest solid food:

ASTIGMATA

Acaridae *Tyrophagus similis* 1♀, 2 deutonymphs

3♀♀ ; 3♀♀, 2 deutonymphs ; 2♀♀

Feed on fungus and plant detritus.

CRYPTOSTIGMATA

Oribatulidae *Zygoribatula* sp. 1♀ ; 13♀♀ ; 7♀♀ ; 2♀♀ . Feed on fungus and plant detritus.

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