Chapter 12

EFFECTS OF CULTIVATION AND PESTICIDE USE ON SOIL BIOLOGY

L.A. Douglas

While most Australian studies have concentrated on the effect of tillage techniques and pesticide applications in achieving yield increases, few data have been obtained for the effects of these management tools on the soil biology. This is regrettable, as the few results available indicate that the soil biology is an important contributor to soil fertility.

In this chapter, a review of data obtained in Australia for the effects of tillage and pesticide use on soil biology is given. The first section considers tillage results, while the second section deals with pesticide studies.

TILLAGE EFFECTS

Earthworms

Most species of earthworm (soil-living Oligochaeta) found in Australia have been introduced from other countries, although Barley (1959) and Abbott and Parker (1980a) reported the existence of previously undescribed members of the family Megascoleidae in South Australia and Western Australia, respectively.

From their results (Table 12.1), Abbott and Parker (1980a) concluded that in Western Australia, clearing of the native vegetation in the 350-500 mm annual-rainfall belt, followed by cultivation and the planting of clovers and grasses that were regularly fertilised, made the soil environment more suitable for earthworms. The most widespread species were *Allolobophora trapezoides* and *Microscolex dubius*. These species, and others, had been introduced in the period 1829-1905 (Michaelsen, 1907).

Table 12.1 Presence/absence of earthworms in sites sampled in the Western Australian wheatbelt, August 1979 (Abbott and Parker, 1980a)

Site	Number of sites	
	Earthworms present	Earthworms absent
Pasture	29	25
Cultivated	6	28
Virgin	3	10

Increases in earthworm numbers, which occurred with clearing and the introduction of vigorous pasture plants, were attributed to increases in food supply which accompanied these activities. In contrast, tillage did not encourage the proliferation of earthworms, presumably due to the low availability of organic food supplies in cultivated soil (Clarke and Russell, 1977).

Similar observations (Figure 12.1) were made by Barley (1959) at a site near Adelaide where the climate is a Mediterranean type, with an annual rainfall of 627 mm. The principal species found at this site were *Eisenia rosea* and *Allolobophora caliginosa.* Biennial cultivations were found to keep numbers and weights of worms low, while cultivation of a pasture, comprising phalaris, annual ryegrass and subterranean clover, dramatically reduced worm populations. Worm numbers and weights in permanent pasture were maintained at high levels. The decline in worm numbers with cultivation of the pasture was attributed to the decrease in the food supply that resulted from ploughing in the ley.

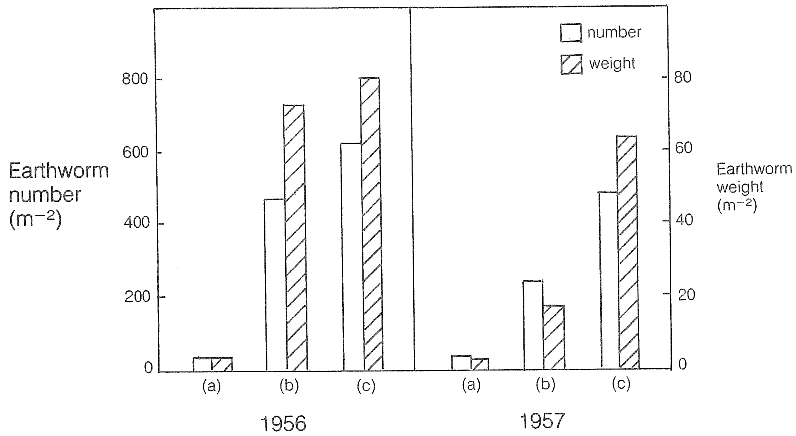

Figure 12.1 The effect of rotations on the weight and number of earthworms present (Barley, 1959):
(a) 2-year rotation; pasture 1956, wheat 1957
(b) 4-year rotation; pasture 1954, 1955, fallow 1956, wheat 1957
(c) permanent pasture (phalaris, annual ryegrass, subterranean clover)

The higher content of soil organic matter associated with conservation farming practices (Chapters 6 and 11) is likely to increase earthworm populations and contribute to improved soil structure (Chapter 6). This has not been confirmed by research.

Arthropods

Many representatives of the phylum Arthropoda live in soil. Microscopic animals such as mites and springtails live in pore spaces and in cavities made by larger animals. They are too small to influence the physical properties of soils and are not considered here.

Macroscopic animals such as termites, ants and beetles burrow through the topsoil, creating pores that may allow the soil's infiltration capacity to increase. Thus they may have similar beneficial effects on soil properties as do earthworms, and be of particular importance when these Oligochaetes are absent (Abbott *et al.*, 1979; Lee, 1983).

In their study of the animals present in three Western Australian soils, Abbott and Parker (1980b) found that the main taxonomic groups represented were Acarina (mites), Collembola (springtails), Protura, Pauropoda, Isoptera (termites), Hymenoptera (ants), Coleoptera (beetles - adults, larvae), Diptera (maggots), Chilopoda (centipedes), Aranae (spiders), Isopoda and Thysanoptera (thrips). Large (> 2 mm length) soil animals (mainly termites, ants and beetles) were more prevalent in virgin soils, or those not ploughed and stocked for at least 7 years, than in adjacent cultivated soils (Table 12.2).

Table 12.2 Numbers of large animals and infiltration-rate data for three Western Australian soils (Abbott *et al.*, 1979)

Soil	Season	Animal numbers per core	Water infiltration rate ($s\ cm^{-1}$)
1 V	W	192	70
1 C	W	6	109
1 V	S	10	27
1 C	S	10	101
2 V	W	32	22
2 C	W	2	98
2 V	S	8	26
2 C	S	3	124
3 V	W	17	53
3 C	W	–	150
3 V	S	9	32
3 C	S	–	102

1 = non-calcic brown 2 = solodised solonetz 3 = lithosol
V = virgin C = cultivated
W = winter S = summer

It was also noted that resistance to a penetrometer (an index of soil compaction) was lower and infiltration faster in the virgin than in the cultivated soils (Table 12.2). Measurements of the area of voids in soils 1 and 2 paralleled the infiltration results. These data led the authors to conclude that the activity of large soil animals reduced compaction and increased infiltration rate. Conversely, disturbance of the soils by cultivation and stocking reduced infiltration rates and increased compaction. The success of reduced tillage techniques in some areas could therefore be due at least in part to the activities of large (> 2 mm) soil animals (Lee, 1983).

Nematodes

Of the many nematode species in soils, the most important in Australia is the cereal cyst nematode (*Heterodera avenae*). This soil animal causes serious losses in wheat production in southern Australia by infesting the roots of plants and using the plant nutrients for its own metabolic purposes (Rovira and Ridge, 1983).

Recently, a number of control measures involving reduced cultivation and the use of nematicides have been shown to reduce the effects of this pest. Responses to these practices are summarised in Table 12.3 and reviewed fully in Chapter 14.

Microorganisms

Bacteria, fungi, actinomycetes, algae, protozoa and viruses are found in the soil. The most numerically abundant of these are the bacteria, though fungi usually account for the largest

Table 12.3 Effect of tillage and Aldicarb applications on nematode damage to roots and wheat yields (Rovira, 1981)

Tillage	Aldicarb[a] (2 kg ha^{-1})	Root[b] damage	Wheat[c] yield (t ha^{-1})
Conventional	–	4.6	0.81
Direct drill	–	3.2	1.40
Conventional	+	1.0	1.92
Direct drill	+	0.8	2.04

[a] Application rate was 2 kg active ingredient ha^{-1}
[b] Root damage by nematodes was estimated on a scale of 0–5
[c] Wheat had been fertilised with 40 kg N ha^{-1}

mass of the total microbial protoplasm (Alexander, 1977). Soil microorganisms play a major role in nutrient cycling and may also form a significant reservoir of nutrients in the soil (Paul and Voroney, 1980). Table 12.4 from Waid (1984) shows the activities of soil organisms that may affect plant productivity. Many of these activities are involved with nutrient cycling through the soil and are common to all microbial environments. Others such as degradation of xenobiotics are unique to man's activities and may have direct bearing on agricultural practice (see also Chapter 13). For example, it is possible that prolonged use of persistent herbicides may select a soil population able to degrade them quickly, so reducing the persistent nature of these chemicals. All these activities are dependent directly or indirectly on carbon inputs from plants and are sensitive to changes in environmental conditions. Tillage practices have an influence both on the carbon inputs into the soil and on the environmental conditions in the soil and so would be expected to affect both the numbers and the population structure of soil microorganisms. This section deals with the effects of tillage on non-pathogenic soil microorganisms. Pathogens are dealt with in Chapter 14.

Table 12.4 Soil biological processes affecting plant productivity (modified from Waid, 1984)

- Formation of soil biomass
- Heterotrophic activities of soil microorganisms
- Decomposition of soil organic matter (plant, animal, microorganisms)
- Combined activities of soil populations to produce or degrade compounds
- Production and release of enzymes into the soil
- Mineralisation of organic compounds containing N, S, P and release of CO_2
- Nitrification
- Denitrification
- Ammonification
- Nitrogen fixation by free-living organisms
- Oxidation of inorganic sulphur compounds
- Formation of reduced inorganic and organic compounds
- Activities of rhizosphere organisms influencing root growth and permeability
- Decomposition of xenobiotics (e.g. herbicides and pesticides)
- Soil-borne plant pathogens
- Symbiotic organisms

Unfortunately, little work has been done in Australia on the influence of tillage practices on soil microorganisms. Smith (1978) investigated the effect of tillage on the spores of vesicular-arbuscular endophytes in a Western Australian soil. He observed that tillage had no effect on total spore numbers, but soil that had been direct drilled had more spores in the surface 80 mm and fewer in the 80-150 mm layer than the conventionally tilled plots. This difference in distribution of spores was thought to be the consequence of the mechanical inversion of soil, which was caused by cultivation. Ferris, Holland and Felton (personal communication) measured the microbial biomass of a soil under mechanical cultivation, hand weeding and herbicide treatments. Although the variation between samples was high the biomass in the top 2 cm of soil was up to 48% lower in the mechanically cultivated soil. Roper (1984) observed that asymbiotic nitrogenase activity increased significantly in soils that contained straw residues compared with controls lacking the residues. The increases varied considerably depending on soil type but it was concluded that straw may form a suitable energy source for free-living nitrogen-fixing bacteria to contribute significantly to the nitrogen status of soils.

There is also a paucity of work done overseas on the influence of tillage on soil microorganisms. The microbial biomass of soil under direct drilled conditions was significantly greater than soil under conventional cultivation (Lynch and Panting, 1980). Lynch (1984) reviewed the interaction of biological processes and cultivation. He concluded that changes in tillage practice, particularly those related to the retention of straw, may have both detrimental and beneficial effects on plant growth. Detrimental effects included the production of phytotoxic substances by pseudomonads (Wallace and Elliot, 1979; Elliot and Lynch, 1984) and possible increases in denitrification. Both of these effects occurred under wet soil conditions where the availability of a carbon source stimulated microbial activity. However, the role of pseudomonads in plant yields is contradictory as it has been reported (for example, see Wong and Baker, 1984) that they may be a significant factor in the control of take-all (*Gaeumannomyces graminis*) of wheat. Reduced tillage systems may favour these organisms such that under some conditions the advantage of biological control of take-all may outweigh any risk of production of phytotoxic compounds. Beneficial effects of minimum tillage on soil microorganisms suggested by Lynch (1984) include an increase in nitrogen fixation by free-living nitrogen fixing organisms, such as reported by Roper (1984).

Soil enzymes are thought to be derived mainly from microorganisms and are important in many soil biochemical reactions (Burns, 1978). In experiments in the Mallee region of Victoria, W. Roberts (personal communication) found in the short term that urease, phosphatase and sulphatase activities were not affected greatly by tillage. In the long term, however, as tillage results in a significant decrease in the content of organic matter in the soil, it is expected that the enzyme activity will decrease due to the reported correlation between these two properties (Zantua and Bremner, 1976; Klein and Koths, 1980). Dick (1984) reported on the effects of long-term no-tillage practices on soil enzymes in trials in Ohio. Significantly higher levels of a range of enzyme activities were found in the top 7.5 cm of the soil. The increased levels seemed to be related to the higher levels of organic matter in the no-tillage treatments. Klein and Koths (1980) suggested that increased enzyme levels may result in higher residual nutrient concentrations and increased fertiliser use in minimum tillage crops. However, this must be balanced against the possible undesirable effects of increased loss of nitrogen through ammonification and denitrification and the faster degradation of persistent pesticides (Dick, 1984).

Caution should be used in extrapolating from the overseas studies to Australian conditions as soil and environmental conditions are likely to be different. In addition, the lack of data makes it impossible to generalise. Perhaps the only conclusion that can be drawn is that reduced tillage systems result in higher concentrations of organic matter in the top layer of the soil, leading to an increase in microbial numbers and activities. With the limited knowledge available it is not possible to decide if these increases are likely to be beneficial or detrimental to short- or long-term agricultural productivity.

PESTICIDE EFFECTS

When chemicals are applied to plants or soils in order to achieve the control of specific pests or diseases, it is inevitable that some (up to 50%) of the compounds will contact non-target organisms in the soil. Anderson (1978) reviewed the effects of pesticides on non-target organisms. Table 12.5 has been extracted from his review. It lists the effect-ratios of herbicides on microbial processes in soil (see also Chapter 13). The effect-ratio has been defined by forming a ratio of all studies that show stimulations or no effects over studies that show inhibitory effects. These ratios give a crude measure of the possible effect of a herbicide on a microbial activity. It can be seen from the table that processes such as denitrification tend to be stimulated by herbicides while other processes, such as the growth of pathogens and their antagonists, are inhibited. Some of the processes stimulated are likely to be of benefit to agriculture (for example 'free-living' N_2 fixation) but other processes (such as denitrification) may lead to decreases in plant productivity. In this section, a discussion of the few Australian results for the effect of pesticides on non-target soil organisms is given.

Table 12.5 Effect ratios[a] of herbicides on microbial processes in soil (modified from Anderson, 1978)

Parameter	Effect ratio
Bacterial numbers	1.20
Nitrification	1.40
Denitrification	1.82
Rhizobium and legume nodulation	0.94
'Free-living' nitrogen fixation	1.65
Fungi and actinomycetes	1.09
Pathogens and antagonists	0.81
Algae	0.45
Cellulytic activity and organic matter degradation	1.31
Respiratory activity	0.91
Other enzyme activity	1.70
Ammonification	1.74

[a] The effect ratio is calculated by forming a ratio of all studies that show an increase or no effect on the nominated activity over those studies that show a decrease.

Nitrification bacteria

Nitrification is reported to be one of the most sensitive conversions in soil, as the rate of ammonium oxidation is often decreased at concentrations of pesticides that do not affect other soil processes (Alexander, 1977). Concentrations of herbicides in soil that were found to inhibit nitrification in three Victorian soils are given in Table 12.6. These data show that none of the herbicides tested affected nitrification when applied at rates approaching those used in the field (< 10 ppm, soil basis).

Table 12.6 Herbicide concentrations needed to inhibit nitrification in a solonised brown soil (Fraser and Douglas, 1981)

Herbicide	Concentration causing inhibition ($\mu g\ g^{-1}$ soil)
dicamba	> 1000
Vorax AA	100
2, 4-D	1000
2, 4, 5-T	100
Hoegrass	1000
trifluralin	100
paraquat	> 1000
diquat	> 1000

N-fixation bacteria

Symbiotic Legume-based pastures are an important part of Australian farming systems, and it is vital that none of the pesticides being applied in the field to soils or plants affects the legume-*Rhizobium* symbiosis. Data shown in Table 12.7, obtained recently by Eberbach (unpublished data) and Eberbach and Douglas (1983) show that of the herbicides tested only residues of amitrole, atrazine and glyphosate had significant effects on nitrogen fixation (acetylene reduction) associated with subterranean clover growing in a Mallee soil (82% sand). In contrast, W. Blowes (unpublished data) found no evidence that glyphosate residues inhibited the growth and nodulation of pasture legumes growing in clay, clay loam, sandy clay loam and sandy loam soils at Horsham (Vic), Gama (Vic), Hart (SA) and York (WA), respectively. This presumably indicates either that glyphosate did not persist in these soils, or the residues did not inhibit nitrogen fixation associated with the pasture legumes grown in this experiment. Clearly more research is needed to determine the exact conditions that lead either to glyphosate persistence or to adverse effects of the residues. The extrapolation of overseas results to Australian sites is unacceptable for such subjects as pesticide persistence, as soil and climatic conditions in this country differ markedly from those in most other countries.

Table 12.7 Herbicide effects on N fixation (acetylene reduction) associated with *Trifolium subterraneum* (P.L. Eberbach, unpublished data)

Herbicide	% inhibition of N-fixation (C_2H_2 reduction)*
paraquat	0 a**
2, 4-D	6 a
Hoegrass	9 a
glyphosate	100 b
diquat	6 a
trifluralin	0 a
amitrole	87 b
atrazine	100 b

*C_2H_2-reduction assays performed using intact plants of age 19 weeks. Seeds were sown 4 months after application of 4 ppm (soil basis) herbicide to the Mallee sand.

**Numbers not followed by the same letter are significantly different.

Non-symbiotic In experiments with pure cultures, Mackenzie and MacRae (1972) and Wood and MacRae (1974) found that the insecticides DDT, lindane, chloropyrifos, Davco 214, methidathion, diazinon and fensulfothion did not affect nitrogen fixation (acetylene reduction) by *Azotobacter vinelandii.* A transitory effect of Nemacur on fixation was noted, while Dowco 217 caused some inhibition, apparently due to the formation of 2-hydroxy-3,5,6-trichloropyridine.

MacRae and Celo (1974) also reported that naled, coumophos, dichlorvos, chloropyritos, Dowco 217, Nemacur, Terracur, malathion, and Dowco 214 at concentrations of 100 ppm inhibited the respiration of washed suspensions of *Azotobacter vinelandii.* These inhibitory effects, which have been observed in experiments with pure cultures, may be significantly reduced when the pesticides are added to soil because adsorption and degradation reactions may combine to reduce the effective concentrations of active chemicals.

CONCLUSIONS

This chapter has highlighted the current inadequacies in the understanding of interactions between soil organisms, pesticides and plants. In some cases there is considerable detailed knowledge on specific organisms or processes but in other cases very little is known. Because of this lack of information the connection between soil biological processes and agricultural productivity is poorly understood. This lack of knowledge is due to the difficulties in studying a system that is opaque, highly heterogeneous, and very complex. Despite these difficulties it is important that soil biology be included in studies on tillage. The biological component of soil must be considered as much a resource to be managed and conserved as the physical component.

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