THE ECOLOGY AND MANAGEMENT
OF LUMBRICID EARTHWORMS
IN THE MIDLANDS OF TASMANIA

by

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(ROGER GARNSEY)

Abstract

Earthworms have the ability to impart substantial physical, chemical and biological effects on the soil through their burrowing and casting activities. Earthworm communities are distributed throughout Tasmania's agricultural soils, however in the low rainfall region of the Midlands of Tasmania (< 600 mm p.a.), earthworm density and species diversity is low. This may be restricting potential gains in pasture production in the region. The purpose of this study was to examine the ecology and management of earthworms in the Midlands, and their effect on pasture production during 1991-1993. The earthworm *Aporrectodea longa* was also introduced at two sites in the Midlands to determine its effects on pasture production. This knowledge can then be utilised to increase earthworm activity and hence, pasture productivity in the Midlands.

Earthworm population dynamics were studied at 14 sites in the Midlands during 1992-1993. Earthworm number and biomass was recorded monthly and found to be significantly correlated with soil moisture; maximum earthworm activity in the surface soil was evident during the wetter months of winter and early spring, followed by an aestivation in the surface and sub-soils during the drier summer months. The two most abundant earthworm species found in the Midlands were *Aporrectodea caliginosa* (maximum of 174.8/m^2 or 55.06 g/m^2) and *A. trapezoides* (86/m^2 or 52.03 g/m^2), with *Octolasion cyaneum* (22/m^2 or 13.0 g/m^2) and *Lumbricus rubellus* (31/m^2 or 13.58 g/m^2) combined constituting < 15 % of the total population. However, the behaviour of *A. caliginosa* to rainfall and soil texture was contrary to that of *A. trapezoides* in this study. *A. caliginosa* was particularly dependent upon rainfall in the Midlands: population density, cocoon production and adult development of *A. caliginosa* was reduced under low rainfall. The number and biomass of *A. caliginosa* also tended to be lower on the sandy soil in this study. In contrast, the density and biomass of *A. trapezoides* was unaffected by rainfall between 425-600 mm p.a.; cocoon production and adult development continued unabated at low rainfall. Density and biomass of *A. trapezoides* was similar on all soil types.

The depth of earthworm aestivation was examined during the summers of 1992-1994 from the same sites used to examine earthworm population dynamics. Aestivation behaviour of earthworms was similar in each year. Most individuals were in aestivation at a depth of 150-200 mm, regardless of species, soil moisture or texture. Smaller aestivating individuals were located nearer the soil surface, shown by an increase in mean mass of aestivating individuals with depth. There was a high mortality of up to 60 % for juvenile, and 63 % for

adult earthworms associated with summer aestivation in 1993 in the Midlands. Cocoons did not survive during the summers of 1992 or 1994, but were recovered in 1993, possibly due to the influence of rainfall during late winter and early spring.

The influence of ivermectin on earthworm growth and cocoon production was investigated. The growth and cocoon production of four pasture earthworm species provided with dung from sheep treated with ivermectin were not significantly impeded over a five week laboratory study.

Pastures at Oatlands and Perth were chosen in the Midlands to determine the effects of lime (L), nitrogen (N), organic matter (O) and fertilisers (F), and the introduction of *A. longa*, on earthworm numbers and pasture growth. Treatment application and introduction of *A. longa* produced contrasting results at Oatlands and Perth. *A. longa* increased pasture production at Perth within seven months by up to 17 %, but had no effect at Oatlands. Application of F and L at Oatlands increased pasture growth, whilst O and L initially decreased pasture growth at both sites. Numbers of *A. trapezoides* and *A. longa* were increased at Oatlands by L and O, whilst F increased numbers of *A. trapezoides* and *L. rubellus*. The increase in earthworm numbers in response to treatments appears to be an indirect response to greater amounts of high N food reserves in the soil. In contrast, the initially low population density of earthworms at Perth were further reduced by N and F. The differences in response at Perth and Oatlands to treatment application and *A. longa* introduction is discussed in terms of differences in climate, soil type and pasture composition between sites.

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TABLE OF CONTENTS

LIST OF FIGURES

Figure

LIST OF TABLES

LIST OF PLATES

LIST OF APPENDICES

I. GENERAL INTRODUCTION

Earthworms have the ability to improve the physical, chemical and biological status of the soil. The burrowing and casting activities of earthworms facilitate soil inversion and mixing, as well as improved soil porosity and water infiltration (Stockdill, 1982; Syers and Springett, 1983; Lee, 1985). Earthworms improve the availability of nutrients in the soil (Satchell, 1967; Edwards and Lofty, 1977; Lavelle and Martin, 1992; Lee, 1985), as well as the dispersal and number of microorganisms in the soil through their casting activity (Stockli, 1928, cited by Edwards and Lofty, 1977; Parle, 1963a; Stephens *et al.* 1993c). Improvements in soil properties associated with earthworm activity culminates in an increase in plant productivity (Stockdill and Cossens, 1969; Hopp and Slater, 1949; Hoogerkamp *et al.* 1983; Garnsey *et al.* submitted). Several texts extensively review the management and ecology of earthworms (Edwards and Lofty, 1977; Lee, 1985) and are frequently referred to in the following sections.

The majority of earthworm species found in Australia's agricultural soils have been accidentally introduced during white settlement from Britain and Europe, and have readily colonised pastoral and arable soils. These species, which belong to the Lumbricidae family, have replaced Australia's indigenous earthworm population (Megascolecidae) which do not survive the removal of native bushland and the implementation of modern agricultural practices. This study focuses on these lumbricids because of their importance to agriculture in Australia.

Lumbricid earthworms were established in Tasmania before the end of the last century (Anon, 1896), and are now present throughout the State's agricultural soils (Kingston and Temple-Smith, 1988; Kingston and Garnsey, in preparation). However, in the drier Midlands region of Tasmania (< 600 mm rainfall p.a.), earthworm population density and diversity is lower than the higher rainfall areas of northern Tasmania (Temple-Smith, 1991), but comparable to areas of similar rainfall in southern Australia (Abbott and Parker, 1980; Mele, 1991; Baker 1991). The aims of this study were to gain a better understanding of the ecology and management of lumbricid earthworms in the Midlands in an attempt to increase population densities and, as a result, pasture production. In the Midlands, this involved examination of:

(a) the climate, geology, ecology and landuse of the area;
(b) the population dynamics of earthworm species;
(c) the summer aestivation of earthworm species;
(d) the management of earthworm populations;
(e) the effect of ivermectin on earthworms.

II. LITERATURE REVIEW

2.1 Earthworm ecology

Population size

Estimates of earthworm populations are expressed as numbers ($/m^2$) or biomass (g/m^2). Often both parameters are used since earthworm numbers alone fail to express differences between large and small individuals. Earthworm numbers can be as high as 2000 $/m^2$ constituting a biomass of up to 300 g/m^2 or 3t/ha.

Earthworm populations may be estimated by handsorting individuals from the soil, however smaller (<0.2 g) or darker coloured earthworms are often missed (Nelson and Satchell, 1962). Other methods include soil washing, which is a more efficient but time consuming method of earthworm extraction, and electrical expulsion from soil using metal probes, the efficiency of which depends on soil factors (e.g. pH, moisture). Chemical expulsion using potassium permanganate and formalin often kills earthworms and can fail to extract all species equally well. Even mixed emulsions of mustard have even been successfully trialled as a more environmentally acceptable form of earthworm expulsion (Gunn, 1992). Other less common practices use heat and vibration, however handsorting is probably the most efficient method of earthworm extraction from the soil (Edwards and Lofty, 1977).

Population distribution

<u>*Horizontally*</u>

Earthworm populations are not randomly distributed across a paddock, but are subdivided into smaller units which make up the total population. The size of these units is dependent upon environmental factors, such as soil moisture, temperature, aeration and herbage cover (Guild, 1952) as well as the reproductive and dispersive capabilities of the species.

<u>*Vertically*</u>

Different earthworm species occupy different regions of the soil profile. The New Zealand megoscolecoids are classified as either leaf or litter mould species (O horizon), topsoil species (A horizon) or subsoil species (B or C horizon). The European Lumbricidaes are classified under similar groups. Species are labelled as 'epigee' when living in the mineral soil surface, 'aneciques' when residing in burrows and feeding on dead leaves and 'endogees' when inhabiting and feeding in the mineral soil horizon and on any organic matter. The litter feeding species are darker coloured, whilst the subterranean species are usually pale (Edwards and Lofty, 1977).

Burrowing

Burrows are formed by earthworms in search of food in the subsurface horizons of the soil. Earthworms create small diameter, mucus-lined tunnels which also serve as protection against predators and abrupt environmental changes. Burrows range in diameter from 3-12 mm and up to three metres deep, depending on the species (Edwards and Lofty, 1977).

Lee (1985) outlines the three basic types of earthworm burrow: the first are permanent burrows, usually formed by large earthworm species (e.g. *L. terrestris*) which extend vertically and may branch into several outlets to the soil surface. Aneciques or some topsoil species excavate permanent burrow systems which provide access to food at the surface. More extensive, permanent burrows exist which consist of more horizontal components created by endogee species and some topsoil species. Finally, temporary, vertical burrow systems are used by surface dwelling species as they retreat to depth to enter their resting stage (diapause or quiescence) and as they return to the surface during more favourable conditions (see 'seasonal activity'). These burrows are formed quickly and used only once. Unlike the more permanent burrow systems, the walls of these temporary burrows are not well cemented together with mucous secretions and earthworm casts.

Casting

Casts consist of soil, inorganic minerals, organic matter, micro-organisms and enzymes (e.g. proteases, lipases and cellulases) defecated by earthworms. Earthworms are usually subsurface casters, rarely surface casters but can often be both. To add further confusion, variation in behaviour occurs within a species. For instance, *A. caliginosa*, *A. longa* and *L. terrestris* are considered to be surface casting species, however greater quantities of faeces are passed into subsurface crevices in heavier soils (Edwards and Lofty, 1977). Similarly, in a compacted soil, subsurface casting species may cast on the soil surface (Lee, 1985). Subsurface casts are deposited into earthworm burrows or other crevices, whilst surface casting species usually construct vertical burrow systems that open at the surface. Surface casts range from globular units, which can persist for several months, to granular, fine-textured units which are easily washed away (Lavelle, 1988). In extreme cases, the vertical height of casts may exceed 20 cm and weigh 1.6 kg (Lee, 1985).

Seasonal activity

The number and activity of earthworms found near the soil surface is determined primarily by climatic conditions. Earthworms remain active in the soil when temperature and moisture conditions are favourable but retreat deeper into the soil profile to enter a resting stage when the surface layers of the soil become increasingly arid or the temperature increases to 14-16 ^{o}C or falls below 5 ^{o}C (Evans and Guild, 1947; Gerard, 1967; Daugbjerg, 1988). In England, Gerard (1967) found that earthworms retreated to below 80 mm when the soil temperature dropped below 5 ^{o}C or during summer when the soil dried out. In the Mediterranean climate of South Australia (500-900 rainfall p.a.), Baker et al. (1992a) found the highest numbers of *A. trapezoides* and *A. caliginosa* in the top 100 mm of the soil from winter to early spring. Earthworms entered a dormancy state at a depth of 200-300 mm from late spring to early autumn when the soil was driest (figure 2.1). However, earthworms may have retreated further down the profile because diapause sampling was limited to a depth of 300 mm. In the higher rainfall region of northern Tasmania (1200 mm p.a.), *A. caliginosa* retreated to a depth of 120-200 mm over the drier summer months (Kingston, 1988).

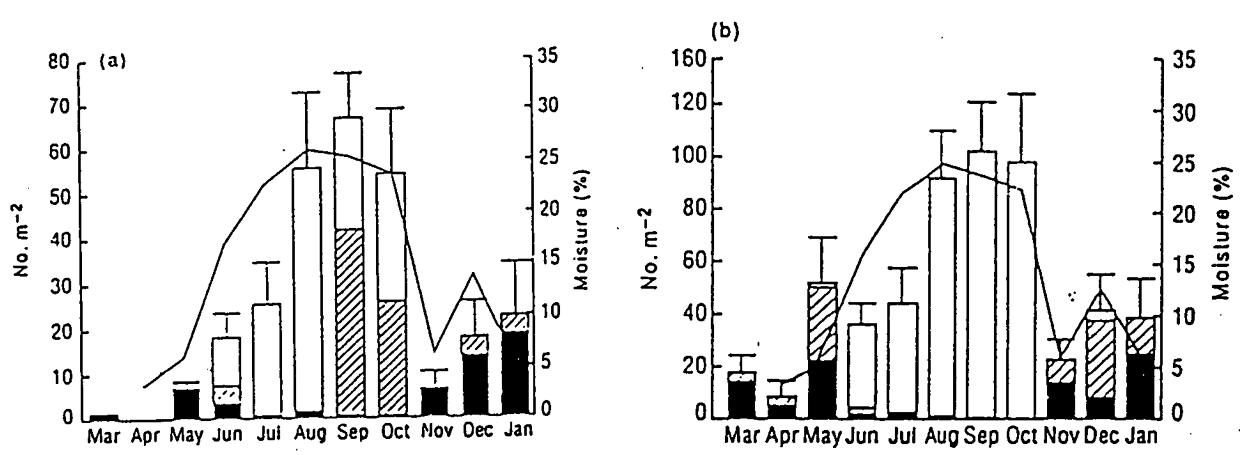


Figure 2.1: Populations of (a) *A. caliginosa* and (b) *A. trapezoides* at 0-10 cm (□) 10-20 cm (▨) and 20-30 cm (■) depths at Birdwood, Mt Lofty Ranges, South Australia (Baker, *et al.* 1992a).

Lee (1985) defined the resting stage or aestivation of the earthworm as the stage when they enter either a diapause or a quiescence. Earthworms enter diapause during periods of drought. Earthworms stop feeding, void contents of the gut and excavate a faecal lined chamber where each individual coils up into a spherical ball. This minimises water loss so that earthworms only lose weight during diapause and suffer no physiological damage.

Diapause may be either facultative or obligatory. Facultative diapause may be broken at any time by increasing soil moisture to favourable levels for renewed activity. Obligatory diapause is initiated by drought or severe caudal injury, but once entered it cannot be artificially interrupted by increasing soil moisture.

During quiescence, the earthworm's metabolism is reduced in response to adverse conditions such as drought, low soil temperatures or, to a lesser extent, a reaction to toxicity in the soil. Earthworms do not create a dormancy chamber or become entirely dormant, but appear sluggish and cease feeding in this state and can quickly resume normal activity when conditions become favourable.

The type of resting phase deployed by an earthworm species is dependent upon the genetic stock and the severity of the stress imposed on individual populations (Lee, 1985). Consequently, it is difficult to assign a particular species of earthworm to one type of resting stage.

Species associations

An estimation of the number of earthworm species is indicative of the species richness of a habitat, but it fails to reflect the degree of association between these species. Phillipson et al. (1976) found two species associations from two years study of an English beechwood. These were: a) *Aporrectodea rosea*, *Lumbricus terrestris*, *L. castaneus*, *Satchellues mammalis* and b) *A. rosea*, *A. caliginosa*, *L. terrestris* and *S. mammalis*. The same author used data from Nordstrom and Rundgren (1973) to evaluate earthworm species recovered from 36 beechwoods, 37 deciduous woods other than beech, 38 coniferous woods and 43 permanent pastures. Of the top 10 species recorded in the study by Phillipson et al. (1976), *A. caliginosa*, *A. rosea*, *D. rubida* and *L. castaneus* were considered to be predominantly beechwood species, *L. terrestris* as deciduous woodland pasture species, and *A. longa*, *A. chlorotica* and *O. cyaneum* as permanent pasture species. Soil type is one of the most important factors determining associations between species (Phillipson *et al.* 1976). However, Edwards and Lofty (1977) review some species associations which are a form of commensalism and act independently of environmental factors such as soil type. Examples include the repeated return of a megoscolecoid species of earthworm to the giant earthworm *Dendrobaena grandis* when separated, and the commensal association between lumbricids such as *D. mammalis* with *A. terrestris* and *A. longa*.

Predators and parasites

<u>*Predators*</u>

Earthworms are an attractive food source to subterranean predators that excavate the soil in search of food, and surface feeders that capture earthworms from plant litter.

Earthworms are preyed upon by species ranging from amphibians, mammals and birds to ants and crickets. Predation by birds, such as gulls, starlings, crows and robins is common. In Western Switzerland, 90% (by weight) of the diet of Black-headed Gulls from cultivated fields was composed of earthworms (Cuendet, 1983).

Mammals including foxes, moles and badgers capture and store large quantities of earthworms in caches. To ensure their catch does not escape, 3-5 anterior segments of the earthworm are bitten off which induces diapause. Predation by snakes, salamanders and toads has also been recorded (Edwards and Lofty, 1977). However, a detailed review of vertebrate predation of earthworms by Macdonald (1983) suggests that its effects on earthworm populations is insignificant.

Invertebrates, including ants and the adult larval stages of ground beetles (e.g. *Quedius (Microsaurus) mesomelinus*) prey on earthworms. Megascolecoid earthworms may eat other earthworms (e.g. some *Agastrodrilus* spp.), as well as certain species of centipedes, leeches and flatworms.

<u>*Parasites and pathogens*</u>

Earthworms are rarely free of parasites. They act as adventitious, intermediate or primary hosts of several parasites including protozoa, platyhelminths, bacteria, fungi, rotifers, nematodes, mites and dipterous larvae. The gregarine protozoa are probably the most widely recognised parasite of earthworms and have been located in the alimentary canal, coelom, blood system, testes, spermathecae, seminal vesicles and in cocoons of earthworms (Edwards and Lofty, 1977). Bacterial infestations of *Bacillus botulinus* have been recorded but the extent of their effects on earthworms has not been determined. Nematodes have been located in the tissues of earthworms, whilst platyhelminth worms have been found in the alimentary canal and body tissues of earthworms (Edwards and Lofty, 1977). The effects of parasitization on earthworms varies from lethal infestation to symbiotic commensalism.

Insects, such as the cluster fly (*Pollenia rudis*) and the calliphorid fly (*Calliphora dispar*), lay their eggs in earthworms and the resultant larvae continue to develop until they eventually devour their host.

2.2 The effects of earthworms on soil properties

Physical effects

The burrowing and casting action of earthworms has a significant effect on the physical status of the soil. Burrows create macropores in the soil which facilitate entry of water and air into the soil, whilst earthworm casting encourages mixing of soil horizons as well as breakdown and recycling of organic matter in the soil.

Soil structure

Numerous authors have intensively scrutinised the physical effects of earthworm activity on soils (Satchell, 1958; Edwards and Lofty, 1977; Syers and Springett, 1983; Lee, 1985). Earthworms affect the physical status of the soil in two ways: they alter the structure of the soil and they mechanically mix soil horizons together. Soil structure is a combination of pore size distribution and stability of structure. Hence, any changes in soil structure are expressed as improved water infiltration, soil aggregation, water holding capacity, soil aeration, porosity and drainage (figure 2.2).

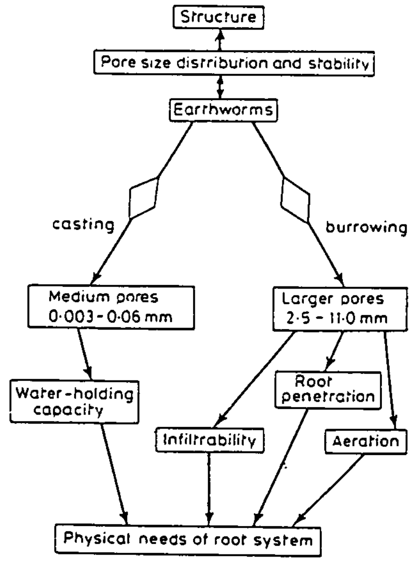


Figure 2.2: Interrelationships of soil physical characteristics as influenced by earthworm activities (Syers and Springett, 1983).

Whilst plant roots create channels in the soil, earthworms exert greater pressure than roots in forming large diameter channels (McKenzie and Dexter, 1988a, 1988b). Consequently, the water infiltration, drainage and water holding capacity of soils is substantially improved where earthworms are present. Addition of *A. caliginosa* to soil columns significantly increased hydraulic conductivity and percolation rates (Joschko *et al.* 1992). Stockdill and Cossens (1966) recorded increases in field capacity of up to 17% in soils where earthworms were present due to improved soil structure and organic content. Stockdill (1982) found improved infiltration rates and levels of available moisture at sites where earthworms were present (table 2.1). The decrease in the macroporosity of soils with earthworms is probably due to a greater network of smaller diameter pores from earthworm burrowing. This would account for the increased infiltration rate in soils with earthworms. Two years after earthworm introduction into permanent raised beds under zero tillage, mean infiltration rates increased up to 120% (Springett *et al.* 1992). However, due to their large diameter, earthworm burrows will have minimal influence on infiltration rates unless channels extend to the soil surface where they are in contact with water in a tension force state. They essentially act as an additional drainage system during heavy rainfall or irrigation when the quantity of surface water is beyond the capillary intake by the soil.

Table 2.1: The effect of earthworms on physical characteristics of the soil (Stockdill, 1982).

Parameter	Depth (cm)	With worms	Without worms
Field capacity (% by weight)	0-10 0-30	52 43	42 37
1,5 MPa retention# (% by weight)	0-10 0-30	16 14	16 14
Bulk density (g cc^{-1})	0-10 0-30	0.9 1.0	0.7 1.0
Available moisture (mm)	0-10 0-30	31 84	18 66
Macro porosity (%)	0-10 0-30	22 23	45 29
Organic carbon (% by volume)	0-10 0-30	4 3	4 2
Infiltration (mm)	5hr intake Basic rate hr^{-1}	608 26	290 14

1 bar = 1. 10^5 Pa [Pascall]; 1,5 MPa = 15 bar [wilting point]

Similarly, the absence of earthworms from pastures results in a steady decline in soil structure. Earthworms eliminated from perennial ryegrass pasture for 20 years by frequent application of the pesticide phorate led to a significant increase in soil bulk density, shear strength, penetrability and depth of leaf litter (Clements *et al.* 1991). Sharpley et al. (1979) found a two-fold increase in the volume of surface runoff and a three-fold increase in the infiltration rate from a permanent pasture devoid of earthworms following application of carbaryl.

Soil aeration may be substantially improved by earthworms due to their burrowing activity in the soil. Springett et al. (1992) introduced *A. caliginosa*, *L. rubellus*, *O. cyaneum* and *A. trapezoides* into intensively cropped soil under five different cropping regimes and found an overall increase in air permeability of 40% after 2 years. However, soil texture influences the extent to which earthworms affect soil aeration. Earthworms consume and cast greater quantities of soil and will have more influence on soil aeration in heavier soil types than on the lighter soils (Guild, 1955).

Earthworms can also influence soil porosity. Springett (1985) found a significant increase in soil porosity from 10-20 cm depth where *A. longa* had been introduced (figure 2.3). However, Nordstrom and Rundgren (1974) failed to find any relationship between earthworm numbers or biomass and soil porosity after examination of 20 forest, meadow and pasture sites in Sweden.

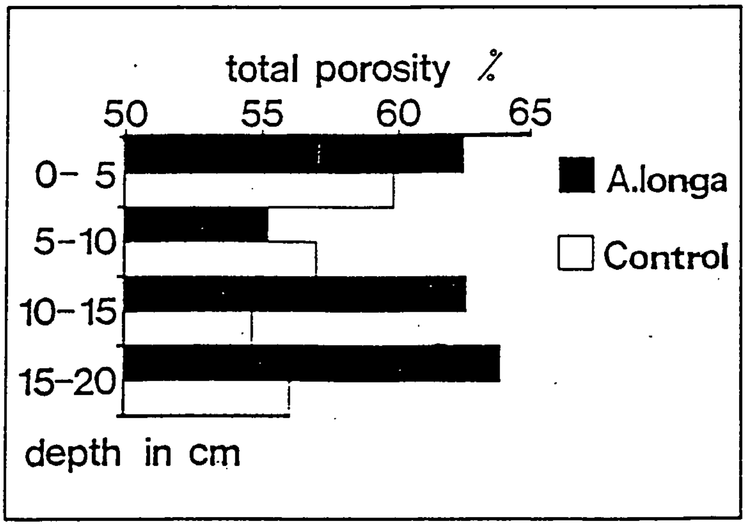


Figure 2.3: Effect of introduction of *A. longa* on soil porosity (Springett, 1984).

Earthworms improve soil aggregation which impedes erosion, compaction and waterlogging of the soil. It is well documented that worm-casts often contain more water-stable aggregates than the surrounding soil (Hopp and Hopkins, 1946; Swaby, 1949; Guild, 1955). The extent of this stability is dependent upon the organic matter source, the feeding behaviour of individual species and the level of microbial activity in the excreted casts (Guild, 1955; Lee, 1985). Contention exists over the exact mechanism responsible for improved aggregation in earthworm casts. Aggregates may possibly be reinforced by the fibrous plant residues of ingested food. Certainly, some authors suggest a strong association exists between wormcast stability and the organic matter of casts (Zhang and Schrader, 1993). The addition of high protein material, such as alfalfa, to soil increased aggregation in castings (Dawson, 1948; Dutt, 1948). But attempts to experimentally reproduce aggregates from soil and macerated roots have been unsuccessful (Swaby, 1949).

Alternative theories regard cementing agents secreted from the earthworm's intestines as an explanation for improved aggregation in earthworm casts. Secretions of calcium humate, derived from a combination of decaying organic matter in the earthworm's intestine, and calcite from the calciferous glands, may act as cementing agents to improve the aggregate stability of earthworm casts (Meyer, 1943, cited in Satchell, 1958).

Earthworm casts also contain greater numbers of bacteria (Stockli, 1928, cited by Edwards and Lofty, 1977; Parle, 1963a) which may directly influence soil aggregation. Many of the bacteria residing in casts have the ability to produce polysaccharide gums which are effective in soil aggregation (Geoghegan and Brian, 1948), and may be responsible for improving aggregation in earthworm casts (Satchell, 1958; Edwards and Lofty, 1977). However, Parle (1963b) found no direct relationship between the polysaccharide content of casts and the proportion of water-stable aggregates in casts. In addition, the levels of polysaccharide gums produced in the field are considered inadequate for good aggregation of soil to occur (Arthur, 1965). Exposure of casts to acidified hydrogen peroxide, which would oxidise polysaccharide gums and calcium humate, failed to have any deleterious effect on aggregate stability (Arthur, 1965). Indeed, Swaby (1949) found inoculation of pasture soil with earthworm castings increased aggregation, not due to bacterial growth but rather fungal hyphae, which increase in number and length with cast age (Parle, 1963b). It may well be a combination of the binding effects of intestinal gums, fungal hyphae and organic matter which result in the good aggregate structure of earthworm casts.

Comminution

Earthworms have been held responsible for the comminution of mineral particles in the soil resulting in a smaller proportion of coarse sand in wormcasts compared to the surrounding soil (Evans, 1948; Satchell, 1958; Edwards and Lofty, 1977). The grinding action of the gizzard is considered responsible for the alteration in the physical status of the soil. However, due to the short residence time of soil in the gizzard and the inadequate pressures present, comminution is unlikely to have any significant influence on the particle size distribution in the soil in comparison to natural weathering processes (Edwards and Lofty, 1977; Lee, 1985).

It is more likely that earthworms preferentially ingest smaller sized particles from the soil (Nye, 1955; Sharpley and Syers, 1976; Zhang and Schrader, 1993). The size of the particles ingested is largely governed by the size of the earthworm species. Bolton and Phillipson (1976) found the particle size of minerals in the posterior gut of three earthworm species to be directly proportional to the diameter of each earthworm species.

Soil mixing

Earthworms have the ability to move large quantities of soil through their casting activities. This encourages inversion of soil horizons in the profile as quantities of between 0.25 and 25.75 kg/m^2 per annum can be deposited on the soil surface (table 2.2).

Table 2.2: Annual rate of surface cast production of lumbricids in various regions of the world (adapted from Lee, 1985).

Location	Vegetation	Earthworm biomass (g/m^2)	Earthworm frequency (no./m^2)	Cast weight (kg/m^2)	Period of cast production
England	Pastures	165.4	-	0.75-1.60	Spring-Autumn
France	Pasture	96.5	-	7.0	Spring-Autumn
Germany	Pasture	-	179	25.75	Spring-Autumn
Russia	Grass ley	-	-	5.2	Spring-Autumn
Germany	Oak wood	-	-	5.8	Spring-Autumn
Germany	Beech wood	-	-	6.8	Spring-Autumn
New Zealand	Pasture	62-78	460-625	2.5-3.0	Autumn-Spring
Australia	Pasture			0.25	Autumn-Spring

Soil inversion by earthworms also facilitates the incorporation of granulated fertilisers and insecticides applied to the soil surface. This improves the efficacy of these products as they are transported and dispersed throughout the root zone where they are most effective. This is particularly important for relatively insoluble fertilisers, such as lime, which move slowly down the soil profile. Baker et al. (1993d) found that the surface application of lime at 4 t/ha significantly increased soil pH after 5 months to a depth of 15 cm where *A. trapezoides* was present, and from 2 to 6 cm in the presence of *A. caliginosa*. Application of DDT for control of *Costelytra zealadica* to plots containing earthworms resulted in complete elimination of the scarabaeid beetle, whilst larval populations of 430 /m^2 were recovered from plots where earthworms had yet to colonise newly developed pasture (Stockdill and Cossens 1966).

Chemical effects

<u>*Decomposition and incorporation of organic matter*</u>

Earthworms facilitate the breakdown of organic matter in the soil. This is primarily due to the rapidity of organic matter consumption and metabolism by earthworms within the soil. Earthworms are particularly important in the initial stages of decomposition of plant and animal organic matter in the soil. Ingested organic matter is macerated, but very little is thoroughly digested by earthworms. Instead, it is mixed with ingested inorganic matter and exposed to the intestinal enzymes of the earthworm which aid in the breakdown of the tougher parts of the plant, including the leaves, stem and roots (Edwards and Lofty, 1977). The resultant castings have undergone minimal chemical alteration, but have been physically finely ground and are consequently prone to further decomposition by soil microbes.

The amount of organic matter that earthworms can consume is largely governed by the amount available, rather than their capacity to ingest it (Satchell, 1967; Edwards and Lofty, 1977). However, even if supplied unlimited quantities of organic matter, earthworms continue to ingest some soil (Barley, 1961). Several attempts by researchers to quantify consumption of plant litter by earthworm species have been made. Edwards and Lofty (1977) review several studies which calculate daily consumption by *L. rubellus* to be 20.4 mg of hazel litter per fresh weight of worm, 27 mg for alder leaves and 80 mg for elm leaves. Raw (1962) found soils supporting a biomass of *L. terrestris* of either 168 g/m^2 or 53 g/m^2 could remove up to 20 g of apple leaves per m^2 per day. A population of *L. terrestris* could therefore consume the annual leaf fall from a mixed English forest (300 g/m^2) in about three months (Satchell, 1967).

Decomposition of animal dung is also enhanced by the activity of earthworms. Estimations of dung consumption range from 40 mg of oven-dried cattle dung (Guild, 1955) to 80 mg for sheep dung per gram of fresh weight of *A. caliginosa* per day (Barley, 1959b). Satchell (1967) estimated that the amount of dung produced by dairy cattle (6-7.5 tonnes/ha) would be about one quarter of the amount a typical earthworm population could consume.

Effects on C, N and the C:N ratio

Lee (1985) reviewed several studies which compare the C, N and C:N ratio of casts to the surrounding soil. He found the amount of C in casts was about 1.5-2 times that of the surrounding soil, the N content was about 1.2-1.7 times that of the soil and consequently, the C:N ratio of casts was slightly higher than that of the surrounding soil.

Attempts at quantifying levels of C and N excreted in casts on the soil surface have been made, however considerable variation exists between estimates (table 2.3). Addition of organic matter, in the form of dung, clearly influences total cast production and, more importantly, the amount of C and N deposited in casts.

Table 2.3: Estimates of the total cast production and the carbon and nitrogen content of casts from pasture soils (adapted from Lee, 1985).

Locality	Cast production (t/ha/y)	Annual output (g/m^2)	
		C	N
New Zealand	33	142	13
Germany	258	2137	134
Poland (grazed)	7.8	17	2
Poland (grazed+dung)	35	78	5

Consumption of plant litter by earthworms gradually reduces the C:N ratio of the litter during metabolism. Undecomposed plant litter, such as oak leaves, which has high amounts of cellulose and lignin has a C:N ratio of 43.5:1. Feeding by earthworms reduces this to less than 20:1 which allows plants to readily absorb mineral N while most of the C is lost through respiration (Edwards and Lofty, 1977).

Nitrogen fluxes in the soil

Earthworms directly influence nitrogen cycling in the soil through deposition of casts, urine, cutaneous mucus secreted to assist locomotion and dead tissue in the soil (Lee, 1985). Needham (1957) found half of the N excreted by *Eisenia fetida* and *L. terrestris* was protein, probably mucus, with most of the remainder occurring as urea and ammonia.

Despite some contention in the literature, there is substantial evidence suggesting earthworms contribute considerable amounts of N to the soil in their castings. Curry and Byrne (1992) calculated earthworms had the potential to supply 30% of a wheat crop's N requirement. After feeding young *A. caliginosa* finely ground clover litter, only about 6% of the non-available nitrogen ingested by the worms was excreted in an available form (Barley and Jennings, 1959). Higher numbers of N fixing bacteria recorded in these plots may have also contributed to this result. Haimi et al. (1992) found a two-fold increase in the N content of birch leaves grown in pots with earthworms compared to plots without earthworms. In the tropics, Lavelle and Martin (1992) recorded a short-lasting N increase in castings of *Pontoscolex corethrurus* of up to 369% in total mineral N, 558% in microbial biomass, 59% in NO_3 and 1494% in NH_4 in comparison to the control. This N stock rapidly declined during the 12 hours after deposition but levels remained greater than the control for up to 16.5 days when the experiment ceased. Temple-Smith (unpublished) also found an almost 3-fold increase in nitrate levels in castings of *A. longa* compared to the surrounding soil (table 2.4).

The N content of paddy rice was compared between control plots which had received a combination of farmyard manure (FYM) and recommended doses of N, P and K, and experimental plots receiving vermicompost, P, K and half the recommended amount of N (Kale *et al.* 1992). There was no difference in the total N content in the soil between control and experimental plots, yet the total N content of rice shoots was more than three times greater in experimental plots compared to control plots. This indicates that N was in a more available form to rice plants on experimental plots receiving vermicompost applications.

Following deposition of casts, nitrification proceeds rapidly and the level of NO_3 increases whilst NH_4 decreases as a proportion of total N in castings. Parle (1963b) reported high initial levels of NH_4 (measured as NH_3) in castings of *L. terrestris* which declined from 97% to about 60% of total N whilst the proportion of NO_3 increased from 10% to 60%. Similar trends have been recorded in castings of *P. corethrurus* (Lavelle and Martin, 1992), *L. rubellus* (Syers *et al.* 1979) and in soil containing clover residues inoculated with either *L. rubellus* or *Eisenia fetida* (Ruz-Jerez *et al.* 1992). However, Syers et al. (1979) considers N mineralisation in the earthworm's gut to be less than what would occur in litter *in situ*.

Table 2.4: Nutrient analysis of *A. longa* casts compared to the surrounding soil (Temple-Smith, unpublished).

SAMPLE	pH H_2O (1:1.5)	ORGANIC CARBON %	1:1.5 WATER EXTRACTABLE (ppm)					COLWELL EXTRACTABLE (ppm)	
			NO_3	P	K	Ca	Mg	P	K
SOIL (0-100mm)	6.2	3.6	1.7	3.5	16	23	6	17	153
SURFACE CASTS	6.6	5.8	4.7	6.5	34	33	9.7	55	327
VOIDED GUT MATERIAL	6.9	7.5	1.9	14	80	28	10	154	768

Excretion by earthworms is mainly in the form of ammonia and urea. Excretion directly to the exterior occurs from the nephridiopores into the drilosphere (a zone of 2 mm thickness around the walls of the earthworm burrow). Lee (1983, 1985) outlines in detail how alterations in nutrition, temperature, soil texture or water availability can significantly alter the proportions of urea and ammonia between and within species. Lee (1983) calculated the total nitrogen input of urine from earthworms to be 18-50 kg/ha/year, assuming an average output of 200 ug/g/day of nitrogen as urea and ammonia.

The contribution of nitrogen from dead earthworms in the soil ranges from < 10 g/m^2/year to 200 kg/ha/year (Lee, 1985). This input of nitrogen is derived from a high mortality of individuals, which have a protein content of around 60-80% of dry weight. Two weeks after the addition of dead *L. terrestris* to pots containing soil, the earthworms had completely disintegrated and the associated nitrogen input comprised of 25% nitrate, 45% ammonia, 3% soluble organic compounds and 27% remaining as undecomposed residues (Satchell, 1967).

Mineral nutrients in the soil

Earthworms improve the availability of nutrients in the soil through their casting activity. They effectively recycle organic matter to redistribute nutrients from the soil surface to lower down in the root zone, thereby reducing loss of nutrients in surface runoff. Several studies have shown increases in pH, organic carbon, nitrate, P, K, Ca and Mg in earthworm casts compared to the surrounding soil (Powers and Bollen, 1935; Lunt and Jacobson, 1944; Nye, 1955; De Vleeschauner and Lal, 1981). Higher concentrations of Ca, Mg and K are attributed to the higher plant content of casts compared to the soil (Lee, 1985). Table 2.4 typifies the greater concentration of mineral nutrients found in castings compared to the underlying soil (Temple-Smith, unpublished).

The pH of the casts is higher than that of the soil, which ultimately affects the solubility of nutrients in the casts. Edwards and Lofty (1977) adapted data from Salisbury (1925) who found the difference in pH between castings and the soils in which they were derived differed less as the soil pH approached 7.0. Castings from more acid soils were 0.3-0.6 pH units higher than the soil, whilst casts from more alkaline soils did not differ from the soil as much (figure 2.4). A higher pH value is probably due to release of calcium carbonate from the calciferous glands into the intestine and breakdown of organic matter in the gut (Barley, 1961; Lee, 1985) or the intestinal secretion of ammonia (Edwards and Lofty, 1977).

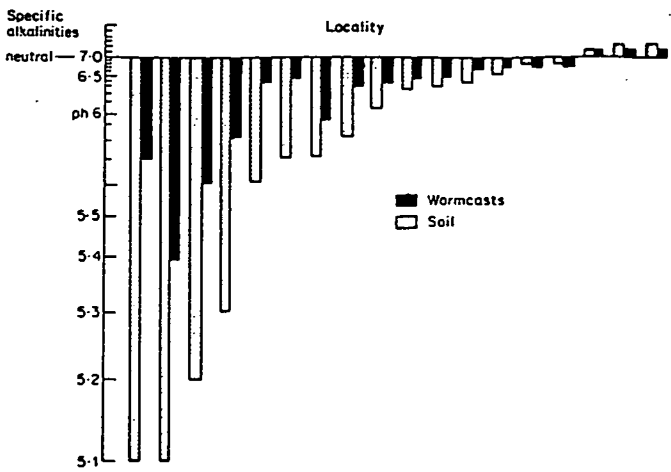


Figure 2.4: The effect of soil pH on the pH of earthworm castings (Edwards and Lofty, 1977, adapted from Salisbury, 1925).

Plant growth is often limited by P availability in Australia's highly weathered soils. To add to this dilemma, P ions diffuse over very short distances (< 1 mm) in the soil. Earthworms offer a means of increasing the availability of P in soils five to ten times that of the surrounding soil through their casting activity (Lee, 1985). Application of vermicompost to rice paddy fields almost doubled P levels in both the soil and rice plant shoots compared to control plots receiving recommended applications of FYM, N, P, and K (Kale *et al.* 1992).

Estimates of surface deposits of P in casts have been put at 14 kg/ha of inorganic P and 11 kg/ha of organic P (Sharpley and Syers, 1976). Mouat and Keogh (1986) found greater levels of water-soluble P in subsurface wormcasts and burrow linings than the surrounding soil which amounted to about 8.5 kg water soluble P /ha/year. This trend continued down the profile, however its magnitude decreased with depth due to an increase in adsorptive capacity for P by the surrounding soil with depth.

Sharpley and Syers (1977) found the total P content of fresh casts remains fairly constant throughout the year, however the inorganic P content decreases from a maximum in May to a minimum in August, whilst organic P demonstrates a reverse trend (figure 2.5). This is attributed to declining soil temperatures which reduce phosphatase enzyme activity and hence, the conversion of organic to inorganic P.

Sharpley and Syers (1977) also showed the rate of release of inorganic P from casts was about 4 times that of the underlying soil for up to 3 days after excretion. However, inorganic P release from surface casts was closely related to the pattern of seasonal cast production and independent of the inorganic P content of the casts over the year (figure 2.5). Neither temperature nor enzyme activity of casts could explain this result.

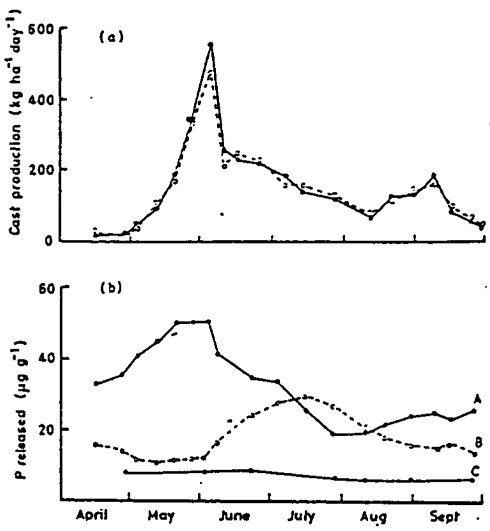


Figure 2.5: Seasonal surface cast production (oven dried basis) on (a) 6^{o} (solid line) and 13^{o} (dashed line) slopes and (b) release to 0.1 M NaCl of inorganic P from casts (A) and underlying 0-10 cm soil (C), and of organic P from casts (B) during 1 h at a solution/solid ratio of 400:1 (Sharpley and Syers, 1977).

Earthworms have the ability to improve the availability of P applied as a fertiliser to soils. A glasshouse trial showed ingestion of phosphate rock fertiliser by earthworms led to a 32% increase in Bray-extractable soil P after 70 days where *L. rubellus* had been introduced compared to soils devoid of earthworms (Mackay *et al.* 1983). This was probably due to an increase in the degree of intimate contact of the rock phosphate particles with soil during passage through the earthworm's intestine.

Biological effects

<u>*Effect on soil microorganisms*</u>

Earthworms influence the number and dispersal of micro-organisms in the soil. Earthworms possess no indigenous gut microflora, apart from parasitic protozoans, and hence use the micro-organisms from the surrounding soil as an integral part of their diet. During passage through the gut, the numbers of microorganisms can increase dramatically, probably due to increases in the amount of water and water-soluble organic matter of soil following ingestion by earthworms (Trigo and Lavelle, 1993). Stockli (1928), cited by Edwards and Lofty (1977) first showed that during passage through the gut of *L. terrestris*, numbers of bacteria and actinomycetes increases dramatically (table 2.5). Parle (1963a) also recorded an increase in numbers of actinomycetes and bacteria of around 1000-fold after passage through the gut of *L. terrestris*, *A. caliginosa* and *A. longa*, which persisted for up to 20 days after casts were formed (Parle, 1963b).

Table 2.5: Numbers of micro-organisms in different parts of the intestine of *L. terrestris* (Stockli, 1928, cited by Edwards and Lofty, 1977).

Taxa	Numbers (x 10^6)		
	Fore gut	Mid gut	Hind gut
Actinomycetes	26	358	15 000
Bacteria	475	32 900	440 700

However, this increase is not true of all microorganisms in earthworm casts. Several workers have reported no alteration in numbers of fungi or yeasts following passage through the earthworm's intestine (Parle, 1963a; Day, 1950). Day (1950) studied the change in the numbers of several microorganisms following passage through the gut of *L. terrestris*. He reported no consistent change in the numbers of actinomycetes, bacteria, fungi or nitrifying bacteria, yet numbers of *Bacillus cereus* var *mycoides* were reduced and *Serratia marcescens* was completely exterminated. He concluded that the spores had survived but vegetative cells had been digested. Species may escape digestion by formation of a tougher, multilayered coat, secretion of antibodies (Aichberger, 1914, cited by Edwards and Lofty, 1977).

Changes in numbers of protozoa in the gut following ingestion are more varied. Soil protozoa may reside in the earthworm's gut without deleterious effects (Dixon, 1975), whilst other species form an integral part of the earthworm's diet. Normal growth of *E. fetida* from cocoons to maturity was only realised when the soil was inoculated with motile protozoa (Miles, 1963). The ciliate protozoan, *Colpidium campylum* was immediately immobilised and usually disintegrated after injection into the fluid of the mid gut of *L. terrestris*, but was unaffected by exposure to pharyngeal and hind gut fluids (Piearce and Phillips, 1980).

Differences in the growth of microbial numbers during gut transit may be attributed to differences in feeding habit between earthworm species. Kristufek et al. (1992) found the numbers of bacteria, actinomycetes and microfungi increased from the fore gut to the hind gut of *L. rubellus*. However, numbers of bacteria and actinomycetes in *A. caliginosa* decreased from the fore gut to the mid gut, and numbers did not alter from the mid gut to the hind gut. Microfungal numbers were not altered during gut transit. The difference in microbial population growth during gut transit between earthworm species was attributed to differences in feeding habit, or more specifically, the chemical composition of food in the gut. *L. rubellus* consumes less-decomposed food, rich in chemical substrates, which is utilised as a food source to increase microbial populations. In contrast, *A. caliginosa* consumes well humified plant remains which are resistant to breakdown and do not stimulate gut microbial growth. The consumed soil biota are therefore utilised as a food source by *A. caliginosa* which reduces the microbial population during passage along the gut. Kulinska (1961) took a more simplified view and considered the physiological status of the individual to be important, whilst Satchell (1983) considered an increase in microbial numbers during gut transit to be a result of selective feeding of plant residues and their associated microflora. Pedersen and Hendriksen (1993) consider differential bacterial consumption in the fore gut and growth in the mid and hind gut was responsible for differences in microbial growth in the gut of *Lumbricus* spp. following ingestion.

After earthworm casts are deposited, the composition of the microflora in the casts is altered. Parle (1963b) reports that Stockli (1928) found the total cell count in earthworm casts doubled in the first week after they were deposited. However, Parle (1963b) reported no consistent changes to the numbers of bacteria or actinomycetes in ageing casts. However, the number of yeasts and fungi increased for up to 20 days after the casts were deposited, as did the number and length of germinating fungal spores for up to 15 days after deposition. Fungal hyphal length then declined slowly, but even after 45 days it was still greater than that of fresh casts.

Earthworms can aid in the dispersal of beneficial soil organisms. *A. trapezoides* and *A. rosea* significantly increased root infection of *Rhizobium meliloti* in alfalfa seedlings to a depth of 9 cm after 18 days, in comparison to infection to 3 cm depth in the control (Stephens *et al.* 1993c). Earthworms have significantly improved the dispersal of biological control agents, such as the nematode *Steinernema carpocapsae* (Shapiro *et al.* 1993) and the bacterium *Pseudomonas corrugata* (Doube *et al.* 1993c; Stephens *et al.* 1993b). Vesicular-arbuscular mycorrhiza (VAM) are soil fungi which improve plant growth by forming a symbiotic association with plant roots to enhance nutrient uptake. Spores of VAM and root fragments with VAM infection were found in the casts of 13 earthworm species which infected the roots of *Sorghum bicolor* (Redell and Spain, 1991; Gange, 1993). Earthworms have also been responsible for decreasing infection of cereal root diseases, such as *Rhizoctonia solani* (Stephens *et al.* 1993a).

Unfortunately, earthworms can also aid in the dispersal of unfavourable species of bacteria, such as the spores of dwarf butt (*Tilletia controversa*), Pythium, Fusarium and Histomanos, which are implicated in blackhead disease in poultry (Edwards and Lofty, 1977). *Serratia marcescens* and *E. coli* are killed when ingested by *L. terrestris* (Day, 1950), whilst *Salmonella enteriditis* ser. *typhyimurium* populations have been reduced 2000-fold where earthworms were present in comparison to the control (Brown and Mitchell, 1981). It is important that the role of earthworms as carriers of microorganisms from human faeces be determined as vermiculture becomes more popular as a means of addressing increasing sewage disposal problems.

Production of plant growth promotants

The castings produced by earthworms contain several plant growth promotants, some of which have been identified (Tomati *et al.* 1988; Krishnamoorthy and Vajranabhaiah, 1986) (table 2.6). These are comparable to levels found in the soil and the rhizosphere of many plants and remain stable for up to 3 weeks under dark, moist conditions (Krishnamoorthy and Vajranabhaiah, 1986). The extent to which these substances influence plant growth is uncertain.

Table 2.6: The levels of growth promoting substances in earthworm casts (Tomati *et al.* 1988[a]; Krishnamoorthy and Vajranabhaiah, 1986[b]).

Growth promotant	Amount (ug equiv./g d.w.)	
	a	b
Gibberellins	2.75	-
Cytokinins	1.05	3.43×10^{-3}
Auxins	3.80	43.27×10^{-3}

Springett and Syers (1978) examined the effects of castings from *A. caliginosa* and *L. rubellus* on ryegrass root growth. Ryegrass seedling roots grown amongst castings from *A. caliginosa* tended to grow straight downwards, whilst roots grew more horizontally or vertically upwards into the casts where *L. rubellus* resided. It is likely that the casts of *L. rubellus* contained some auxin-like substance or a substance which reacts with the plant's natural auxins to cause the negatively geotropic growth of ryegrass roots in the soil.

Grappelli et al. (1985) grew *Ficus elastica*, *Dieffenbachia amoena*, *Cordyline terminalis* and *Dracaena deremensis* in either sphagnum moss, earthworm casts mixed with sphagnum or casts alone. Six weeks later, root initiation, elongation and biomass was greater for all four species grown in the casts alone than in the other two media. Krishnamoorthy and Vajranabhaiah (1986) grew wheat seedlings in various proportions of acid washed sand, garden soil and earthworm casts. As the proportion of earthworm casts was increased in the medium, wheat seedling growth progressively improved until shoot elongation was 82% greater than the control and shoot biomass was 89% greater in cultures of pure castings.

Effects on plant growth

The physical, chemical and biological effects associated with earthworm activity culminates in an increase in agricultural production as water and nutrient uptake by plant roots is enhanced (Logsdon and Linden, 1992). Several overseas studies have quantified yield increases of pasture and crops associated with increased earthworm activity from pot and field trials: pasture increases of 19-111% in New Zealand (Nielson, 1952; Waters, 1951; Duff, 1958; Stockdill and Cossens, 1969; Springett, 1985), 83% for crops in USA (Hopp and Slater, 1949), 2400 % for tree seedlings (Pashanasi *et al.* 1993), and pasture, wheat and apple yield increases of 10%, 111% and 3% in Holland (Hoogerkamp *et al.* 1983, and Van Rhee, 1965 and 1977 respectively) have been reported. In Australia, pasture production has increased in Tasmania up to 58% where *A. caliginosa* was introduced and 75% where both *A. caliginosa* and *A. longa* were introduced (Garnsey *et al.* submitted). In Queensland, Blakemore (unpublished) tested the effects of 12 separate species on pasture growth and found increases of up to 64%, whilst introduction of *A. trapezoides* into pots increased wheat yields after one year by 62% in Western Australia (McCredie and Parker, unpublished), and 35% in South Australia (Williams and Baker, 1993). In the latter study, wheat biomass also increased by 39% and grain N content by 12%.

2.3 Factors affecting earthworm populations

Many of the factors which affect earthworm populations in the soil can be manipulated through management to increase earthworm activity. This offers producers a window for increasing agricultural production which can be utilised and exploited without deleterious effects to the environment.

Food source

The availability of food, as dead and decaying plant and animal remains as well as living microorganisms, fungi and mesofauna, is a primary determinant of earthworm populations (Satchell, 1967). Annual applications of manure on arable and grassland soils have resulted in an increase in earthworm numbers (table 2.7).

Table 2.7: Effect of organic materials on earthworm numbers ($/m^2$) on arable soils (Evans, unpublished) and permanent grassland (Satchell, 1967).

Soil status	Unmanured plots	Manured plots
Arable	74.1	271.8
Grassland	7.4	22.1

Birch leaf litter applied at rates similar to natural leaf fall (not presented) led to an increase in earthworm numbers from 1 /20m2 to between 5 and 100 /20m2 (Satchell, 1967).

Clearly, the type of food provided will affect earthworm growth in the soil. Earthworms generally favour dung or succulent herbaceous materials, instead of the woody, fibrous parts of the plant (Marshall, 1977). Tian et al. (1993) found earthworm numbers were negatively correlated with the lignin:N ratio of plant residues. Barley (1959b) showed a greater change in earthworm body weight as the N% of the diet was increased (table 2.8).

Table 2.8: Change in body weight of *A. caliginosa* when fed for 40 days on various diets (Barley, 1959b).

Diet	N content of diet %	Change in body weight %
Soil only	0.04	-53
Phalaris roots	0.8	-26
Phalaris leaves	2.0	-26
Clover roots	2.6	-2
Clover leaves	4.5	+18
Dung on surface	3.3	+171
Dung, incorporated	3.3	+111
L.S.D. ($P<0.05$)		32

The reason for earthworm's response to N is not fully understood. Edwards and Lofty (1982b) consider increased pasture production and the resultant increased food source for earthworms to be responsible. Discriminant feeding of high protein foods may also occur since they contain high levels of sugar which earthworms can detect (Laverack, 1960), whilst litter high in tannins or polyphenols is avoided (King and Heath, 1967; Satchell and Lowe, 1967).

The extent of decomposition of the food source is important in the regulation of earthworm populations (Evans and Guild, 1948). Cocoon production of *A. chlorotica* and *L. castaneus* was significantly reduced when both undecayed and well decayed sources of organic matter were added. On the other hand, partially decayed forms of organic matter encouraged high cocoon production.

Soil texture

Earthworms prefer clay to loamy soils, rather than the lighter, sandy soils which are more drought prone and more abrasive. Alternatively, soils with a high clay content located in high rainfall areas also contain low earthworm populations as they encounter periods of oxygen deficit. Guild (1948) found four beneficial earthworm species which preferred the clay-loam soils (figure 2.6), however soil moisture, available food and Cation Exchange Capacity (CEC) may be indirectly responsible for this trend, rather than soil type *per se* (Satchell, 1967). Temple-Smith and Kingston (unpublished) found a positive correlation ($P<0.01$) between the total number of beneficial earthworm species and the clay content in the top 500 mm of the soil in Tasmania (< 600 mm rainfall p.a.) whilst Baker et al. (1992b) found % clay was the most important soil parameter affecting earthworm number and biomass in the Fleurieu Peninsula, South Australia.

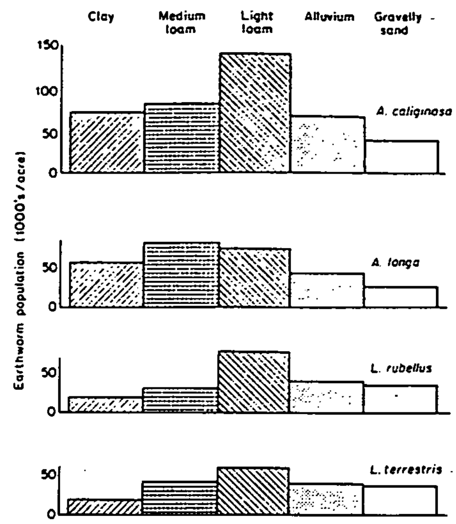


Figure 2.6: Density of four earthworm species in various soil types in Scotland (Edwards and Lofty, 1977, adapted from Guild, 1948).

Moisture

The seasonal activity of earthworms in the upper soil horizon is largely determined by the amount of moisture in the soil (see 'Seasonal activity'). Activity is restricted to periods when soils contain sufficient moisture to maintain the plant's water relations between wilting point and field capacity (pF 2-4.2) (Lee, 1985). Failure to reach these moisture levels in the soil results in earthworm desiccation or retreat to greater soil depths to enter aestivation. The adoption of irrigation would therefore extend the 'earthworm season' and, presumably the time available for breeding, ultimately leading to increases in earthworm numbers in the soil. Churchman and Tate (1986) found irrigation on a silt loam soil increased the number of *A. caliginosa* in pastures from 503/m^2 on dryland plots to 680/m^2 on irrigated plots, and *L. rubellus* from 8/m^2 to 198/m^2.

Noble and Mills (1974) applied three frequencies of irrigation to a sandy loam in NSW: low (three irrigations in spring), medium (13 irrigations) and high (22 irrigations). In each year, the biomass and number of *A .caliginosa* was greater under medium and high irrigation frequencies than the low irrigation frequency. But at the high irrigation frequency, *A. caliginosa* number and biomass declined by around 55% from the first to the second year of the trial. Noble and Mills (1974) believed that under high irrigation frequency, earthworms were moving close to the soil surface to avoid excessive levels of water in the soil, rendering them more prone to predation by birds.

However, Tasmanian researchers have found a shift in earthworm species composition under irrigation in dairy pastures. After 15 months of irrigation to a pasture grazed by dairy cattle, Kingston (1988) found a 90% reduction in the number of *A. caliginosa*, and only a 6% increase in the number of *L. rubellus* compared to dryland plots, largely due to effects of soil texture and stock management. Kingston (1988) considers that earthworms, particularly *A. caliginosa*, were trampled or asphyxiated due to the higher clay content of this soil which left it prone to smearing and compaction by cattle under the wetter conditions of irrigation. The presence of a dipteran fly, *Calliphora dispar* also caused earthworm mortality, but its relative contribution to the reduction in earthworm numbers was not determined.

On a similar soil type, Lobry de Bruyn (1993) also found the number of *A. caliginosa* in irrigated plots declined by more than 50% whilst the number of *L. rubellus* increased 300% after three years of irrigation. However, there was no difference in earthworm density between plots which had been irrigated before or after grazing. Several factors were considered responsible for the differences in response to irrigation between the two earthworm species. *L. rubellus* appears to better suited to the conditions of summer irrigation than *A. caliginosa*, probably due to its greater capacity to reproduce. *L. rubellus* produces more cocoons (80-100 per year) than *A. caliginosa* (30 per year), but with the advent of summer irrigation, cocoon production by *L. rubellus* increases due to the combination of increased moisture and temperature (Evans and Guild, 1948). *L. rubellus* also favours dung pats as a food source which are avoided by stock and therefore, trampling.

Cultivation

Adoption of minimal or zero tillage rather than conventional cultivation has repeatedly led to increased earthworm populations (Barnes and Ellis, 1979; Gerard and Hay, 1979; Edwards and Lofty, 1982b; Haukka, 1988; Buckerfield, 1993). Earthworm numbers can be more than doubled on arable soils by adopting direct drill techniques, but stubble retention is desirable if earthworm numbers are to significantly increase (Table 2.9). This suggests that conservation of the earthworm's habitat and increased food reserves are primarily responsible for increased earthworm numbers under direct drilling. Additional benefits may arise from reduced soil compaction, which increases earthworm number, biomass and age diversity within a population (Bostrom, 1986; Pizl, 1992; Sochtig and Larink, 1992). Improvements in soil moisture retention and insulation from temperature extremes may also be important (Gerard and Hay, 1979; Haines and Uren, 1990).

Inclusion of a pasture phase in crop rotations further enhances earthworm numbers (Buckerfield *et al.* 1992).

Table 2.9: Influence of cultivation and stubble management on the biomass and total earthworms in the surface 10 cm of the soil (CCB, conventional cultivation, stubble burnt; DDB, direct drilling, stubble burnt; DDR, direct drilling, stubble retained) (Haines and Uren, 1990).

Treament	Wet biomass g/m^2	Total earthworms $no./m^2$
CCB	9.7	117
DDB	21.1	123
DDR	25.8	275

Tillage operations using tined cultivation shatters the soil causing the most deleterious effects on earthworm populations, whilst disc ploughing has less dramatic effects on earthworms since it inverts the soil removing earthworms and cocoons from the soil surface (Gerard and Hay, 1979). Deep disc ploughing (300-350 mm) resulted in high earthworm mortality.

Overseas studies (Barnes and Ellis, 1979; Gerard and Hay, 1979; Edwards, 1983) indicate stubble retention under direct drilling favours an increase in the deeper-burrowing species (e.g. *L. terrestris*, *A. nocturna* and *A. longa*). Edwards and Lofty (1982b) found the number of deep burrowing species declined dramatically with cultivation, yet the surface feeders are less affected. The depth of burrowing of these species under Australia's drier climate and shallower soils has not been examined and it may be that these species behave very differently under local conditions.

pH and the effect of lime

Earthworms are not adversely affected in soils with pH (1:5 soil:water) of >5.0 (Temple-Smith, unpublished). In more acidic soils, lime can be applied to increase the pH of the soil to make conditions more favourable for earthworm activity. Application of 2.5 t/ha of lime to pasture increased pH_{CaCl2} from 4.3 to 4.7 and resulted in an increase in earthworm numbers (from $290/m^2$ to $350/^2$) and biomass ($82\ g/m^2$ to $125\ g/m^2$) (Buckerfield, 1993).

There is some evidence which suggests individual species respond differently to lime applications. Doube et al. (1993a) increased soil pH_{CaCl2} from 4.1 to 6.7 by incorporating annual applications of lime for four years. Numbers of *A. rosea* and *M. dubius* increased significantly whilst the abundance of *A. trapezoides* was unaffected. However, application of 1.25 t/ha of lime by Buckerfield and Doube (1993) increased numbers of *A. trapezoides* and decreased numbers of *M. phosphoreus* with a pH_{CaCl2} increase from 4.3 to 4.4.

Whilst calcium (Ca) plays an important role in the metabolism of earthworms, Springett and Syers (1984) showed that pH *per se* has a far greater influence on earthworm activity (as cast production) than Ca concentration in the soil. All four sources of Ca increased the level of Ca in the soil, but only $CaCO_3$ and $Ca(OH)_2$ affect soil pH (figure 2.7). Therefore, increased earthworm cast production was confined to Ca compounds that ultimately led to an increase in soil pH.

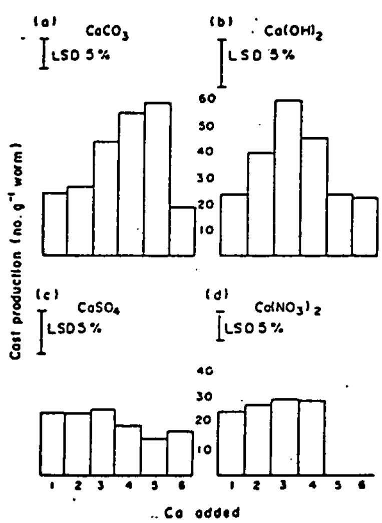


Figure 2.7: Cast production as influenced by the amounts of extractable Ca (g/kg) in the soil (Springett and Syers, 1984).

Fertilisers

The application of inorganic and organic fertilisers to soils can significantly increase the numbers of resident earthworms. However, since earthworms react adversely to acidic conditions in the soil, the effect of the fertiliser on soil pH should be determined prior to application. Response of earthworm populations to application of inorganic fertilisers is well documented (Satchell, 1967; Edwards and Lofty, 1977; Lee, 1985). The widespread application of FYM onto farmland in Europe provided a basis for the study of the effects of organic fertilisers on earthworm populations. Edwards and Lofty (1982a) examined the effects of fertiliser application to arable and grassland systems on earthworm populations. Application of sewage cake and FYM at 200 kg N/ha to arable land for two consecutive years increased earthworm populations. The greatest increases were found following application of sewage cake when earthworm numbers and biomass were more than doubled (figure 2.8).

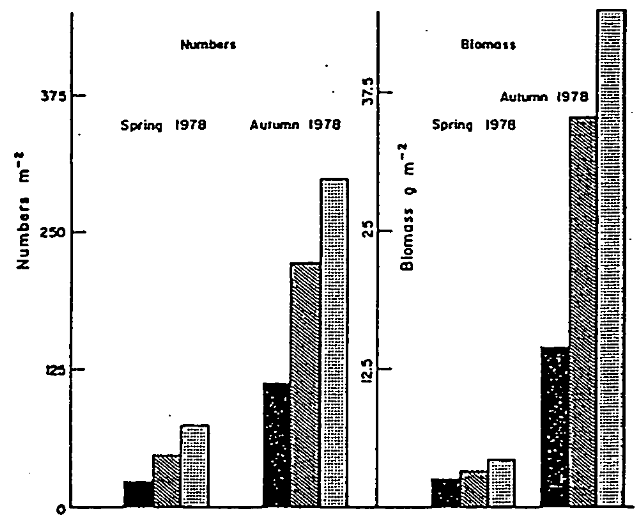


Figure 2.8: The effects of sewage cake and FYM on earthworm populations (solid columns-no organic matter; cross-hatched column-FYM; dotted columns-sewage cake) (Edwards and Lofty, 1982a).

The same author recorded a 16-fold increase in the total number of earthworms on arable land under continuous wheat which had received annual applications of FYM (@ 35 t/ha) since 1843. Under the same experiment, FYM combined with $(NH_4)_2SO_4$ or $NaNO_3$, and combinations of inorganic P, K, and Mg (magnesium) were applied to the site. Application of all types of N fertiliser increased earthworm numbers and biomass relative to the control, whilst a further small increase in the numbers of earthworms was detected by the addition of P, K and Mg. Increases in earthworm numbers and biomass were greater under organic fertiliser application than inorganic, probably due to the additional food supplied by organic fertilisers.

However, a response to inorganic fertiliser application by earthworms is probably due more to an alteration in the composition and quantity of vegetation, and an increase in dung return which is ultimately used by earthworms as food. Some contention exists in the literature over the effects of superphosphate applications on the resident earthworm population. Earthworm biomass has increased (Barley, 1959a; Fraser *et al.* 1993) and remained unchanged (Baker *et al.* 1993a; Sarthchandra *et al.* 1993) following application of superphosphate. Sears and Evans, (1953) reported a decrease in earthworm biomass and number following superphosphate application to a grass/clover pasture, but there was no indication if this result was in fact significant. Certainly, further investigation into this commonly applied fertiliser is warranted.

Pesticides
The application of pesticides to the soil is an essential component of integrated pest management in agriculture. A wide variety of pesticides exist, including insecticides, herbicides, nematicides, fungicides and fumigants. Their effects on earthworms are also diverse and have been extensively reviewed by Lee (1985). Some of the organochlorines, such as chlordane, endrin, heptachlor and toxaphene, are toxic to earthworms whilst DDT, aldrin and dieldrin are not detrimental to growth. The organophosphates and carbamates are less persistent insecticides developed to replace the organochlorines. Most of the carbamates are toxic to earthworms, whilst organophosphates range from highly toxic (e.g. fensulfothion, enthoprop and phorate) to relatively harmless (e.g. malathion, menazon).

Fungicides are generally highly toxic to earthworms, particularly repeated use of copper oxychloride in orchards, as well as benomyl, thiabendazole, carbendazim and thiophanate-methyl. Binapicnyl and ditalimfos have minimal impact on earthworm populations. Herbicides usually have no permanent effects, but repeated low doses of glyphosate has reduced growth rates of *A. caliginosa* (Springett and Gray, 1992).

Stocking rate
The stocking rate of livestock affects earthworm populations in the soil, probably due to its effects on soil compaction and water infiltration. Hutchinson and King (1980) examined the effect of sheep stocking rates of 10, 20 and 30 sheep/ha on earthworm populations. Earthworm numbers and biomass increased from 10 to 20 sheep/ha, but then severely declined from 20 to 30 sheep/ha. The increase in the earthworm population from 20 to 30 sheep/ha was attributed to the fact that the most optimal carrying capacity for the area was also 20 sheep/ha.

Heavy trampling of cattle to pasture resulted in a reduction in earthworm number and biomass (Cluzeau *et al.* 1992). There was an increasing proportion of adult earthworms with trampling, but the vertical distribution of individual earthworms and cocoons was unaffected. Smaller, epigeic species (e.g. *L. castaneus*) experienced the greatest reduction in numbers due to trampling whilst larger and endogeic species (e.g. *A. caliginosa*) were less affected. Boyd (1960) compared earthworm numbers on grazed and ungrazed plots over the year and generally found numbers to be higher on ungrazed plots compared to grazed plots. Varying stocking rates for 13 years from 5 to 22.5 sheep/ha had no effect on either earthworm number or biomass in a Victorian pasture (Baker *et al.* 1993a).

III. GENERAL MATERIALS AND METHODS

3.1 Earthworm sampling procedure

Earthworms were sampled from 0.04 m^2 areas to a depth of 150 mm during the wetter months from early autumn to late spring. Sampling involved handsorting of earthworm eggs, juveniles and adults from the soil which were returned to the laboratory to determine fresh wet weights to an accuracy of 0.01 g. Sampling of earthworms in aestivation (during the summer) involved digging further down the profile to a depth of 500 mm.

3.2 Assessment of pasture growth

Pasture growth was recorded only from the management trials at York Plains and Symmons Plains. Pasture growth was determined by cutting three randomly selected 0.25 m^2 quadrats from each plot using motorised hand shears. Samples were oven dried at 95^{o}C to constant weight. Pasture composition was recorded by visual assessment of plots after each pasture cut and averaged over treatments.

3.3 Soil assessments

The soils of the management trial and life cycle sites were sampled to ascertain the nutrient status of all trial sites. Surface soil samples (0-75 mm) were collected randomly every metre using a metal nutrient sampling probe to allow several representative samples of soil to be collected for each treatment. This composite sample was then analysed for pH (1:5 soil:water), electrical conductivity (EC), extractable phosphorus (P) and potassium (K), organic carbon (OC) and total nitrogen (N). Bulk density measurements were determined on management trials at Oatlands and Perth by randomly selecting two samples from each plot by the core method (Blake and Hartge, 1986).

3.4 Determination of sexual development of earthworms

In addition to recording earthworm number and biomass, I also noted the stage of sexual maturity. Individuals were categorised into one of the following groups:

j - clitellum and associated glands not detectable;

a - clitellum fully formed and also raised.

b - clitellum fully formed but not raised;

c - clitellum and associated glands detectable;

3.5 Statistical analysis of data

All data collected was analysed using GENSTAT (GENSTAT 5 Committee, 1987) to generate means and test for significant differences using analysis of variance where appropriate. Fitted verses residual values were graphed to test for normality and homogeneity of variance. Least significant differences were used to ascertain significant differences between treatment means.

IV. THE MIDLANDS ENVIRONMENT

4.1 Introduction

The Midlands is roughly bounded by the 600 mm isohyet and extends from Perth in the north of Tasmania to Bridgewater in the south (figure 4.1). This region is a lowland basin characterised by widespread alluvial plains, formed due to extensional faulting during the Tertiary period. Soils range from alluvial to lateritic podzolic. Utilised principally for sheep grazing, almost one third of Tasmania's wool clip is derived from the area. Cropping is also practised, whilst smaller vegetable and horticultural pursuits permit diversification.

Earthworm populations are distributed throughout the Midlands, however densities are generally lower than the higher rainfall regions of northern Tasmania, but are comparable to southern Australian mainland states. However, isolated areas support numbers of up to 600/m^2 (Temple-Smith, unpublished), suggesting that higher earthworm densities could be attained in the Midlands.

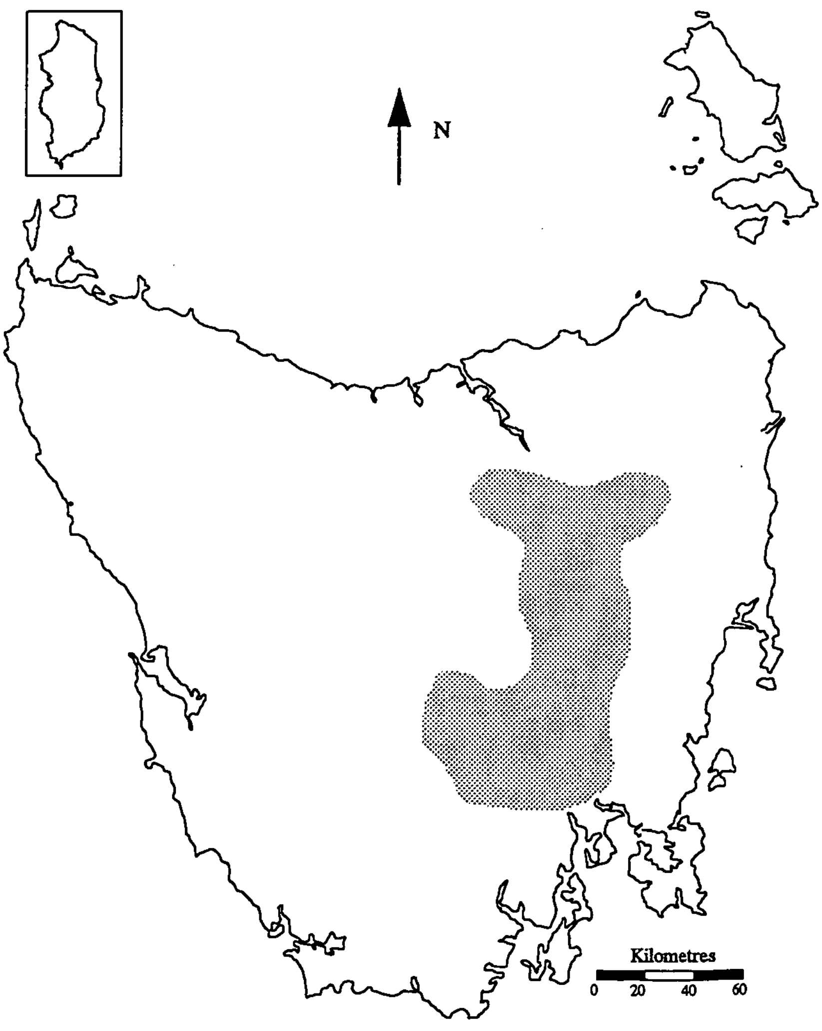


Figure 4.1: The Midlands of Tasmania.

4.2 Geology, physiography and drainage

The Midlands region may be subdivided into three areas: southern, central and northern. During the Tertiary period, the region was extensively faulted forming several large grabens in the South Esk, central Midlands and Derwent Valley. Graben structures form due to regional extension and associated block faulting (figure 4.2).

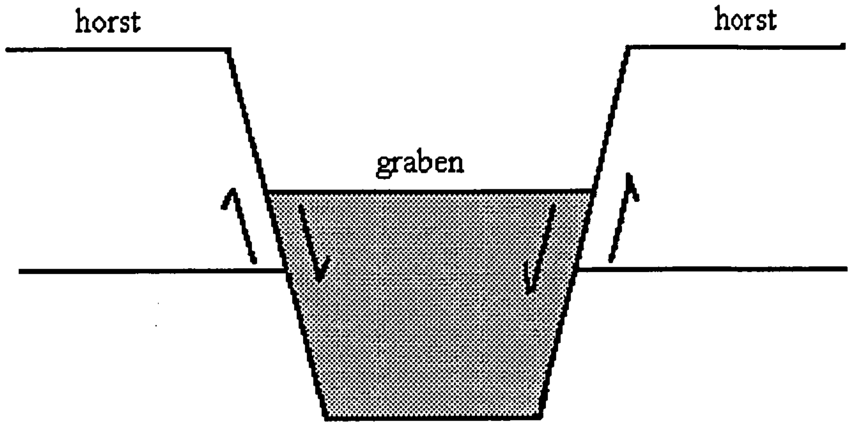


Figure 4.2: The formation of graben structures as a result of block faulting.

The northern and central Midlands lie within the geological structure named the Launceston Tertiary Basin (Johnston, 1875). This is the only extensive inland plain in Tasmania and spans from the mouth of the Tamar Estuary to Oatlands (approximately 380 000 ha). It has an elevation of 150 to 250 m and lies between the uplifted plateaus of the Great Western Tiers in the west (1000 m elevation) and Ben Lomond in the east (1400 m elevation). These plateaus are capped by thick (300 m) Jurassic dolerite which overlie older Triassic and Permian sedimentary rocks (Matthews, 1983).

The basin is comprised of a sequence of river terraces and an extensive modern flood plain. The terrace surfaces evolved from downcutting of the unconsolidated basin sediments, such as Tertiary clays, sandy clays, sand beds and quartz gravel layers. Windblown sands derived from the river valleys have formed valley sand dunes and sand sheets (Nicolls, 1958). The main rivers of the area are the Macquarie and the South Esk River and their tributaries.

From the central to the southern Midlands, the basin's elevation increases to more than 400 m. Extensive alluvial plains (350-450 m) underlain by older gravels have been formed around Oatlands, Tunnack, Jericho and Bothwell from the Clyde, Jordan and the Coal rivers. Low divides separate these valleys, some of which have been cut down through the sediments, dissecting the flats. Where dolerite bars occur further downstream, river terraces have not experienced incision and combined with the hills surrounding them, rise to an elevation of 460 m (Cowie, 1961).

Further to the south lies the Derwent Valley (approximately 100 000 ha). This is a graben structure which lies between the uplifted horst blocks of the Field-Wellington ranges (1000 m) and the Eastern Highlands (600 m). This valley extends from Ouse (5 m a.s.l) to New Norfolk (700 m a.s.l.) in the southern Midlands, but continues further north, climbing in elevation from five metres at New Norfolk to 700 m at the Derwent Bridge.

4.3 Soils

The soils encountered in the Midlands are diverse, indicative of the considerable variation in geology and topography of the area. This section will provide a brief overview of the broad range of common soil types encountered in the Midlands, based on several reconnaissance soil surveys of the area (Nicolls, 1958; Cowie, 1959; Leamy, 1961; Doyle, 1993).

Soils of the Central Plateau and Great Western Tiers

Soils encountered at higher altitudes of the Midlands (> 500 m) are generally fertile but stony and develop on rolling, steep and very steep slopes (> 32 %). Although of valuable forestry and conservation use, they are of marginal agricultural importance. The main soils are yellow-brown soils developed on solifluction deposits of dominantly dolerite clasts. They occur on the slopes of the Great Western Tiers and the Central Plateau at altitudes of 500-1400 m. The surface soil consists of humic, very stony, very dark brown loams which above yellowish brown to reddish yellow or red, stony, clay loam subsoils.

Acid peats and organic gley soil develop in depressions and bogs on the Cental Plateau. These soils are wet for most of the year and their thick sedge, rush and grass vegetation is utilised for cattle grazing.

Lower slopes of the Great Western Tiers

Podzolic soils occur on dolerite throughout the higher rainfall regions of the Midlands (> 600 mm p.a.) at altitudes of 200-750 m on rolling to steep slopes (10-56 %). The profile typically consists of very dark greyish brown, stony, loams topsoils above bleached sandy loams commonly with ferruginous nodules present abruptly over olive brown, brown or yellowish brown blocky clay subsoils. These soils are principally utilised for forestry and extensive sheep grazing.

A variety of soils of differing agricultural importance occur on the foot hills of the Great Western Tiers (450 m a.s.l.) on rolling to steep and some very steep slopes (>10%). These include podzolic soils and minor Podzols derived from siliceous sandstone which occur throughout the Midlands. The Podzols are more evident in higher rainfall areas. The topsoil of the podzolics commonly consist of a stony, dark grey or greyish brown loamy bleached sand which overlies a yellowish brown sandy clay loam or clay. Podzols consist of dark sandy topsoils above bleached grey sands, grading to a grey sandy clay. These soils are naturally infertile.

Podzolic soils developed on Permian siliceous mudstone occur throughout the Midlands. The surface soil consists of a shallow grey sand overlying a brown or yellowish grey stony clay loam which grades to a greyish yellow clay. These generally infertile soils are utilised for extensive grazing.

Brown soils developed from siliceous sandstone occur in the southern Midlands, often in close association with the podzolic soils. The topsoils are generally dark brown sandy loams or loamy sands overlying yellowish sandy clay subsoils. Improved pastures have been established on many of these soils.

Brown soils developed from Triassic micaceous sandy mudstones, shales, siltstones and sandstones border the Midlands highway between Melton Mowbray and Spring Hill. Surface soils consist of dark brown loams overlying loamy sands or sands which pass abruptly down to olive clays. These soils support both native and improved pastures.

Brown soils occur on siliceous and feldspathic sandstone in the southern Midlands. Shallow brown to yellow sandy loam topsoils overlie reddish brown clay subsoils, which rest on red-brown sandy clays containing sandstone fragments. Dolerite or basalt intrusions often occur resulting in a variety of profile forms. Unimproved pastures have been established on these soils.

Shallow brown soils occur on dolerite throughout the Midlands, usually at a lower elevation and rainfall than the podzolic soils on dolerite. These soils often consist of stony red-brown loam topsoils which change abruptly to red-brown clay subsoils. These soils are utilised for both native and improved pasture production. Isolated areas of black cracking soils formed from dolerite occur north of Tunbridge.

Small areas of brown and black soils developed above basalt occurring throughout the Midlands, mainly on hill crests and gentle slopes at elevations of 200-600 m. Brown soils consist of brown stony loam topsoils overlying yellowish brown stony clay subsoils. Black soils consist of a dark grey to black clay topsoils which develop into a yellowish brown clay subsoils at about 35 cm, often containing carbonate deposits. Basalt stones are common at the soil surface above elevations of 600 m. Brown soils support unimproved pastures, whilst productive improved pastures and crops are often grown on the black cracking soils.

Alluvial soils

Alluvial soils occur throughout the Midlands at elevations of about 150-250 m. Doyle (1993) provides a cross-sectional depiction of alluvial soils of the Launceston Tertiary Basin (figure 4.3), which corresponds to many of the alluvial soils encountered in the Midlands. A sequence of river terraces evolved during the Tertiary period and increase in fertility as altitude decreases. The oldest and highest of these terraces is the Woodstock surface (Nicolls, 1958) which occurs at elevations ranging from 170-240 m and are characterised by the presence of ferruginous gravels in the upper profile. Surface soils are brownish grey loamy sands overlying grey-brown sandy loams or sands which rests on friable clay subsoils. The prevalence of ferruginous gravels and in places ferricrette in these soils, and their low fertility restrict their use to extensive grazing and forestry. Small areas of lateritic krasnozems occur in association with these soils where dolerite crops out.

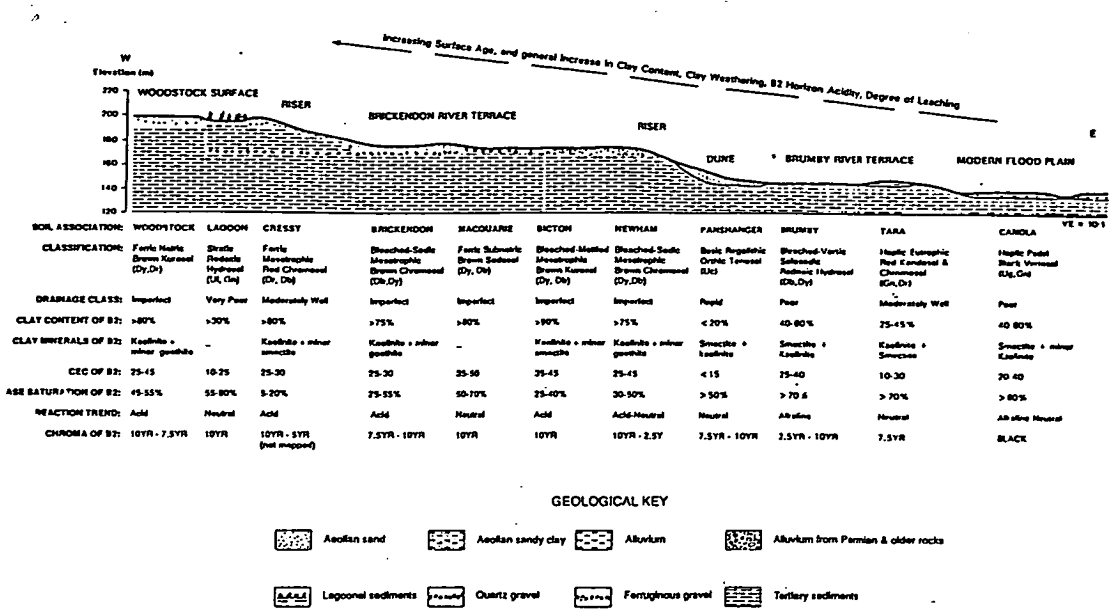


Figure 4.3: Cross section of alluvial soils encountered in the Launceston Tertiary Basin (Doyle, 1993).

At a lower level on the Brickendon surface the ferruginous gravels are largely replaced by quartz gravels and a lighter textured topsoils of very dark grey sand of the Brickendon soils (Nicolls, 1958). These soils are also utilised for grazing and timber harvesting.

Below the Brickendon surface (140-180 m a.s.l.), are the alluvial solodic soils developed on the Brumby surface (Nicolls, 1958). The topsoil consists of greyish brown sandy loam overlying a bleached grey sandy loam or loamy sand containing some ferruginous nodules. The bleach horizon overlies mottled yellowish brown to olive brown heavy clays. These solodic soils often suffer from perched watertables, and are utilised for both the establishment of improved pastures and cereal cropping.

Black soils derived from alluvium constitute the most recently formed flood plain, named the Canola surface (Nicolls, 1958). These soils have deep topsoils and occur below 140 m elevation and consist of light to heavy clays throughout the profile. Alluvial black soils are utilised for a variety of grazing and cropping pursuits but are prone to flooding.

Deposits of windblown sands (Panshanger soils, Nicolls, 1958) can be found on all of the alluvial surfaces and flanking many hillslopes. Weakly developed, deep grey-brown sandy topsoils overlie clay subsoils at 0.75-1.0 m. These soils are utilised for grazing and cropping, such as cereals and more recently for potatoes, but they are particularly susceptibility to summer dryness and wind erosion.

4.4 Climate

Rainfall

The average annual rainfall of the Midlands varies from 430 to 691 mm (table 4.1). The central Midlands receives the least rainfall due the 'rain shadow' effect of the Western Tiers which extends north-east from Melton Mowbray and Jericho to Oatlands and York Plains. Further south, a similar effect due to Mt Field is concentrated around Ouse and Hamilton in the Derwent Valley (Bureau of Meteorology, 1972).

Table 4.1: Average annual rainfall for the Midlands (Bureau of Meteorology, pers. comm.; Department of Primary Industry and Fisheries, unpublished).

Meteorological Station	Rainfall (mm p.a.)	Years of record
Perth	691	53
Campbell Town	543	77
Oatlands	558	110
Tunbridge	470	20
Ross	515	77
Bothwell	559	79
New Norfolk	430	13

Rainfall distribution is fairly even over the year, apart from in the extreme northern Midlands where winter rainfall exceeds that of summer (Appendix 1).

Temperature

Average temperatures range from a maximum of 25 ^{o}C in the spring and summer, to a minimum of 0 ^{o}C during winter (Appendices 2 and 3). Extremes of -1 ^{o}C and 38 ^{o}C have also been recorded (Bureau of Meteorology, 1972).

The elevation and location of the Midlands renders it susceptible to frosts from late autumn to early spring. Oatlands records an average of 83 frosts per year, which increase in frequency from June to August. Snowfalls rarely occur in the northern Midlands, whilst an average of 4 snow falls per year occur at Oatlands which usually only persist for a few days. The relative humidity ranges from 44 % over summer to 70 % in the winter months.

4.5 Vegetation

The native vegetation of the Midlands is comprised of sclerophyll forest or savannah woodland. The higher rainfall, more fertile areas support sclerophyll forest species dominated by Ash (*Eucalyptus obliqua*, *E. delegatensis* and *E. pauciflora*) or Peppermint (*E. amygdalina*) eucalypts with a ground cover of *Banksia*, *Exocarpus*, *Bursaria* and *Casuarina* (Jackson, 1981).

A shift to savannah woodland occurs with decreasing rainfall and increasing fire frequency. Eucalyptus species such as *E. pauciflora* and *E. ovata* occur with a ground cover of medium to low shrubs or native grasses of *Poa caespitosa*, *Themeda australis* and *Danthonia* spp. (Cowie, 1961).

4.6 Landuse

The Midlands is utilised predominantly for sheep grazing, but also for an assortment of cereal, vegetable and horticultural pursuits (table 4.2). Almost one third of Tasmania's wool clip is derived from this area (Australian Bureau of Statistics, 1993).

Cropping also facilitates diversification and may provide additional feed for livestock during the colder winter months. Grain crops include legumes and cereals, particularly oats, whilst poppies are also extensively grown throughout the area. Intensive cultivation of vegetables and fruit crops also occurs in the southern municipality of Richmond.

Table 4.2: Agricultural land use in the Midlands[1], 1991-1992 (Australian Bureau of Statistics, June 1993).

General agricultural land use	Midlands	% of Tasmania[2]
Agricultural establishments (no.)	310	9
Area of crops ('000 ha)	15.5	20.4
Area of sown pasture ('000 ha)	192.6	23.2
Balance of establishments ('000 ha)	249.8	26.6
Total area ('000 ha)	457.6	24.8
Area of selected crops		
Barley-grain (ha)	3898.5	34
Oats-grain (ha)	3998.0	44
Others-grain (ha)	622.5	26
Cereals for hay (ha)	152.0	20
Cereals fed off, green feed (ha)	2900.5	39
Total of all cereals (ha)	10647.5	33
Vegetables		
Onions, white and brown (ha)	28.0	2
Peas, green (ha)	250.0	5
Potatoes (ha)	391.0	7
Other vegetables (ha)	89.5	4
Total vegetables (ha)	758.5	5
Other crops		
Fruit, including grapes (ha)	30.0	1
Legumes for grain (ha)	245.0	21
Oil poppies (ha)	1108.5	15
Crops for stock feed (ha)	2299.5	20
Vegetables for seed (ha)	117.5	17
Other crops (ha)	172.0	6
Total other crops (ha)	3972.0	17
Livestock numbers		
Beef cattle	33293	7
Dairy cattle	548	0.4
Total cattle	33841	6
Sheep	1054186	31
Lambs	296429	32
Total sheep	1350615	31

[1] based statistics from Campbell Town, Oatlands, Ross, Bothwell, Green Ponds, Brighton and Richmond municipalities.

[2] % of the total for Tasmania.

4.7 Earthworm populations

Temple-Smith and Kingston (unpublished) conducted a survey of earthworms in the Midlands during 1989-1990 and reported low population densities and species diversity. The earthworm composition of the Midlands is dominated by introduced earthworm species (table 4.3), as populations of native species have been reduced following deforestation and implementation of modern agricultural practices. Earthworm populations are distributed throughout the Midlands occupying 95 % of sites sampled. The most widespread species was *A. trapezoides*, inhabiting 55 % of sites sampled, followed by *A. caliginosa* which occupied 52 %, but species diversity is low, with < 5 % of sites containing four or more earthworm species, 15 % for three species, 40 % for two species, 30 % for one species and 9 % of sites competely devoid of earthworms. Compared to the higher rainfall regions of northern Tasmania, *A. trapezoides* is more widespread in the Midlands, whilst *A. longa* and *L. rubellus* occupy fewer sites than in northern Tasmania. In areas of comparable rainfall in N.S.W, Victoria and South Australia, the distribution of earthworms is similar to that of the Midlands (table 4.3). However, *Microscolex phosphoreus* and *M. dubius* which were not found in Tasmanian pastures, were recovered from N.S.W., Victorian and South Australian pastureland. McCredie et al. (1992) (not presented in tables 4.3 and 4.4) has also reported *M. dubius* in Western Australian pastures.

The average earthworm density for the Midlands was $101/m^2$ (range $0\text{-}565/m^2$), with *A. caliginosa* recording the highest mean density of $71/m^2$ (table 4.4) and the highest maximum of $395/m^2$ (Temple-Smith and Kingston, unpublished). Earthworm numbers in the Midlands are lower than the higher rainfall regions of northern Tasmania, but comparable to populations in the pastures of South Australia, southern N.S.W. and northern Victoria (table 4.4). In contrast, the more fertile, higher rainfall areas of Europe and the United Kingdom support 5-10 different earthworm species reaching densities of up to $2000/m^2$ (Lee, 1985).

The total number of all earthworm species in the Midlands was positively correlated with the % clay content of the soil (Temple-Smith and Kingston, unpublished). The number of *A. trapezoides* was positively correlated with conductivity, organic carbon, P, K and total N, but was negatively correlated with the C:N ratio of the soil. Organic carbon was also positively correlated with numbers of *L. rubellus* and *O. cyaneum*, which have low population densities and are poorly distributed in the Midlands. No significant correlation between pH and total earthworm number was found.

Table 4.3 Earthworm population distribution in pasture soils of Tasmania and southern Australia (Temple-Smith, 1991; Baker 1991; Mele, 1991; Kingston, pers. comm.).

Region	Sites occupied (%)									
	A. caliginosa	A. trapezoides	A. longa	L. rubellus	O. cyaneum	A. rosea	A. chlorotica	M. phosphoreus	M. dubius	Native
Midlands	52	55	5	20	10	<1	<1	0	0	20
Nth Tas	68	14	34	55	26	4	2	0	0	9
NSW/Vic	60	96	0	11	0	29	0	56	56	60
Sth Australia	36	95	0	0	<1	38	0	24	61	37

Table 4.4 Mean earthworm population densities in pasture soils of Tasmania and southern Australia (Temple-Smith, 1991; Baker 1991; Mele, 1991; Kingston, pers. comm.).

Region	Mean earthworm density (no./m^2)									
	A. caliginosa	A. trapezoides	A. longa	L. rubellus	O. cyaneum	A. rosea	A. chlorotica	M. phosphoreus	M. dubius	Native
Midlands	71	31	9	8	3	25	2	0	0	19
Nth Tas	248	50	51	60	29	<20	<20	0	0	<20
NSW/Vic	55	48	0	2	0	10	0	5	2	38
Sth Australia	24	96	0	0	2	26	0	<1	6	14

V. POPULATION DYNAMICS OF EARTHWORMS IN THE MIDLANDS

5.1 Introduction

Since European settlement, Australia's agricultural soils have deteriorated due to increased soil erosion, acidity, salinity, compaction and sodicity (Stace *et al.* 1968; Abbott, *et al.* 1979). Amelioration of soil degradation in the past has utilised chemical and physical soil amendments, such as lime, deep ripping and direct drilling. However, increasing attention is being directed into the potential of soil fauna to alleviate many of Australia's soil degradation problems.

Earthworms constitute a substantial proportion of the soil biota, exerting significant chemical, physical and biological effects on the soil (Edwards and Lofty, 1977; Syers and Springett, 1983; Lee, 1985). In order to optimise earthworm activity in Australia's agricultural systems and predict population responses to experimental treatments, fundamental understanding of earthworm ecology is required. These studies in the past have concentrated on the examination of European lumbricids which readily invade newly developed agricultural land. A great majority of the indigenous earthworm species of Australia cannot persist following the removal of native vegetation and implementation of modern agricultural practices (Abbott and Parker, 1980; Mele, 1991; Baker *et al.* 1992a, 1992b, 1993a; McCredie *et al.* 1992). This is certainly the case in Tasmania. The population dynamics of *Aporrectodea caliginosa* and *Lumbricus rubellus* have been studied in the high rainfall regions of Tasmania by Kingston (1988), yet the lower rainfall region (< 600 mm p.a.) of the Midlands of Tasmania has escaped attention. This study examines the population dynamics of the most common introduced earthworm species found in the Midlands.

5.2 Materials and methods

Earthworms were sampled from 14 permanent pastures in the Midlands from May 1992 until November 1993. Total earthworm numbers at sites were above average (> 200/m^2) for the Midlands (Temple-Smith, 1991). Appendix 8 shows sites varied from duplex soils with brown clay B horizons (Dy) to uniform fine textured cracking clays (Ug) (Northcote, 1984).

A reference line of 100 m was pegged out across each site and sampling was replicated at ten randomly selected points along this line. Sampling occurred monthly and involved removal of earthworm cocoons, juveniles and adults from a 0.04 m^2 excavation to a depth of 150 mm to determine earthworm number, mass and stage of maturity for individual species. Gravimetric moisture determination was measured for each site (Appendix 7) and matric suctions (soil pF) were determined using the filter paper technique (Greacen *et al.* 1989). Curves relating soil pF to gravimetric moisture contents were calculated to enable a comparison of mositure availability between sites, regardless of texture.

An estimate of cocoon incubation time was obtained by retaining a mixture of 17 *A. caliginosa* and *A. trapezoides* cocoons from field sampling in July and August, 1992. Cocoons were kept in the laboratory at 16^{o} in 30 ml vials with a small amount of water to prevent dehydration, and monitored daily to determine hatching time.

5.3 Results

Earthworm density and biomass

The density and biomass of each earthworm species was averaged over sites since the population dynamics of individual earthworm species was similar between sites and soil type (data files stored on D.P.I.F. mainframe). *Aporrectodea caliginosa* (figures 5.1a and b) and *A. trapezoides* (figures 5.2a and b) were the most common species found in the Midlands, whilst *Octolasion cyaneum* (figures 5.3a and b) and *Lumbricus rubellus* (figures 5.4a and b) were also found but combined constituted less than 15 % of the total earthworm population. *A. caliginosa* was the most abundant species (up to 173.8/m^2 or 55.06 g/m^2), followed by *A. trapezoides* (up to 86/m^2 or 52.30 g/m^2), *O. cyaneum* (up to 22/m^2 or 13.00 g/m^2) and *L. rubellus* (up to 31/m^2 or 13.58 g/m^2). *A. rosea* was also recovered, but only in August and September, 1993 (up to 17.5/m^2 or 14.25 g/m^2) at two sites. *A. caliginosa*, *A. trapezoides* and *O. cyaneum* were present at all 14 sites, whilst *L. rubellus* occurred at two sites (sites 8 and 9, Appendix 8). Maximum earthworm activity (all species combined) was 260/m^2 or 91.51 g/m^2 (915 kg/ha) in August 1993.

The total density and biomass of all earthworms was significantly ($P<0.001$) correlated to soil moisture content through time (figure 5.5a and b). This trend was consistent for each earthworm species, apart from numbers of *L. rubellus*. The number and biomass of the most abundant species, *A. caliginosa* and *A. trapezoides*, was highest during winter and early spring (May to October in 1992, and July to September in 1993) and decreased significantly ($P<0.05$) to a minimum in late spring and summer (October to April in 1992/93). The density and biomass of these species increased significantly ($P<0.05$) by early winter in 1993 when most earthworms resumed activity as soil moisture increased. The number and biomass of *A. caliginosa* and *A. trapezoides* did not differ significantly during the winter/spring activity, or the summer dormancy period, apart from a significant ($P < 0.05$) peak in earthworm activity in August 1992 and 1993 for both species.

Population dynamics of the less abundant species, *O. cyaneum* and *L. rubellus* exhibited a similar pattern to *A. caliginosa* and *A. trapezoides*, but were generally less variable due to the lower population densities encountered. L.S.D.'s were not calculated for *L. rubellus* numbers or biomass due to insufficient numbers and the erratic population growth of this species (figures 5.4a and b). The number and biomass of *O. cyaneum* and *L. rubellus* did not differ significantly from 1992-1993, apart from a significant ($P < 0.05$) peak in the numbers of *O. cyaneum* in October 1992 (figures 5.3a and b).

Cocoons produced by *A. caliginosa* and *A. trapezoides* were found in 1992 and 1993, but could not be recovered in the field for *O. cyaneum* and *L. rubellus* due to their small size and discreet colour. Production of cocoons by *A. caliginosa* and *A. trapezoides* in 1992 and 1993 coincided with maximum earthworm activity during winter and early spring. Cocoons persisted up until February in 1992 for both species, but were only found until October in 1993 for *A. trapezoides*. Mean hatching time of cocoons was 60 days (Appendix 4), which did not differ significantly between species.

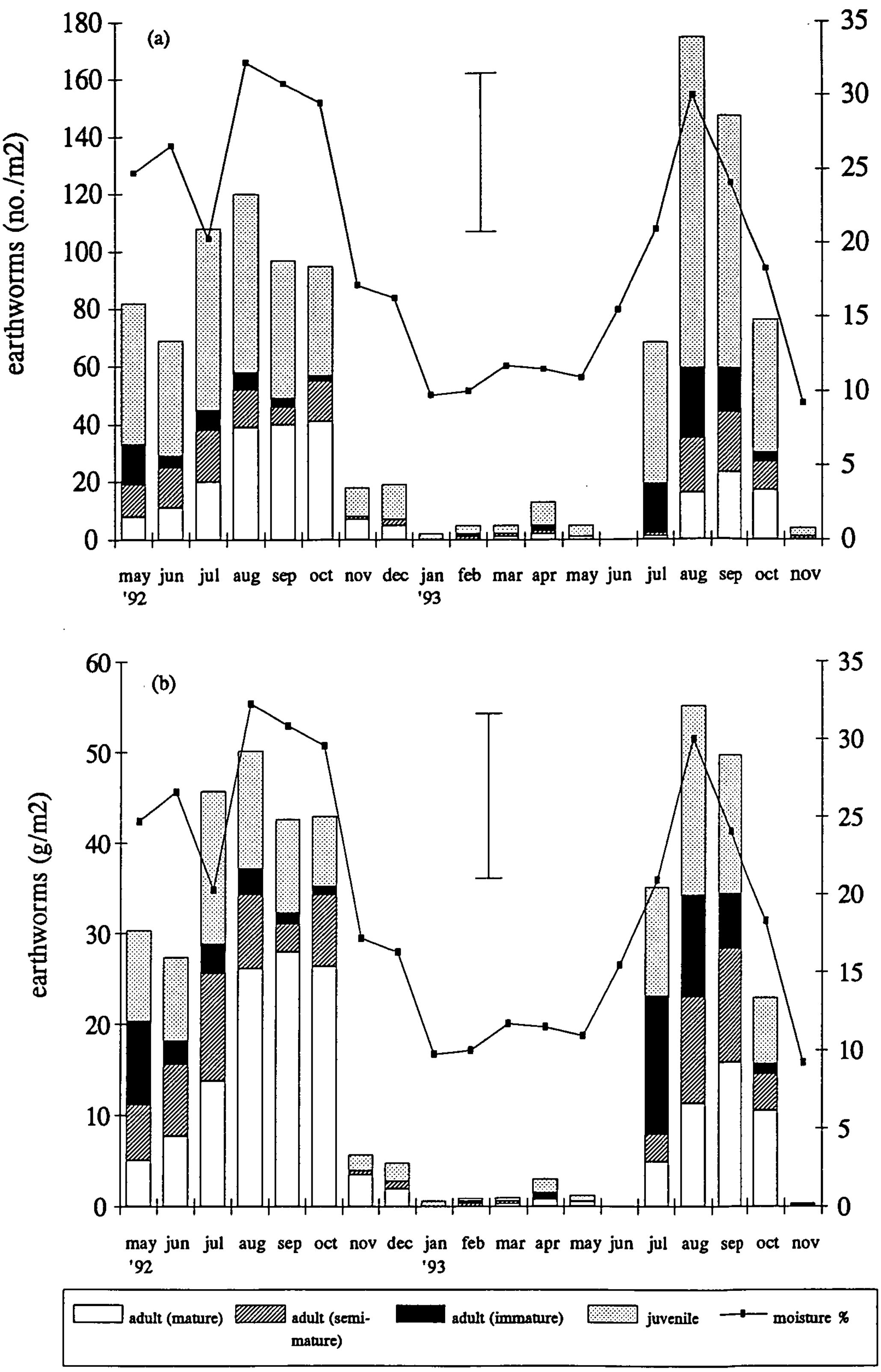


Figure 5.1: Mean (a) density and (b) biomass of *A. caliginosa* from 14 sites in the Midlands in 1992-1993 (error bars represent 5 % L.S.D.'s for comparison of totals between months).

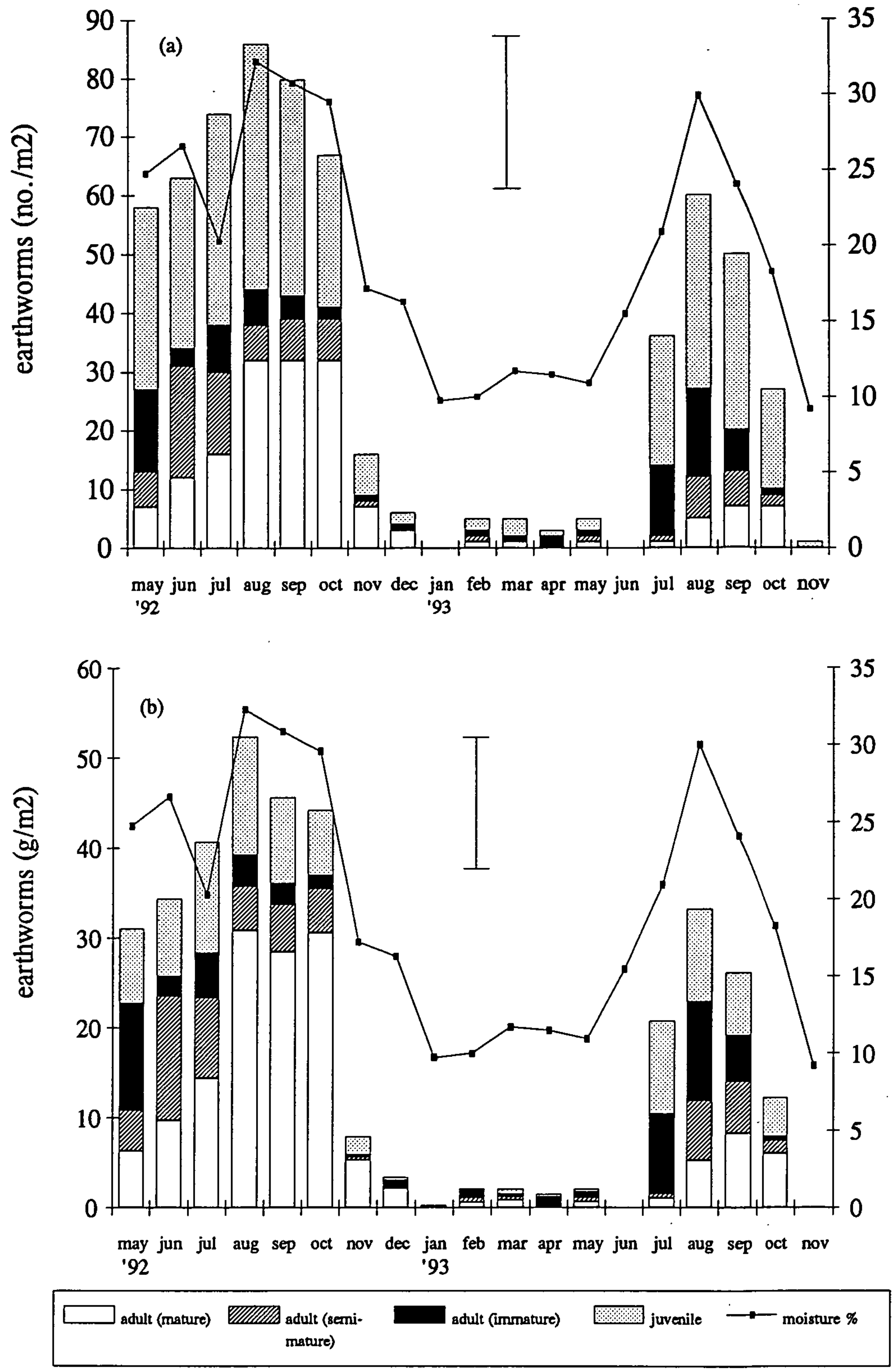


Figure 5.2: Mean (a) density and (b) biomass of *A. trapezoides* from 14 sites in the Midlands in 1992-1993 (error bars represent 5 % L.S.D.'s for comparison of totals between months).

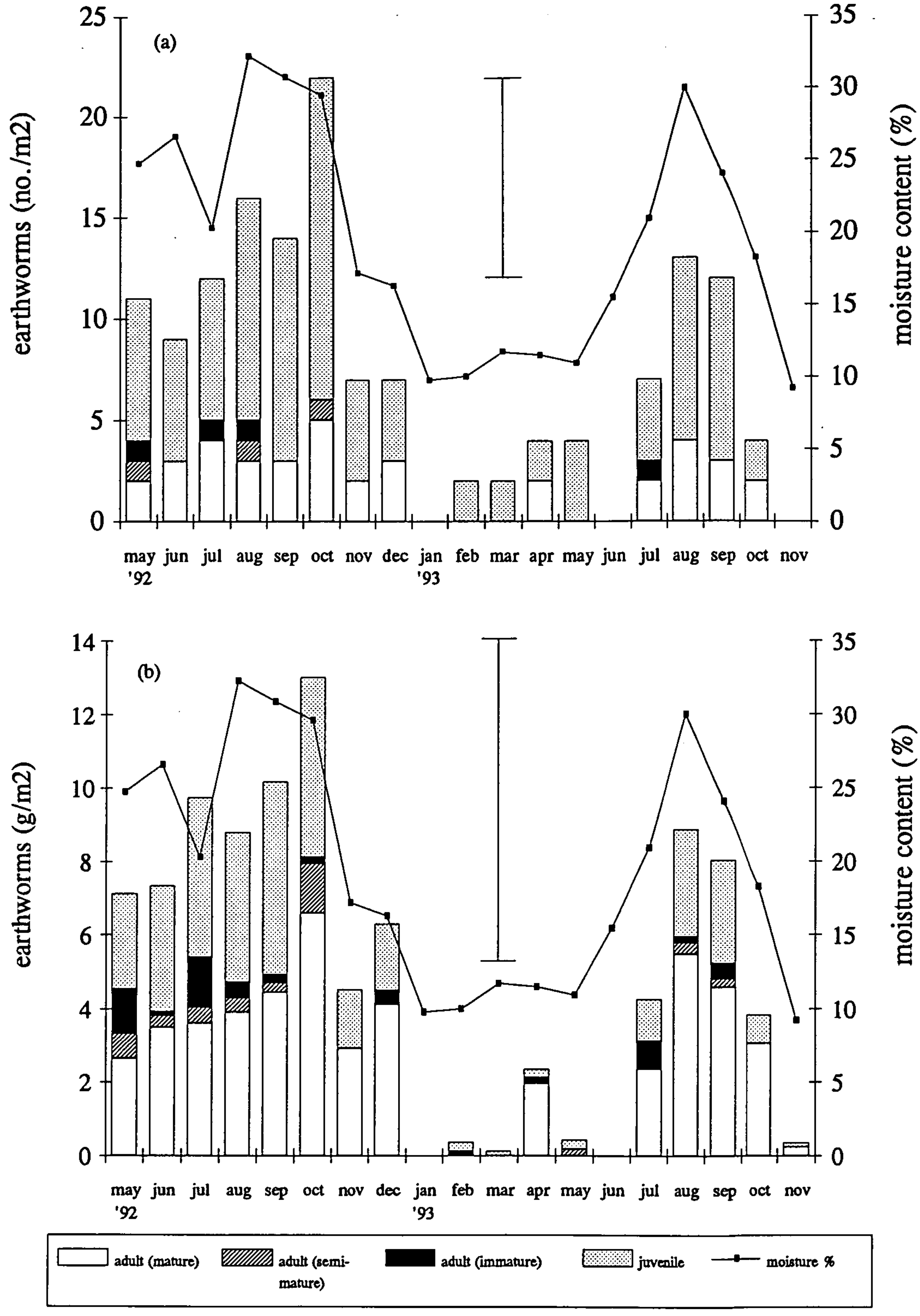


Figure 5.3: Mean (a) density and (b) biomass of *O. cyaneum* from 14 sites in the Midlands in 1992-1993 (error bars represent 5 % L.S.D.'s for comparison of totals between months).

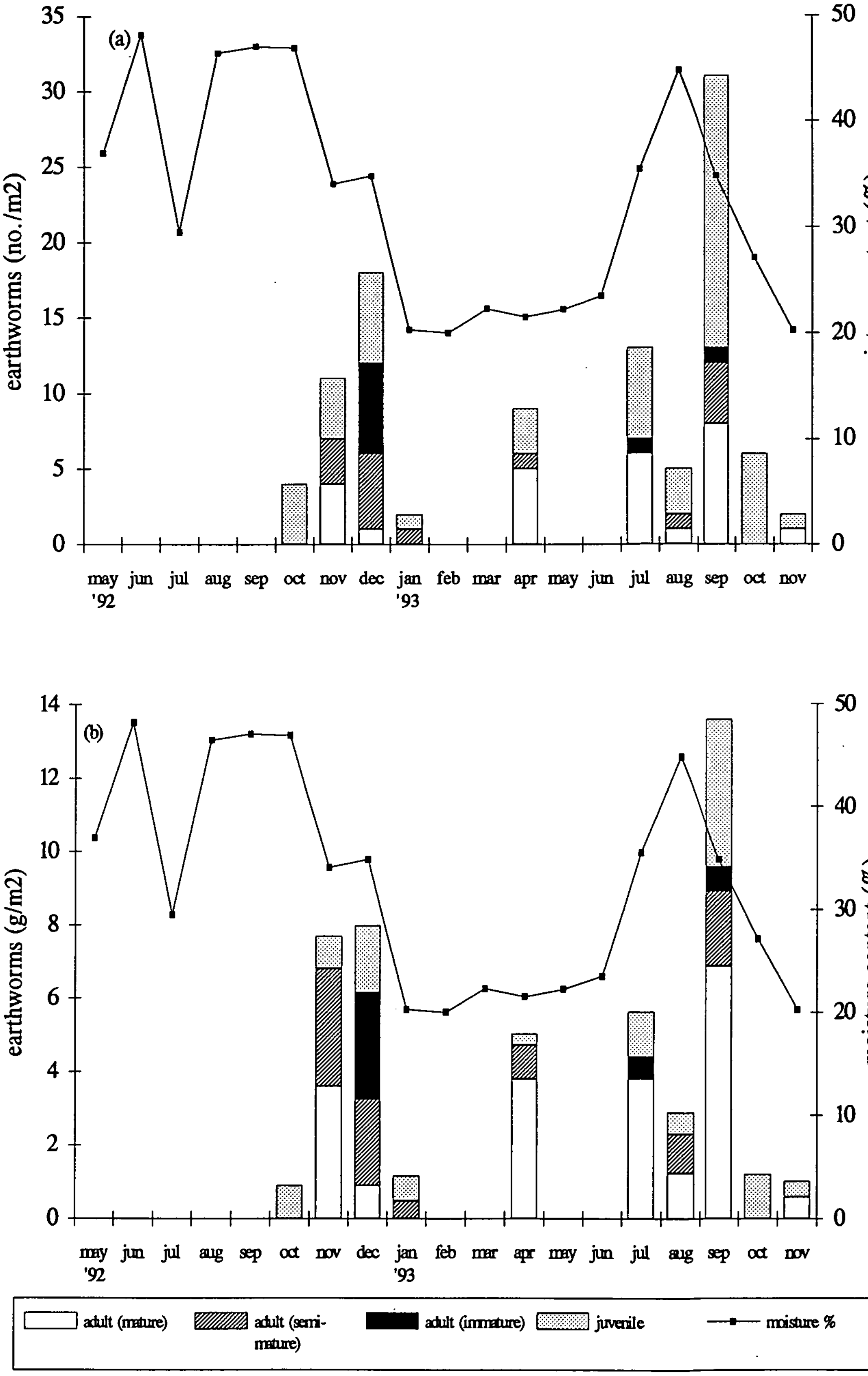


Figure 5.4: Mean (a) density and (b) biomass of *L. rubellus* from sites 8 and 9 in the Midlands in 1992-1993.

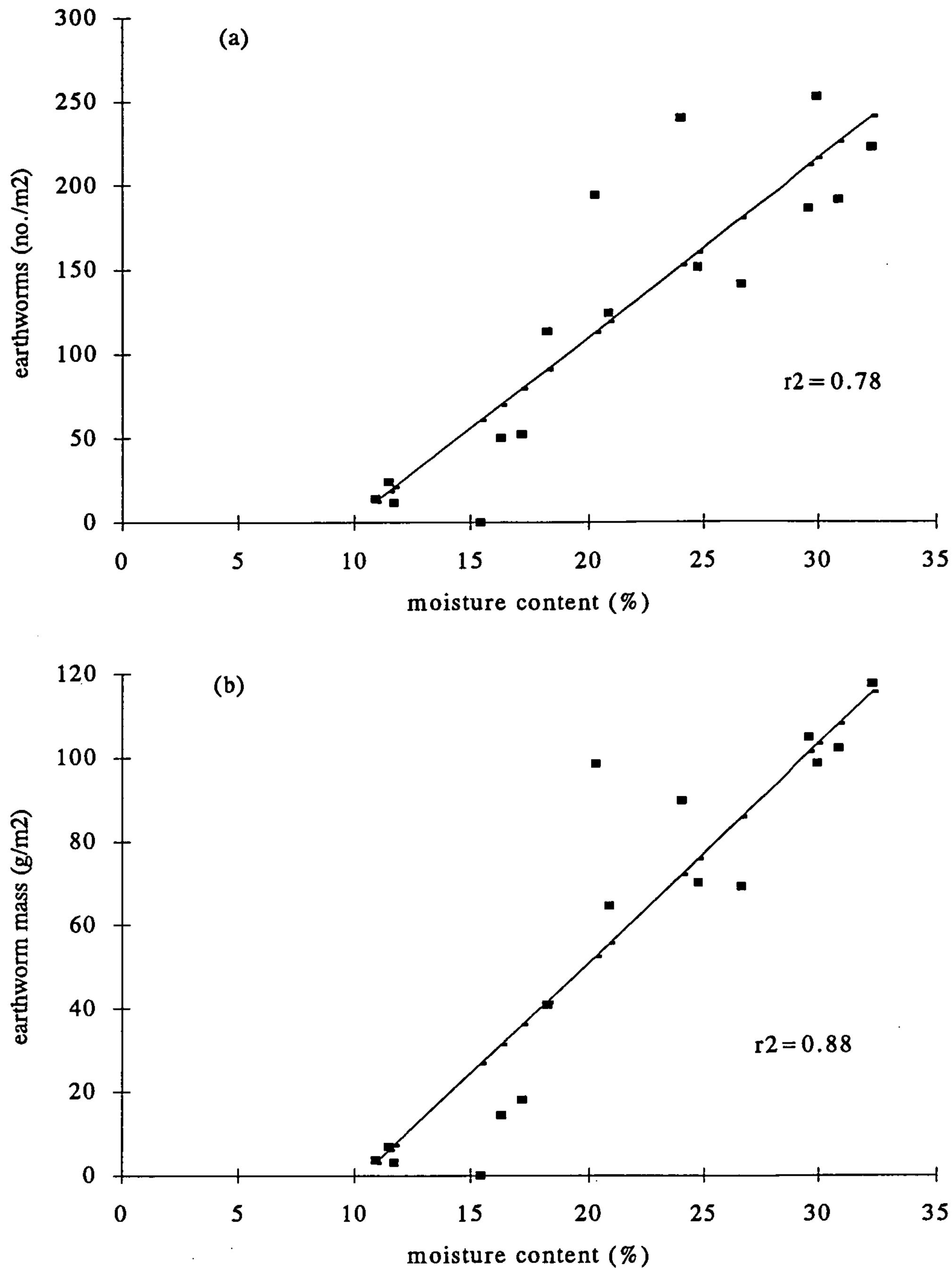


Figure 5.5: Relationship between soil moisture (%) and (a) total earthworm numbers and (b) biomass in the Midlands in 1992 and 1993.

Population structure

The two most common earthworm species found in the Midlands, *A. caliginosa* and *A. trapezoides* demonstrated similar changes in population structure during 1992 and 1993. The proportion of adult *A. caliginosa* and *A. trapezoides* increased during the winters of 1992 and 1993. Following the initiation of earthworm activity in the soil surface in May 1992, the number of juveniles was significantly ($P<0.05$) greater than numbers of adults. Yet, by August 1992, the numbers of adult *A. caliginosa* and *A. trapezoides* had significantly ($P<0.05$) increased, resulting in similar densities of adult and juveniles. By October 1992, the number of adults was significantly ($P<0.05$) greater than juveniles for *A. caliginosa*, and by September for *A. trapezoides*. With the initiation of drier weather in late spring and early summer, soil pF increased to 2.5-3.5 across all sites (Appendix 9) provoking most earthworms into entering aestivation at a depth of > 150 mm. This resulted in similar numbers of active adults and juveniles remaining in the surface soil, whilst most of the population was in aestivation further down the profile.

A similar pattern emerged in 1993, however due to the low winter rainfall, earthworm activity in the surface soil of all sites was evident from only July to October. This shorter earthworm season restricted time available for adult development, resulting in a greater number of juveniles than adults throughout 1993 for *A. caliginosa*, yet the number of adult *A. trapezoides* exceeded juveniles by October.

Population dynamics of the less common earthworm species, *O. cyaneum* and *L. rubellus*, showed less variation. There were a significantly ($P<0.05$) greater number of *O. cyaneum* juveniles than adults throughout 1992 and 1993, apart from late spring and summer when numbers did not differ. Numbers of adult and juvenile *O. cyaneum* remained static throughout 1992 and 1993, apart from a significant ($P<0.05$) increase in October 1992. There were no consistent changes in the population structure of *L. rubellus* during 1992 and 1993, due to the low population densities encountered.

Soil type

Soils from all sites were categorised as either sand, loam or clay, on the basis of soil profile descriptions (Appendix 8) to examine the effect of soil type on earthworm populations. Of the 14 sites, one was categorised as a sand, seven as loam and six as clay. Earthworm number and biomass did not differ significantly between soil types, however the number and biomass of *A. caliginosa* (figures 5.6a and b) and *O. cyaneum* (figures 5.8a and b) were consistently lower on the sandy soil (site 12) compared with all sites combined in 1992 and 1993. The number and biomass of *A. trapezoides* (figures 5.7a and b) was similar on all soil types encountered. There was also fewer juveniles recovered from the sandy soil, particularly for *A. caliginosa*. Figures for the sandy soil are presented on the same scale as for all sites combined (figures 5.1-5.4) to highlight differences between soil types. No L.S.D.'s were calculated due to the insufficient numbers encountered.

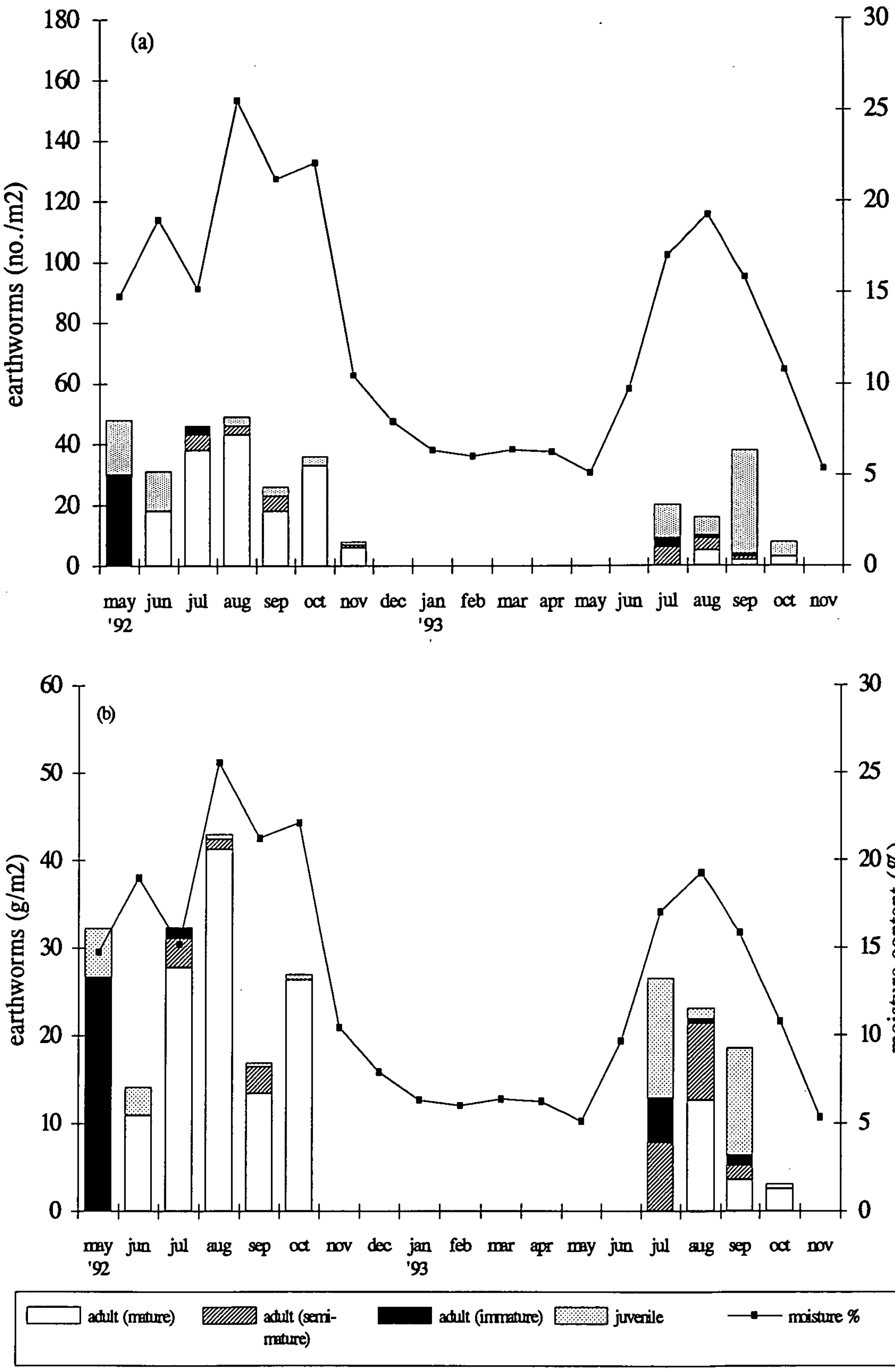
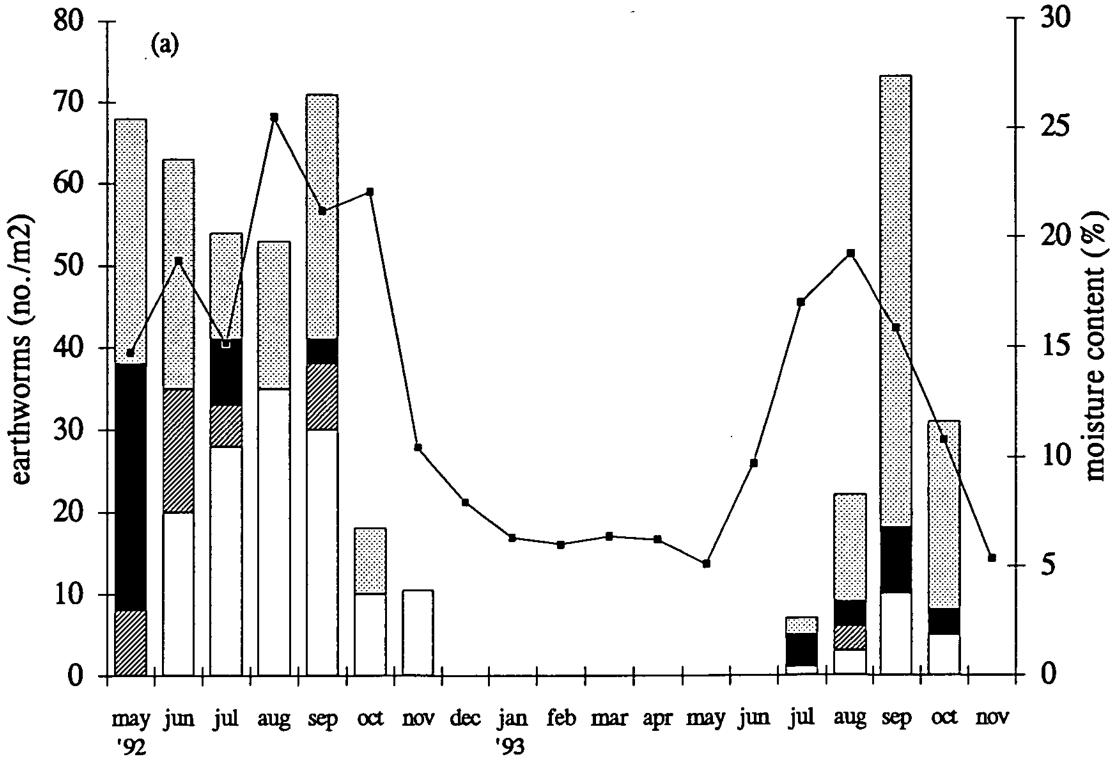


Figure 5.6: Mean (a) density and (b) biomass of *A. caliginosa* in a sandy soil in the Midlands in 1992-1993.



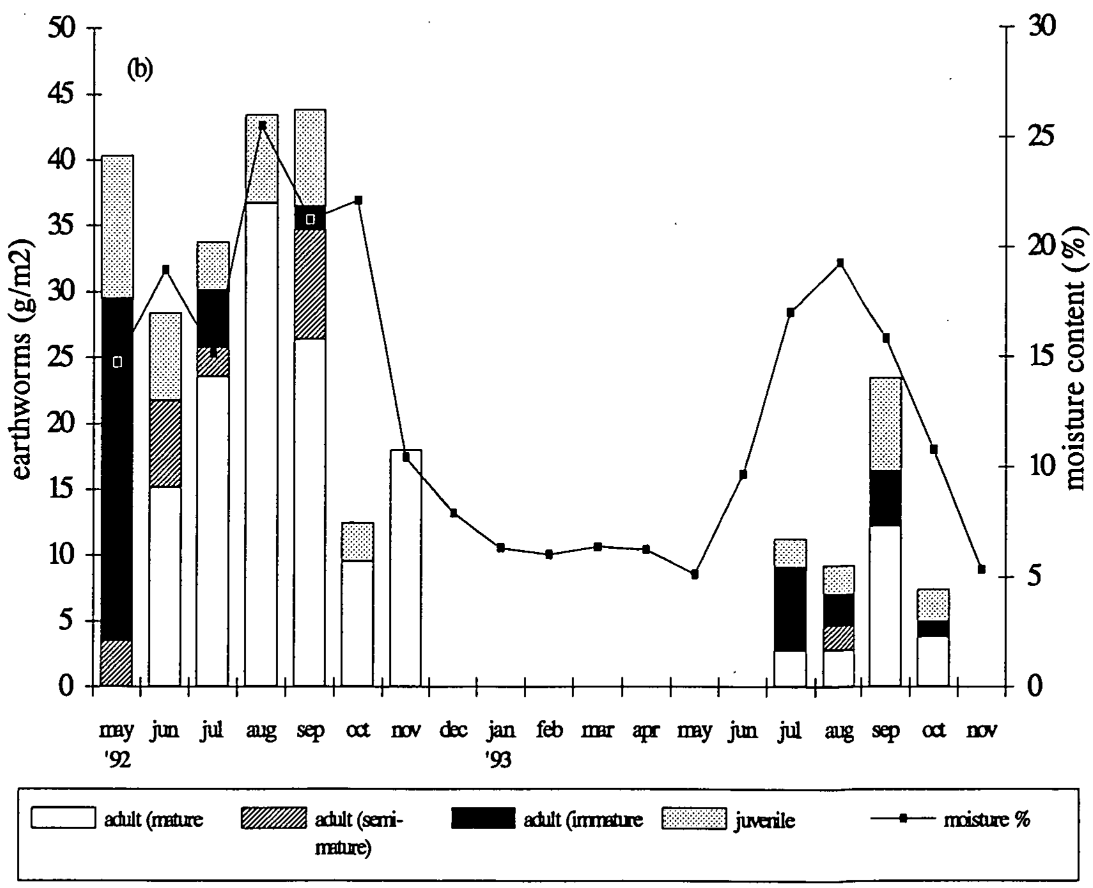


Figure 5.7: Mean (a) density and (b) biomass of *A. trapezoides* in a sandy soil in the Midlands in 1992-1993.

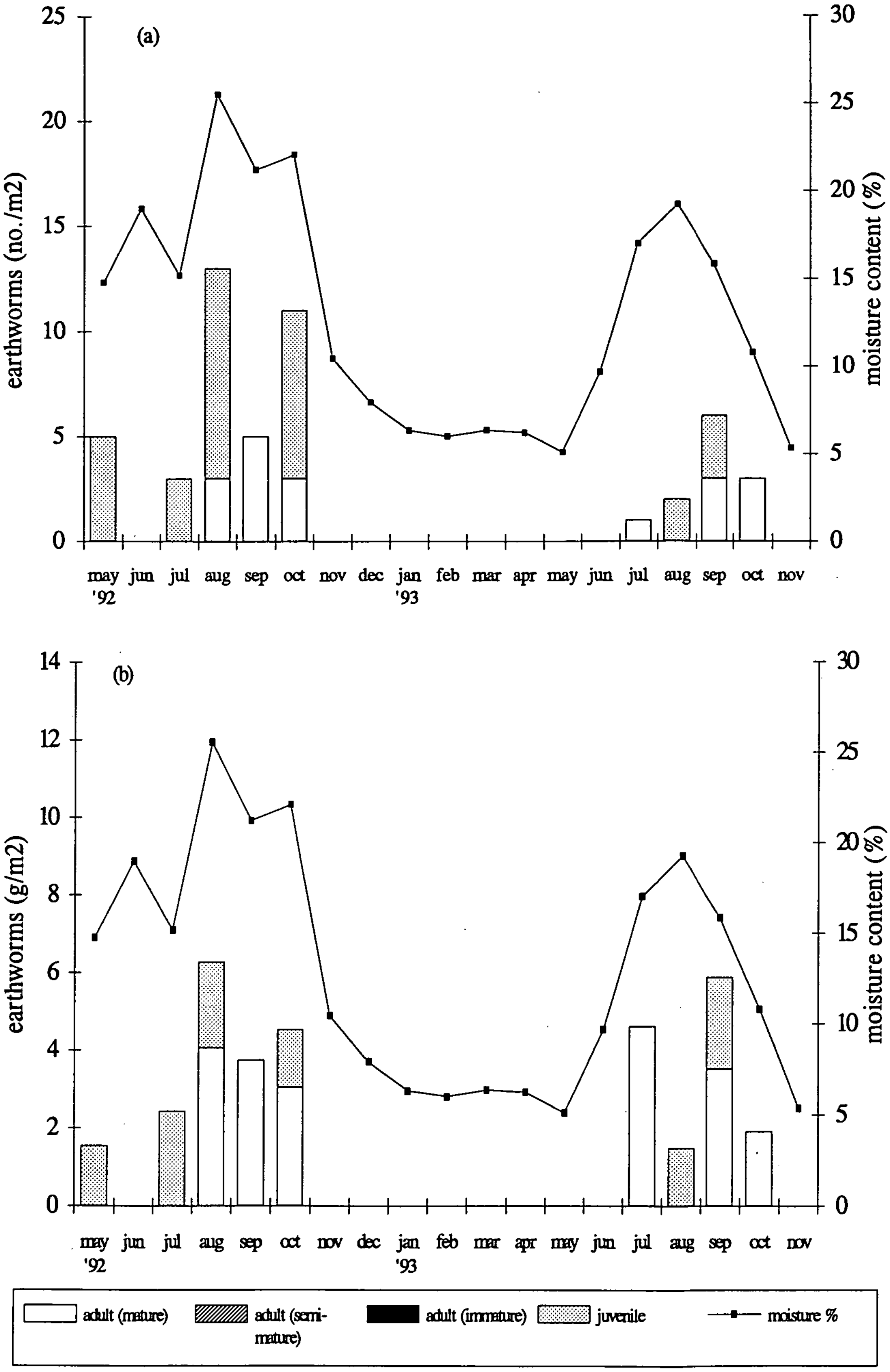


Figure 5.8: Mean (a) density and (b) biomass of *O. cyaneum* in a sandy soil in the Midlands in 1992-1993.

Effect of rainfall on earthworm distribution

The mean number of earthworms for individual earthworm species was calculated for each site for 1992 and 1993 to examine the effect of rainfall variability between sites on earthworm density. Mean annual rainfall for each site was determined from long-term property records at each site. Over a range of 425-600 mm rainfall p.a., a weak but significant ($P<0.01$) increase in the mean numbers of *A. caliginosa* and *O. cyaneum* was found with increasing rainfall in 1992 and 1993. The behaviour of *A. caliginosa* and *O. cyaneum* to rainfall was not significantly different and was consequently fitted to a single regression line. Numbers of *A. trapezoides* was unaffected by rainfall over the same range (figure 5.9).

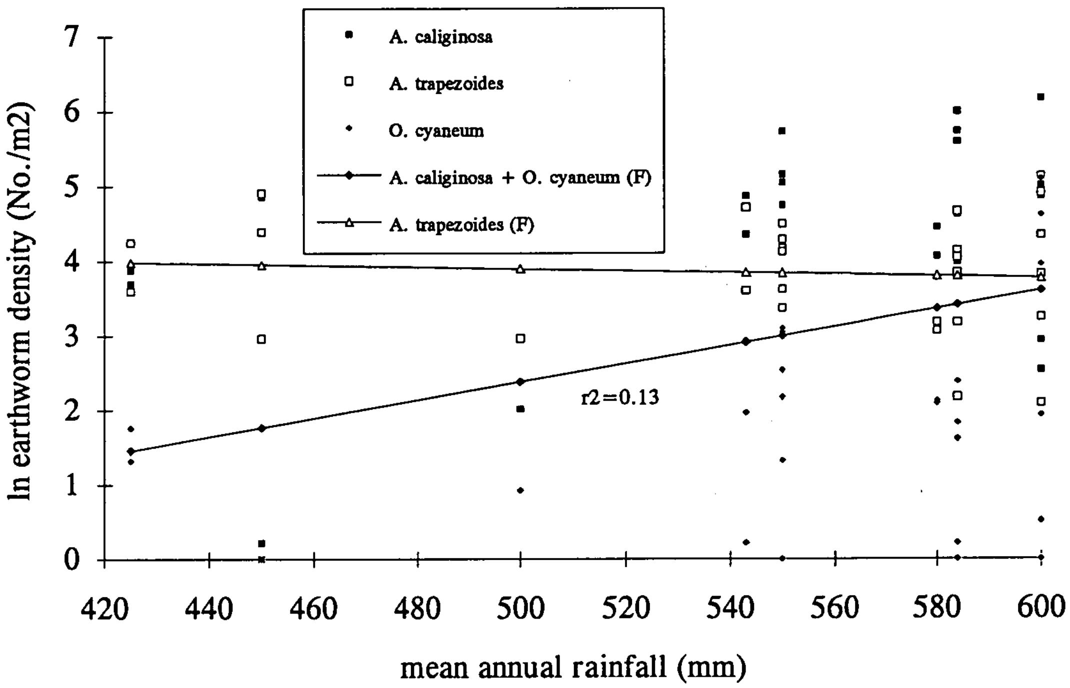


Figure 5.9: Effect of rainfall on the mean density of earthworms (no./m^2) in 1992 and 1993 (F denotes fitted values).

5.4 Discussion

Changes in the population dynamics of *A. caliginosa*, *A. trapezoides*, *O. cyaneum* and *L. rubellus* in the Midlands follow a similar pattern to other earthworm studies in permanent pastures and cropping soils of southern Australia (Mele, 1991; Baker *et al.* 1992a, 1993b, 1993c; Buckerfield, 1992; McCredie *et al.* 1992). These studies have also reported similar population densities and increases in the proportion of adults in the population during the year. A survey of earthworm populations in the Midlands by Temple-Smith and Kingston (unpublished) found lower earthworm population densities ($120/m^2$) than those reported in this study ($260/m^2$). However, pasture sites with high population densities were chosen in this study to enable seasonal trends to be clearly identified. Sites in the present study were also sampled on several occasions in contrast to Temple-Smith and Kingston. Earthworm density and biomass in the Midlands was greatest during the wetter months of winter and early spring, and decreased to a minimum during late spring and summer when mean soil pF > 3.3 (Appendix 9) and soil temperatures reached 17-20^oC (Bureau of Meteorology, pers. comm.). Aestivation was initiated at soil pF values between 2.5 and 4.0. This agrees with Nordstrom (1975), who found initiation of earthworm aestivation at pF > 3.2-3.5 and temperatures above 14-16^oC, whilst Nordstrom and Rundgren (1972) recorded earthworm inactivity at soil pF of 4.0 and a temperature of 17^oC. Given the reliance of earthworms on maintaining internal soil moisture levels for gaseous exchange, N excretion, locomotion and burrowing (Satchell, 1967), the highly significant correlation ($P<0.001$) of earthworm density and biomass to soil moisture is not surprising.

Earthworm communities in the Midlands are dominated by *A. caliginosa* and *A. trapezoides*, with *O. cyaneum* and *L. rubellus* comprising < 15 % of the total population (figures 5.1-5.4). This species diversity is similar to that of southern Australia, apart from the absence of *Microscloex dubius* and *M. phosphoreus* (Abbott and Parker, 1980; Mele, 1991; Baker *et al.* 1992a, 1992b, 1993b, 1993c; McCredie *et al.* 1992). *A. rosea* was also largely absent from the Midlands, as is the case in northern Victoria and southern N.S.W. where low population densities of *A. rosea* ($10/m^2$) were recovered from only 20 % of sites in pasture, and 22 % of cropping soils (Mele, 1991). However, *A. rosea* constitutes some of the most common earthworm species encountered in the pastoral (Baker *et al.* 1992b, 1993c) and cereal growing areas (Baker *et al.* 1993b) of South Australia under similar rainfall. The low population densities of *A. rosea* and, in particular, the absence of *Microscolex* spp. in the Midlands is unusual given the prevalence of these species under similar rainfall in areas of southern Australia.

There was a significant effect of rainfall on the population density of some earthworm species in the Midlands. A weak, but significant increase in numbers of *A. caliginosa* and *O. cyaneum* was found in the Midlands with increasing rainfall in 1992 and 1993, whilst *A. trapezoides* was largely unaffected (figure 5.9). Inclusion of sites > 600 mm rainfall p.a. may have increased the significance of this relationship. Abbott and Parker (1980) found no association between rainfall (300-600 mm p.a.) and the percentage of sites occupied by earthworms in Western Australia. However, the population consisted mainly of *A. trapezoides* and *M. dubius*, whilst *A. caliginosa* was absent.

Rainfall also affected the population dynamics of *A. caliginosa*. In 1993, the low winter rainfall reduced the activity of all earthworm species in the surface soil to four months, compared to six months in 1992. Adult development and cocoon production by *A. caliginosa* was adversely affected as a result. The shorter 'earthworm season' in 1993 resulted in a reduction in the recruitment of adult *A. caliginosa* into the population in 1993 compared to 1992. *A. caliginosa* cocoons were also not recovered in 1993; cocoons were probably present, but in sufficiently low numbers to escape detection by handsorting. Yet, *A. trapezoides* cocoons were found throughout the winter of 1993, and adult numbers increased during the year, unabated by the lower rainfall, to a peak in October when numbers of adults exceeded juveniles. The combined effects of low adult numbers and cocoon production by *A. caliginosa* due to low rainfall are probably important factors contributing to low population densities of *A. caliginosa* in the Midlands. High mortality associated with summer aestivation (see Chapter VI) places further pressure on an already fragile *A. caliginosa* population. Baker (unpublished) found *A. caliginosa* density was significantly correlated with annual rainfall ($r=0.24$), whilst *A. trapezoides* was unaffected. Densities of *A. caliginosa* > 200/m^2 were restricted to sites with an annual rainfall > 650 mm p.a. It was therefore encouraging to find populations of up to 174/m^2 in < 600 mm p.a. rainfall in the Midlands. Several other studies have noted that populations of *O. cyaneum* (Baker *et al.* 1991, 1992b, 1993c) are restricted to the high rainfall regions in South Australia and Western Victoria, and resilience of *A. trapezoides* in the low rainfall areas of South Australia (Baker *et al.* 1992b) and Western Australia (McCredie *et al.* 1992). Given the dependence of *A. caliginosa*, and independence of *A. trapezoides*, on rainfall, the lower populations of *A. trapezoides* compared to *A. caliginosa* in the Midlands cannot be readily explained. It may be that whilst *A. caliginosa* is adversely affected by low rainfall, it is capable of achieving very high reproductive and growth rates

under high rainfall. In contrast, *A. trapezoides* continued to maintain similar reproduction and growth rates in this study, regardless of rainfall.
The number and biomass of *A. caliginosa* and *O. cyaneum* was consistently lower on the one sandy site in this study (site 12) compared to the remaining 13 sites comprising of loam and clay soils. It is highly probable that if additional sandy sites had been included in this study, a significant effect of soil type on earthworm density and biomass would have almost certainly been evident. The difficulty in locating sandy soils supporting high earthworm populations in the Midlands as experimental sites supports this argument. There were also fewer juveniles recovered from the sandy soil, particularly for *A. caliginosa*. Guild (1948) found lower earthworm populations in sandy soils compared to heavier textured soils. A survey of earthworm populations in the Midlands reported clay content as the most important soil characteristic determining earthworm population density (Temple-Smith and Kingston, unpublished;) whilst Baker et al. (1992b) also found earthworm density increased with increasing clay content of the soil.

The low population density of *L. rubellus* in this study indicate poor persistence of this species in the Midlands. Whilst the population density of *O. cyaneum* was also low, this species was more widespread, occurring at 10 of the sites sampled. *L. rubellus* was the least abundant earthworm species in this study (figures 5.4a and b), and was located at only two of the 14 experimental sites in the Midlands. *L. rubellus* was also the only species absent from the sandy soil in this study. This agrees with Temple-Smith (1991) who reported populations of *L. rubellus* occurring at 20 % of the sites sampled in a survey of earthworms in the Midlands, reaching densities of up to $125/m^2$. Mele (1991) also found *L. rubellus* occupied only 11 % of pasture, with a mean density of $2/m^2$ in northern Victoria and southern N.S.W. (300-1300 mm rainfall p.a.), whilst Baker et al. (1992b) failed to recover *L. rubellus* from pastures in South Australia (800 mm rainfall p.a.). However, *L. rubellus* populations in the higher rainfall regions of northern Tasmania are substantially higher (up to $225/m^2$) and more widespread, occupying 55 % of sites sampled. Lobry de Bruyn (1993) reported numbers of *L. rubellus* increased under the warm, moist conditions of irrigation, due to increased fecundity. Activity of *L. rubellus* in 1992 was certainly restricted to the warmer months of October-January, a trend which may have continued into the summer of 1993 if sampling had continued. Earlier activity in 1993 by this species was probably in response to the lack of winter rainfall received during this year. The two sites (8 and 9, of Appendix 8) in this study which supported *L. rubellus* consisted of heavier textured soils which were less prone to drying out in late spring and summer, compared to many of the other lighter textured soils used in this study. This factor, combined with the higher moisture levels at these sites, enabled survival of *L. rubellus* at low population densities in the Midlands. Both sites were located in a higher rainfall area (575-600 mm p.a.), with one site (site 8) maintaining moisture levels at soil pF $\leq$ 2.5 for most of 1992 and 1993 due to overflow from a nearby spring.

The two most common species encountered in this study in the Midlands, *A. caliginosa* and *A. trapezoides*, exhibited very different behaviour to rainfall and soil texture. *A. caliginosa* was particularly dependent on rainfall: population density, adult development and cocoon production were reduced under drier conditions in the Midlands. The density and biomass of *A. caliginosa* also tended to be lower on the sandy soil type in this study. In contrast, *A. trapezoides* density, cocoon production and adult recruitment into the population was not dependent upon rainfall or soil type. Given that some workers do not distinguish between these two species, this result is surprising.

VI. SUMMER AESTIVATION OF EARTHWORMS IN THE MIDLANDS.

6.1 Introduction

Earthworms retreat deeper down the soil profile to enter a resting stage or "aestivation" when conditions become unfavourable for their survival in the surface soil layers. As the soil dries out (pF<2) or temperature extremes of greater than 16 ^{o}C are reached (Evans and Guild, 1947; Gerard, 1967; Lee, 1985; Daugbjerg, 1988), earthworms retreat to depths of between 80 and 600 mm (Barley, 1959a; Gerard, 1967; Rundgren, 1975; Reddy, 1987; Kingston, 1988; Baker *et al.* 1992a), and up to extremes of three metres for *L. terrestris* (Sims and Gerard, 1985). In the northern hemisphere, earthworms enter aestivation in winter if the surface soil horizon freezes, and in summer to avoid high temperatures and desiccation due to inadequate moisture. Further studies in this region (Anderson, 1980; Nordstrom, 1975, 1976; Rundgren, 1975, 1977; Evans and Guild, 1947) have identified the aestivation type, depth, survival and effects on population structure. Australian research has established the general time and depth of aestivation, but detailed study of aestivation is lacking.

This section aims at identifying the depth of earthworm aestivation in the Midlands for different earthworm species, stages of maturity and soil type. The effect of depth of summer aestivation on earthworm survival in the following autumn is reported under Australian conditions for the first time, whilst the relationships between soil moisture, texture and earthworm aestivation is also examined.

6.2 Materials and methods

Earthworms were sampled from 12 sites which ranged from duplex soils consisting of loamy sands overlying clay subsoils, to uniform black clays. These sites were identical to those used to examine earthworm life cycles in the Midlands (Chapter V), however two sites (sites 8 and 9) were not used since earthworms remained active during summer due to higher soil moisture at these sites.

Earthworms were assessed over the summer from late January to early February using a spade to excavate a 200 x 200 mm hole (1992), and a proline auger (figure 6.1) to remove four soil cores of 100 mm diameter (1993 and 1994). In each year, samples to a depth of 50 mm were repeatedly removed until a depth of 500 mm was reached. Each soil sample was washed in a cement mixer and sieved for earthworm and cocoon extraction. Earthworm abundance, mass (1992-1994) and maturity (1993 and 1994 only) were assessed for each species.

This procedure was repeated at five random positions along the 100 m transect. In 1992, the field texture and moisture content of each soil sample was also determined.

After the first autumn rains in 1993, when earthworms had become active in the soil surface, the effect of depth of earthworm aestivation on earthworm survival was assessed. Earthworm life cycle data were collected as normal following initial autumn rains, but sampling points were positioned adjacent to the points previously sampled for the earthworm aestivation study. Earthworm numbers should be similar for the paired points.

Plate 6.1: Proline auger used for summer earthworm sampling.

6.3 Results

Differences in aestivation between earthworm species and soil type

Earthworm aestivation was initiated at a soil pF > 3.3 and continued for eight months during 1992 and 1993 (see Chapter V). There was no difference in the depth or longevity of earthworm aestivation between species or soil type. All results presented are as earthworm number and mass averaged over soil type (data files stored on D.P.I.F. mainframe). Total number and mean mass of earthworms followed a very similar trend in 1992, 1993 and 1994 (table 6.1). Earthworm mass is presented as the mean mass of an individual within each sampling depth, rather than total mass. Samples containing no earthworms were not included in the calculation of mean earthworm mass.

Number of earthworms

There was a greater population of earthworms recovered from the Midlands sites in 1993 and 1994 compared to 1992. The average number of aestivating earthworms in the Midlands was $117/m^2$ in 1992, $301/m^2$ in 1993 and $219/m^2$ in 1994. Most individuals were at a depth of 200 mm in 1992 ($25/m^2$), 1993 ($67/m^2$) and 1994 ($45/m^2$). Data from 1994, when earthworm population density was greatest, will be used to demonstrate general trends which were consistently repeated from 1992-1994. Total earthworm numbers reached a maximum at 150-200 mm, numbers progressively decreasing as depth increased to 500 mm (figure 6.1). In 1993 and 1994, both the number of juveniles (Appendix 10) and adults (Appendix 11) followed a very similar trend to total earthworm numbers, with the maximum number of individuals occurring at a depth of 150-200 mm for both stages, apart from adult earthworms in 1994 which were greatest at 200-250 mm. A quadratic regression was fitted to total earthworm numbers ($P<0.01$) in 1992, 1993 and 1994, adult earthworm numbers ($P<0.001$) in 1993 and 1994 and numbers of juvenile earthworms ($P<0.05$) in 1993 (Appendices 17-20, 22-23). Earthworm cocoons were not found during the summer of 1992, but in 1993 they were concentrated in the top 150 mm of the soil, the numbers decreasing linearly ($P<0.001$, Appendix 21) with depth (figure 6.2).

Table 6.1: Total earthworm density and mean mass of all aestivating individuals in the Midlands during 1992-1994.

Depth (mm)	Sampling year							
	1992		1993		1994		Mean	
	density (no./m^2)	mass (g/m^2)	density (no./m^2)	mass (g/m^2)	density (no./m^2)	mass (g/m^2)	density (no./m^2)	mass (g/m^2)
0-50	3	0.12	14	0.09	2	0.13	6	0.11
50-100	3	0.21	25	0.09	18	0.11	15	0.14
100-150	23	0.12	54	0.13	38	0.11	38	0.12
150-200	25	0.19	67	0.16	45	0.16	46	0.17
200-250	20	0.20	46	0.16	42	0.19	36	0.18
250-300	15	0.22	33	0.17	32	0.21	27	0.20
300-350	12	0.31	22	0.19	18	0.28	17	0.26
350-400	9	0.34	25	0.20	14	0.19	16	0.25
400-450	4	0.23	8	0.32	10	0.22	7	0.26
450-500	3	0.28	7	0.19	0	0	3	0.16
Total	117	-	301	-	219	-	211	-

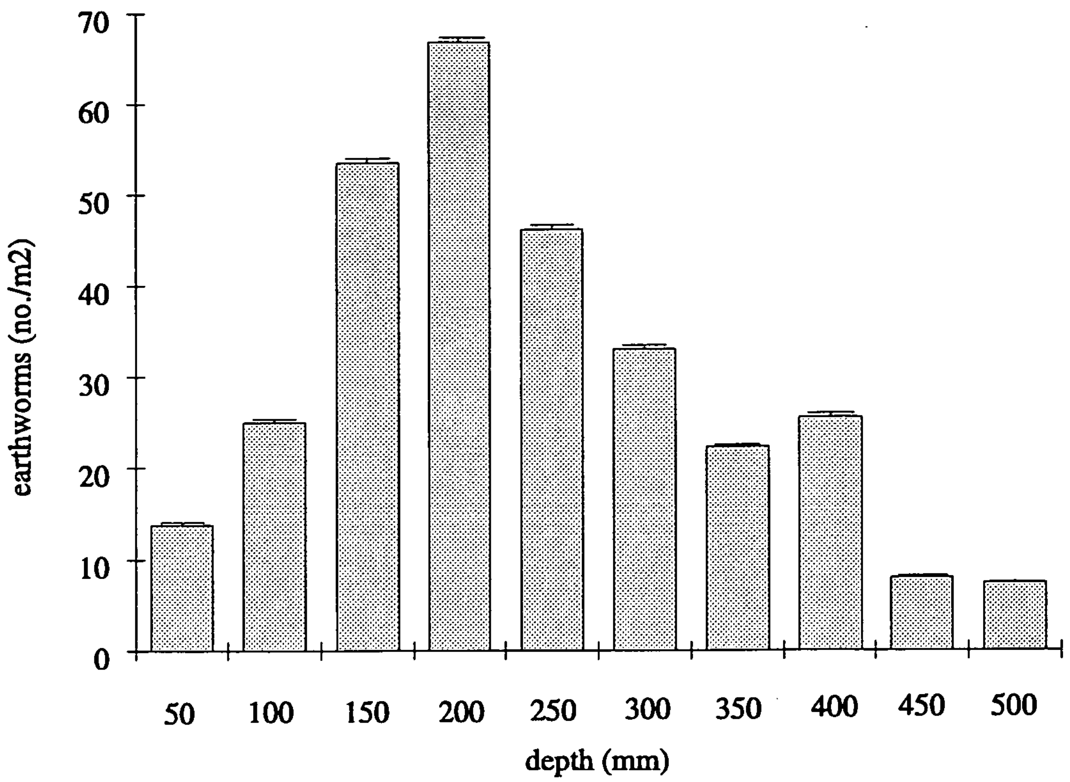


Figure 6.1: Average depth of aestivation of earthworms in the Midlands in 1993 (error bars represent 1 s.e.).

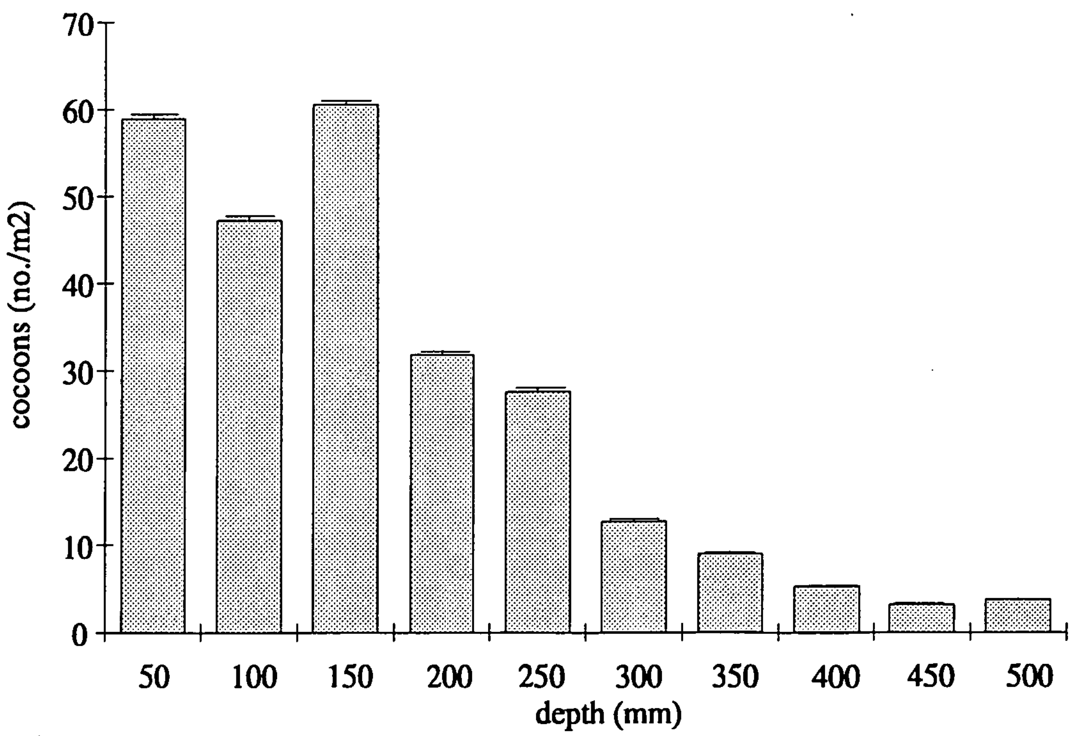


Figure 6.2: Average depth of cocoons in the Midlands in 1993 (error bars represent 1 s.e.).

Earthworm mass

There was no association between adult earthworm mass and depth in 1993 (figure 6.3) or 1994. However, the mean mass of juveniles increased linearly ($P<0.001$, Appendix 15) with depth to a maximum of 0.21 g in 1993 at a depth of 400-450 mm (figure 6.4). This trend is reflected in the mean earthworm mass of all individuals during 1993 which also shows a linear increase ($P<0.001$, Appendix 14) in earthworm mass with depth (figure 6.5). The total numbers of all earthworms from the summer sampling of 1992 (Appendix 13) and 1994 (Appendix 16) shows a similar increase with depth ($P<0.01$), but mean juvenile mass failed to increase with depth in 1994.

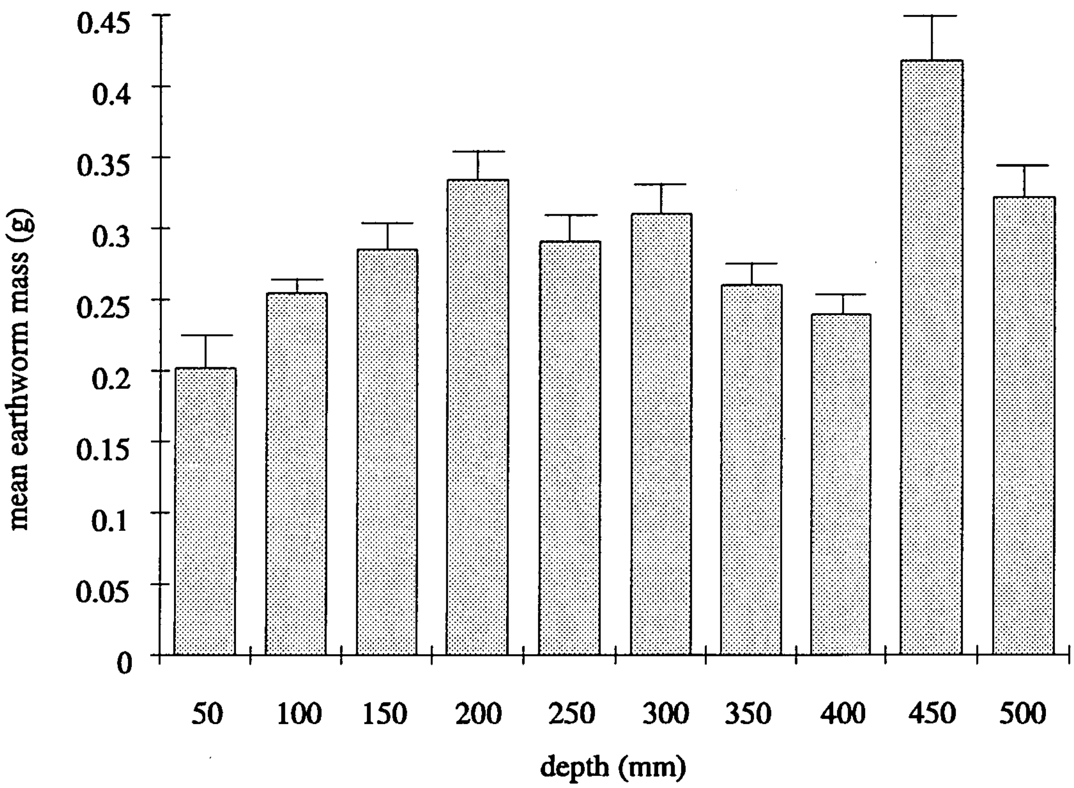


Figure 6.3: Average mass of adult individuals in aestivation in the Midlands in 1993 (error bars represent 1 s.e.).

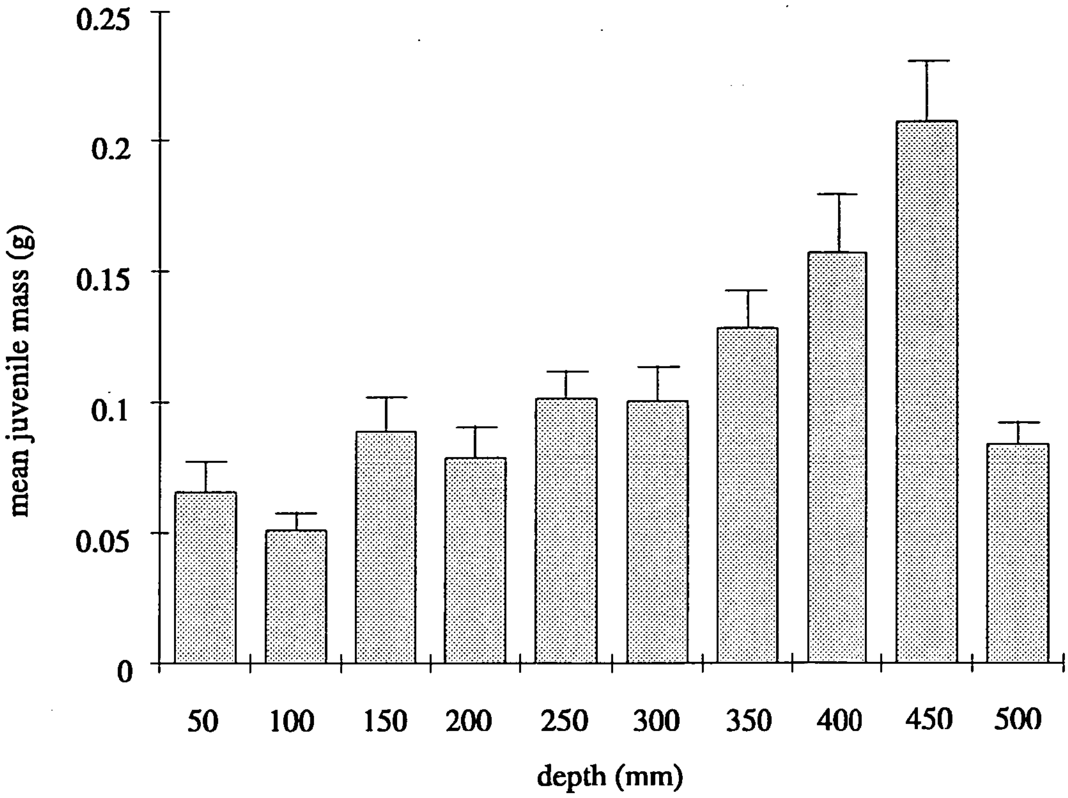


Figure 6.4: Average mass of juvenile individuals in aestivation in the Midlands in 1993 (error bars represent 1 s.e.).

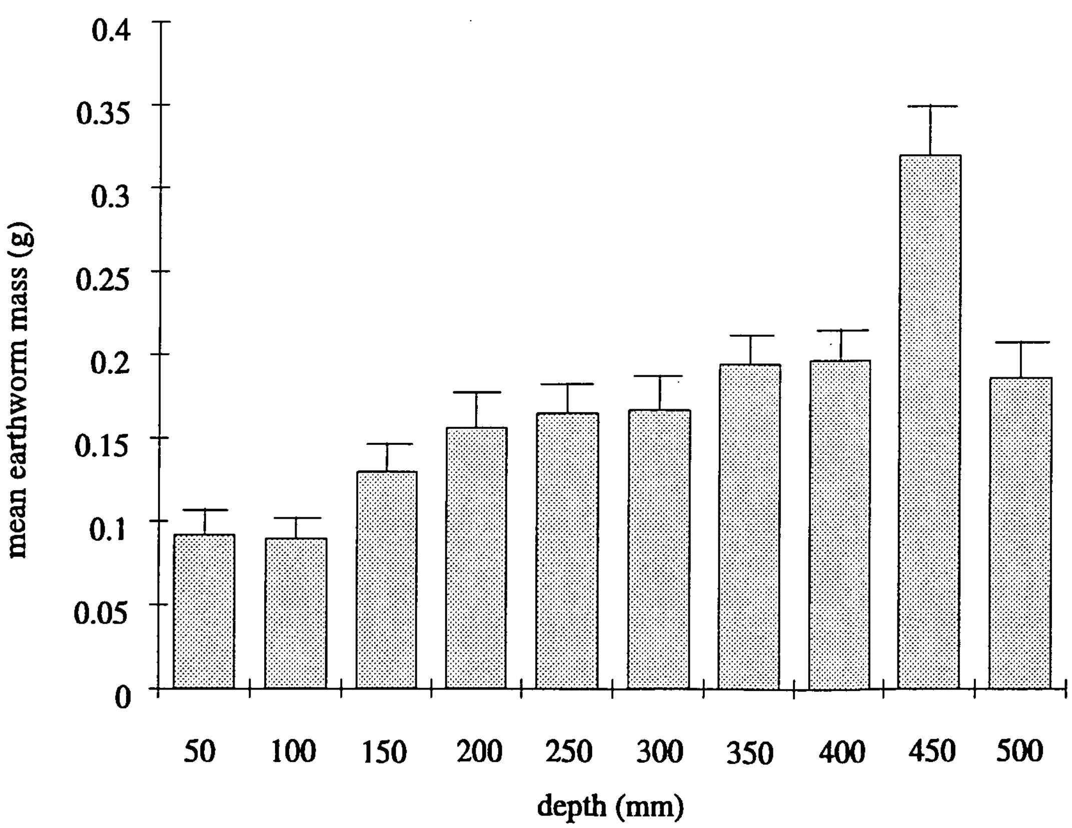


Figure 6.5: Average mass of all individuals in aestivation in the Midlands in 1993 (error bars represent 1 s.e.).

Survival of earthworms during aestivation

Comparison of earthworm numbers in October 1992, when earthworms were last active in the upper soil horizons, and January 1993, when earthworms were in aestivation, shows adult earthworm numbers had significantly decreased by 18 % ($P<0.001$), whilst juveniles had increased significantly by 158 % ($P<0.001$). By July 1993 when earthworm activity had resumed in the surface soil, adult numbers had been significantly reduced ($P<0.001$) by 63 %, whilst the number of juveniles were reduced to 60 % of levels of the previous summer. As a result, the number of juveniles in autumn were reduced to a density similar to that of the previous spring (figure 6.6). These trends were consistent across most of the 12 sites (Appendix 12).

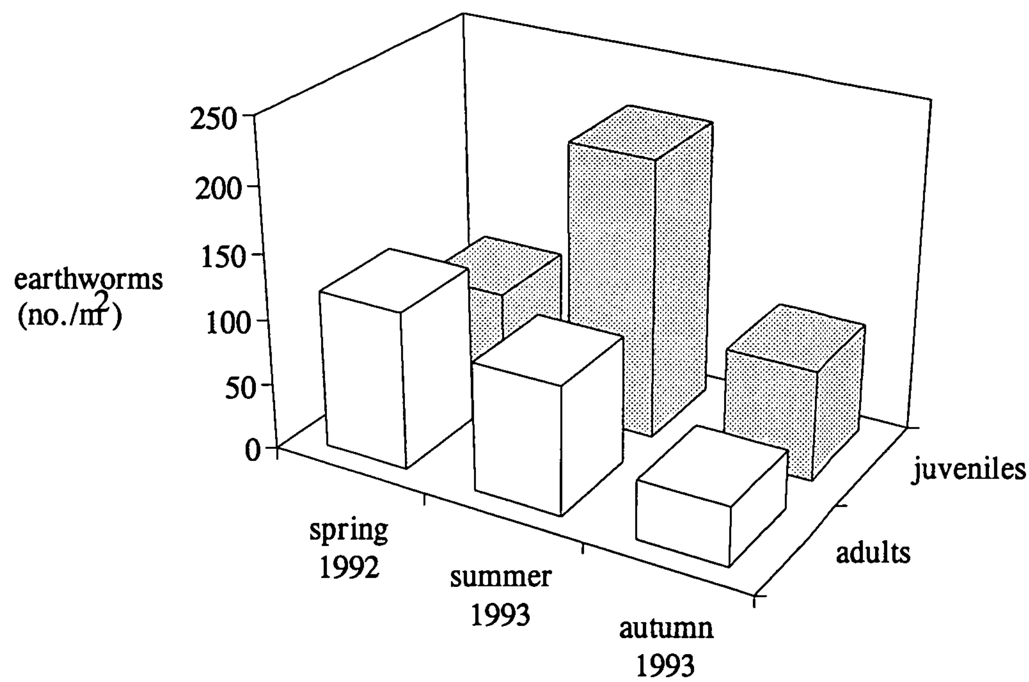


Figure 6.6: Survival of adult and juvenile earthworms during aestivation in the Midlands (n=12).

Relationship between soil texture, moisture and earthworm aestivation

There was no significant correlation between depth of earthworm aestivation and soil moisture content or texture (full details of data in Appendix 24).

6.4 Discussion

Consistent aestivation behaviour by earthworms was exhibited over three years in the Midlands. Aestivating earthworms in the Midlands were concentrated at a depth of 200 mm during the drier summer months of 1992, 1993 and 1994. Under similar rainfall near Adelaide (575-900 mm p.a.), Baker et al. (1992a) and Barley (1959a) found most individuals were in aestivation at 150-300 mm depth. In the Midlands, there was no difference in depth or length of aestivation between the two most prevalent earthworm species, *A. caliginosa* and *A. trapezoides*. This is hardly surprising given that some researchers classify these as identical species (Sims and Gerard, 1988). Nordstrom (1975) found *A. rosea* resumed activity earlier after aestivation than *A. caliginosa* or *A. longa*. Gerard (1967) showed *A. chlorotica* had a shorter aestivation than *A. caliginosa, A. rosea, A. nocturna, A. longa* or *L. terrestris*. Comparison between these results and the present study are difficult since neither *A. rosea, A. nocturna, A. longa* or *L. terrestris* are found in substantial numbers in the Midlands.

A facultative aestivation was exhibited by *A. caliginosa* and *A. trapezoides* in the Midlands during the summers of 1992 and 1993. Each individual remained coiled up in a spherical chamber from October to July, apart from two sites where surface activity resumed for about 8 weeks when summer rainfall increased soil pF >3.3 (see Chapter V). *A. caliginosa* was also described as entering a 'facultative diapause' even under the wetter conditions of Britain (Evans and Guild, 1947) and Sweden (Anderson, 1980). Whilst individual earthworms in the Midlands appeared to be in a resting stage similar to diapause, a more detailed examination of individuals would have confirmed this. However, given the poor condition of aestivating earthworms after removal from soil samples, this was inappropriate.

Earthworms entered aestivation at a soil pF > 3.3 in the Midlands. Several studies have also reported activity of *Aporrectodea* spp. is restricted to soil pF$>$3.2-3.5 (Gerard, 1967; Nordstrom and Rundgren, 1975; Nordstrom, 1975). This has been indirectly linked to declining food reserves and microbial activity in the soil (Waters, 1955), but in the extended dry conditions of the Midlands, this is probably a direct response to declining moisture levels and avoidance of desiccation.

The aestivating stage of the earthworm's life cycle caused high mortality of earthworms in the Midlands, which increased with the length of aestivation (figure 6.6). Numbers of adult earthworms significantly decreased by 18 % from October 1992 (active) to January 1993 (aestivating), and 63 % by July 1993 when earthworms resumed activity in the upper soil horizons. However, the number of juveniles increased significantly by 158 % from October to January, probably due to the occurrence of summer rains during this period (Appendix 25). This may have extended cocoon survival to permit juveniles to escape desiccation, hatch and enter aestivation (Baker *et al.* 1992a). However, a dry period from March to May probably caused desiccation of many of the hatchlings which entered aestivation close to the soil surface (figure 6.4). This resulted in no net change in the number of juveniles from when they were last active in the surface soil in October 1992 to the end of aestivation in July 1993. Anderson (1980) found that under the higher rainfall of southern Sweden and a shorter aestivation (three months compared to eight months in the Midlands), the numbers of adult *A. caliginosa* remained unchanged. Juvenile numbers increased by 96 %, which is consistent with the 158 % increase from October to January in the Midlands in 1993. The high mortality rates of aestivating earthworms in the Midlands, particularly amongst adults, may be associated with the drier conditions and longer aestivation of earthworms in the area compared to higher rainfall regions (e.g. Sweden). Research in South Australia did not determine survival rates after an aestivation of 5-9 months (Baker *et al.* 1992) and eight months (Buckerfield, 1992). Hendrix et al. (1992) recorded a high population turnover due to limited downward migration and high adult mortality during a summer aestivation of only 3-4 months in the warm-temperate area of Georgia, U.S.A.

Smaller aestivating juveniles were located nearer the soil surface in 1993 than larger juveniles and adults (figure 6.4), a trend which was also reflected in the mean mass of all aestivating earthworms (figure 6.5). An identical pattern emerged in 1994 for the mean mass of all individuals, but not for mean juvenile mass, probably due to the low population densities encountered in 1994. Rundgren (1975) reported smaller aestivating earthworms were located in the surface soil layers in southern Sweden for four lumbricids in an elm-ash wood, and for *A. rosea* in a permanent pasture. But this was during a period of high soil temperature and low soil moisture and it is debatable whether earthworms were actually in aestivation under these conditions. Smaller juveniles may have entered aestivation at a shallower depth than adults and larger juveniles due to the depth at which they hatched, their weak burrowing ability and the abundance of available food in the upper soil horizon (Rundgren, 1975). Both mature and immature earthworms entered aestivation in the Midlands, in contrast to reports in Britain of mature, but not immature, earthworms retreating to greater soil depths to enter a resting stage (Evans and Guild, 1947; Gerard, 1967).

High soil temperatures and low soil moisture in summer are considered to be important determinants of the vertical distribution of the more beneficial pasture lumbricid species, such as *A. caliginosa* and *A. longa* (Rundgren, 1975). However, in this study, soil moisture did not determine the depth of aestivation. Soil texture was also not related to aestivation depth of earthworms in summer.

Cocoons were recovered during the summer of 1993, but they were not found in 1992 or 1994. It is therefore seems doubtful that earthworm cocoons oversummer in the Midland considering the extended dry periods which are endured. Cocoons may have survived in the summer of 1993 due to the higher rainfall during late winter and early spring in 1992, which was not received at the same time in 1991 or 1993. This allowed earthworm activity and cocoon production in the surface soil to extend until later in the year. Further rainfall in December and January would have ensured survival of cocoons into January when sampling took place. However, by the autumn break in July 1993, no cocoons were found in the soil indicating that all individuals had hatched and probably died from desiccation following a lack of rainfall from March to July. Gerard (1967) found cocoons in summer concentrated in the top 75 mm of the soil in the wetter conditions of England. Barley (1959a) reported juvenile hatchlings in autumn from cocoons which had survived over the drier summer conditions at the Waite Institute at Adelaide, whilst Baker et al. (1992a) failed to recover any cocoons from the nearby Mt Lofty Ranges.

VII. MANAGEMENT OF EARTHWORM POPULATIONS IN THE MIDLANDS.

7.1 Introduction

The burrowing and casting activities of earthworms can improve the chemical, physical and biological status of the soil thereby improving plant growth.

However, recent earthworm surveys in the lower rainfall agricultural regions of southern Australian reported low population densities and species diversity (Baker, 1991; Mele, 1991; Temple-Smith, 1991), which may be restricting potential gains in plant productivity.

At least eight species of lumbricid earthworms have become widely established in the Midlands of Tasmania (< 600 mm rainfall p.a.), but population densities are lower than the higher rainfall regions of northern Tasmania (Temple-Smith, 1991). Populations in the Midlands are often dominated by *Aporrectodea caliginosa* and *A. trapezoides*, whilst *A. longa* is rare. Potential exists to increase the density of resident earthworm populations by determining factors which are limiting their numbers in the Midlands. Additional species, such as *A. longa*, could also be introduced to increase earthworm species diversity and pasture production. Garnsey et al. (submitted) found introduction of *A. longa* to the lower rainfall areas of northern Tasmania (700 mm p.a.) containing *A. caliginosa* led to greater gains in pasture production than pastures containing *A. caliginosa* alone. The purpose of this study was to increase earthworm activity, and hence pasture production in the Midlands by identifying factors which are limiting earthworm populations in the Midlands and by introducing the earthworm *A. longa*.

7.2 Materials and methods

Experimental sites

Two properties in the Midlands of Tasmania were chosen as experimental sites: "Turvue" (42^{o} 16'S 147^{o} 39'E) near Oatlands and "Symmons Plains" (41^{o} 39'S 147^{o} 16'E) near Perth.

<u>Oatlands</u>

"Turvue" (600 mm rainfall p.a) is a grazing property of gently undulating topography in the central Midlands (370 m a.s.l.) carrying sheep for wool and fat lamb production, as well as a small herd of beef cattle. Earthworm populations are higher than the average for the Midlands ($\bar{X}$=101/m^2, Temple-Smith and Kingston, unpublished), reaching a mean density of 300/m^2.

The soil at the trial site was a grey-brown podzolic (Db2.82, Northcote, 1984) derived from Jurassic dolerite (Plate 7.1), which was typical of the property. Pastures of perennial ryegrass (*Lolium perenne*), cocksfoot (*Dactylis glomerata*), subterranean clover (*Trifolium subterraneum*) and white clover (*Trifolium repens*) have been established over most of the property. Native vegetation was removed from the trial site for turnip production before pasture establishment in 1978. The site received superphosphate @ 250 kg/ha in 1978, 1980 and 1988 as well as 190 kg/ha of 0-7-11 in 1989.

Perth

"Symmons Plains" (580 mm rainfall p.a.) lies in the northern Midlands at 150 m a.s.l. It consists of alluvial plains which are utilised primarily for wool and fat lamb production, as well as some cash cropping, including cereals, turnips, potatoes, vegetables, parsley and mint. Earthworm populations at this site ($75/m^2$) are lower than the mean density for the Midlands.

Soil type at the trial site (Plate 7.2) was a yellow duplex (Dy3.72, Northcote, 1984) which was sown in 1989 to cocksfoot (*Dactylis glomerata*), perennial ryegrass (*Lolium perenne*), subterranean clover (*Trifolium subterraneum*) and white clover (*Trifolium repens*). A grass dominant pasture had evolved by 1991 when the trial began. Superphosphate was applied to the trial site @ 125 kg/ha at the time of sowing, but since then has not received fertilisers.

Soil database No: 195
Property Name: Tervue
Property Owner: Burbury, J.
Nearest Town: Oatlands
Describer: Richard Doyle
Type of Desc: Undisturbed soil core

Rainfall: 600 mm
Elevation: 370 m
AMG Easting: 554100 E
AMG Northing: 5320450 N

Soil Class: Eastfield
Northcote PPF: Db2.82
Great Soil Group: Grey-Brown Podzolic
Drainage: Imperfectly drained
Permeability: Slowly permeable
Runnoff: Very slow

Isbell Class: Bleached-Ferric, Eutrophic, Brown, Chromosol; medium, loamy, non gravelly
Landform: Element level, flat, geomorphic agent overbank streamflow (unchannelled), valley-flat; Pattern undulating rises 9-30 m 3-10%, low hills;
Land Surface: Complete clearing; pasture but never cultivated; Surface soil hard setting; Coarse Fragments few (2-10%), gravels (20-60 mm); Rock Outcrops 2% bedrock exposed,
Vegetation: pasture species
Substrate: dolerite

A1 0 - 14 cm

Very dark greyish brown (10YR 3/2 moist); greyish brown (10YR 5/2 dry); loam; moderate fine-medium (10-20mm) angular blocky parting to moderate very fine (2-5mm) angular blocky structure; very weak (moist); moderately weak (dry); rough-ped fabric; few (<1 per 100mm²) fine (1-2mm) macropores; no cutans; few (2-10%) ferruginous nodules; common fine (1-2mm) live roots; 5.7 field pH; 0.0 dSm-1; abrupt (5-20mm) smooth boundary

A2 14 - 26 cm

Dark greyish brown (10YR 4/2 moist); pale red (2.5 YR 7/1 dry); gravelly sandy loam; single grain plus weak very fine (2-5mm) subangular blocky structure; very weak (moist); loose (dry); sandy fabric; many (>5 per 100mm²) fine (1-2mm) macropores; no cutans; many (20-50%) ferruginous nodules; few fine (1-2mm) live roots; 6.7 field pH; 0.0 dSm-1; sharp (<5mm) wavy boundary.

B21 26 - 50 cm

Olive brown (2.5 Y 3/3 moist); common (10-20%) medium (5-15mm) distinct brown (7.5YR 4/4) primary mottles; heavy clay; massive structure; moderately firm (moist); earthy fabric; few (<1 per 100mm²) very fine (0.075-1mm) macropores; common (10-50%) distinct slickensides; few (2-10%) manganiferous nodules; few fine (1-2mm) live roots; 7.1 field pH; 0.0 dSm-1; diffuse (>100mm) boundary

B22 50-75 cm

Dark greyish brown (2.5Y 4/3 moist); heavy clay; massive structure; very firm (moist); earthy fabric; no macropores; common (10-50%) distinct slickensides; v few (<2%) manganiferous nodules; no live roots; 6.8 field pH; 0.0 dSm-1; gradual (50-100mm) boundary

B3 75-90+cm

Olive (5Y 4/4 moist); medium clay; massive structure; moderately strong (moist); earthy fabric; no macropores; few (<10%) distinct clay skisn; no segragations; few (2-10%) very weak dispersed gravels (6-20mm) dolerite; no live roots; 7.2 field pH; 0.0 dSm-1;

Profile Note: B21 and B22 few clay skins, dispersion in B21 slightly milky next to aggregate, B21 mottles decrease with depth, B3 looks like strongly weathered dolerite fragments? present.

Chemical Data:

Horizon	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	Ca (meq/ 100g)	Mg (meq/ 100g)	Na (meq/ 100g)	K (meq/ 100g)	CEC	ESP*	ESP#
A1	5.7	0.05	15	81	3.0	7.35	3.59	0.22	0.16	15.58	1.41	1.94
A2	3.0	0.04	3	76	0.8	2.46	1.27	0.17	0.05	6.69	2.54	4.30
B21	6.6	0.07	3	41	0.8	16.08	14.52	1.24	0.18	33.84	3.66	3.87
B22	6.9	0.17	3	32	0.7	18.30	17.11	1.68	0.19	40.44	4.15	4.51
B3	7.2	0.18	3	29	0.5	25.07	23.76	2.4	0.13	46.59	5.14	4.67

ESP by *CEC and #total bases

Plate 7.1: Soil profile for Oatlands management trial.

Soil database No: 156
Property Name: Symmons Plains
Property Owner: Youl, J.C. & S.L..
Nearest Town: Perth
Describer: Richard Doyle
Type of Desc: Auger boring

Rainfall: 650 mm
Elevation: 150 m
AMG Easting: 521600 E
AMG Northing: 5390200 N

Soil Class: Brumby
Northcote PPF: Dy3.72
Great Soil Group: Solodized Solontz
Drainage: Imperfectly drained
Permeability: Slowly permeable
Runnoff: Slow

Isbell Class: Bleached - Mottled, Mesotrophic, Brown, Chromosol; very deep thick loamy, new gravelly
Landform: Element level, flat, geomorphic agent overbank streamflow (unchannelled), terrace plain; Pattern level plain <9m <1%, terraced land;
Land Surface: Slope angle 0%; complete clearing; pasture but never cultivated; Srface soil soft;
Vegetation: pasture species
Substrate: massive, clays (argillaceous), clay, lacustrine sediment;

A1 0-15 cm
Dark greyish brown (10YR 4/2 moist); greyish brown (10YR 5/2 dry); fine sandy loam; weak fine (5-10 mm) subangular blocky plus single grain structure; very weak (moist); loose (dry); sandy fabric; common (1-5 per 100mm²) fine (1-2mm) macropores; no cutans; v few (<2% ferruginous nodules; no coarse fragments; common very fine (<1mm) live roots; 5.5 field pH; 0 dSm-1; gradual (50-100mm) boundary
A2 15-35 cm
Greyish brown (10YR 5/2 moist); light brownish gray (10YR 6/2 dry); gravelly fine sandy loam; single grain plus weak fine (5-10mm) subangular blocky structure; loose (moist); loose (dry); sandy fabric; common (1-5 per 100mm²) fine (1-2mm) macropores; no cutans; few (2-10%) ferruginous nodules; no coarse fragements; few very fine (<1mm) live roots; 6.3 field pH; 0 dSm-1: abrupt (5-20mm) boudary
B21tg 35-55 cm
Light olive brown (2.5Y 5/4 moist); common (10-20%) fine (<5mm) distinct yellowish brown (10YR 5/6) primary mottles; medium clay; massive structure; moderately firm (moist); very firm (dry); earthy fabric; few (<1 per 100mm²) fine (1-2mm) macropores, few (<10%) distinct slickensides; no segragations; no coarse fragments; no live roots; 6.1 field pH; 0 dSm-1; gradual (50-100mm) boundary
B22tg 55-90+cm
Light olive brown (2.5Y 5/6 moist); common (10-20%) medium (5-15mm) distinct light brownish grey (2.5Y 6/2) primary mottles; 10Y56 (10Y 5/6) secondary mottles; medium clay; massive structure; very firm (moist); moderately strong (dry); earthy fabric; no macropores; few (<10%) distinct slickensides; no segragations; no coarse fragments; no live roots; 6.5 field pH; 0.1 dSm-1.
Chemical Data:

Horizon	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	Ca (meq/100g)	Mg (meq/100g)	Na (meq/100g)	K (meq/100g)	CEC	ESP*	ESP#
A1	5.5	0.06	62	180	4.0	1.87	0.52	0.37	0.42	18.6	1.98	11.64
A2	5.9	0.09	3	80	0.8	1.22	0.74	0.31	0.14	13.0	2.38	12.86
B21tg	6.6	0.09	1	121	0.8	5.55	9.91	1.23	0.37	33.6	3.66	7.21
B22tg	6.6	0.17	1	101	0.6	4.54	11.97	1.88	0.38	48.7	3.86	10.02

ESP by *CEC and #total bases

Plate 7.2: Soil profile for Perth management trial.

Experimental treatments

In October 1991, six treatments (table 7.1), replicated four times, and arranged in a complete randomised block design were applied to 5x5 m plots at Perth and Oatlands. Plots were separated by a 5 m buffer zone to reduce movement of earthworms into adjacent plots (figure 7.1). The experiment was designed as an omission trial to examine the effects of removing one factor (either L, N, O or F) on earthworm populations and pasture growth. An omission design also allowed examination of treatment interactions. A factorial design would have required more treatment combinations and a greater area than the omission design.

Table 7.1: Management treatments applied at Perth and Oatlands.

Factor*	Treatment					
	1	2	3	4	5	6
L	√		√	√	√	
N	√	√		√	√	
O	√	√	√			
F	√	√	√	√	√	

*L=agricultural ground limestone @ 5t/ha; N=ammonium nitrate as Nitram® @ 50 kg N/ha; O=organic matter as pea straw @ 5t/ha; F=superphosphate @ 200 kg/ha and potash @ 100 kg/ha.

Data was analysed using analysis of variance with GENSTAT (GENSTAT Committee, 1987). Least significant differences were used to ascertain significant differences between means of:

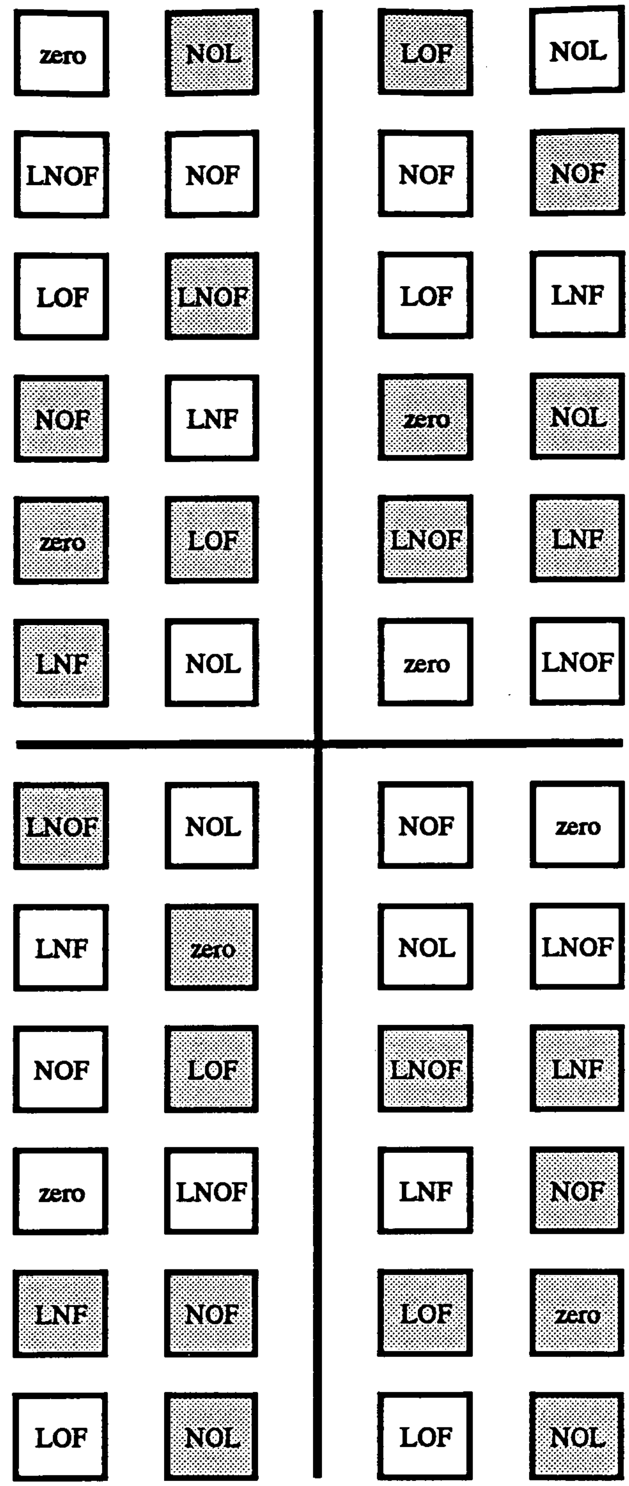
(a) LNOF and NOF: effect of lime (L) application;
(b) LNOF and LOF: effect of nitrogen (N) application;
(c) LNOF and LNF: effect of organic matter (O) application;
(d) LNOF and NOL: effect of fertiliser (F) application.

Grazing

Trial sites were fenced off from livestock, with grazing after each pasture cut. Mowers were used to remove rank herbage rejected by stock after grazing.

Soil analysis

Prior to treatment application in September 1991, and in the final year of the trial, pH and electrical conductivity (EC) (1:5 H_2O), organic carbon (OC) (Walkley and Black, 1934), bicarbonate extractable phosphorus (P) and potassium (K) (Colwell, 1963) were measured for each plot. Total nitrogen (N) and bulk density, measured by the core method (Blake and Hartge, 1986), were determined in the final year of the trial. Details of soil tests are in Appendices 42-45, and Appendices 46-47 for bulk density.



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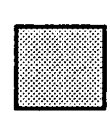


A. longa introduction

L **Lime**

N **Nitrogen**

O **Organic matter as pea straw**

F **Fertilisers as P & K**

Figure 7.1: Trial site plan for Perth and Oatlands.

Pasture production

The effects of treatments and *A. longa* introduction on pasture growth and composition were examined from 1991-1993 (see General Materials and methods). Five pasture cuts were taken from each site (table 7.2).

Table 7.2: Pasture and earthworm sampling (shaded) dates at Oatlands and Perth.

Sample	Oatlands	Perth
1	26-11-91	27-11-91
2	15-10-92	29-9-92
3	18-11-92	16-12-92
4	30-3-93	26-8-93
5	30-9-93	16-11-93

Earthworm density

Treatment effects on the numbers of the resident earthworm population, introduced *A. longa* and the larvae of common pasture pests were determined during the winters and springs of 1991-1993. Individuals were counted from 0.04 m^2 excavations to a depth of 150 mm. Areas which had been sampled for pasture growth were also sampled for earthworm and pasture grub species. This enabled examination of possible correlations between total earthworm numbers, pasture grubs and pasture growth. Sufficient pasture growth for pasture cuts was usually not evident until late winter and early spring and hence, pasture and earthworm sampling was largely confined to these periods. Unfortunately, maximum pasture growth in spring does not coincide with maximum earthworm activity, as some earthworms would be entering aestivation with decreasing soil moisture. Earthworms were initially sampled after every pasture cut, but this was considered excessive and was reduced to annual sampling. Earthworms were not sampled at Perth in 1991 due to the dry conditions prevailing immediately after establishment of the trial. Earthworm mass was estimated from earthworm counts (Appendix 50), but data are not presented since it shows a similar pattern to that of earthworm numbers.

A. longa introduction

D.P.I.F staff handsorted *A. longa* in May 1992 from paddocks at "Woolnorth", in north-western Tasmania which were transported to trial sites for introduction. To quantify the increase in pasture production associated with *A. longa* introduction, half of the plots at Perth and Oatlands were inoculated with this species (figure 7.1). This plan also allowed examination of effects of treatments on *A. longa*. Four adult individuals were introduced into 91 small openings made with a spade on a 0.5 m grid. This procedure resulted in an introduction to each plot of 364 individuals, giving a density of $15/m^2$.

7.3 Results

(i) Oatlands

<u>Earthworm numbers</u>

Numbers of *A. trapezoides* were significantly increased ($P<0.05$) by application of L, O and F 13 months after treatment application (figure 7.2), whilst numbers of *A. longa* were also increased by application of L ($P<0.01$) and O ($P<0.05$) 16 months after their introduction (figure 7.3). *L. rubellus* numbers were significantly increased ($P<0.05$) by F almost two years after treatment application (figure 7.4). Total earthworm numbers were not significantly increased by treatment application during 1991-1993. Full details of the effects of treatment application on earthworm numbers at Oatlands are available in Appendices 26-29.

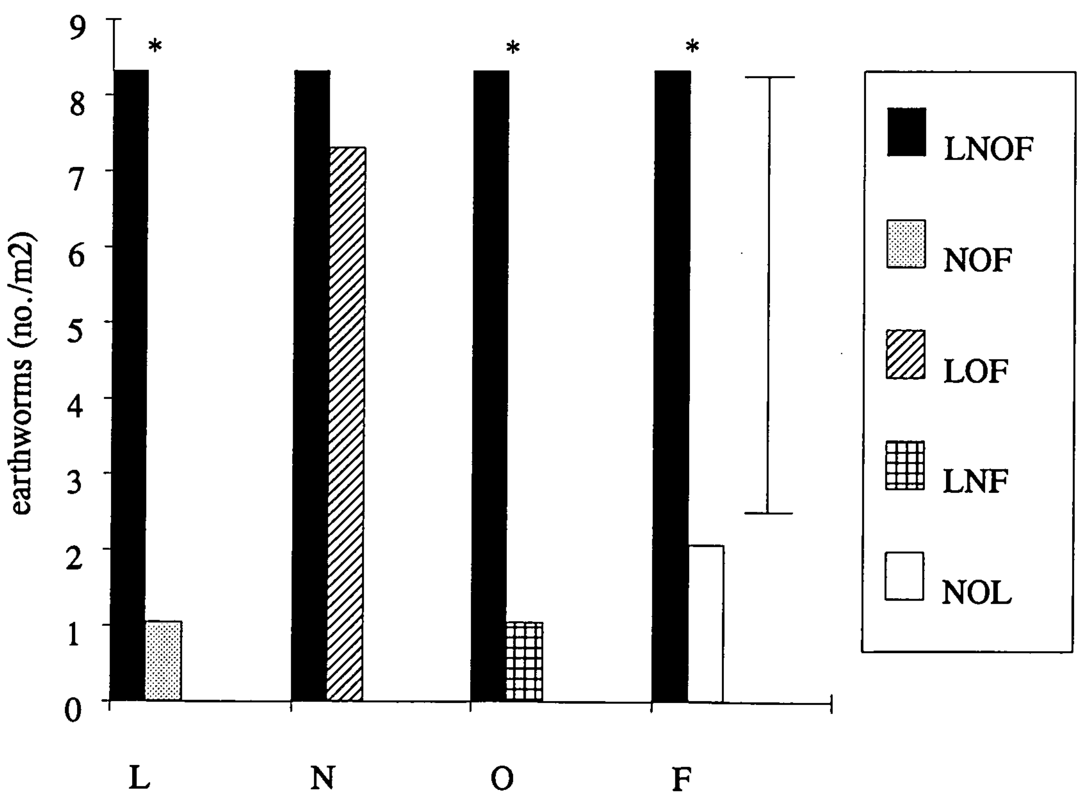


Figure 7.2: Effect of treatments on the number of *A. trapezoides* by 18-11-92 at Oatlands (error bar represents 5 % L.S.D.; * $P<0.05$).

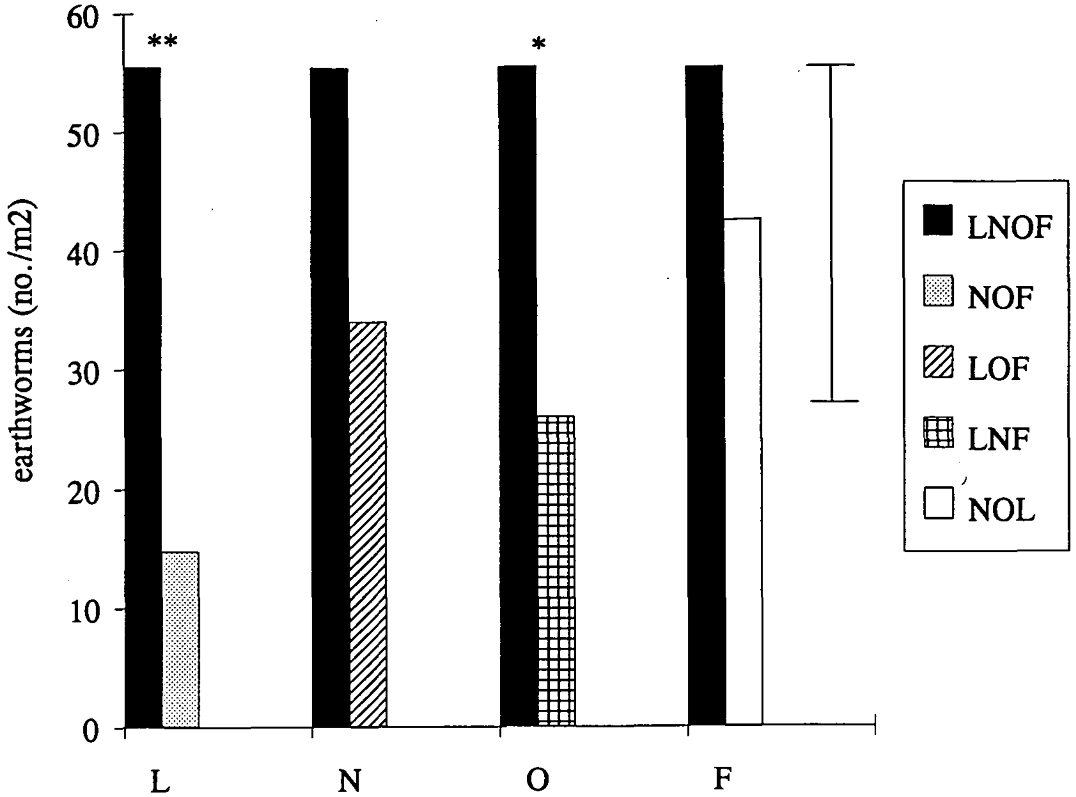


Figure 7.3: Effect of treatments on the number of *A. longa* by 30-9-93 at Oatlands (error bar represents 5 % L.S.D.; $^{*}P<0.05$; $^{**}P<0.01$).

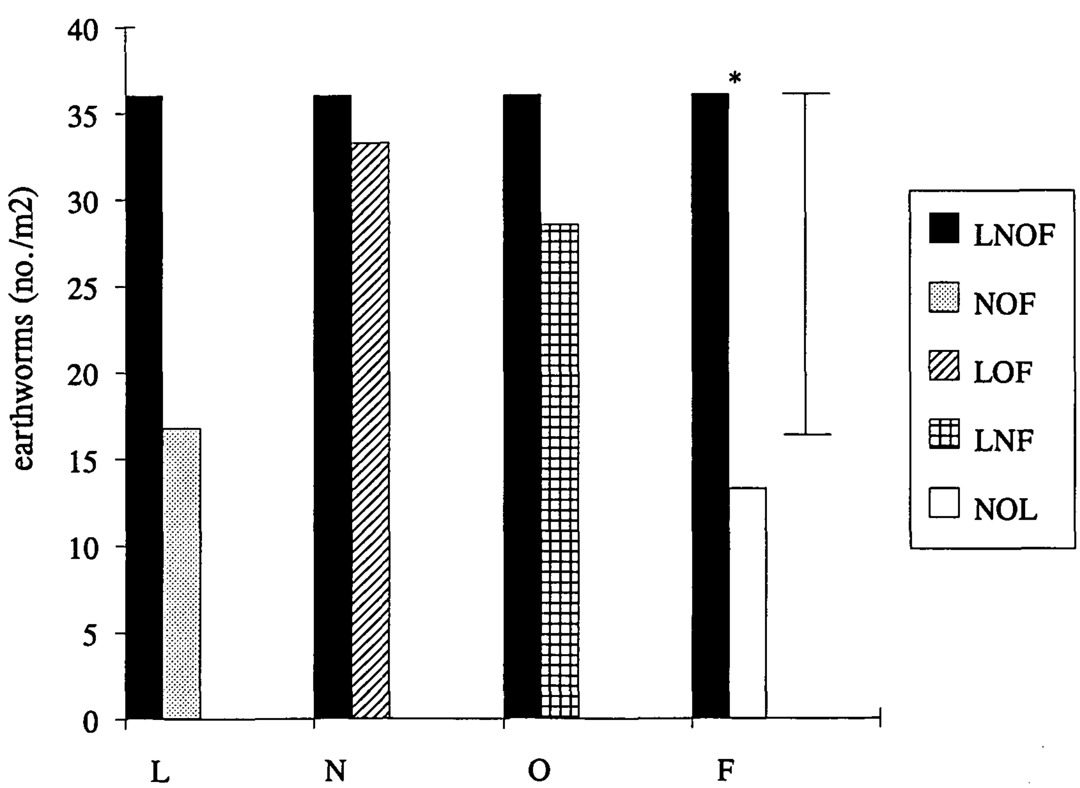


Figure 7.4: Effect of treatments on the number of *L. rubellus* by 30-9-93 at Oatlands (error bar represents 5 % L.S.D.; $^{*}P<0.05$)

Larvae of common pasture pests

The density of pasture grubs were low at this site (50/m^2) and were not affected by treatment application or *A. longa* introduction during 1991-1993.

Pasture production

For brevity, pasture production is presented as a change in pasture production between LNOF and each of the other treatment combinations (see Materials and methods). Pasture cuts were taken on five occasions at Oatlands (figure 7.5) from 1991-1993, three of which produced significant differences between treatments. One month after treatments were applied, N increased ($P<0.05$) pasture growth, whilst O ($P<0.001$) and L ($P<0.05$) significantly decreased pasture production. However, pasture production was increased by F and L 13 months after application ($P<0.01$), and by F ($P<0.001$) 23 months after treatment application. I found no significant effect of factors on pasture production 12 and 22 months after treatment application. Pasture production was positively correlated to total earthworm numbers 13 months ($P<0.001$) and 23 months ($P<0.01$) after treatment application.

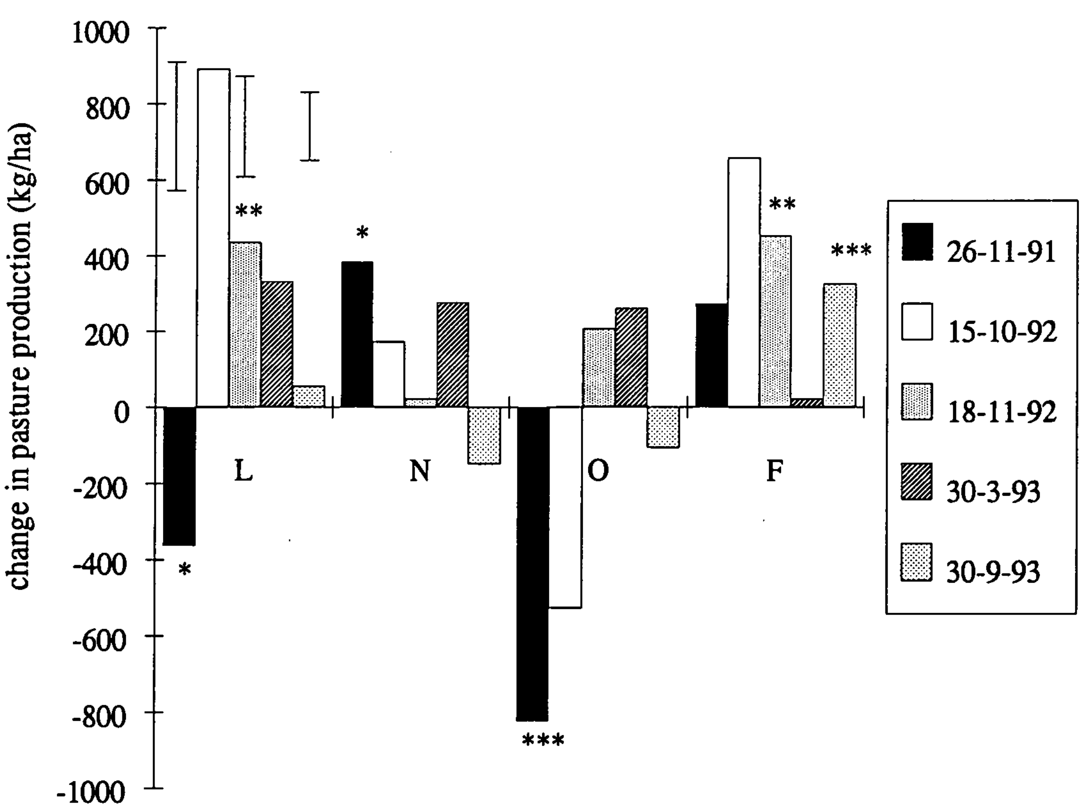


Figure 7.5: Change in pasture production at Oatlands during 1991-1993 (error bar represents 5 % L.S.D within a sampling period.; * $P<0.05$; ** $P<0.01$; *** $P<0.001$).

The percentage of clover in the sward was significantly ($P<0.05$) increased by up to 70 % throughout the trial by application of F and by up to 40 % following application of L after one year and after 23 months (table 7.3). N generally decreased clover growth, significantly ($P<0.001$) reducing the amount of clover 22 months after application. O did not significantly effect the amount of clover in the pasture sward. Full details of the effects of treatment application on pasture production at Oatlands are available in Appendices 32-36.

Table 7.3: Increase (%) in the clover content of the pasture following treatment application at Oatlands (* $P<0.05$; ** $P<0.01$; *** $P<0.001$).

Date	Treatment			
	L	N	O	F
26-11-91	34	-3	-2	70**
15-10-92	40*	-26	9	38*
18-11-92	-	-	-	-
30-3-93	10	-22***	2	16*
30-9-93	24***	-9	0	35***

A. longa introduction

Introduction of *A. longa* had no significant effect on pasture production during 1991-1993 at Oatlands, but population growth indicates successful establishment at this site. Within five months of introduction, cocoon production by *A. longa* had been initiated resulting in a high number of juveniles 16 months later (figure 7.6). Over the same period, there was a decline in the number of adults resulting in total numbers remaining static.

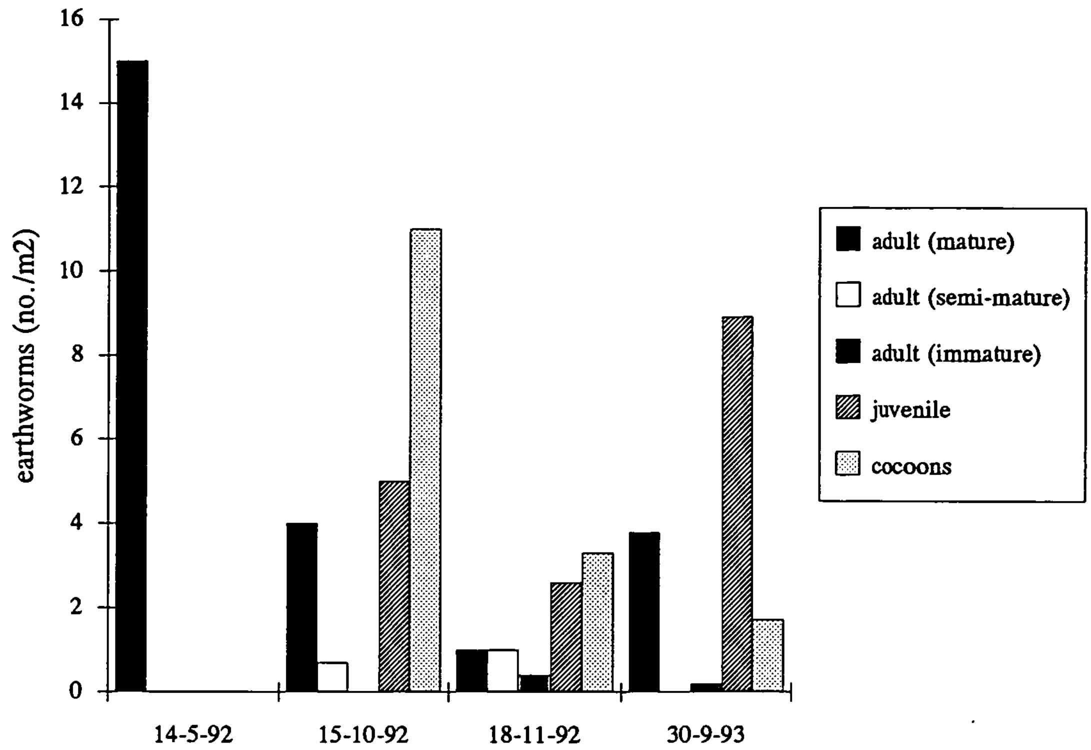


Figure 7.6: Change in the population structure of *A. longa* since introduction at Oatlands in May 1992.

<u>Soil analysis</u>

Application of L significantly increased soil pH at Oatlands ($P<0.05$) from 5.9 to 6.7 (Appendix 43), but no other soil nutrient test was affected by treatment application. Soil bulk density at Oatlands was not affected in January 1994 by treatment application (Appendix 48) or *A. longa* introduction (Appendix 49).

(ii) Perth

<u>Earthworm numbers</u>

Numbers of *A. trapezoides* were significantly reduced by N ($P<0.01$) and F ($P<0.05$) 11 months after application (figure 7.7). *A. longa* numbers were also significantly reduced ($P<0.01$) by application of N and F after 22 months (figure 7.8). Total earthworm numbers were not significantly affected by treatment application during 1991-1993. Full details of the effects of treatment application on earthworm numbers at Perth are available in Appendices 30-31.

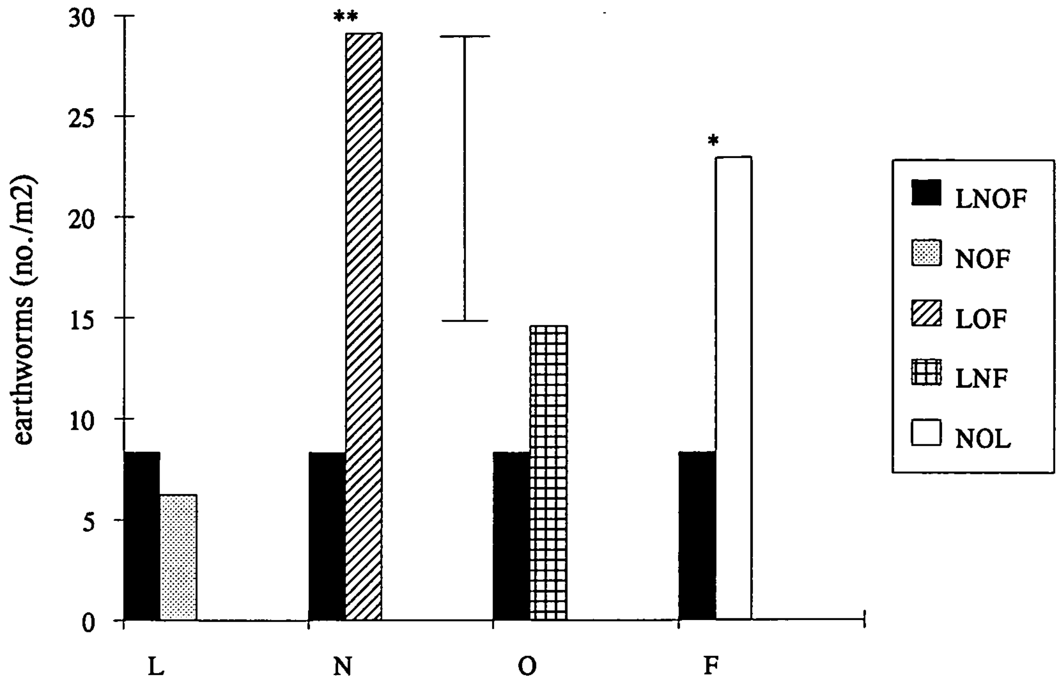


Figure 7.7: Effect of treatments on the number of *A. trapezoides* by 29-9-92 at Perth (error bar represents 5 % L.S.D.; * P<0.05; ** P<0.01).

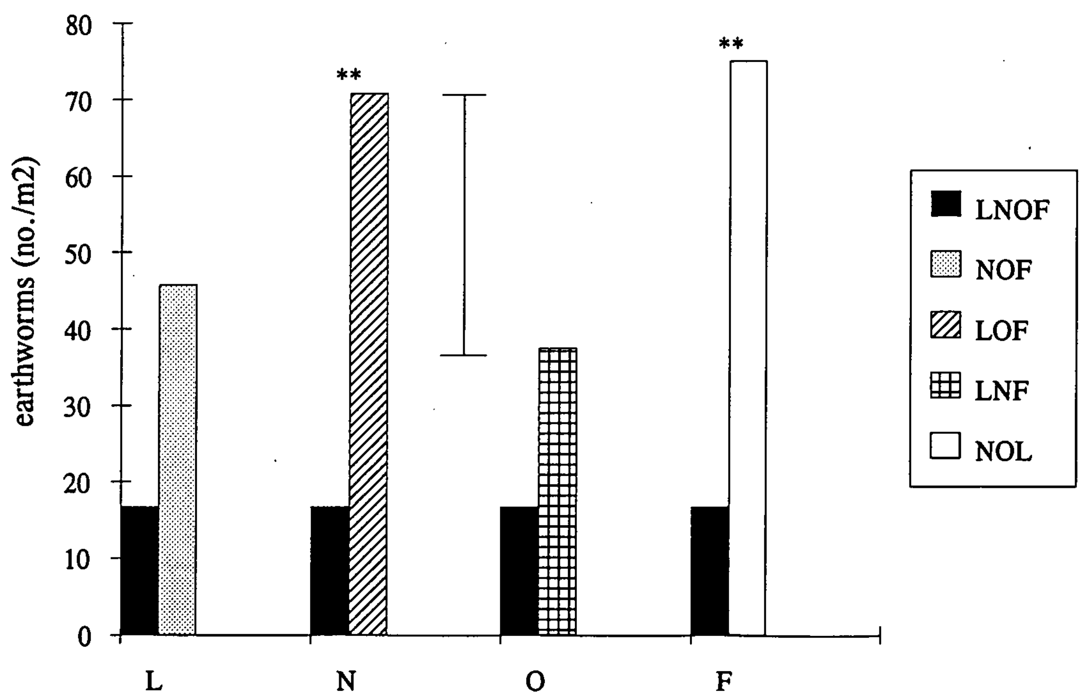


Figure 7.8: Effect of treatments on the number of *A. longa* by 26-8-93 at Perth (error bar represents 5 % L.S.D.; ** P<0.01).

Larvae of common pasture pests

Populations of larval pasture pests were high at Perth from 1992-1993. In 1992, corby grubs had reached almost 400/m^2 and were eradicated by Fenitrothion® @ 800 ml/ha. In 1993, numbers of red-headed cockchafer larvae had increased to 120/m^2, but were unable to be chemically controlled. Populations of red-headed cockchafer larvae were not significantly affected by the total earthworm numbers at this site.

Pasture production

Pasture production was measured on five occasions at Perth (figure 7.9) from 1991-1993, two of which produced significant differences between treatments. Pasture production was decreased by application of O ($P<0.001$) and L ($P<0.05$) 11 months after treatment application. Application of O continued to decrease pasture production ($P<0.001$) after 13 months but by 22 months, O no longer suppressed pasture growth. Pasture production was positively correlated ($P<0.01$) with total earthworm numbers 22 months after treatment application.

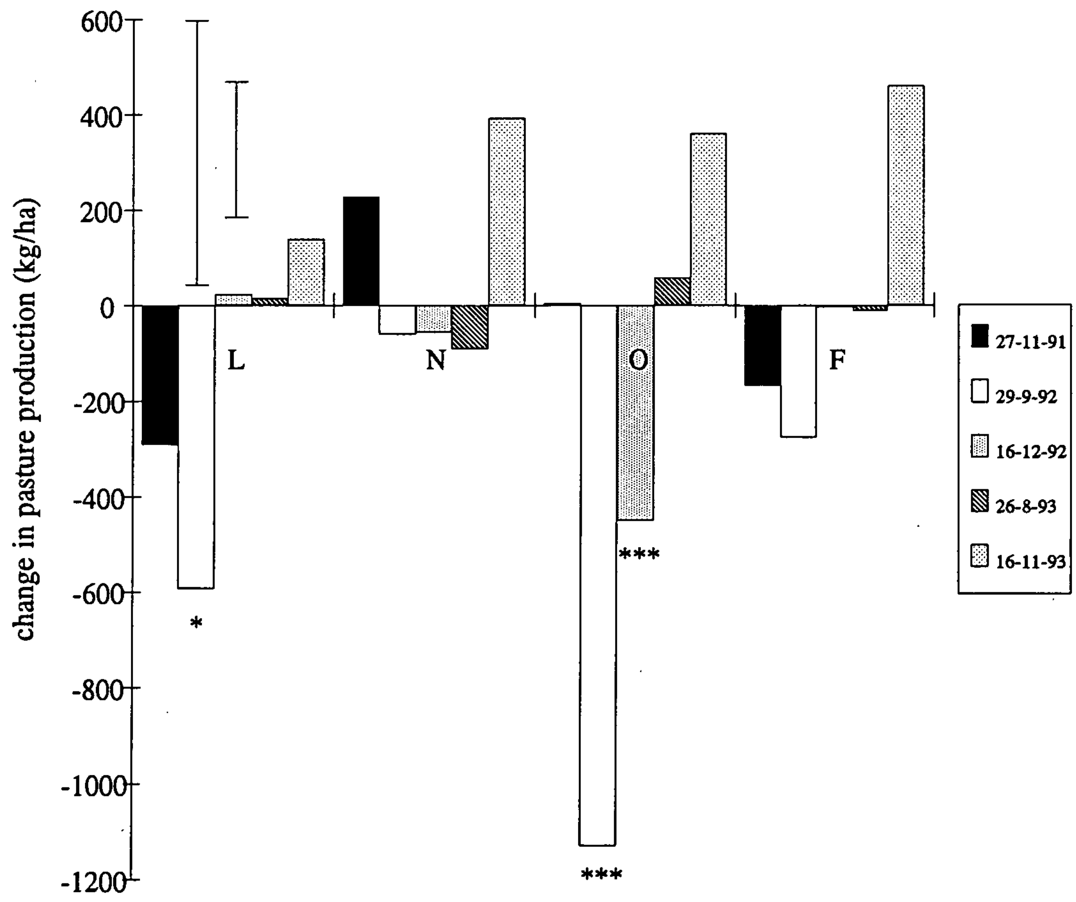


Figure 7.9: Change in pasture production at Perth during 1991-1993 (error bar represents 5 % L.S.D. within a sampling period; * $P<0.05$; *** $P<0.001$).

Application of N and O significantly decreased clover growth at Perth by up to about 10 % (table 7.4). The lack of response of clover to treatment application at Perth is probably due to the dominance of grass in the pasture sward at this site. Full details of the effects of treatment application on pasture production at Perth are available in Appendices 37-41.

Table 7.4: Increase (%) in the clover content of the pasture following treatment application at Perth (* $P<0.05$; ** $P<0.01$; *** $P<0.001$).

Date	Treatment			
	L	N	O	F
27-11-91	-2	0	-4	-1
29-9-92	-1	-8*	-10**	1
16-12-92	-	-	-	-
26-8-93	-	-	-	-
16-11-93	3	-1	-7***	-1

A. longa introduction

Introduction of *A. longa* significantly ($P<0.05$) increased pasture production by 13 % seven months after introduction, and by 17 % after 15 months (figure 7.10).

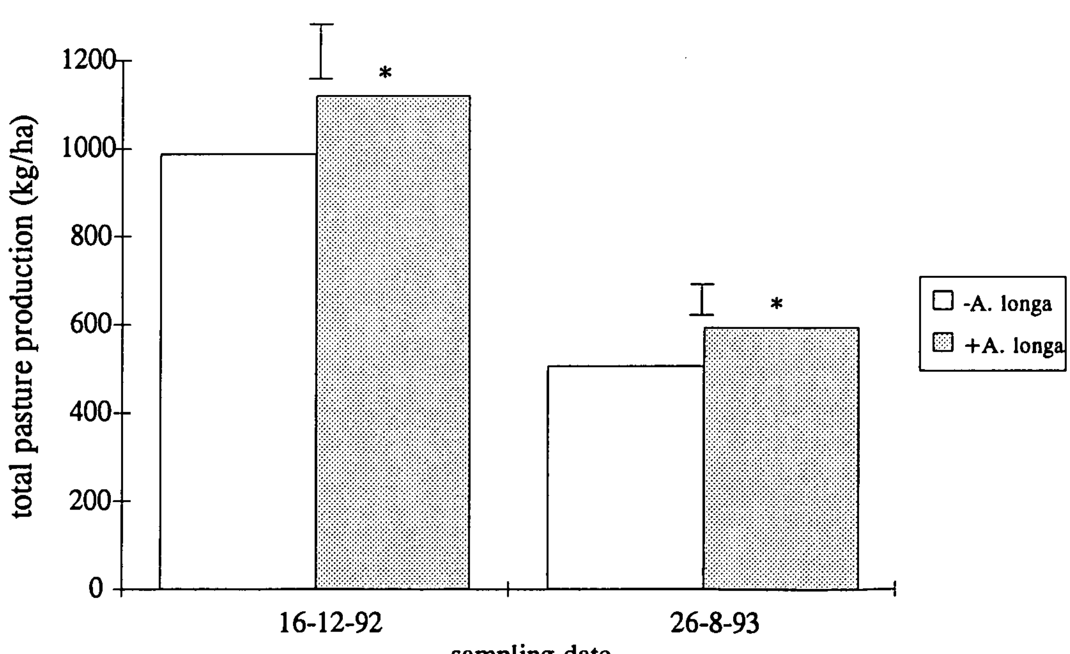


Figure 7.10: Effect of *A. longa* on pasture production at Perth seven and 15 months after introduction (error bar represents 5 % L.S.D.; * $P<0.05$).

Population growth of *A. longa* at Perth showed a similar pattern to results from Oatlands, with rapid cocoon production within four months resulting in high numbers of juveniles 15 months after introduction (figure 7.11). Numbers of adults also decreased with time, resulting in the total numbers of *A. longa* remaining constant.

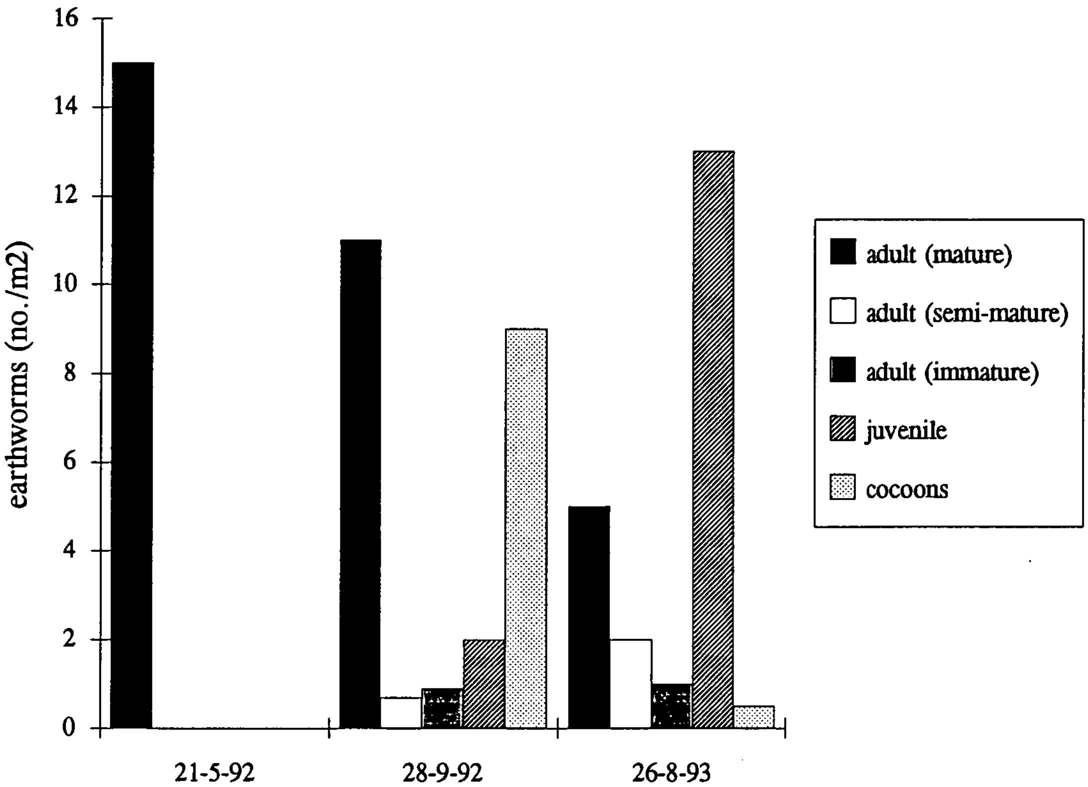


Figure 7.11: Change in the population structure of *A. longa* since introduction at Perth in May 1992.

<u>*Soil analysis*</u>

Application of L significantly increased soil pH at Perth ($P<0.05$) from 6.3 to 6.7, but no other soil nutrient was affected by treatment application (Appendix 45). Soil bulk density at Perth was not affected in January 1994 by treatment application (Appendix 48) or *A. longa* introduction (Appendix 49).

7.4 Discussion

Treatment application to increase earthworm population densities and pasture growth produced contrasting results at the two Midland sites.

Earthworms

The population density of earthworm species was increased at Oatlands by treatment applications (figures 7.2-7.4), but decreased at Perth (figures 7.7-7.8). Numbers of *A. trapezoides* and *A. longa* at Oatlands increased due to application of lime (L), and *A. trapezoides* and *L. rubellus* due to application of fertilisers (F). Application of organic matter (O) increased numbers of *A. trapezoides* after 13 months and *A. longa* after 23 months.

Earthworms at Oatlands appeared to be particularly responsive to increased levels of high N food reserves initiated by application of L, F and O. The importance of a readily available supply of organic N to earthworms has been well documented (Satchell, 1962; Watkin and Wheeler, 1966; Mattson, 1980; Hendriksen, 1990). Some workers consider the amount of available food to be the most important factor limiting earthworm populations (Edwards and Lofty, 1977; Waters, 1955). The response of *A. trapezoides* and *A. longa* to application of L may have been due to the increased amount of available calcium provided by lime (Nielson, 1951), yet Springett and Syers (1984) showed earthworms responded more to an increase in soil pH, rather than the calcium content of the soil. At a pH of 5.9 at Oatlands, it is doubtful if earthworm numbers were limited by soil acidity, since responses to lime application by earthworms are usually restricted to a soil pH_{H_2O} < 5.2-5.7 (Lee, 1985). Earthworm population densities were also not related to soil pH from 5.0-7.6 in a survey of pastures in the Midlands (Temple-Smith and Kingston, unpublished). It is more probable that an increase in earthworm numbers due to application of lime at Oatlands was an indirect response to the increased clover composition of the pasture due to lime (table 7.3). Several workers have reported improved earthworm growth associated with an increase in the availability of high N food sources, such as clover residues (Barley, 1959a; Edwards and Lofty, 1982a). Application of L at Oatlands increased the clover content of the pasture by 40 % after one year, and 24 % after 23 months (table 7.3), probably due to increased clover nodulation and Rhizobia populations in the soil. Coventry et al. (1985) found application of lime increased *Rhizobium trifolli* populations and the number of nodules when pH_{H_2O} increased from 6.1 to 6.77. This trend persisted for three growing seasons.

A similar explanation can be used for the response to F by *A. trapezoides* and *L. rubellus* at Oatlands. This site contained low levels of P and K (Appendix 43), and application of F resulted in a significant increase in clover composition of between 16 % and 70 % during the trial (table 7.3). Several other workers have noted that earthworm populations of cf. $400/m^2$ have been increased following application of superphosphate alone (Barley, 1959a; Fraser *et al.* 1993) and combined with lime (Sears and Evans, 1953). These findings indicate that where reasonably good earthworm populations exist in the Midlands ($300/m^2$) in a clover/grass pasture, the most effective method of increasing earthworm densities, and pasture production as a result, is by increasing the amount of clover in the pasture sward. In this instance, clover was increased by amending the soil's fertility through application of superphosphate, potash and lime.

Application of O as pea straw also increased numbers of *A. longa* and *A. trapezoides* at Oatlands. The pea straw contained moderate levels of N (1.2 %, Department of Primary Industry and Fisheries laboratories) making it an attractive food source for earthworms. Several authors have recorded an increase in earthworm density, particularly the deeper-burrowing species of Europe and Britain such as *L. terrestris* and *A. longa* (Barnes and Ellis, 1979; Edwards and Lofty, 1979), when cereal straw is retained rather than burnt (Haines and Uren, 1990; Doube *et al.* 1993b). The response of the deeper-burrowing species in these studies may be due to the preferential ingestion of larger food particles, such as cereal straw, by these species (Piearce, 1978). Boye Jensen (1985) found the loss of straw from the soil surface was greater in the presence of *A. longa* than the smaller species, *A. caliginosa.*

The application of N as an inorganic fertiliser failed to significantly increase earthworm populations at Oatlands. This is probably a consequence of the consistently lower levels of clover in the pasture following N application (table 7.3) which were significant 18 months after N application. The application of inorganic N ultimately led to a reduction in the amount of organic N residues available to earthworms as a food source in the soil. Tasmanian studies (Fisher, 1963; Martin and Carpenter, 1974) have shown application of N at similar rates to those used in this study resulted in vigorous grass growth in the sward which reduced the amount of clover due to competition.

The initially low population density of earthworms at Perth ($75/m^2$) were further reduced by application of N and F fertilisers (figures 7.7-7.8). Some studies indicate a similar trend following fertiliser application to pastures with initially low earthworm population densities Gerard and Hay (1979) found application of up to 100 kg N/ha increased the numbers of four lumbricid species from an initial population density of cf. $20/m^2$, but decreased the numbers of *A. rosea* which had a low initial population density of $9/m^2$. However, numbers of *Lumbricus* species increased in the same study from an initial density of $3/m^2$ following N application. Sears and Evans (1953) applied superphosphate to a grass/clover pasture supporting an initial earthworm population of $87/m^2$ and found fewer earthworms on plots receiving superphosphate compared to plots which had received no fertiliser. But it is unclear whether this result is statistically significant. There is no obvious explanation for the decrease in earthworm populations at low population densities from fertiliser application. My findings, and those of other authors, may be merely emphasising the variability associated with earthworm sampling, a dilemma which is exacerbated at low population densities.

Application of treatments affected different species at various stages of the trial, and no treatment consistently affected an individual earthworm species throughout the trial. This may be an indication of the different feeding patterns of the species studied. *A. trapezoides* feeds in the surface soil layers and may therefore respond to surface application of treatments sooner than *A. longa*, which is reported as a deeper burrowing species in Britain and Europe (Edwards and Lofty, 1977; Satchell, 1967). Further study of the ecology of *A. longa* is required to determine its depth of burrowing in the shallower, often drier soils of Australia compared to Europe and Britain. Field observations of *A. longa* at greater depths than *A. caliginosa* or *A. trapezoides* in this study indicate that it may indeed be a deep burrowing species. *L. rubellus* is a surface feeder, which prefers feeding on high protein food sources, such as dung pats or clover residues (Svendsen, 1957; Boyd, 1958; Holter, 1983). This species responded to F application after 23 months. The slow response of *L. rubellus* may be due to the time taken for clover residues, increased by F, to accumulate and decompose in the soil.

A. longa was successfully established into the low rainfall pastureland of Tasmania. The initiation of cocoon production and the resultant succession of juveniles into the population indicates conditions at the experimental trial sites were suitable for *A. longa* establishment. The total numbers of *A. longa* remained constant over 16 months, but the recruitment of juveniles into the population should procure the future establishment of *A. longa* at these experimental sites. Considering the low population density of *A. longa* at introduction sites, minimal credence should be given to the apparent decline in numbers of adult *A. longa*. Studies of population growth of *A. longa* have not been reported in the literature to date. On the basis of these results, the scarcity of *A. longa* from 95 % of pastures in the Midlands (Temple-Smith, 1991) is curious, given the close proximity of widespread *A. longa* populations in the north-east and north-west of Tasmania. Intensive production of *A. longa* would be desirable to facilitate the spread of this species into pastures in the Midlands and mainland Australia. Certainly, identification of optimal temperature and nutrition requirements, similar to research by Butt et al. (1992) on *L. terrestric* would aid in the intensive production of *A. longa*.

The dominant species at Oatlands, *A. caliginosa*, was not affected by treatment application and consequently, considerable scope exists for further increases in earthworm density and pasture production in the Midlands. In contrast, the numbers of the surface feeding species, *L. rubellus*, increased from treatment application, utilising the higher N content of the clover litter. Watkin and Wheeler (1966) also found *L. rubellus* performed better under a clover/grass sward in comparison to *A. caliginosa*. This indicates that some other factor is limiting *A. caliginosa* at Oatlands. It seems likely that *A. caliginosa* is particularly dependent upon rainfall, more so than any other species found in the Midlands, since greater densities are found in the higher rainfall regions of the Midlands (figure 5.9 of Chapter V). Baker (unpublished) has also found *A. caliginosa* restricted to the higher rainfall regions of South Australia.

There was no significant relationship between numbers of earthworms and red-headed cockchafers in this study. This was based on a single sampling period and several years data is needed to confirm this trend. Similar studies in Tasmanian pastureland have noted a decrease in the density of pasture pests due to an increase in earthworm populations. Garnsey et al. (submitted) found numbers of yellow-headed cockchafers (*Saulostomus villosus* and *Scitala sericans*) were reduced by 48 % when *A. caliginosa* and *A. longa* were introduced into Tasmanian pasture. However, numbers of pasture and red-headed cockchafers were unaffected by earthworm introduction. McQuillan (unpublished) also speculates a negative relationship between densities of red-headed cockchafers and earthworms exists, given both species are discriminant feeders of organic matter. Given the conjecture in the literature, the relationship between pasture pests, such as the red-headed cockchafer, and earthworm density requires closer scrutiny.

Pasture production

There was a strong relationship between earthworm numbers and pasture production at Oatlands and Perth. Both L and F increased pasture growth and earthworm numbers at Oatlands after 13 and 23 months. L decreased pasture growth within the first year at both sites, which cannot be explained. O also significantly decreased pasture production within the first 14 months at both sites, probably due to shading effects of the pea straw on the pasture. N boosted pasture production at Oatlands for a month after application, but decreased the amount of clover in the sward after 18 months. Pasture production at Perth during 1991-1993 was not significantly improved by any treatment application, although pasture growth, though not significant, was increasing under all treatments by the final pasture cut. Total earthworm numbers were also positively correlated to pasture production on two occasions at Oatlands and one at Perth. It is difficult to determine if earthworms have been directly affected by treatment application, or whether they have been indirectly influenced by changes in pasture production brought about by application of treatments.

Introduction of *A. longa* increased pasture production at Perth after only seven months, yet no significant increase was found at Oatlands during 1991-1993. One possible explanation for these conflicting results lies with the difference in earthworm density and soil type between Oatlands and Perth. Total earthworm numbers were increased by 20 % at Perth following the introduction of *A. longa*, since resident earthworm populations were initially low ($75/m^2$). Although this site was not sodic at the soil surface, soil chemical analysis indicates Na has been important in its formation (Plate 7.1). Several other similar soils from the Perth district are classified as sodic to a depth of over a metre (Doyle, pers. comm). The site was certainly prone to hardsetting in summer and waterlogging in winter. It is likely that *A. longa* has had some impact on the soil's physical status at Perth, although attempts to quantify this failed to produce a significant reduction in bulk density due to *A. longa*. Considering the lower rainfall and the lighter textured soil at this site in comparison to Oatlands, plant growth was probably improved by *A. longa* introduction due to an improvement in the availability of water to plants. In contrast, Oatlands supported more than three times the number of earthworms than Perth at the initiation of the trial, and introduction of *A. longa* made an insignificant contribution to the population overall. Water was probably less limiting to plants at this site due to the heavy textured soil compared to Perth. Baker (unpublished) found a similar response in pasture production from *A. longa* introduction in South Australia. Introduction of *A. longa* into pastures supporting low populations of resident earthworms ($113/m^2$) significantly increased the total pasture production over six months by 60 % compared to controls. However, *A. longa* introduction did not affect pasture growth where the resident earthworm population density was high ($566/m^2$). Springett (1985) introduced *A. longa* into pasture in New Zealand at a greater density than this study (@ $150/m^2$) and reported an increase in pasture production of 12 %, 15 % and 27 % after two, three and 14 months, respectively. This was associated with measurable increases in soil porosity, water infiltration and root biomass due to *A. longa* introduction.

The difference in the response of earthworms and pasture growth to treatment application between sites at Perth and Oatlands is probably due to differences in climate, earthworm density, soil type and pasture composition between the two sites. The Oatlands site has a higher rainfall, altitude and lower evapotranspiration than at Perth. There was also a greater earthworm population and more responsive soil to fertilisers than at Perth. These factors alone indicate that earthworms and pasture production at Oatlands would be more responsive to treatment application than Perth. The pasture at Oatlands also contained a higher clover content than the site at Perth, a factor which proved valuable in determining the effect of treatments (L and F in particular) on earthworm numbers and pasture growth in this study.

VIII. THE EFFECTS OF IVERMECTIN ON EARTHWORM GROWTH AND COCOON PRODUCTION IN THE LABORATORY

8.1 Introduction

Ivermectin (22,23-dihydroavermectin B_1) is a recently developed, broad-spectrum, highly persistent drug which is administered to cattle, horses, sheep and pigs for control of parasitic gastrointestinal and pulmonary nematodes, mites, lice, warble flies and ticks.

Following administration, ivermectin is partially metabolised by the animal, and most of the drug is excreted in the faeces (Campbell *et al.* 1983) where it can affect non-target, dung-inhabiting organisms. The concentration and persistence of ivermectin in faeces depends on the dosage, method of administration and treatment duration (Strong, 1993).

Following excretion, the rate of ivermectin degradation increases under sunlight and in contact with organic matter in the faeces and soil (Halley *et al.* 1993). During winter, and under dark conditions in the laboratory, ivermectin degrades slowly with a half-life of between 90 and 240 days in cattle dung. This is reduced to 7-14 days in outdoor summer conditions and only three hours under direct sunlight (Halley et al. 1989a).

Most studies of the environmental effects and kinetics of ivermectin have been confined to cattle, since the degradation and invertebrate activity in the large pats of cattle is particularly important to livestock health and pasture productivity. Similar studies on ivermectins in sheep have been limited to effects on adult blowflies and dung inhabiting flies and beetles including *Musca vetustissima, Euoniticellus fulvus, Onthophagus australis* and *O. posticus* (Cook, 1991, 1993; Mahon and Wardhaugh, 1991; Wardhaugh and Mahon, 1991). However, ivermectin is administered orally to sheep, whilst cattle receive a subcutaneous injection. Combined with differences in ivermectin metabolism and the drug formulation for sheep and cattle, the excretion rate of ivermectin is likely to be different between these two species (Bogan and McKellar, 1988; Fink and Porras, 1989; Wardhaugh and Mahon, 1991).

Several studies have found dung from cattle (Miller *et al.* 1981; Ridsdill-Smith, 1988; Wardhaug and Rodriguez-Menendez, 1988; Roncalli, 1989; Lumaret *et al.* 1993) and sheep (Cook, 1991, 1993; Mahon *et al.* 1993; Wardhaugh *et al.* 1993; Mahon and Wardhaugh, 1991; Wardhaugh and Mahon, 1991) treated with ivermectin can adversely affect invertebrates such as dung beetles and flies. Dung pat decomposition may be retarded as a result (Wall and Strong, 1987; Madsen *et al.* 1990). However, conjecture exists in the literature over its impact on earthworms. Wall and Strong (1987) found a reduction in the number of invertebrates in cattle pats containing ivermectin for up to 80 days. Whilst earthworm numbers in the same study were not significantly reduced due to ivermectin, they were not found in dung pats from treated cattle until day 80. However, the LC_{50} ivermectin level for *Eisenia fetida* (Halley *et al.* 1989a) is more than 17 000 times greater than levels in sheep dung following drenching (Halley *et al.* 1989b). Madsen et al. (1990) found numbers and biomass of *Aporrectodea* spp. and *Lumbricus* spp. were not significantly reduced under dung pats after 30 days exposure to cattle dung containing ivermectin. Wratten et al. (1993) examined the number and biomass of earthworms in a paddock grazed by cattle treated with ivermectin for two consecutive years and concluded there was no effect of ivermectin on earthworms. But, this was over a large area and involved formalin expulsion of earthworms at random points over the paddock. The current trial examines the effects of feeding dung from sheep treated with ivermectin on the growth and cocoon production of four earthworm species in the laboratory.

8.2 Materials and methods

The following earthworm species were used in a randomised complete block design, replicated four times, to investigate the effects of dung from sheep treated with ivermectin on earthworm growth and survival:

a) *Aporrectodea caliginosa*
b) *A. trapezoides*
c) *A. longa*
d) *Lumbricus rubellus*

Screw top jars (1 L capacity) were partially filled with 700 g of a light sandy clay loam soil (table 8.1), and 40 g of dung from either drenched or undrenched sheep was applied to the soil surface. Jars were kept at a constant temperature of 15 ^{o}C in complete darkness. After 30 days, three sexually mature earthworms of either *A. caliginosa*, *A. trapezoides* or *L. rubellus*, or one immature *A. longa* were individually weighed and added to jars. Only one *A. longa* individual was added to the jars due to the greater size and biomass of this species compared to the other earthworm species used in the study. Sexually mature specimens of this species were unavailable at the time of the trial.

Table 8.1: Soil analysis for ivermectin trial.

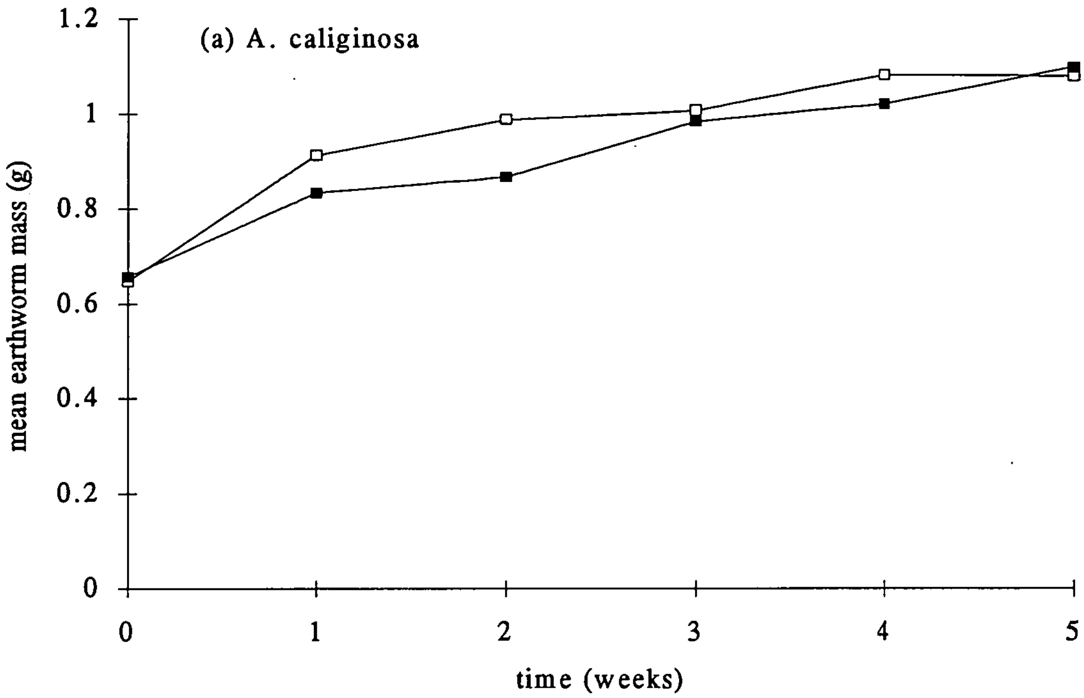
Soil test	Quantity
pH (1:5 H_2O)	6.5
EC (dS/m)	0.24
P (mg/kg)	65
K (mg/kg)	735
N (%)	0.28
Organic carbon (g/100g)	2.8

Sheep were injected with a single oral administration of ivermectin (Ivomec®) @ 2.5 ml/10 kg liveweight and dung collected 6-36 hours after injection. At the same time, dung was collected from undrenched sheep as a control. Soil had been air-dried, sieved (< 4 mm) and wetted to a 60 % field capacity. Earthworms were weighed at weekly intervals for five weeks. Cocoons were then counted from each jar to determine the effects of ivermectin on cocoon productions. There was no cocoon production from the immature *A. longa*.

8.3 Results

Effect of ivermectin on earthworm growth

The growth of four pasture earthworm species was not significantly impeded over five weeks by providing dung from sheep treated with ivermectin (figures 8.1a-d; refer Appendix 51 for full details of data).



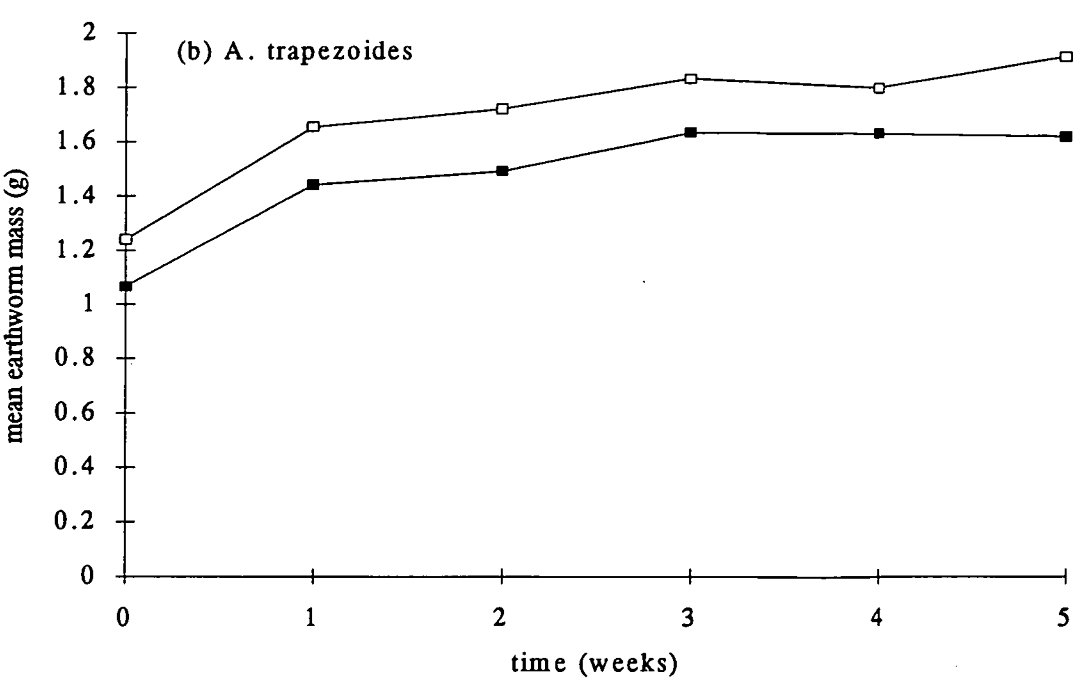
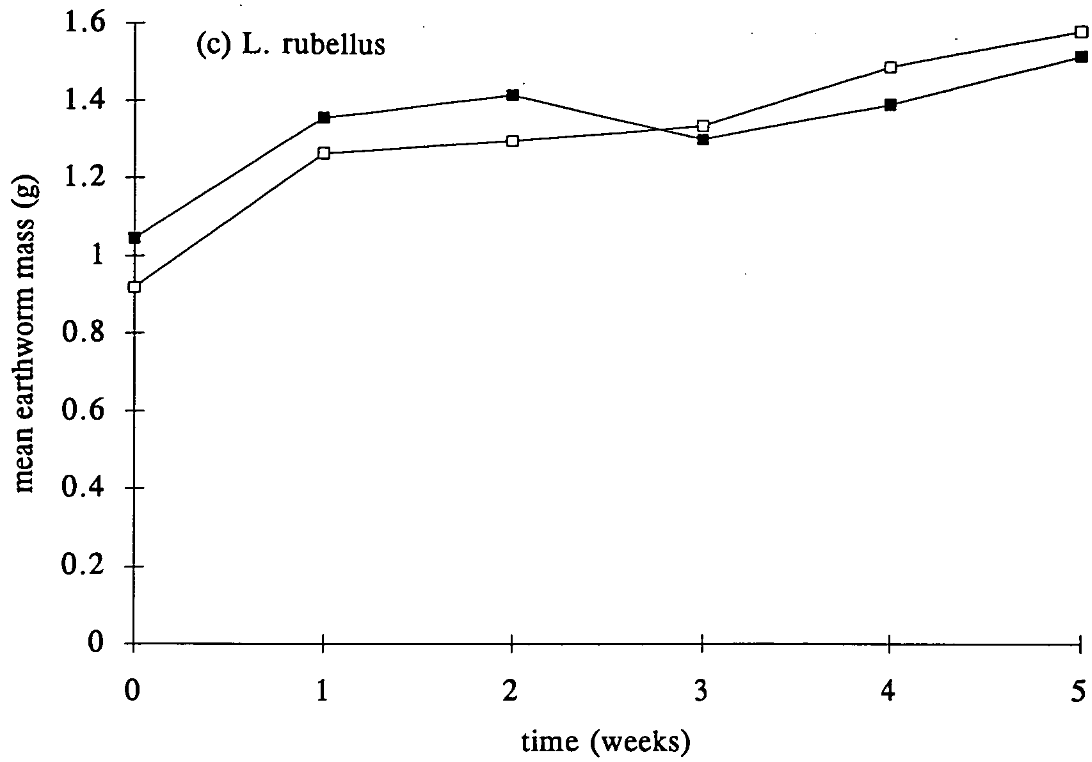


Figure 8.1: The effect of dung from sheep drenched with ivermectin (——■——) and without ivermectin (——□——) on the growth of (a) *A. caliginosa* and (b) *A. trapezoides*.



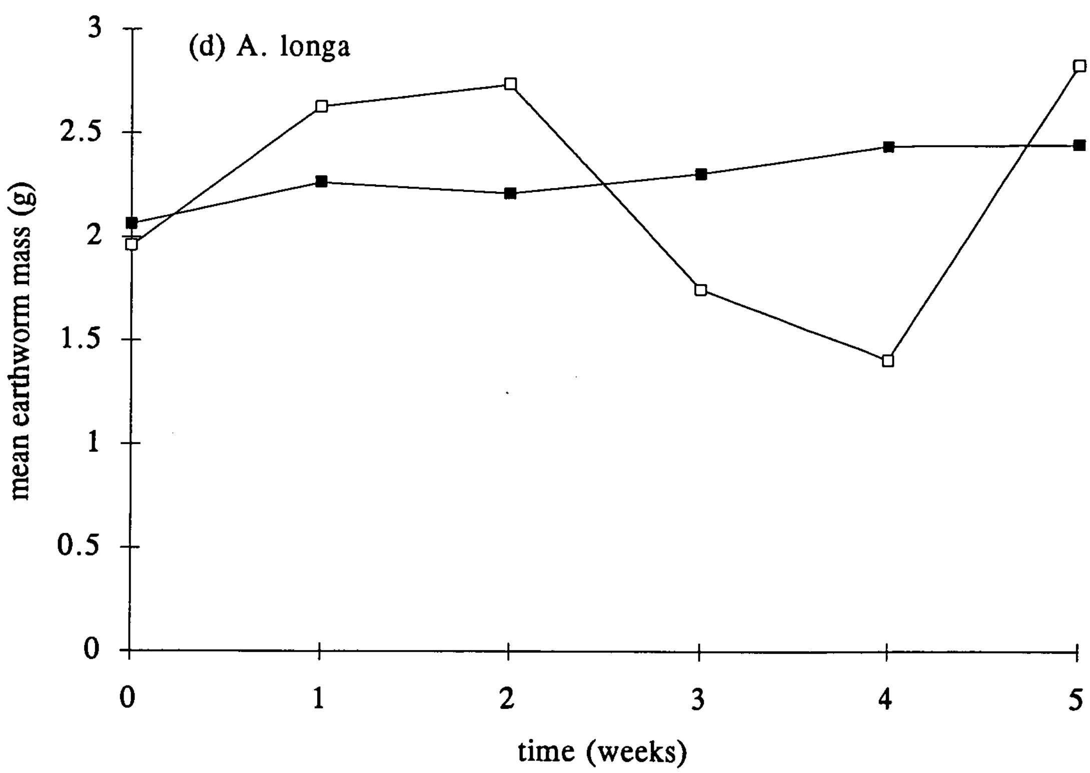


Figure 8.1: The effect of dung from sheep drenched with ivermectin (——■——) and without ivermectin (——□——) on the growth of (c) *L. rubellus* and (d) *A. longa*.

Effect of ivermectin on earthworm cocoon production

Earthworm cocoon production was not significantly reduced by ivermectin after five weeks (figure 8.2; refer Appendix 52 for full details of data).

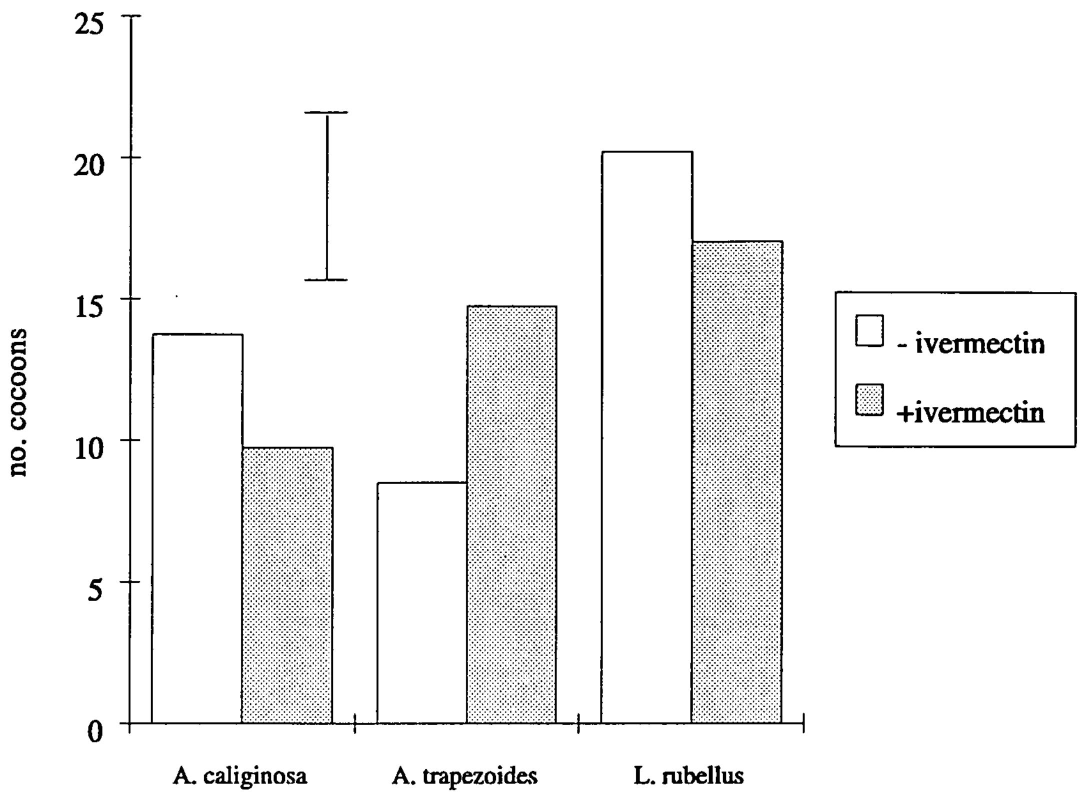


Figure 8.2: Effect of ivermectin in dung on the cocoon production of three earthworm species after five weeks (error bar represents 5 % L.S.D. between species and across treatments).

Cocoon production differed significantly between earthworm species with *L. rubellus* producing significantly ($P<0.05$) more cocoons over the five weeks than either *A. caliginosa* or *A. trapezoides*.

8.4 Discussion

Faeces from sheep treated with an ivermectin did not reduce the growth or cocoon production of four pasture earthworm species over five weeks in the laboratory. There are two possible explanations for this result. Firstly, the quantity of ivermectin excreted in sheep faeces may have been so minimal that earthworm growth was not adversely affected. The LC_{50} concentration of 315 ppm for *Eisenia fetida* (Halley *et al.* 1989a) is more than 17000 times greater than the levels of ivermectin in sheep dung (18 ppb, Halley *et al.* 1989b). Whilst, *E. fetida* was not used in this study, Halley et al. (1989a) considers the response of other species should be similar. The second, less likely possibility is that the amounts of ivermectin excreted may have been initially high enough to affect earthworm growth, but were reduced to levels which were not detrimental to earthworms following partial decomposition of the dung. Some degradation of dung needs to occur before it becomes an attractive food source to earthworms (Evans and Guild, 1948). In this study, dung was allowed to decompose for 30 days before earthworms were added. This would have only reduced ivermectin levels from the time of deposition by between 7 % and 16 %, based on the estimated half-life of ivermectin in cattle faeces in the laboratory (Halley et al. 1989a). Response to ivermectin by earthworms in the field should be similar to the laboratory results reported here, given the similar half-life of ivermectin (Halley et al. 1989a) under laboratory conditions (93-240 days) and outdoor winter conditions (91-217 days).

Studies on the faecal elimination of ivermectin in sheep has been limited to associated effects on dung beetles and the sheep blowfly. Research to date has focussed on the excretion of ivermectin in cattle and the subsequent effects on dung fauna, especially dung beetles. Research with cattle by Madsen et al. (1990) which parallels the current study found no reduction in earthworm number or biomass of *Aporrectodea* spp. and *Lumbricus* spp. under dung pats after 2-3 months, collected from cattle 1, 10, 20 or 30 days after injection with ivermectin. But, *A. trapezoides* and *L. rubellus* which were included in the current trial, were not included by Madsen et al. This is of particular significance given the attraction of *Lumbricus* species such as *L. rubellus* to dung pats (Svendsen, 1957; Boyd, 1958; Holter, 1983). Peak elimination of ivermectin in cattle faeces range from two to five days after subcutaneous injection (Lumaret *et al.* 1993; Sommer and Steffansen 1993; Steel, 1993). Similar studies on the kinetics of ivermectin faecal excretion in sheep is needed.

Further examination of the effects of ivermectin on juvenile earthworms is needed, since mature adults of three species were used and immature adults of *A. longa*. Juveniles may be more sensitive to ivermectin than adults, as is the case for some species of dung beetle, including *Onthophagus binodis*, *O. gazella, Bubuas bubabus* and *Copris hispanus* for cattle (Wardhaugh and Rodriguez-Menendez, 1988; Ridsdill-Smith, 1988; Halley et al. 1989c; Picton and Burrows, cited by Roncalli, 1989) and *E. fulvus* in sheep (Wardhaugh *et al.* 1993). The growth of *A. longa* immatures was not significantly affected by ivermectin in this study. However, this result is unreliable given the erratic growth of *A. longa* juveniles over the five weeks in the absence of ivermectin (Figure 8.1d). The erratic growth of *A. longa* is probably a reflection of the difficulty associated with rearing this large and active pasture species in a restricted volume. The reason for the irregular growth in the absence of ivermectin, and the more typical increase in *A. longa* biomass in the presence of ivermectin cannot be explained.

The higher fecundity of *L. rubellus* compared to *A. caliginosa* and *A. trapezoides* reported in this study agrees with analysis of data from Evans and Guild (1948) cited by Satchell (1967) who reported that cocoon production of *L. rubellus*, residing at the soil surface, was 3-4 times as high as the topsoil species *A. caliginosa*.

IX. SYNTHESIS AND CONCLUSION

Potential exists for farmers in the Midlands to increase earthworm population density and diversity and, as a result, pasture production in the Midlands by several methods. Firstly, increased pasture production can be achieved from the introduction of *A. longa*. This study demonstrated that increases in pasture production can be achieved from increased earthworm activity in the Midlands. Increased earthworm species diversity in the Midlands from introduction of *A. longa* resulted in an increase in pasture production in this study after seven and 15 months, by up to 17 %. Application of fertilisers, lime and organic matter also increased the population of individual earthworm species at Oatlands in the Midlands. An increase in the availability of high N residues appears to be largely responsible for the increase in earthworm numbers. However, contrasting results were recorded at Perth, indicating the importance of considering all components in the management of earthworm populations, including climate, soil fertility and vegetation type. Long-term assessment of the effects of *A. longa* on pasture production is required to confirm the trends reported here.

Significant differences were observed between the two most abundant earthworm species in the Midlands in response to rainfall and soil texture. *A. caliginosa* numbers and biomass tended to be lower on sandy soils, and was adversely affected by low rainfall: population density, cocoon production and adult development were impaired under low rainfall. Despite this reliance on rainfall, *A. caliginosa* remained the most abundant species in the Midlands, suggesting it may be an opportunistic species which compensates for poor performance under low rainfall by achieving high rates of growth and reproduction during periods of higher rainfall. In contrast, the population density, cocoon production and adult development of *A. trapezoides* was unaffected by rainfall between 425-600 mm p.a. Population density of *A. trapezoides* was also less affected by soil texture in contrast to *A. caliginosa*. *A. trapezoides* appears to be better suited to the drier climate of the Midlands where soil moisture often limits activity in the surface soil to only a few months. However, this species is unable to reach the density or biomass of *A. caliginosa*, possibly due to lower rates of fecundity and development. Further monitoring of sites currently supporting *A. caliginosa* and/or *A. trapezoides* would determine the relative persistence of these species when confronted with extended periods of low rainfall.

The current study provides the first report of earthworm aestivation survival under Australian conditions. Mortality associated with aestivation increased with the length of aestivation, reaching up to 60 % for juveniles and 63 % for adults. Earthworm aestivation of up to eight months in the Midlands, and a short period of surface earthworm activity and available breeding time of only around four months provides some explanation for the low population densities encountered in the Midlands. Further investigation into the parameters affecting depth of earthworm aestivation is required. Neither soil type nor texture were related to depth of aestivation in this study, however soil pF was not measured in the aestivation trial due to financial and staffing constraints of the project.

Ivermectin in sheep dung did not affect the growth or cocoon production of four common pasture earthworm species. This agrees with more superficial studies of the effects of ivermectin in cattle dung on earthworms. Unfortunately, levels of ivermectin were not measured in the dung in this study due to financial constraints of the project, but would have added further credence to the reported findings.

Further investigation into the relationship between earthworms and pasture pests is needed. Findings in this study reported no association between these two soil organisms, but this was based on a single infestation of red-headed cockchafers, and a more detailed study is needed to clarify the relationship.

This study has identified several factors limiting earthworm populations in the Midlands; the availability of high N residues in the soil, the short periods of surface earthworm activity combined with an extended aestivation were important contributers to the low earthworm population densities encountered in the Midlands. A greater understanding of the relative importance of rainfall and soil texture to common earthworm species was also determined in the Midlands, which will aid in future management of earthworms in the area.

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XI. APPENDICES

Appendix 1: Average rainfall (mm) for the Midlands (Bureau of Meteorology, pers. comm.).

Meteorological Station	J	F	M	A	M	J	J	A	S	O	N	D	Annual
Perth	40	41	41	56	62	62	80	79	63	63	51	53	691
Campbell Town	39	36	36	44	46	43	48	48	48	56	47	54	543
Oatlands	44	39	41	48	45	49	44	46	42	54	50	56	558
Ross	39	32	37	40	40	39	44	46	45	51	44	53	516
Tunbridge	37	18	35	40	42	34	42	42	41	42	46	45	470
Bothwell	38	37	39	51	46	48	47	48	46	55	52	52	559
New Norfolk	43	21	37	36	35	32	44	49	45	55	35	47	430
Average	40	32	38	45	45	44	50	51	47	51	46	51	538

Appendix 2: Average maximum monthly temperature (^{O}C) for the Midlands (Bureau of Meteorology, pers. comm).

Meteorological Station	J	F	M	A	M	J	J	A	S	O	N	D
Perth	23	23	21	17	14	11	11	12	14	16	19	21
Campbell Town	24	25	22	17	15	11	11	13	15	17	20	22
Oatlands	22	22	19	16	12	10	9	11	13	15	17	20
Ross	-	-	-	-	-	-	-	-	-	-	-	-
Tunbridge	-	-	-	-	-	-	-	-	-	-	-	-
Bothwell	23	23	21	17	14	11	11	12	14	17	18	20
New Norfolk	24	24	21	18	14	11	11	13	15	18	19	21
Average	23	23	21	17	14	11	11	12	14	17	19	21

Appendix 3: Average minimum monthly temperature (^{O}C) for the Midlands (Bureau of Meteorology, pers. comm.).

Meteorological Station	J	F	M	A	M	J	J	A	S	O	N	D
Perth	10	10	9	7	5	3	2	3	4	6	7	9
Campbell Town	9	9	8	5	3	0	0	2	3	4	6	8
Oatlands	9	9	8	6	4	2	1	2	3	5	6	8
Ross	-	-	-	-	-	-	-	-	-	-	-	-
Tunbridge	-	-	-	-	-	-	-	-	-	-	-	-
Bothwell	8	8	7	4	2	0	0	1	2	3	6	7
New Norfolk	11	11	10	7	5	3	2	3	5	6	8	10
Average	9	9	8	6	4	2	1	2	3	5	7	8

Appendix 4: Mean hatching time of *A. caliginosa* and *A. trapezoides* cocoons.

Species	Collection date	Hatching date	Hatching time (days)
A. trapezoides	17-7-92	21-9-92	66
A. caliginosa	13-7-92	31-8-92	49
A. caliginosa	13-7-92	31-8-92	49
A. caliginosa	13-7-92	2-9-92	51
A. trapezoides	15-7-92	8-9-92	57
A. trapezoides	15-7-92	8-9-92	55
A. caliginosa	13-7-92	8-9-92	57
A. trapezoides	15-7-92	8-9-92	55
A. trapezoides	15-7-92	8-9-92	55
A. trapezoides	16-7-92	15-9-92	61
A. caliginosa	13-7-92	15-9-92	64
A. trapezoides	13-7-92	21-9-92	70
A. trapezoides	13-7-92	21-9-92	70
A. caliginosa	16-8-92	4-9-92	50
A. caliginosa	20-8-92	29-9-92	71
A. caliginosa	20-8-92	29-9-92	71
A. caliginosa	20-8-92	29-9-92	71
Mean			60

Appendix 5: Mean earthworm numbers and annual rainfall for 1992 and 1993.

year	rainfall	A. caliginosa	A. trapezoides	O. cyaneum
1992	425	40.42	69.58	5.83
1992	450	1.25	134.17	0
1992	450	128.33	79.58	0.417
1992	543	128.33	110.42	7.08
1992	550	112.50	63.75	20.83
1992	550	113.33	37.08	12.50
1992	550	301.67	88.42	3.75
1992	580	85.0	21.25	8.33
1992	584	112.50	8.75	0.83
1992	584	52.92	62.08	0.417
1992	584	100.0	104.17	10.83
1992	600	146.25	167.92	1.67
1992	600	128.33	76.25	100.0
1992	600	18.75	25.42	162.50
1993	425	48.13	36.25	3.75
1993	450	0	19.38	0
1993	500	7.50	19.38	2.50
1993	543	76.88	36.25	1.25
1993	550	36.88	28.75	8.75
1993	550	153.10	71.88	21.88
1993	550	171.25	61.25	0.63
1993	580	57.50	23.75	8.13
1993	584	102.50	23.75	5.00
1993	584	393.75	56.88	1.25
1993	584	263.75	46.25	6.25
1993	600	471.88	133.75	0.63
1993	600	148.75	45.63	51.88
1993	600	12.50	8.125	6.88

Appendix 6: Analysis of variance table for the effect of rainfall on mean earthworm density in 1992 and 1993

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	5	118.23	23.645	20.05
Residual	78	91.97	1.179	
Total	83	210.20	2.532	
Change	-5	-118.23	23.645	20.05

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	-4.27	2.02	-2.11	0.038
Rainfall	0.01534	0.00367	4.18	< 0.001
A. trapezoides	8.76	2.86	3.06	0.003
O. cyaneum	1.05	2.86	0.36	0.717
Rainfall. A. trapezoides	-0.01650	0.00519	-3.18	0.002
Rainfall. O. cyaneum	-0.00615	0.00519	-1.18	0.240

Appendix 7: Mean (n=10) monthly moisture content (%) for earthworm life cycle sites.

Site	Monthly average mositure content (%)																	
	May-92	Jun-92	Jul-92	Aug-92	Sep-92	Oct-92	Nov-92	Dec-92	Jan-93	Feb-93	Mar-93	Apr-93	May-93	Jun-93	Jul-93	Aug-93	Sep-93	Oct-93	Nov-93
1	19.55	17.16	16.19	19.14	24.2	25.04	12.85	10.13	1.88	2.38	3.78	4.61	4.11	11.76	19.53	19.59	18.37	14.43	4.09
2	19.03	21.56	21.87	39.14	37.64	28.78	11.08	12.04	5.26	6	6.05	5.6	4.93	13.68	23.12	26.2	25.81	21.58	10.49
3	33.53	26.22	20.87	29.7	31.3	27.62	16.7	20.59	15.64	13.71	13.03	15.4	14.82	22.15	33.23	36.95	27.3	28.94	11.82
4	19.11	30.15	21.4	38.17	35.45	33.11	5.38	13.22	7.3	8.86	7.57	8.48	9.2	16.91	26.78	30.6	29.43	30.68	11.01
5	23.84	27.29	18.9	33.84	31.65	31.51	11.93	10.76	7.36	6.93	11.62	10.68	9.29	17.19	30.75	30.54	30.16	31.1	10.52
6	13.73	17.68	12.25	21.75	19.19	19.28	9.78	8.8	3.91	6.59	4.87	5.7	4.28	8.32	15.43	21.78	12.35	9.36	5.23
7	16.02	18.48	12.82	23.59	19.12	20.76	12.79	14.17	2.56	3.63	5.97	5.77	6.46	7.3	13.27	18.95	10.99	4.85	2.1
8	16.61	17.4	15.52	28.37	23.81	22.04	12.97	7.27	5.45	9.36	8.67	8.6	8.6	9.4	18.66	22.42	15.6	6.49	5.62
9	14.77	18.99	15.19	25.56	21.25	22.13	10.45	7.92	6.32	5.95	6.36	6.23	5.1	9.67	17.01	19.24	15.84	10.78	5.34
10	24.99	36.97	20.6	46.74	42.37	24.02	19.86	11.97	7.56	5.46	30.66	9.16	9.67	12.31	24.8	26.99	23.53	10.47	9.13
11	44	22.09	29.99	27.61	24.92	39.46	30.22	28.59	22.83	25.72	9.05	26.07	21.1	25.46	45.47	46.55	33.4	14.43	15.98
12	43.66	61.52	38.34	60.56	62.03	62.34	42.77	46.11	29.17	30.2	31.35	29.54	32.09	33.32	44.09	58.06	49.52	41.69	29.29
13	30.1	34.93	20.68	32.41	32.22	31.63	25.4	23.59	11.41	13.62	13.15	13.4	12.29	13.55	26.82	31.54	20.15	12.51	11.18
14	17.61	22.3	19.49	30.48	26.94	26.53	18.43	13.08	2.69	3.12	5.99	7.45	6.84	12.18	20.91	25.19	19.35	7.68	5.72
Mean	24.75	26.62	20.3	32.29	30.86	29.59	17.19	16.3	9.74	14.15	11.7	11.48	10.92	15.44	26.07	29.96	24.03	18.25	9.82

Appendix 8: Soil profile desciptions for life cycle study sites.

Soil database No: 151
Property Name: Scone
Property Owner: Gibson, W. R.
Nearest Town: Perth
Describer: Richard Doyle
Type of Desc: Soil pit

Rainfall: 650 mm
Elevation: 150 m
AMG Easting: 515800 E
AMG Northing: 5394900 N

Soil Class: Brickendon
Northcote PPF: Dy5.31
Great Soil Group: Grey-Brown Podzolic Soil
Drainage: Imperfectly drained
Permeability: Slowly permeable
Runoff: Slow

Isbell Class:	Bleached-Sodic, Mesotrophic, Brown, Chromosol; deep, medium, loamy, non gravelly
Landform:	Element level, flat, geomorphic agent overbank streamflow (unchannelled), terrace plain; Pattern level plain <9m <1%, terraced land;
Land Surface:	Slope angle 0 %; complete clearing - pasture but never cultivated; surface soil soft; Erosion minor or present, stabilized, wind; Inundation none; Coarse Fragments v few (<2%) stones (60-200mm); Rock Outcrops none;
Vegetation:	pasture species
Substrate:	massive, clays (argillaceous), clay, kaolinized, lacustrine sediment;

A1 20 cm
Dark greyish brown (10YR 4/2 moist); greyish brown (10YR 5/2 dry); fine sandy loam; weak medium (20-50mm) subangular blocky plus single grain structure; slightly sticky; slightly plastic; sandy fabric; common (1-5 per 100mm2) very fine (0.075-1mm) macropores; no segregations; v few (<2%) strong rounded gravels (6-20mm) quartz; common very fine (<1mm) live roots; 5.1 field pH; clear (20-50mm) irregular boundary;
A21 20 - 32 cm
Brown (10YR 5/3 moist); light grey (10YR 7/2 dry); common (10-20%) fine (<5mm) faint yellowish brown (10YR (5/6) primary mottles; light fine sandy loam; weak coarse (50-100mm) angular blocky parting to weak fine (5-10mm) angular blocky structure; sandy fabric; common (1-5 per 100mm2) very fine (0.075-1mm) macropores; no segregations; few (2-10%) strong rounded gravels (6-20mm) quartz; common very fine (<1mm) live roots; 6.0 field pH; clear (20-50mm) smooth boundary;
A22 32 - 40 cm
Brown (10YR 5/3 moist); light grey (10YR 7/2 dry); gravelly loamy sand; single grain structure; sandy fabric; common (1-5 per 100mm2) very fine (0.075-1mm) macropores; few (2-10%) <2mm manganiferous nodules; many (20-50%) strong rounded gravels (6-20mm) quartz; few very fine (<1mm) live roots; 6.4 field pH; abrupt (5-20mm) wavy boundary;
B2t 40 - 50+ cm
Yellowish brown (10YR 5/6 moist); yellowish brown (10YR 5/6 dry); common (10-20%) medium (5-15mm) prominent dark yellowish brown (10YR 4/6) primary mottles; common (10-20%) coarse (15-30mm) distinct light brownish grey (2.5Y 6/2) secondary mottles; medium clay; moderate medium (20-50mm) angular blocky structure; rough-ped fabric; common (1-5 per 100mm2) very fine (0.075-1mm) macropores; no segregations; no coarse fragments; few very fine (< 1mm) live roots; 6.4 field pH;
Substrate Note: Parent material is sand on gravelly sand over clay.
Profile Note: Only a shallow soil pit.

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	5.8	0.10	31.0	267.0	2.4	0.16

Plate 11.1: Soil profile for life cycle site no.1.

Soil database No: 152
Property Name: Scone
Property Owner: Gibson, W. R.
Nearest Town: Perth
Describer: Richard Doyle
Type of Desc: Auger boring

Rainfall: 650 mm
Elevation: 141 m
AMG Easting: 516900 E
AMG Northing: 5394400 N

Soil Class: Brumby
Northcote PPF: Dy3.72
Great Soil Group: Solodized Solonetz
Drainage: Imperfectly drained
Permeability: Slowly permeable
Runnoff: Very slow

Isbell Class: Vertic, Subnatric, Brown, Sodosol; very deep, thick, loamy, non gravelly
Landform: Element level, flat, geomorphic agent overbank streamflow (unchannelled), terrace plain; Pattern level plain <9m <1%, terraced land;
Land Surface: Slope angle 2 %; complete clearing - pasture but never cultivated; surface soil soft;
Vegetation: Top Stratum Form pasture species, <0.25m;
Substrate: massive, clays (argillaceous), clay, lacustrine sediment;

A1 0 - 20 cm
Dark greyish brown (10YR 4/2 moist); greyish brown (10YR 5/2 dry); fine sandy loam; single grain plus weak ex fine (<2mm) subangular blocky structure; very weak (moist); loose (dry); sandy fabric; common (1-5 per 100mm2) very fine (0.075-1mm) macropores; no segregations; no coarse fragments; common fine (1-2mm) live roots; non-calcareous; 5.3 field pH; 0 dSm-1; clear (20-50mm) boundary;
A21 20 - 36 cm
Greyish brown (10YR 5/2 moist); light brownish grey (10YR 6/2 dry); light sandy loam; single grain plus weak fine (5-10mm) subangular blocky structure; very weak (moist); very weak (dry); sandy fabric; common (1-5 per 100mm2) very fine (0.075-1mm) macropores; no segregations; no coarse fragments; few very fine (<1mm) live roots; non-calcareous; 5.6 field pH; 0 dSm-1; clear (20-50mm) boundary;
A22 36 - 50 cm
Pale brown (10YR 6/3 moist); very pale brown (10YR 7/3 dry); loamy sand; single grain structure; loose (moist); loose (dry); sandy fabric; common (1-5 per 100mm2) very fine (0.075-1mm) macropores; few (2-10%) <2mm ferruginous nodules; no coarse fragments; few very fine (<1mm) live roots; non-calcareous; 6.0 field pH; 0 dSm-1; abrupt (5-20mm) boundary;
B2 50 - 70+ cm
Light olive brown (2.5Y 5/4 moist); light olive brown (2.5Y 5/4 dry); common (10-20%) fine (<5mm) distinct yellowish brown (10YR 5/5) primary mottles; common (10-20%) fine (<5mm) prominent red (2.5YR 4/8) secondary mottles; medium clay; weak coarse-very coarse (100-200mm) columnar structure; firm (moist); strong (dry); rough-ped fabric; few (<1 per 100mm2) very fine (0.075-1mm) macropores; few (<10%) distinct slickensides; no segregations; no coarse fragments; few very fine (<1mm) live roots; non-calcareous; 6.5 field pH; 0 dSm-1;
Substrate Note: Parent material is alluvial, sand on clay.
Profile Note: The columnar structure in the B2tg is suggested by fine sand transported down cracks in the medium clay material.

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	6.0	0.06	10.1	203.8	2.4	0.16

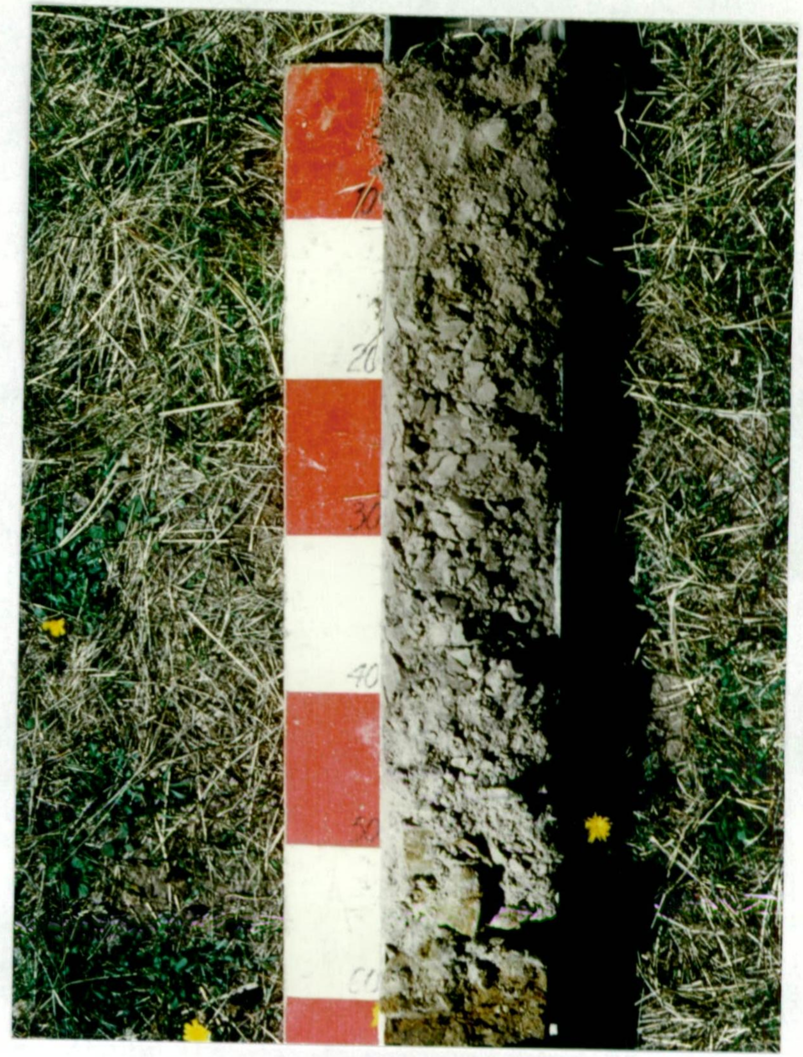


Plate 11.2: Soil profile for life cycle site no. 2.

Soil database No: 154
Property Name: Scone
Property Owner: Gibson, W. R.
Nearest Town: Perth
Describer: Richard Doyle
Type of Desc: Auger boring

Rainfall: 650 mm
Elevation: 140 m
AMG Easting: 513900 E
AMG Northing: 5392700 N

Soil Class: Canola
Northcote PPF: Gn2.12
Great Soil Group: Black Earth
Drainage: Imperfectly drained
Permeability: Slowly permeable
Runnoff: Slow

Isbell Class: Haplic, Self-Mulching, Black, Vertosol; moderate, fine, non gravelly
Landform: Element level, flat, geomorphic agent overbank streamflow (unchannelled), plain; Pattern level plain <9m <1%, flood plain;
Land Surface: Slope angle 0 %; complete clearing - pasture but never cultivated; Surface soil soft; Microrelief normal gilgai; Inundation more than one per year
Vegetation: pasture species
Substrate: massive, clay, alluvium;

A1 0 - 17 cm
Very dark grey (10YR 3/1 moist); very dark grey (10YR 3/1 dry); heavy clay loam; moderate ex fine (<2mm) granular structure; very weak (moist); weak (dry); earthy fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no segregations; no coarse fragments; abundant very fine (<1mm) live roots; 5.7 field pH; 0 dSm-1; clear (20-50mm) boundary;
A12 17 - 45 cm
Black (10YR 2/1 moist); very dark grey (10YR 3/1 dry); light clay; weak fine (5-10mm) angular blocky plus moderate ex fine (<2mm) granular structure; very weak (moist); weak (dry); earthy fabric; no segregations; no coarse fragments; common very fine (<1mm) live roots; 6.0 field pH; 0 dSm-1; gradual (50-100mm) boundary;
A13 45 - 65 cm
Very dark grey (10YR 3/1 moist); dark grey (10YR 4/1 dry); clay loam; weak fine (5-10mm) subangular blocky structure; weak (moist); very weak (dry); earthy fabric; no segregations; no coarse fragments; few very fine (<1mm) live roots; 6.2 field pH; 0 dSm-1; gradual (50-100mm) boundary;
A14 65 - 95 cm
Very dark greyish brown (10YR 3/2 moist); light brownish grey (10YR 6/2 dry); clay loam; weak fine (5-10mm) subangular blocky plus single grain structure; loose (moist); loose (dry); earthy fabric; few (2-10%) <2mm manganiferous soft segregations; no coarse fragments; few very fine (<1mm) live roots; 6.4 field pH; 0 dSm-1; gradual (50-100mm) boundary;
Cg 95 - 115+ cm
Dark greyish brown (2.5Y 4/3 moist); dark greyish brown (2.5Y 4/2 dry); common (10-20%) fine (<5mm) distinct dark yellowish brown (10YR 4/8) primary mottles; sandy clay loam; single grain plus weak fine (5-10mm) subangular blocky structure; very weak (moist); very weak (dry); earthy fabric; few (2-10%) <2mm manganiferous soft segregations; no coarse fragments; few very fine (<1mm) live roots; 6.7 field pH; 0 dSm-1;
Substrate Note: Parent material is fine textured alluvium.

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	5.8	0.07	41.5	281.5	5.5	0.44

Plate 11.3: Soil profile for life cycle site no. 3.

Soil database No: 155
Property Name: Symmons Plains
Property Owner: Youl, J.C. & S.L.
Nearest Town: Perth
Describer: Richard Doyle
Type of Desc: Auger boring

Rainfall: 650 mm
Elevation: 150 m
AMG Easting: 522600 E
AMG Northing: 5390200 N

Soil Class: Brumby
Northcote PPF: Db2.72
Great Soil Group: Solodized Solonetz
Drainage: Poorly drained
Permeability: Slowly permeable
Runnoff: Very slow

Isbell Class: Vertic, Subnatric, Brown, Sodosol; deep, medium, silty, non gravelly
Landform: Element level, flat, geomorphic agent overbank streamflow (unchannelled), terrace plain; Pattern level plain <9m <1%, terraced land;
Land Surface: Slope angle 0 %; complete clearing - pasture but never cultivated; surface soil soft; Erosion minor or present, partly stabilized;
Vegetation: pasture species;
Substrate: massive, clay, lacustrine sediment;

A1 0 - 16 cm
Dark greyish brown (10YR 4/2 moist); light brownish grey (10YR 6/2 dry); few (2-10%) fine (<5mm) distinct yellowish brown (10YR 5/6) primary mottles; silty loam; weak ex fine (<2mm) subangular blocky structure; very weak (moist); loose (dry); sandy fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no cutans; no segregations; v few (<2%) very strong subrounded grit (2-6mm) quartz; common fine (1-2mm) live roots; 5.1 field pH; 0 dSm-1; clear (20-50mm) boundary;
A2 16 - 30 cm
Light grey (10YR 7/2 moist); light grey (10YR 7/2 dry); silty loam; weak ex fine (<2mm) subangular blocky plus single grain structure; loose (moist); loose (dry); sandy fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no cutans; few (2-10%) <2mm ferruginous nodules; few fine (1-2mm) live roots; 5.6 field pH; 0 dSm-1; abrupt (5-20mm) boundary;
B21tg 30 - 45 cm
Brown (10YR 4/3 moist); brown (10YR 4/3 dry); common (10-20%) fine (<5mm) distinct strong brown (7.5YR 4/6) primary mottles; common (10-20%) medium (5-15mm) distinct very dark greyish brown (10YR 3/2) secondary mottles; medium clay; weak fine (5-10mm) prismatic structure; firm (moist); very firm (dry); earthy fabric; few (<1 per 100mm2) fine (1-2mm) macropores; no cutans; few (2-10%) <2mm manganiferous nodules; few fine (1-2mm) live roots; 6.0 field pH; 0 dSm-1; gradual (50-100mm) boundary;
B22tg 45 - 110+ cm
Dark greyish brown (2.5Y 4/2 moist); dark greyish brown (2.5Y 4/2 dry); few (2-10%) fine (<5mm) distinct yellowish brown (10YR 5/6) primary mottles; medium clay; massive structure; very firm (moist); strong (dry); earthy fabric; no fine (1-2mm) macropores; common (10-50%) distinct slickensides; few (2-10%) <2mm manganiferous nodules; no live roots; 6.9 field pH; 0.3 dSm-1;
Substrate Note: Parent material is sand on alluvial clay.

Chemical Data:

Site	Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
4	0 - 7.5	6.4	0.08	47.1	661.8	4.2	0.31
5	0-7.5	5.6	0.11	24.7	429.5	4.7	0.34

Plate 11.4: Soil profile for life cycle sites no. 4 and 5.

Soil database No: 158
Property Name: Brooklands
Property Owner: Nicholson, R.J.
Nearest Town: Antill Ponds
Describer: Richard Doyle
Type of Desc: Soil pit

Rainfall: 500 mm
Elevation: 310 m
AMG Easting: 536200 E
AMG Northing: 5325500 N

Soil Class: Blessington Association
Northcote PPF: Db4.12
Great Soil Group: Solodic
Drainage: Moderately well drained
Permeability: Moderately permeable
Runnoff: Moderately rapid

Isbell Class: Basic, Subnatric, Brown, Sodosol; moderate, medium, clay loamy, gravelly
Landform: Element gently inclined, flat, geomorphic agent channelled streamflow, fan; Pattern undulating plains <9m 3-10%, alluvial fan;
Land Surface: Slope angle 3 %; complete clearing - pasture but never cultivated; surface soil periodicly cracks; Coarse Fragments few (2-10%) gravels (6-20mm);
Vegetation: pasture species;
Substrate: massive, feldspar, sandstone;

A1 0 - 18 cm
Black (7.5YR 2/1 moist); very dark grey (7.5YR 3/1 dry); clay loam sandy; moderate fine (5-10mm) subangular blocky parting to moderate ex fine (<2mm) subangular blocky structure; weak (moist); weak (dry); rough-ped fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no segregations; common (10-20%) subangular gravels (20-60mm) sandstone; many fine (1-2mm) live roots; 6.4 field pH; 0 dSm-1; clear (20-50mm) irregular boundary;
B2t 18 - 30 cm
Dark brown (7.5YR 3/2 moist); dark brown (7.5YR 3/2 dry); common (10-20%) fine (<5mm) distinct strong brown (7.5YR 4/6) primary mottles; heavy clay; moderate coarse (50-100mm) angular blocky parting to moderate medium (20-50mm) angular blocky structure; very firm (moist); smooth-ped fabric; few (<1 per 100mm2) fine (1-2mm) macropores; few (<10%) distinct organic-humus coatings black (7.5YR 2/0); v few (<2%) <2mm manganiferous soft segregations; few (2-10%) subangular gravels (20-60mm) sandstone; common fine (1-2mm) live roots; 6.7 field pH; 0 dSm-1; gradual (50-100mm) smooth boundary;
B3 30 - 45 cm
Brown (10YR 4/3 moist); brown (10YR 4/3 dry); common (10-20%) medium (5-15mm) distinct yellowish brown (10YR 5/6) primary mottles; gritty medium clay; moderate very coarse (200-500mm) angular blocky structure; firm (moist); earthy fabric; few (<10%) distinct organic-humus coatings very dark grey (10YR 3/1); few (2-10%) <2mm manganiferous soft segregations; common (10-20%) subangular gravels (6-20mm) sandstone; few very fine (<1mm) live roots; 6.8 field pH; 0 dSm-1;
C 45 - 46+ cm
No segregations; sandstone coarse fragments;
Substrate Note: Parent material is feldspathic sandstone (strongly metamorphosed sandstone).
Profile Note: Shallow auger observation only, classification tentative.

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	6.1	0.09	43.7	525.1	3.6	0.27

Plate 11.5: Soil profile for life cycle site no. 6.

Soil database No: 159
Property Name: Brooklands
Property Owner: Nicholson, R.J.
Nearest Town: Antill Ponds
Describer: Richard Doyle
Type of Desc: Auger boring

Rainfall: 500 mm
Elevation: 310 m
AMG Easting: 536200 E
AMG Northing: 5325500 N

Soil Class: Canola Association
Northcote PPF: Db4.12
Great Soil Group: Solodic
Drainage: Moderately well drained
Permeability: Moderately permeable
Runnoff: Moderately rapid

Isbell Class:	Haplic, Self-Mulching, Black, Vertosol; moderate, fine, non gravelly
Landform:	Element gently inclined, mid-slope, fan; Pattern gently inclined 3-10%, Extremely low <9m, alluvial fan;
Land Surface:	Slope angle 3 %; Aspect 000; cultivation - rainfed; surface soil self-mulching, periodic cracking; Coarse Fragments v few (<2%) stones (200-600mm);
Vegetation:	pasture species,
Substrate:	massive, clays (argillaceous), clay, alluvium;

A11 0 - 2 cm
Black (7.5YR 2/0 moist); black (7.5YR 2/0 dry); light clay; strong ex fine (<2mm) granular structure; moderately sticky; moderately plastic; very weak (moist); very weak (dry); rough-ped fabric; many (>5 per 100mm2) fine (1-2mm) macropores; 6.4 field pH; 0 dSm-1; abrupt (5-20mm) smooth boundary;
A12 2 - 30 cm
Black (7.5YR 2/0 moist); black (7.5YR 2/0 dry); light clay; moderate medium (20-50mm) angular blocky parting to weak ex fine (<2mm) angular blocky structure; moderately sticky; moderately plastic; weak (moist); firm (dry); rough-ped fabric; many (>5 per 100mm2) fine (1-2mm) macropores; many fine (1-2mm) live roots; 6.8 field pH; 0 dSm-1; gradual (50-100mm) smooth boundary;
A13 30 - 65 cm
Black (7.5YR 2/0 moist); black (7.5YR 2/0 ry); medium clay; weak coarse (50-100mm) angular blocky structure; moderately sticky; very plastic; very weak (moist); strong (dry); smooth-ped fabric; common (1-5 per 100mm2) coarse (>5mm) macropores; few (<10%) distinct slickensides; few (2-10%) <2mm calcareous nodules; common very fine (<1mm) live roots; 7.9 field pH; 0.1 dSm-1; clear (20-50mm) smooth boundary;
Ck 65 - 100+ cm
Dark greyish brown (2.5Y 4/2 moist); dark greyish brown (2.5Y 4/2 dry); heavy clay; massive parting to weak coarse (50-100mm) angular blocky structure; moderately sticky; very plastic; very firm (moist); strong (dry); earthy fabric; common (10-50%) prominent organic-humus coatings black (7.5YR 2/0); common (10-20%) <2mm calcareous nodules; few very fine (<1mm) live roots; 8.0 field pH; 0.2 dSm-1;
Substrate Note: Parent material is a fine fan alluvium.
Profile Note: Brief auger description, classification tentative.

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	6.6	0.11	42.7	202.1	6.2	0.44

Plate 11.6: Soil profile for life cycle site no. 7.

Soil database No: 160
Property Name: Tervue
Property Owner: Burbury, J.
Nearest Town: Oatlands
Describer: Richard Doyle
Type of Desc: Soil pit

Rainfall: 575 mm
Elevation: 380 m
AMG Easting: 554350 E
AMG Northing: 5320900 N

Soil Class: Un-named Alluvial
Northcote PPF: Dy5.12
Great Soil Group: Humic Gley
Drainage: Imperfectly drained
Permeability: Slowly permeable
Runnoff: Slow

Isbell Class: Basic, Sodosolic, Redoxic, Hydrosol; deep, medium, clay loamy, non gravelly
Landform: Element gently inclined, flat, geomorphic agent overbank streamflow (unchannelled), terrace plain; Pattern moderately inclined 10-32%, Very low 9-30m, terraced land;
Land Surface: Slope angle 3 %; Aspect 180; complete clearing - pasture but never cultivated; surface soil soft;
Vegetation: pasture species;
Substrate: massive, clays (argillaceous), clay, alluvium;

A1 0 - 16 cm
Black (10YR 2/0 moist); dark grey (10YR 4/1 dry); silty clay loam; moderate medium (20-50mm) angular blocky parting to weak fine (5-10mm) angular blocky structure; weak (moist); weak (dry); rough-ped fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no segregations; no coarse fragments; common very fine (<1mm) live roots; 5.9 field pH; 0.1 dSm-1; abrupt (5-20mm) smooth boundary;
B21g 16 - 45 cm
Grey (10YR 5/1 moist); many (20-50%) medium (5-15mm) distinct yellowish brown (10YR 5/8) primary mottles; silty medium clay; massive parting to weak very coarse (200-500mm) angular blocky structure; firm (moist); very firm (dry); earthy fabric; few (<1 per 100mm2) fine (1-2mm) macropores; few (<10%) distinct organic-humus coatings dark grey (10YR 4/1) lining pores/cracks; no segregations; no coarse fragments; few very fine (<1mm) live roots; 6.1 field pH; 0.1 dSm-1; gradual (50-100mm) smooth boundary;
B22g 45 - 65+ cm
Grey (5Y 5/1 moist); common (10-20%) medium (5-15mm) distinct yellowish brown (10YR 5/6) primary mottles; silty medium clay; massive structure; firm (moist); earthy fabric; no macropores; no segregations; no coarse fragments; few very fine (<1mm) live roots; 5.6 field pH; 0.1 dSm-1;

Substrate Note: Parent material is alluvial clay fan on an alluvial plain.

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	5.9	0.19	34.3	210.5	7.3	0.54

Plate 11.7: Soil profile for life cycle site no. 8.

Soil database No: 161
Property Name: Tervue
Property Owner: Burbury, J.
Nearest Town: Oatlands
Describer: Richard Doyle
Type of Desc: Soil pit

Rainfall: 600 mm
Elevation: 380 m
AMG Easting: 554600 E
AMG Northing: 5320300 N

Soil Class: Un-named Alluvial
Northcote PPF: Gn3.12
Great Soil Group: Solonized Brown Soil
Drainage: Well drained
Permeability: Moderately permeable
Runnoff: Moderately rapid

Isbell Class: Sodic, Mesotrophic, Brown, Dermosol; deep, medium, loamy, non gravelly
Landform: Element moderately inclined, mid-slope, geomorphic agent gravity, fan; Pattern moderately inclined 10-32%, Very low 9-30m, low hills;
Land Surface: Slope angle 14 %; Aspect 315; Surface soil soft;
Vegetation: pasture species,
Substrate: massive, sandstone, colluvium;

A1 0 - 17 cm
Very dark greyish brown (10YR 3/2 moist); greyish brown (10YR 5/2 dry); loam; moderate fine (5-10mm) angular blocky plus moderate ex fine (<2mm) angular blocky structure; very weak (moist); very weak (dry); rough-ped fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; few (2-10%) angular gravels (6-20mm) sandstone; many very fine (<1mm) live roots; 6.2 field pH; 0 dSm-1; clear (20-50mm) irregular boundary;
AB 17 - 32 cm
Dark brown (7.5YR 3/3 moist); brown (7.5YR 4/3 dry); common (10-20%) medium (5-15mm) distinct very dark grey (10YR 3/1) primary mottles; gritty sandy clay loam; weak ex fine (<2mm) subangular blocky structure; very weak (moist); very weak (dry); earthy fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; common (10-20%) angular gravels (6-20mm) sandstone; common very fine (<1mm) live roots; 6.0 field pH; 0 dSm-1; clear (20-50mm) wavy boundary;
B21t 32 - 50 cm
Dark brown (7.5YR 3/4 moist); dark brown (7.5YR 3/4 dry); heavy clay loam; moderate medium (20-50mm) angular blocky plus medium (20-50mm) angular blocky structure; weak (moist); weak (dry); smooth-ped fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; many (>50%) distinct clay skins dark brown (7.5YR 3/4) coating ped faces; v few (<2%) <2mm manganiferous soft segregations; v few (<2%) angular gravels (6-20mm) sandstone; few very fine (<1mm) live roots; 6.3 field pH; 0 dSm-1; clear (20-50mm) wavy boundary;
B22t 50 - 60+ cm
Brown (7.5YR 4/4 moist); gritty clay loam; weak medium (20-50mm) angular blocky structure; very firm (moist); weak (dry); smooth-ped fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; common (10-50%) distinct clay skins dark brown (7.5YR 3/4) coating ped faces; v few (<2%) <2mm manganiferous soft segregations; common (10-20%) angular gravels (6-20mm) sandstone; few very fine (<1mm) live roots; 6.5 field pH; 0 dSm-1;
Substrate Note: Parent material is metamorphosed silicaceous sandstone. A gravelly colluvium.

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	5.3	0.55	73.9	672.1	5.0	0.43

Plate 11.8: Soil profile for life cycle site no. 9.

Soil database No: 162
Property Name: York Plains
Property Owner: Gregg, R.
Nearest Town: Oatlands
Describer: Richard Doyle
Type of Desc: Auger boring

Rainfall: 550 mm
Elevation: 310 m
AMG Easting: 536200 E
AMG Northing: 5319800 N

Soil Class: Unnamed Sandstone
Northcote PPF: Dy3.42
Great Soil Group: Solodic
Drainage: Imperfectly drained
Permeability: Slowly permeable
Runnoff: Moderately rapid

Isbell Class:	Basic, Subnatric, Brown, Sodosol; moderate, thick, loamy, non gravelly;
Landform:	Element moderately inclined, mid-slope, hillslope; Pattern gently inclined 3-10%, Low 30-90m, hills;
Land Surface:	Slope angle 9 %; Aspect 337; complete clearing - pasture but never cultivated;
Vegetation:	pasture species;
Substrate:	massive, sandstone;

A1 0 - 30 cm
Very dark greyish brown (10YR 3/2 moist); greyish brown (10YR 5/2 dry); fine sandy loam; single grain plus weak ex fine (<2mm) subangular blocky structure; loose (moist); very weak (dry); sandy fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no segregations; no coarse fragments; common fine (1-2mm) live roots; 5.3 field pH; 0 dSm-1; clear (20-50mm) boundary;
A2 30 - 42 cm
Light grey (10YR 7/1 moist); white (10YR 8/1 dry); fine sandy loam; single grain plus weak ex fine (<2mm) subangular blocky structure; loose (moist); loose (dry); sandy fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no segregations; no coarse fragments; few fine (1-2mm) live roots; 5.6 field pH; 0 dSm-1; clear (20-50mm) boundary;
B21tg 42 - 60 cm
Brown (10YR 5/3 moist); common (10-20%) fine (<5mm) distinct yellowish brown (10YR 5/8) primary mottles; common (10-20%) fine (<5mm) faint dark grey (10YR 4/1) secondary mottles; heavy clay; massive plus moderate coarse (50-100mm) angular blocky structure; very firm (moist); very firm (dry); smooth-ped fabric; few (<1 per 100mm2) fine (1-2mm) macropores; common (10-50%) distinct organic-humus coatings very dark grey (10YR 3/1) lining pores/cracks; no segregations; no coarse fragments; few fine (1-2mm) live roots; 6.0 field pH; 0 dSm-1; gradual (50-100mm) boundary;
B22g 60 70+ cm
Dark greyish brown (2.5Y 4/2 moist); common (10-20%) medium (5-15mm) distinct yellowish brown (10YR 5/6) primary mottles; heavy clay; massive structure; very firm (moist); very firm (dry); smooth-ped fabric; few (<1 per 100mm2) fine (1-2mm) macropores; common (10-50%) distinct organic-humus coatings very dark grey (10YR 3/1) lining pores/cracks; no segregations; no coarse fragments; few very fine (<1mm) live roots;
Substrate Note: Parent material is sandstone on clay, mapped as Bfs (feldspathic sandstone).

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	5.9	0.09	68.9	315.9	3.6	0.24

Plate 11.9: Soil profile for life cycle site no. 10.

Soil database No: 170
Property Name: Bon View
Property Owner: Gordon, W.
Nearest Town: Campbell Town
Describer: Richard Doyle
Type of Desc: Undisturbed soil core

Rainfall: 550 mm
Elevation: 220 m
AMG Easting: 540000 E
AMG Northing: 5359800 N

Soil Class:
Northcote PPF: Gn4.12
Great Soil Group: No suitable group
Drainage: Moderately well drained
Permeability: Moderately permeable
Runnoff: Moderately rapid

Landform: Element moderately inclined, crest, maximal, geomorphic agent sheet wash (surface wash), hillcrest; Pattern very gently inclined 1-3%, Extremely low <9m, low hills;

Land Surface: Slope angle 9 %; Aspect 045; Condition of surface soil soft; Erosion minor or present, partly stabilized, wind; minor or present, partly stabilized, sheet erosion; Coarse Fragments v few (<2%) gravels (6-20mm); Rock Outcrops <2% bedrock exposed, Basalt;

Substrate: massive, dark minerals, weak, basalt, volcanic rocks;

A1 0 - 10 cm
Dark reddish brown (5YR 3/2 moist); reddish brown (5YR 4/3 dry); heavy clay loam; strong fine-medium (10-20mm) granular parting to strong fine (5-10mm) granular structure; weak (moist); firm (dry); rough-ped fabric; many (>5 per 100mm2) medium (2-5mm) macropores; no coarse fragments; many very fine (<1mm) live roots; high aggregate stability; 5.5 field pH; 0 dSm-1; clear (20-50mm) smooth boundary;

B21wt 10 - 25 cm
Dark reddish brown (2.5YR 3/4 moist); light clay; moderate fine-medium (10-20mm) angular blocky parting to fine (5-10mm) angular blocky structure; weak (moist); firm (dry); rough-ped fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no coarse fragments; few very fine (<1mm) live roots; low aggregate stability; 5.8 field pH; 0.2 dSm-1; gradual (50-100mm) irregular boundary;

B22t 25 - 52 cm
Dark reddish brown (2.5YR 3/4 moist); light medium clay; weak medium (20-50mm) angular blocky structure; very firm (moist); strong (dry); rough-ped fabric; few (<1 per 100mm2) fine (1-2mm) macropores; common (10-50%) distinct clay skins; common (10-20%) <2mm manganiferous soft segregations; common (10-20%) subangular gravels (6-20mm); no live roots; low aggregate stability; 6.8 field pH; 0 dSm-1; gradual (50-100mm) irregular boundary;

B3 52 - 70 cm
Dark yellowish brown (10YR 4/4 moist); very pale brown (10YR 7/4 dry); common (10-20%) fine (<5mm) distinct strong brown (7.5YR 5/8) primary mottles; light medium clay; weak coarse (50-100mm) angular blocky structure; weak (moist); weak (dry); earthy fabric; few (<1 per 100mm2) fine (1-2mm) macropores; common (10-50%) prominent clay skins very dark grey (10YR 3/1); few (2-10%) <2mm manganiferous soft segregations; common (10-20%) subangular gravels (6-20mm); no live roots; low aggregate stability; 7.1 field pH; 0.1 dSm-1; diffuse (>100mm) smooth boundary;

Cw 70 - 85+ cm
Pale olive (5Y 6/4 moist); pale yellow (2.5Y 8/3 dry); common (10-20%) fine (<5mm) faint light red (2.5YR 6/5) primary mottles; light clay; moderate parting to single grain structure; weak (moist); very weak (dry); earthy fabric; few (<1 per 100mm2) fine (1-2mm) macropores; common (10-50%) prominent clay skins very dark grey (10YR 3/1); few (2-10%) 2-6mm calcareous soft segregations; few (2-10%) subrounded gravels (6-20mm); no live roots; low aggregate stability; 7.6 field pH; 0.1 dSm-1;

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	5.4	0.09	13.8	167.9	2.3	0.19

Plate 11.10: Soil profile for life cycle site no. 11.

Soil database No: 172
Property Name: Lewisham
Property Owner: Young, R.T.
Nearest Town: Ross
Describer: Richard Doyle
Type of Desc: Undisturbed soil core

Rainfall: 525 mm
Elevation: 220 m
AMG Easting: 541600 E
AMG Northing: 5351400 N

Soil Class: Brumby
Northcote PPF: Dd2.23
Great Soil Group: Solodized Solonetz
Drainage: Imperfectly drained
Permeability: Very Slowly permeable
Runnoff: Slow

Isbell Class: Vertic, Subnatric, Brown, Sodosol; very deep, silty, loamy, non gravelly
Landform: Element very gently inclined, flat, geomorphic agent overbank streamflow (unchannelled), terrace plain; Pattern moderately inclined 10-32%, Very low 9-30m, terraced land;
Land Surface: Slope angle 2 %; Aspect 090; complete clearing - pasture but never cultivated; Surface soil soft; Erosion moderate, partly stabilized, wind; minor or present, partly stabilized, sheet erosion;
Vegetation: pasture species, Substrate: massive, clays ;

A2 0 - 10 cm
Very dark grey (10YR 3/1 moist); grey (10YR 5/1 dry); sandy loam; moderate medium (20-50mm) subangular blocky plus moderate coarse (50-100mm) subangular blocky structure; slightly sticky; slightly plastic; weak (moist); weak (dry); sandy fabric; common (1-5 per 100mm2) medium (2-5mm) macropores; common fine (1-2mm) live roots; moderate aggregate stability; 5.7 field pH; 0.1 dSm-1; clear (20-50mm) smooth boundary;

B21tg 10 - 26 cm
Black (2.5Y 2/1 moist); very dark grey (2.5Y 3/1 dry); common (10-20%) fine (<5mm) faint dark yellowish brown (10YR 4/6) primary mottles; heavy clay; moderate coarse (50-100mm) angular blocky plus moderate fine-medium (10-20mm) subangular blocky structure; moderately sticky; very plastic; strong (moist); very strong (dry); smooth-ped fabric; few (<1 per 100mm2) medium (2-5mm) macropores; few fine (1-2mm) live roots; moderate aggregate stability; 6.6 field pH; 0.1 dSm-1; gradual (50-100mm) smooth boundary;

B22tg 26 - 47 cm
Very dark greyish brown (2.5Y 3/2 moist); very dark greyish brown (2.5Y 3/2 dry); few (2-10%) fine (<5mm) distinct olive (5Y 4/6) primary mottles; heavy clay; moderate medium (20-50mm) lenticular parting to single grain structure; moderately sticky; very plastic; strong (moist); strong (dry); smooth-ped fabric; few (<1 per 100mm2) fine (1-2mm) macropores; many (>50%) slickensides; few very fine (<1mm) live roots; moderate aggregate stability; 7.5 field pH; 0.2 dSm-1; abrupt (5-20mm) smooth boundary;

B23 47 - 52 cm
Greyish brown (2.5Y 5/3 moist); light brownish grey (2.5Y 6/3 dry); sandy clay loam; massive structure; weak s; ; ; weak (moist); very weak (dry); sandy fabric; few (<1 per 100mm2) fine (1-2mm) macropores; 7.8 field pH; 0.2 dSm-1; abrupt (5-20mm) wavy boundary;

B24tg 52 - 84 cm
Dark greyish brown (2.5Y 4/2 moist); dark greyish brown (2.5Y 4/2 dry); common (10-20%) medium (5-15mm) distinct dark yellowish brown (10YR 4/4) primary mottles; common (10-20%) medium (5-15mm) distinct light brownish grey (2.5Y 6/2) secondary mottles; heavy clay; massive structure; strong (moist); very strong (dry); rough-ped fabric; few (<1 per 100mm2) fine (1-2mm) macropores; few (<10%) slickensides; common (10-20%) <2mm manganiferous soft segregations; no coarse fragments; no live roots; no aggregate stability; 8.0 field pH; 1.0 dSm-1; clear (20-50mm) irregular boundary;

B25tg 84 - 95+ cm
Olive grey (5Y 4/2 moist); olive grey (5Y 4/2 dry); heavy clay; massive parting to weak medium (20-50mm) angular blocky structure; very firm (moist); very strong (dry); earthy fabric; no macropores; no cutans; many (20-50%) 6-20mm calcareous soft segregations; no coarse fragments; no live roots; low aggregate stability; 8.4 field pH; 0.9 dSm-1;

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	5.8	0.06	32.3	132.8	1.3	0.17

Plate 11.11: Soil profile for life cycle site no. 12.

Soil database No: 173
Property Name: Glenmorey
Property Owner: Burbury, S.V.
Nearest Town: Woodbury
Describer: Richard Doyle
Type of Desc: Undisturbed soil core

Rainfall: 500 mm
Elevation: 200 m
AMG Easting: 538900 E
AMG Northing: 5330000 N

Soil Class: Un-named Alluvial
Northcote PPF: Gn4.13
Great Soil Group: Solodized Solonetz
Drainage: Imperfectly drained
Permeability: Slowly permeable
Runnoff: Slow

Isbell Class: Vertosol;
Landform: Element very gently inclined, flat, geomorphic agent overbank streamflow (unchannelled), terrace plain; Pattern level <1%, Extremely low <9m, terraced land;
Land Surface: Slope angle 2 %; Aspect 000; complete clearing - pasture but never cultivated; Surface soil firm, hard setting; Erosion minor or present, active, wind; minor or present, active, sheet erosion;
Vegetation: pasture species, Substrate: massive, clays (argillaceous), strong, clay, alluvium;

A11 0 - 10 cm
Dark brown (10YR 3/3 moist); grey (10YR 5/1 dry); clay loam; moderate medium (20-50mm) subangular blocky parting to moderate fine-medium (10-20mm) subangular blocky structure; weak (moist); weak (dry); rough-ped fabric; common (1-5 per 100mm2) medium (2-5mm) macropores; no cutans; no segregations; few (2-10%) subangular gravels (6-20mm) dolerite; common fine (1-2mm) live roots; moderate aggregate stability; 5.2 field pH; 0.1 dSm-1; clear (20-50mm) irregular boundary;

A12 10 - 25 cm
Very dark grey (10YR 3/1 moist); very dark grey (10YR 3/1 dry); clay loam; moderate coarse (50-100mm) subangular blocky parting to moderate medium (20-50mm) subangular blocky structure; very firm (moist); strong (dry); rough-ped fabric; few (<1 per 100mm2) medium (2-5mm) macropores; common (10-50%) distinct other cutans; few (2-10%) subangular gravels (6-20mm) dolerite; common fine (1-2mm) live roots; moderate aggregate stability; 6.2 field pH; 0.2 dSm-1; gradual (50-100mm) smooth boundary;

A13 25 - 38 cm
Very dark grey (10YR 3/1 moist); very dark grey (10YR 3/1 dry); light clay; moderate medium (20-50mm) angular blocky parting to moderate fine-medium (10-20mm) angular blocky structure; very firm (moist); strong (dry); smooth-ped fabric; few (<1 per 100mm2) fine (1-2mm) macropores; few (<10%) distinct slickensides; no segregations; few (2-10%) subangular gravels (6-20mm) dolerite; few fine (1-2mm) live roots; low aggregate stability; 6.9 field pH; 0.3 dSm-1; gradual (50-100mm) irregular boundary;

B21t 38 - 55 cm
Dark greyish brown (2.5Y 4/2 moist); dark greyish brown (2.5Y 4/2 dry); few (2-10%) coarse (15-30mm) faint brown (7.5YR 4/3) primary mottles; heavy clay; massive structure; very firm (moist); strong (dry); rough-ped fabric; no macropores; common (10-50%) distinct slickensides; few (2-10%) <2mm calcareous nodules; few (2-10%) subangular gravels (6-20mm) dolerite; no live roots; low aggregate stability; 7.9 field pH; 0.6 dSm-1; clear (20-50mm) wavy boundary;

B22tk 55 - 66 cm
Greyish brown (2.5Y 5/3 moist); greyish brown (2.5Y 5/3 dry); few (2-10%) medium (5-15mm) distinct yellowish brown (10YR 5/8) primary mottles; gritty light clay; weak medium (20-50mm) angular blocky structure; very firm (moist); strong (dry); earthy fabric; no macropores; common (10-50%) distinct carbonate coatings; common (10-20%) <2mm calcareous nodules; few (2-10%) subangular gravels (6-20mm) dolerite; 8.5 field pH; 0.9 dSm-1; clear (20-50mm) wavy boundary;

B23tg 66 - 85+ cm
Light brownish grey (2.5Y 6/2 moist); light grey (2.5Y 7/1 dry); many (20-50%) medium (5-15mm) distinct yellowish brown (10YR 5/6) primary mottles; light medium clay; massive structure; very firm (moist); strong (dry); earthy fabric; no macropores; few (<10%) distinct clay skins; few (2-10%) <2mm calcareous nodules; few (2-10%) subangular gravels (6-20mm) dolerite; no live roots; no aggregate stability; 8.1 field pH; 1.7 dSm-1;

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 7.5	5.7	0.14	28.6	344.1	1.7	0.29

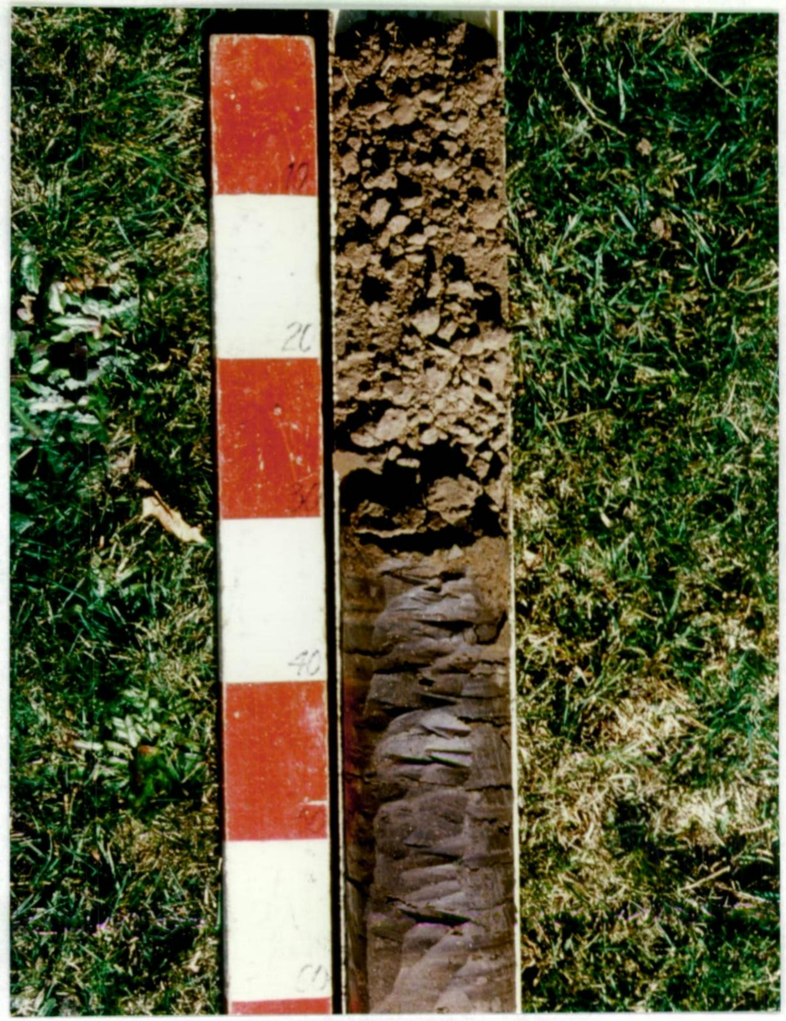


Plate 11.12: Soil profile for life cycle site no. 13.

Soil database No: 174
Property Name: Mona Vale
Property Owner: Cameron, E.A.
Nearest Town: Ross
Describer: Richard Doyle
Type of Desc: Undisturbed soil core

Rainfall: 550 mm
Elevation: 220 m
AMG Easting: 542400 E
AMG Northing: 5353000 N

Soil Class: Un-named Sandstone
Northcote PPF: Db4.13
Great Soil Group: Solodized Solonetz
Drainage:
Permeability:
Runoff:

Isbell Class: Brown, Sodosol;
Landform: Element very gently inclined, flat, geomorphic agent overbank streamflow (unchannelled), terrace plain; Pattern very gently inclined 1-3%, Very low 9-30m, terraced land;
Land Surface: Slope angle 2 %; Aspect 180; complete clearing - pasture but cultivation at some stage; Condition of surface soil loose; Erosion moderate, active, wind; minor or present, active, sheet erosion;
Vegetation: pasture species, Substrate: massive, unidentified, sedimentary rocks;

A11 0 - 10 cm
Dark brown (10YR 3/3 moist); brown (10YR 4/3 dry); sandy clay loam; moderate fine (5-10mm) subangular blocky plus moderate fine-medium (10-20mm) subangular blocky structure; slightly sticky; slightly plastic; weak (moist); weak (dry); rough-ped fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no segregations; no coarse fragments; many fine (1-2mm) live roots; moderate aggregate stability; 6.0 field pH; 0 dSm-1; clear (20-50mm) smooth boundary;

A12 10 - 22 cm
Very dark greyish brown (10YR 3/2 moist); dark brown (10YR 3/3 dry); light clay; moderate medium (20-50mm) subangular blocky structure; moderately sticky; moderately plastic; weak (moist); firm (dry); rough-ped fabric; common (1-5 per 100mm2) fine (1-2mm) macropores; no segregations; v few (<2%) angular gravels (6-20mm) chert; common fine (1-2mm) live roots; low aggregate stability; 6.5 field pH; 0 dSm-1; clear (20-50mm) smooth boundary;

B1 22 - 34 cm
Very dark grey (10YR 3/1 moist); very dark greyish brown (10YR 3/2 dry); few (2-10%) fine (<5mm) distinct strong brown (7.5YR 4/6) primary mottles; medium clay; strong very fine (2-5mm) angular blocky structure; firm (moist); strong (dry); smooth-ped fabric; common (1-5 per 100mm2) very fine (0.075-1mm) macropores; no segregations; few (2-10%) angular gravels (6-20mm) chert; few fine (1-2mm) live roots; low aggregate stability; 7.2 field pH; 0.1 dSm-1; gradual (50-100mm) smooth boundary;

B2t 34 - 48 cm
Brown (10YR 4/3 moist); dark yellowish brown (10YR 4/4 dry); common (10-20%) medium (5-15mm) distinct strong brown (7.5YR 4/6) primary mottles; common (10-20%) medium (5-15mm) distinct very dark grey (10YR 3/1) secondary mottles; medium clay; weak medium (20-50mm) angular blocky structure; firm (moist); firm (dry); earthy fabric; few (<1 per 100mm2) very fine (0.075-1mm) macropores; few (<10%) distinct organic-humus coatings very dark grey (10YR 3/1); dno segregations; no coarse fragments; no live roots; no aggregate stability; 7.6 field pH; 0.2 dSm-1; gradual (50-100mm) irregular boundary;

BC 48 - 74 cm
Olive brown (2.5Y 3/3 moist); dark greyish brown (2.5Y 4/3 dry); few (2-10%) medium (5-15mm) distinct strong brown (7.5YR 4/6) primary mottles; few (2-10%) medium (5-15mm) distinct very dark grey (10YR 3/1) secondary mottles; sandy loam; massive structure; weak (moist); weak (dry); sandy fabric; few (<1 per 100mm2) very fine (0.075-1mm) macropores; few (<10%) distinct organic-humus coatings very dark grey (10YR 3/1); no segregations; no coarse fragments; no live roots; no aggregate stability; 8.1 field pH; 0.4 dSm-1; gradual (50-100mm) smooth boundary;

Cw 74 - 95+ cm
Olive grey (5Y 5/2 moist); olive (5Y 5/3 dry); sandy light clay; massive structure; firm (moist); firm (dry); sandy fabric; no macropores; common (10-20%) 2-6mm calcareous veins; no coarse fragments; no live roots; no aggregate stability; moderately calcareous; 8.5 field pH; 0.8 dSm-1;

Chemical Data:

Soil depth (cm)	pH water (1:5)	EC (ds/m)	P (mg/kg)	K (mg/kg)	Org Carb (g/100g)	N (%)
0 - 75	5.8	0.13	15.6	308.0	1.9	0.23

Plate 11.13: Soil profile for life cycle site no. 14.

Appendix 9: The relationship between earthworm aestivation and soil pF.

Site no.	Sampling year					
	1992		1993		mean	
	Soil pF-active	Soil pF-aestivation	Soil pF-active	Soil pF-aestivation	Soil pF-active	Soil pF-aestivation
1	2.6	4.0	3.6	4.5	3.1	4.3
2	2.5	4.2	-	-	2.5	4.2
3	2.0	3.2	2.0	3.6	2.0	3.4
4	2.2	4.2	2.5	4.2	2.4	4.2
5	2.0	4.2	2.5	4.2	2.3	4.2
6	1.5	2.5	1.5	2.5	1.5	2.5
7	2.2	2.5	2.5	4.0	2.4	3.3
8	-	-	-	-	-	-
9	-	-	2.4	2.7	2.4	2.7
10	2.5	3.2	3.0	4.2	2.8	3.7
11	1.7	2.8	2.8	3.5	2.3	3.2
12	1.4	2.6	2.5	3.5	2.0	3.1
13	1.8	2.3	2.0	2.7	1.9	2.5
14	1.5	2.3	2.5	3.0	2.0	2.7

Appendix 10: Mean density and mass of adult aestivating earthworms in the Midlands during 1993-1994.

Depth (mm)	Sampling year					
	1993		1994		Mean	
	density (no./m^2)	mass (g/m^2)	density (no./m^2)	mass (g/m^2)	density (no./m^2)	mass (g/m^2)
0-50	2	0.20	3	0.18	3	0.19
50-100	4	0.25	0	0	2	0.38
100-150	9	0.29	10	0.26	10	0.29
150-200	16	0.33	18	0.33	17	0.33
200-250	12	0.29	29	0.29	21	0.29
250-300	10	0.31	28	0.27	19	0.29
300-350	9	0.26	20	0.41	15	0.35
350-400	10	0.24	15	0.28	13	0.26
400-450	3	0.42	3	0.62	3	0.52
450-500	3	0.32	0	0	2	0.25
Total	78	2.91	126	3.34	105	3.15

Appendix 11: Mean density and mass of juvenile aestivating earthworms in the Midlands during 1993-1994.

Depth (mm)	Sampling year					
	1993		1994		Mean	
	density (no./m^2)	mass (g/m^2)	density (no./m^2)	mass (g/m^2)	density (no./m^2)	mass (g/m^2)
0-50	9	0.07	6	0.11	8	0.09
50-100	16	0.05	19	0.10	18	0.08
100-150	33	0.09	35	0.07	34	0.08
150-200	38	0.08	52	0.09	45	0.09
200-250	24	0.10	27	0.09	26	0.10
250-300	23	0.10	15	0.08	19	0.09
300-350	9	0.12	15	0.12	12	0.12
350-400	10	0.16	10	0.08	10	0.12
400-450	3	0.21	9	0.08	6	0.15
450-500	3	0.09	0	0	2	0.05
Total	168	1.07	188	0.82	178	0.97

Appendix 12: Density (no./m^2) of adult and juvenile earthworms collected from spring 1992 to autumn 1993 (n=12).

Site no.	Spring 1992		Summer 1993		Autumn 1993	
	juveniles	adults	juveniles	adults	juveniles	adults
1	33	75	166	51	20	30
2	173	203	630	204	255	15
3	55	103	337	51	108	125
4	175	168	115	140	148	65
5	30	118	25	76	25	50
6	115	115	102	108	153	48
7	28	125	32	57	3	10
10	73	168	146	83	78	38
11	18	45	76	25	33	38
12	60	120	102	102	48	30
13	30	75	229	64	8	3
14	198	130	586	217	125	80
Mean	82	120	212	98	84	45

Appendix 13: Regression analysis for mean mass of all aestivating earthworms in 1992 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	1	0.03089	0.03089	15.59
Residual	7	0.01387	0.001981	
Total	8	0.04475	0.005594	

Percentage of variance accounted for 64.6.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	0.0743	0.0375	1.98	0.088
Depth*	0.02269	0.00515	3.95	0.006

* for straight line

Appendix 14: Regression analysis for mean mass of all aestivating earthworms in 1993 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	1	0.027940	0.0279404	74.52
Residual	7	0.002625	0.0003750	
Total	8	0.030565	0.0038206	

Percentage of variance accounted for 90.2.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	-0.0035		-0.22	0.834
Depth*	0.02158	0.00250	8.63	< 0.001

* for straight line

Appendix 15: Regression analysis for mean mass of juvenile aestivating earthworms in 1993 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	1	0.016115	0.0161150	39.50
Residual	7	0.002856	0.0004080	
Total	8	0.018971	0.0023714	

Percentage of variance accounted for 82.8.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	0.0105	0.0170	0.61	0.559
Depth*	0.01639	0.00261	6.28	< 0.001

* for straight line

Appendix 16: Regression analysis for mean mass of all aestivating earthworms in 1994 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	1	0.016536	0.016536	15.51
Residual	7	0.007462	0.001066	
Total	8	0.023999	0.003000	

Percentage of variance accounted for 64.5.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	0.0788	0.0275	2.86	0.024
Depth*	0.01660	0.00422	3.95	0.006

* for straight line.

Appendix 17: Regression analysis for numbers of all aestivating earthworms in 1992 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	2	3550	1775.1	10.17
Residual	7	1222	174.6	
Total	9	4772	530.2	

Percentage of variance accounted for 67.1.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	-35.4	15.5	-2.28	0.057
Depth	29.23	6.49	4.5	0.003
Depth2*	-2.496	0.575	-4.34	0.003

* for quadratic.

Appendix 18: Regression analysis for number of all aestivating earthworms in 1993 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	2	9228	4614.1	8.66
Residual	7	3731	533.0	
Total	9	12959	1439.9	

Percentage of variance accounted for 63.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	6.8	27.2	0.28	0.809
Depth	34.8	11.3	3.07	0.018
Depth2*	-3.64	1.00	-3.62	0.009

* for quadratic.

Appendix 19: Regression analysis for number of juvenile aestivating earthworms in 1993 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	2	4840	2420.2	6.48
Residual	7	2613	373.2	
Total	9	7453	828.1	

Percentage of variance accounted for 84.9.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	16.0	22.7	0.70	0.504
Depth	20.57	9.49	2.17	0.067
Depth2*	-2.318	0.841	-2.76	0.028

* for quadratic.

Appendix 20: Regression analysis for number of adult aestivating earthworms in 1993 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	2	891.2	445.59	14.46
Residual	7	215.7	30.82	
Total	9	1106.9	122.99	

Percentage of variance accounted for 74.9.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	-9.03	6.53	-1.38	0.209
Depth	14	2.73	5.13	0.001
Depth2*	-1.295	0.242	-5.36	0.001

* for quadratic.

Appendix 21: Regression analysis for number of earthworm cocoons during summer in 1993 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	1	14587	14587	57.89
Residual	8	2016	252	
Total	9	16602	1844.7	

Percentage of variance accounted for 86.3.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	121.7	10.8	11.23	< 0.001
Depth*	-13.3	1.75	-7.61	< 0.001

* for straight line.

Appendix 22: Regression analysis for number of all aestivating earthworms in 1994 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	2	17989	8994.3	11.32
Residual	7	5560	794.3	
Total	9	23549	2616.5	

Percentage of variance accounted for 69.6.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	-24.1	33.1	-0.73	0.490
Depth	58.1	13.8	4.20	0.004
Depth2*	-5.63	1.23	-4.59	0.003

* for quadratic.

Appendix 23: Regression analysis for number of adult aestivating earthworms in 1994 to soil depth.

Analysis of variance

	DF	sum of squares	mean square	variance ratio
Regression	2	4774	2386.9	14.52
Residual	7	1151	164.4	
Total	9	5925	658.3	

Percentage of variance accounted for 75.0.

Estimates of regression coefficients

	estimate	standard error	t	t probability
Constant	-38.8	15.1	-2.57	0.037
Depth	33.66	6.30	5.34	0.001
Depth2*	-2.992	0.558	-5.36	0.001

* for quadratic.

Appendix 24: Soil texture and soil moisture content (MC) determinations for summer aestivation study in 1992 (*based on soil textural classification by McDonald *et al.* 1990).

Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)
1	1	1	SL	0.6	2	1	1	SL	2.3	3	1	1	CL	6.6	4	1	1	L	2.9	5	1	1	L	3.5
1	1	2	SL	0.4	2	1	2	LS	2.2	3	1	2	CL	8.8	4	1	2	CL	5.1	5	1	2	ZL	4.3
1	1	3	SL	1.9	2	1	3	LS	2.1	3	1	3	LMC	6.0	4	1	3	SCL	5.3	5	1	3	CL	4.4
1	1	4	SL	1.4	2	1	4	CS	1.7	3	1	4	CL	8.8	4	1	4	LC	5.4	5	1	4	CL	5.4
1	1	5	SL	0.8	2	1	5	CS	1.9	3	1	5	CL	7.5	4	1	5	LC	11.5	5	1	5	LMC	8.9
1	1	6	LS	0.5	2	1	6	CS	3.1	3	1	6	CL	10.0	4	1	6	LC	8.8	5	1	6	MC	11.5
1	1	7	LS	0.3	2	1	7	LC	10.6	3	1	7	LC	12.0	4	1	7	LC	10.3	5	1	7	MHC	14.0
1	1	8	LS	0.7	2	1	8	LMC	13.8	3	1	8	LMC	10.8	4	1	8	LC	11.3	5	1	8	LMC	17.1
1	1	9	LS	0.7	2	1	9	LMC	12.3	3	1	9	LMC	6.8	4	1	9	MC	11.6	5	1	9	MHC	15.6
1	1	10	LS	0.3	2	1	10	LMC	12.6	3	1	10	LMC	8.6	4	1	10	MC	9.6	5	1	10	MHC	15.1
1	2	1	SL	1.3	2	2	1	LS	0.7	3	2	1	CL	7.1	4	2	1	L	5.7	5	2	1	L	1.7
1	2	2	SL	1.8	2	2	2	LS	1.0	3	2	2	CL	8.0	4	2	2	CL	5.7	5	2	2	L	3.5
1	2	3	SL	2.0	2	2	3	LS	1.9	3	2	3	CL	8.5	4	2	3	CL	6.5	5	2	3	CL	3.4
1	2	4	LS	1.9	2	2	4	SL	2.0	3	2	4	CL	10.0	4	2	4	CL	6.0	5	2	4	CL	3.9
1	2	5	LS	1.6	2	2	5	SL	1.6	3	2	5	CL	9.8	4	2	5	MC	13.1	5	2	5	LMC	11.8
1	2	6	LS	1.4	2	2	6	SL	1.5	3	2	6	CL	10.4	4	2	6	MC	12.7	5	2	6	MC	11.6
1	2	7	LS	1.1	2	2	7	*	1.8	3	2	7	CL	11.6	4	2	7	MC	14.8	5	2	7	MHC	12.5
1	2	8	LS	1.2	2	2	8	LC	10.1	3	2	8	LC	12.3	4	2	8	LMC	15.1	5	2	8	MC	14.0
1	2	9	LS	0.9	2	2	9	CS	8.5	3	2	9	LC	12.2	4	2	9	LMC	14.7	5	2	9	MHC	14.2
1	2	10	LS	0.1	2	2	10	CS	12.9	3	2	10	LC	11.7	4	2	10	LMC	13.0	5	2	10	MHC	12.5
1	3	1	SL	0.8	2	3	1	SL	0.4	3	3	1	SCL	6.2	4	3	1	L	2.5	5	3	1	L	2.8
1	3	2	SL	1.1	2	3	2	SL	1.0	3	3	2	CL	5.2	4	3	2	CL	4.8	5	3	2	CL	4.4
1	3	3	SL	1.5	2	3	3	SL	1.2	3	3	3	CL	6.5	4	3	3	LC	5.8	5	3	3	CL	4.0
1	3	4	LS	1.5	2	3	4	SL	0.8	3	3	4	CL	7.4	4	3	4	LMC	6.9	5	3	4	LC	12.3
1	3	5	LS	1.0	2	3	5	SL	1.0	3	3	5	CL	7.6	4	3	5	LMC	10.2	5	3	5	LMC	13.1
1	3	6	LS	0.9	2	3	6	SL	0.6	3	3	6	LC	8.8	4	3	6	MC	11.9	5	3	6	LMC	13.7
1	3	7	LS	0.9	2	3	7	SL	*	3	3	7	LC	10.2	4	3	7	LMC	12.5	5	3	7	MHC	13.5
1	3	8	LS	1.0	2	3	8	CS	1.0	3	3	8	LC	10.4	4	3	8	LC	12.0	5	3	8	MHC	14.2
1	3	9	LS	0.9	2	3	9	CS	9.5	3	3	9	LMC	10.5	4	3	9	MHC	9.7	5	3	9	MHC	13.5
1	3	10	LS	0.6	2	3	10	LC	10.5	3	3	10	LMC	8.9	4	3	10	MHC	13.3	5	3	10	MC	14.1
1	4	1	LS	0.9	2	4	1	CS	2.1	3	4	1	SL	2.5	4	4	1	L	3.5	5	4	1	L	2.7
1	4	2	LS	1.8	2	4	2	CS	1.8	3	4	2	SL	0.2	4	4	2	L	4.5	5	4	2	L	3.4
1	4	3	LS	1.9	2	4	3	CS	2.7	3	4	3	SL	5.0	4	4	3	ZL	4.3	5	4	3	CL	3.4
1	4	4	LS	1.6	2	4	4	CL	2.5	3	4	4	SCL	5.8	4	4	4	CL	4.4	5	4	4	MC	3.1
1	4	5	LS	0.4	2	4	5	CL	2.1	3	4	5	SL	6.2	4	4	5	LC	5.1	5	4	5	MC	8.0
1	4	6	LS	1.3	2	4	6	LS	1.7	3	4	6	*	7.6	4	4	6	LMC	7.4	5	4	6	MC	12.0
1	4	7	LS	0.8	2	4	7	CS	2.1	3	4	7	CL	7.6	4	4	7	LC	9.5	5	4	7	MHC	12.1
1	4	8	LS	0.9	2	4	8	CS	2.2	3	4	8	CL	9.8	4	4	8	LC	8.7	5	4	8	MHC	10.1
1	4	9	LS	1.0	2	4	9	CS	3.2	3	4	9	CL	9.8	4	4	9	LC	8.9	5	4	9	MHC	11.4
1	4	10	LS	1.2	2	4	10	CS	7.5	3	4	10	LC	8.5	4	4	10	LMC	9.8	5	4	10	MHC	13.8
1	5	1	LS	1.0	2	5	1	SL	1.3	3	5	1	SL	5.2	4	5	1	L	1.8	5	5	1	L	3.1
1	5	2	LS	2.4	2	5	2	SL	2.2	3	5	2	SL	5.6	4	5	2	CL	2.8	5	5	2	L	3.0
1	5	3	SL	3.0	2	5	3	SL	2.2	3	5	3	SL	5.3	4	5	3	ZCL	2.2	5	5	3	CL	2.6
1	5	4	SL	2.1	2	5	4	SL	2.2	3	5	4	SL	5.4	4	5	4	SCL	1.8	5	5	4	CL	4.6
1	5	5	SL	2.0	2	5	5	SL	1.7	3	5	5	SCL	5.5	4	5	5	SCL	9.6	5	5	5	CL	5.6
1	5	6	SL	1.8	2	5	6	LS	1.7	3	5	6	LC	7.5	4	5	6	ML	9.2	5	5	6	MHC	5.3
1	5	7	S	11.5	2	5	7	LS	1.8	3	5	7	LC	8.2	4	5	7	MC	10.5	5	5	7	MHC	10.6
1	5	8	LS	12.9	2	5	8	MC	12.1	3	5	8	LC	8.4	4	5	8	LMC	11.5	5	5	8	MHC	12.6
1	5	9	LS	8.5	2	5	9	MC	12.9	3	5	9	LC	7.9	4	5	9	LC	9.9	5	5	9	MC	12.3
1	5	10	LC	15.2	2	5	10	SL	13.2	3	5	10	LC	8.2	4	5	10	LC	6.2	5	5	10	MC	15.0

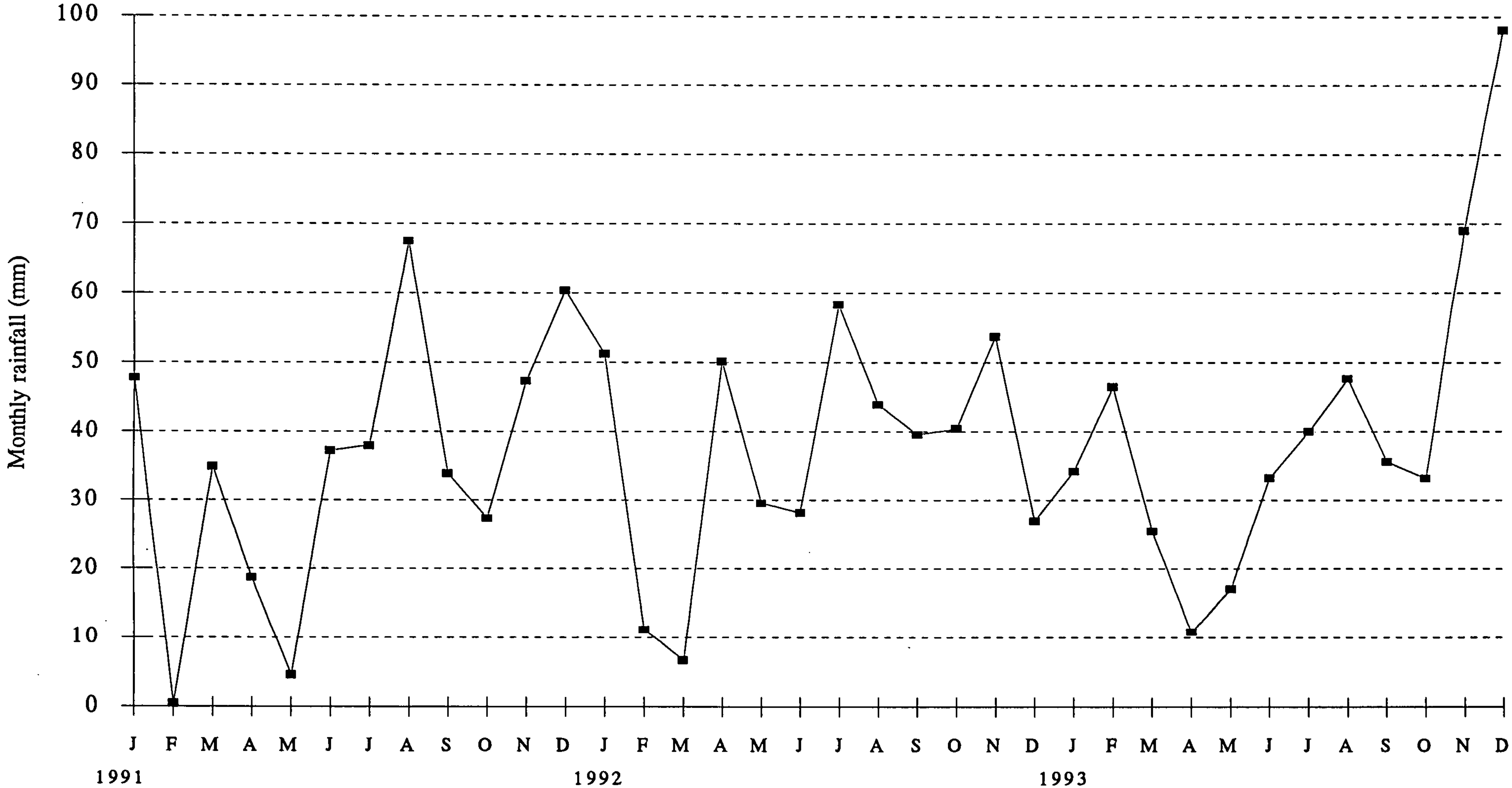
Appendix 24 (Continued).

Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)
6	1	1	L	1.7	7	1	1	LC	2.8	8	1	1	SCL	2.4	9	1	1	LS	1.9	10	1	1	LC	5.0
6	1	2	LS	2.1	7	1	2	CLS	1.7	8	1	2	SCL	2.8	9	1	2	SCL	2.3	10	1	2	*	4.8
6	1	3	SL	*	7	1	3	MC	7.7	8	1	3	SCL	4.8	9	1	3	SCL	2.4	10	1	3	CL	5.6
6	1	4	SL	1.8	7	1	4	SCL	8.6	8	1	4	CL	4.8	9	1	4	SCL	2.1	10	1	4	*	6.4
6	1	5	LS	1.2	7	1	5	CL	13.6	8	1	5	MC	12.1	9	1	5	SL	2.5	10	1	5	LC	7.2
6	1	6	LS	0.7	7	1	6	MC	15.3	8	1	6	MC	10.7	9	1	6	LS	1.9	10	1	6	*	7.4
6	1	7	LS	3.9	7	1	7	CL	11.4	8	1	7	MC	11.7	9	1	7	LMC	8.7	10	1	7	*	10.1
6	1	8	*	8.1	7	1	8	MC	14.9	8	1	8	CLS	11.6	9	1	8	LS	12.9	10	1	8	*	10.3
6	1	9	SCL	7.7	7	1	9	MC	12.5	8	1	9	*	10.9	9	1	9	LC	9.2	10	1	9	*	8.7
6	1	10	MC	7.4	7	1	10	MC	15.4	8	1	10	MC	10.9	9	1	10	CS	10.6	10	1	10	*	10.2
6	2	1	L	1.5	7	2	1	SL	3.8	8	2	1	SCL	1.4	9	2	1	LS	1.8	10	2	1	LC	6.6
6	2	2	SL	1.1	7	2	2	L	4.3	8	2	2	CL	3.7	9	2	2	SCL	1.7	10	2	2	*	9.8
6	2	3	CS	1.1	7	2	3	SCL	5.3	8	2	3	MC	12.4	9	2	3	SL	1.7	10	2	3	LMC	15.1
6	2	4	LS	0.5	7	2	4	LC	8.1	8	2	4	CLS	12.9	9	2	4	LS	1.2	10	2	4	LMC	14.1
6	2	5	SL	1.7	7	2	5	MC	4.1	8	2	5	LC	10.9	9	2	5	LS	0.8	10	2	5	LMC	13.9
6	2	6	LS	0.9	7	2	6	MC	13.7	8	2	6	CLS	14.2	9	2	6	LS	0.5	10	2	6	LMC	13.7
6	2	7	LS	2.9	7	2	7	MHC	14.3	8	2	7	MHC	8.3	9	2	7	LS	1.0	10	2	7	MC	13.0
6	2	8	SCL	5.4	7	2	8	MHC	14.0	8	2	8	LC	12.8	9	2	8	LS	1.3	10	2	8	*	11.1
6	2	9	SCL	11.6	7	2	9	MC	13.4	8	2	9	MC	13.0	9	2	9	LS	7.8	10	2	9	LC	12.6
6	2	10	CLS	13.1	7	2	10	MC	12.8	8	2	10	MC	11.4	9	2	10	CS	7.7	10	2	10	LC	9.8
6	3	1	LS	1.6	7	3	1	*	3.4	8	3	1	SLC	1.5	9	3	1	SL	2.1	10	3	1	CL	*
6	3	2	LS	1.9	7	3	2	L	3.4	8	3	2	SL	4.9	9	3	2	LS	2.6	10	3	2	MHC	*
6	3	3	LS	2.1	7	3	3	SL	2.8	8	3	3	CLS	3.7	9	3	3	LS	3.3	10	3	3	MHC	*
6	3	4	LS	2.6	7	3	4	SL	1.8	8	3	4	MC	13.8	9	3	4	SL	3.1	10	3	4	LC	*
6	3	5	LS	3.9	7	3	5	LS	1.8	8	3	5	LC	12.4	9	3	5	SL	5.3	10	3	5	MC	*
6	3	6	CS	9.4	7	3	6	LS	1.5	8	3	6	MHC	15.3	9	3	6	CS	8.8	10	3	6	MHC	*
6	3	7	LC	9.8	7	3	7	LS	2.1	8	3	7	MC	15.0	9	3	7	SCL	9.1	10	3	7	LC	*
6	3	8	MC	8.7	7	3	8	SL	9.5	8	3	8	LMC	14.3	9	3	8	LMC	10.8	10	3	8	MC	*
6	3	9	CLS	11.0	7	3	9	SL	5.8	8	3	9	LMC	7.3	9	3	9	HC	11.0	10	3	9	MHC	*
6	3	10	SCL	7.7	7	3	10	SL	2.7	8	3	10	MC	13.4	9	3	10	SCL	11.6	10	3	10	*	*
6	4	1	LS	1.6	7	4	1	SL	1.9	8	4	1	CLS	3.5	9	4	1	LS	0.8	10	4	1	SL	*
6	4	2	LS	1.9	7	4	2	CS	5.7	8	4	2	CLS	5.3	9	4	2	LS	1.4	10	4	2	SL	*
6	4	3	LS	2.0	7	4	3	*	7.5	8	4	3	CLS	3.8	9	4	3	LS	0.9	10	4	3	SL	*
6	4	4	LS	1.5	7	4	4	LMC	6.8	8	4	4	LMC	12.0	9	4	4	LS	0.9	10	4	4	SCL	*
6	4	5	LS	0.7	7	4	5	SCL	4.8	8	4	5	LC	15.2	9	4	5	LS	2.6	10	4	5	SCL	*
6	4	6	LS	0.9	7	4	6	LC	10.9	8	4	6	LMC	13.0	9	4	6	LS	0.7	10	4	6	LMC	*
6	4	7	SL	3.3	7	4	7	CL	9.0	8	4	7	LMC	14.0	9	4	7	LS	1.9	10	4	7	MHC	*
6	4	8	SCL	9.8	7	4	8	MHC	5.0	8	4	8	LMC	16.0	9	4	8	LS	0.6	10	4	8	MHC	*
6	4	9	MC	10.0	7	4	9	SL	5.1	8	4	9	LMC	14.4	9	4	9	LS	0.9	10	4	9	MC	*
6	4	10	CLS	10.6	7	4	10	SCL	6.4	8	4	10	LMC	14.6	9	4	10	LS	1.6	10	4	10	*	*
6	5	1	SL	1.7	7	5	1	SCL	2.4	8	5	1	LC	1.7	9	5	1	LS	1.3	10	5	1	CLS	*
6	5	2	LS	*	7	5	2	*	2.5	8	5	2	LC	4.0	9	5	2	LS	1.7	10	5	2	SLC	*
6	5	3	LS	1.5	7	5	3	SL	7.9	8	5	3	MC	3.2	9	5	3	LS	2.2	10	5	3	CLS	*
6	5	4	SL	1.3	7	5	4	MHC	6.5	8	5	4	LMC	12.1	9	5	4	LS	2.3	10	5	4	*	*
6	5	5	LS	1.1	7	5	5	SCL	11.0	8	5	5	MC	11.3	9	5	5	LS	1.3	10	5	5	MC	*
6	5	6	LS	2.7	7	5	6	MHC	9.9	8	5	6	MC	11.4	9	5	6	S	6.3	10	5	6	SCL	*
6	5	7	LS	3.6	7	5	7	CL	8.3	8	5	7	MC	12.7	9	5	7	CS	0.5	10	5	7	LC	*
6	5	8	LS	2.1	7	5	8	MHC	7.3	8	5	8	MC	12.3	9	5	8	CL	9.2	10	5	8	CL	*
6	5	9	LS	0.8	7	5	9	MC	7.5	8	5	9	LMC	10.4	9	5	9	LMC	6.1	10	5	9	LMC	*
6	5	10	LS	2.1	7	5	10	SCL	8.2	8	5	10	LC	*	9	5	10	CS	8.4	10	5	10	*	*

Appendix 24 (Continued).

Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)	Site	Rep	Depth	Texture*	MC (%)
11	1	1	MC	*	12	1	1	LC	8.7	13	1	1	SL	3.5	14	1	1	CL	3.7
11	1	2	*	*	12	1	2	LC	10.2	13	1	2	SL	4.3	14	1	2	L	9.2
11	1	3	*	*	12	1	3	LC	11.7	13	1	3	SL	2.3	14	1	3	*	3.8
11	1	4	LC	*	12	1	4	LC	9.7	13	1	4	CL	4.1	14	1	4	CLS	7.7
11	1	5	*	*	12	1	5	LC	11.3	13	1	5	L	3.6	14	1	5	*	9.4
11	1	6	*	*	12	1	6	LC	11.0	13	1	6	CL	11.0	14	1	6	MC	11.3
11	1	7	MC	*	12	1	7	LC	11.3	13	1	7	LMC	16.1	14	1	7	MHC	8.9
11	1	8	*	*	12	1	8	LC	10.4	13	1	8	CLS	9.4	14	1	8	MHC	10.5
11	1	9	*	*	12	1	9	MC	11.9	13	1	9	*	10.0	14	1	9	MHC	9.8
11	1	10	*	*	12	1	10	LMC	11.5	13	1	10	*	10.7	14	1	10	MC	8.8
11	2	1	LC	*	12	2	1	*	4.0	13	2	1	SL	3.4	14	2	1	CLS	*
11	2	2	LC	*	12	2	2	CL	8.0	13	2	2	SL	3.8	14	2	2	L	*
11	2	3	*	*	12	2	3	CL	8.2	13	2	3	SL	5.6	14	2	3	CL	*
11	2	4	*	*	12	2	4	SCL	8.0	13	2	4	SL	5.0	14	2	4	LC	*
11	2	5	*	*	12	2	5	SCL	11.4	13	2	5	LMC	7.2	14	2	5	MC	*
11	2	6	*	*	12	2	6	LC	9.9	13	2	6	SCL	11.0	14	2	6	MHC	*
11	2	7	*	*	12	2	7	LMC	11.0	13	2	7	LMC	13.6	14	2	7	MC	*
11	2	8	LMC	*	12	2	8	*	9.6	13	2	8	LC	14.0	14	2	8	LMC	*
11	2	9	LMC	*	12	2	9	*	9.7	13	2	9	LMC	12.3	14	2	9	MC	*
11	2	10	*	*	12	2	10	*	9.2	13	2	10	SCL	13.3	14	2	10	HC	*
11	3	1	*	18.4	12	3	1	CL	*	13	3	1	L	*	14	3	1	LS	*
11	3	2	LS	42.6	12	3	2	CL	*	13	3	2	SL	*	14	3	2	LS	*
11	3	3	LS	17.0	12	3	3	LC	*	13	3	3	L	*	14	3	3	L	*
11	3	4	LS	26.3	12	3	4	MC	*	13	3	4	SCL	*	14	3	4	SL	*
11	3	5	LS	39.6	12	3	5	MC	*	13	3	5	CS	*	14	3	5	*	*
11	3	6	LMC	5.2	12	3	6	MC	*	13	3	6	CS	*	14	3	6	SCL	*
11	3	7	LMC	51.0	12	3	7	MC	*	13	3	7	LC	*	14	3	7	SCL	*
11	3	8	LMC	49.3	12	3	8	MC	*	13	3	8	MC	*	14	3	8	LC	*
11	3	9	LMC	7.1	12	3	9	MHC	*	13	3	9	LMC	*	14	3	9	*	*
11	3	10	LMC	36.1	12	3	10	*	*	13	3	10	LMC	*	14	3	10	*	*
11	4	1	*	*	12	4	1	CL	*	13	4	1	SL	*	14	4	1	SCL	*
11	4	2	MC	*	12	4	2	LC	*	13	4	2	SCL	*	14	4	2	SL	*
11	4	3	LMC	*	12	4	3	*	*	13	4	3	SL	*	14	4	3	SL	*
11	4	4	*	*	12	4	4	LMC	*	13	4	4	SL	*	14	4	4	*	*
11	4	5	LC	*	12	4	5	*	*	13	4	5	SCL	*	14	4	5	LC	*
11	4	6	*	*	12	4	6	CLS	*	13	4	6	LC	*	14	4	6	SCL	*
11	4	7	LMC	*	12	4	7	*	*	13	4	7	SCL	*	14	4	7	MC	*
11	4	8	LMC	*	12	4	8	LMC	*	13	4	8	LMC	*	14	4	8	SCL	*
11	4	9	LMC	*	12	4	9	MHC	*	13	4	9	CLS	*	14	4	9	LC	*
11	4	10	MC	*	12	4	10	LMC	*	13	4	10	CLS	*	14	4	10	LC	*
11	5	1	LC	*	12	5	1	CL	*	13	5	1	SL	*	14	5	1	SL	*
11	5	2	*	*	12	5	2	LMC	*	13	5	2	SL	*	14	5	2	CL	*
11	5	3	MC	*	12	5	3	MHC	*	13	5	3	SL	*	14	5	3	*	*
11	5	4	*	*	12	5	4	LMC	*	13	5	4	SL	*	14	5	4	MCL	*
11	5	5	*	*	12	5	5	MHC	*	13	5	5	*	*	14	5	5	MC	*
11	5	6	MC	*	12	5	6	MHC	*	13	5	6	CLS	*	14	5	6	MC	*
11	5	7	ZCL	*	12	5	7	MHC	*	13	5	7	CLS	*	14	5	7	MC	*
11	5	8	*	*	12	5	8	MHC	*	13	5	8	CLS	*	14	5	8	MC	*
11	5	9	*	*	12	5	9	LMC	*	13	5	9	CLS	*	14	5	9	MHC	*
11	5	10	SCL	*	12	5	10	LMC	*	13	5	10	*	*	14	5	10	*	*

Appendix 25: Average monthly rainfall in the Midlands (from Campbell Town, Oatlands, Ross and Tunbridge meterological stations) from 1991-1993.



Appendix 26: Effect of treatment application and *A. longa* introduction on earthworm populations at Oatlands on 26-11-91 (*0- *A. longa* absent; 1- *A. longa* present; BHCg- black-headed cockchafer grubs).

Rep	Treat	Intro*	A. cal		L.rub		O.cya		A.trap		TNo.	TMass	BHCg*	Corby
			No.	Mass	No.	Mass	No.	Mass.	No.	Mass	No.	Mass	No.	No.
1	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0
1	NOL	0	0	0	0	0	0	0	0	0	0	0	1	0
1	NOL	0	3	0.67	3	.45	0	0	0	0	6	1.12	9	0
1	NOF	1	4	.29	5	3.38	0	0	0	0	9	3.67	3	0
1	NOF	1	4	.48	0	0	0	0	0	0	4	.48	4	0
1	NOF	1	4	.33	2	.41	0	0	0	0	6	.74	2	0
1	LNF	0	3	.71	0	0	0	0	0	0	3	.71	1	0
1	LNF	0	1	.31	0	0	0	00	0	0	1	.31	4	0
1	LNF	0	1	.29	2	.6	3	1.63	0	0	6	2.52	2	0
1	NOL	1	8	1.4	0	0	0	0	0	0	8	1.4	2	0
1	NOL	1	7	1.35	4	.94	0	0	0	0	11	2.29	3	0
1	NOL	1	2	0.43	0	0	0	0	0	0	2	.43	2	0
1	LNF	1	0	0	4	1.2	0	0	0	0	4	1.2	5	0
1	LNF	1	0	0	0	0	0	0	0	0	0	0	2	0
1	LNF	1	0	0	0	0	0	0	0	0	0	0	4	0
1	LNOF	1	0	0	0	0	0	0	0	0	0	0	1	0
1	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0
1	LNOF	1	0	0	0	0	0	0	0	0	0	0	5	0
3	zero	1	0	0	0	0	0	0	0	0	0	0	2	0
3	zero	1	0	0	0	0	0	0	0	0	0	0	3	0
3	zero	1	0	0	0	0	0	0	0	0	0	0	1	0
3	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LNOF	0	1	.01	1	.28	0	0	0	0	2	.29	0	0
3	LNOF	0	0	0	1	.45	0	0	0	0	1	.45	0	0
3	LNF	1	0	0	0	0	0	0	0	0	0	0	2	0
3	LNF	1	4	1.09	1	.58	1	1.95	0	0	6	3.62	0	0
3	LNF	1	1	.25	0	0	0	0	0	0	1	.25	0	0
3	NOF	1	1	.27	1	.44	0	0	0	0	2	.71	0	0
3	NOF	1	1	.37	1	.64	0	0	0	0	2	1.01	1	0
3	NOF	1	0	0	1	.53	0	0	0	0	1	.53	1	0
3	zero	0	1	.28	0	0	0	0	0	0	1	.28	3	0
3	zero	0	2	.9	0	0	00	0	0	0	2	.9	0	1
3	zero	0	0	0	0	0	0	0	0	0	0	0	0	0
3	NOL	1	0	0	2	1.02	0	0	0	0	2	1.02	0	0
3	NOL	1	2	.82	0	0	0	0	0	0	2	.82	0	0
3	NOL	1	2	.63	1	.26	0	0	0	0	3	.89	1	0
1	LOF	1	0	0	0	0	0	0	0	0	0	0	5	0
1	LOF	1	4	.37	4	.88	1	.05	0	0	9	1.3	0	0
1	LOF	1	7	1	8	2.37	0	0	0	0	15	3.37	2	0
1	NOF	0	2	.3	1	.35	0	0	0	0	3	.65	0	0
1	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0
1	NOF	0	0	0	0	0	0	0	0	0	0	0	3	0
1	LOF	0	2	.68	1	.87	0	0	0	0	3	1.55	1	0
1	LOF	0	0	0	0	0	0	0	0	0	0	0	1	0

Appendix 26 (Continued).

Rep	treat	Intro*	A. cal No.	Mass	L.rub No.	Mass	O.cya No.	Mass.	A.trap No.	Mass	TNo. No.	TMass Mass	BHCg* No.	Corby No.
1	LOF	0	1	.04	1	.52	0	0	0	0	2	.56	1	0
1	zero	1	0	.68	1	.22	0	0	0	0	1	.9	4	0
1	zero	1	3	0	1	.32	0	0	0	0	4	.32	1	0
1	zero	1	0	0	0	0	0	0	0	0	0	0	0	0
1	LNOF	0	0	0		0	0	0	0	0	0	0	0	0
1	LNOF	0	0	0	0	0	00	0	0	0	0	0	2	0
1	LNOF	0	1	.19	3	1	0	0	0	0	4	1.19	2	0
1	zero	0	0	0	0	0	0	0	0	0	0	0	1	0
1	zero	0	0	0	3	.58	0	0	0	0	3	.58	3	0
1	zero	0	0	0	0	0	0	0	0	0	0	0	2	0
3	NOF	0	1	.32	0	0	0	0	0	0	1	.32	5	0
3	NOF	0	1	.06	0	0	0	0	0	0	1	.06	4	0
3	NOF	0	2	.91	0	0	0	0	0	0	2	.91	1	0
3	NOL	0	2	.55	1	.21	0	0	0	0	3	.76	3	0
3	NOL	0	1	.28	0	0	0	0	0	0	1	.28	1	0
3	NOL	0	9	1.5	0	0	0	0	0	0	9	1.5	0	0
3	LNOF	1	0	0	0	0	0	0	0	0	0	0	1	0
3	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0
3	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0
3	LNF	0	0	0	0	0	0	0	0	0	0	0	3	0
3	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LNF	0	3	.34	2	.74	0	0	0	0	5	1.08	1	0
3	LOF	1	0	0	2	.5	0	0	0	0	2	.5	0	0
3	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0
3	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0
3	LOF	0	1	.04	0	0	0	0	0	0	1	.04	1	0
3	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LOF	0	0	0	3	.63	0	0	0	0	3	.63	1	0
2	NOL	1	1	.09	0	0	0	0	0	0	1	.09	0	0
2	NOL	1	0	0	0	0	0	0	0	0	0	0	0	0
2	NOL	1	0	0	1	.24	0	0	0	0	1	.24	0	0
2	NOF	0	6	1.57	0	0	0	0	0	0	6	1.57	2	0
2	NOF	0	7	1.09	1	.45	0	0	0	0	8	1.54	1	1
2	NOF	0	1	.25	0	0	0	0	0	0	1	.25	1	0
2	LNOF	1	5	1.19	2	.89	0	0	0	0	7	2.08	4	0
2	LNOF	1	7	1.24	0	0	0	0	0	0	7	1.24	3	0
2	LNOF	1	8	1.90	2	1.55	0	0	0	0	10	3.45	3	0
2	LNF	0	4	.95	8	2.3	0	0	0	0	12	3.25	0	0
2	LNF	0	3	1.35	0	0	0	0	0	0	3	1.35	0	0
2	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0
2	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0
2	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0
2	LOF	1	0	0	0	0	0	0	0	0	0	0	1	0
2	NOL	0	0	0	0	.0	0	0	0	0	0	0	2	0

Appendix 26 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	L.rub No.	Mass	O.cya No.	Mass.	A.trap No.	Mass	TNo. No.	TMass Mass	BHCg* No.	Corby No.
2	NOL	0	6	.56	1	.32	0	0	0	0	7	.88	0	0
2	NOL	0	2	.53	1	.11	0	0	0	0	3	.64	0	0
4	NOL	0	0	0	1	.22	0	0	0	0	1	.22	0	0
4	NOL	0	1	.11	0	0	0	0	0	0	1	.11	1	0
4	NOL	0	0	0	0	0	0	0	0	0	0	0	1	0
4	zero	1	0	0	6	2.12	0	0	0	0	6	2.12	0	0
4	zero	1	0	0	0	0	0	0	0	0	0	0	0	0
4	zero	1	1	.33	0	0	0	0	0	0	1	.33	0	0
4	LOF	1	1	.6	2	.54	0	0	0	0	3	1.14	1	0
4	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0
4	LOF	1	0	0	0	0	0	0	0	0	0	0	1	0
4	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LNOF	0	0	0	5	1.46	0	00	0	0	5	1.46	0	0
4	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOF	1	1	.01	0	0	0	0	0	0	1	.01	1	0
4	NOF	1	1	.29	1	.35	0	0	0	0	2	.64	0	0
4	NOF	1	4	.78	0	0	0	0	0	0	4	.78	0	0
4	NOL	1	4	.8	0	0	0	0	0	0	4	.8	0	0
4	NOL	1	6	1.44	0	0	0	0	0	0	6	1.44	0	0
4	NOL	1	3	.47	1	.28	1	1.75	0	0	5	2.5	0	0
2	zero	0	0	0	0	0	0	0	0	0	0	0	2	0
2	zero	0	4	.46	1	.53	0	0	0	0	5	.99	0	0
2	zero	0	1	.37	1	.37	0	0	0	0	2	.74	0	0
2	LNOF	0	1	.2	3	2.1	0	0	0	0	4	2.3	3	0
2	LNOF	0	1	.45	3	1.31	0	0	0	0	4	1.76	2	0
2	LNOF	0	1	.30	1	.4	0	0	0	0	2	.7	3	0
2	LOF	0	9	2.3	3	1.61	0	0	0	0	12	3.91	2	0
2	LOF	0	2	.36	0	0	0	0	0	0	2	.36	1	0
2	LOF	0	4	1.4	0	0	0	0	0	0	4	1.4	3	0
2	NOF	1	4	1.13	2	.9	0	0	0	0	6	2.03	0	0
2	NOF	1	0	0	1	.04	0	0	0	0	1	.04	0	0
2	NOF	1	2	.57	4	1.22	0	0	0	0	6	1.79	0	0
2	zero	1	0	0	4	1.03	0	0	0	0	4	1.03	0	0
2	zero	1	2	.82	0	0	0	0	0	0	2	.82	0	0
2	zero	1	2	1.49	0	0	0	0	0	0	2	1.49	2	0
2	LNF	1	2	.29	16	7.19	0	0	0	0	18	7.48	0	0
2	LNF	1	1	.12	0	0	0	0	0	0	1	.12	1	0
2	LNF	1	5	1.35	0	0	0	0	0	0	5	1.35	0	0
4	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0
4	LNOF	1	1	.14	0	0	0	0	0	0	1	.14	0	0
4	LNOF	1	4	1.17	0	0	0	0	0	0	4	1.17	0	0
4	LNF	0	1	.7	0	0	0	0	0	0	1	.7	0	0
4	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LNF	0	6	.3	0	0	0	0	0	0	6	.3	0	0

Appendix 26 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	L.rub No.	Mass	O.cya No.	Mass.	A.trap No.	Mass	TNo. No.	TMass Mass	BHCg* No.	Corby No.
4	NOF	0	7	2.16	3	.59	0	0	0	0	10	2.75	0	1
4	NOF	0	0	0	3	1.33	0	0	0	0	3	1.33	5	0
4	NOF	0	1	.04	0	0	0	0	0	0	1	.04	0	0
4	zero	0	0	0	0	0	0	0	0	0	0	0	0	0
4	zero	0	2	.29	2	.5	0	0	0	0	4	.79	1	0
4	zero	0	0	0	1	.17	0	0	0	0	1	.17	2	0
4	LNF	1	3	.26	1	.24	0	0	0	0	4	.5	2	0
4	LNF	1	0	0	0	0	0	0	0	0	0	0	0	0
4	LNF	1	2	.34	0	0	0	0	0	0	2	.34	1	0
4	LOF	0	4	1.45	2	.72	0	0	0	0	6	2.17	2	0
4	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LOF	0	0	0	3	.91	00	0	0	0	3	.91	2	0

Appendix 27: Effect of treatment application and *A. longa* introduction on earthworm populations at Oatlands on 15-10-92
(*0- *A. longa* absent; 1- *A. longa* present; BHCg- black-headed cockchafer grubs; BHCa- .black-headed cockchafer adults; RHC- red-headed cockchafers).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
1	NOL	0	7	2	0	0	0	13	4.16	2	.4	1	0	0	0	22	6.56	1	0	3	0	0
1	NOL	0	9	1.8	0	1	.2	10	4.2	1	.2	0	0	0	0	21	6.4	0	0	0	0	0
1	NOL	0	24	6.6	1	4	.8	12	6	2	.62	0	0	0	0	42	14.02	1	0	3	0	0
1	NOF	1	10	2	0	2	1.1	5	3.9	4	1.71	0	1	1.11	4	22	9.82	4	0	0	0	0
1	NOF	1	7	2.6	0	0	0	7	2.1	2	1.31	0	1	.75	0	17	6.76	0	0	0	0	0
1	NOF	1	10	2.6	2	0	0	10	6.6	3	1.51	0	0	0	2	23	10.71	4	0	1	0	0
1	LNF	0	5	1.6	0	2	.4	10	3.89	3	.6	0	0	0	0	20	6.49	0	0	0	0	0
1	LNF	0	13	4.2	0	4	3.2	8	7.2	0	0	0	0	0	0	25	14.6	0	0	0	0	0
1	LNF	0	9	2.4	0	1	.2	17	5.1	2	2.22	0	0	0	0	29	9.92	0	0	1	0	0
1	NOL	1	12	4.2	0	4	2.3	5	1.5	0	0	0	1	.75	1	22	8.75	1	0	1	0	1
1	NOL	1	10	4.4	2	0	0	12	8.35	0	0	0	2	2.22	5	24	14.97	7	0	0	0	1
1	NOL	1	16	5.8	0	1	.2	4	5.38	1	1.11	0	0	0	2	22	12.49	2	0	0	0	0
1	LNF	1	13	3.8	0	1	.9	11	11.4	0	0	0	0	0	4	25	16.1	4	0	1	0	0
1	LNF	1	9	1.8	0	0	0	6	1.8	0	0	0	0	0	0	15	3.6	0	0	0	0	0
1	LNF	1	18	6.6	0	1	1.05	2	.6	1	.2	0	1	1.11	1	23	9.56	1	0	2	0	0
1	LNOF	0	3	.6	0	5	1.7	1	.3	0	0	0	0	0	0	9	2.6	0	0	0	0	0
1	LNOF	0	23	7	0	3	.6	0	0	0	0	0	0	0	0	26	7.6	0	0	0	0	2
1	LNOF	0	15	5.4	0	2	.2	2	.6	0	0	0	0	0	0	19	6.2	0	0	0	1	0
3	zero	0	12	6	0	0	0	3	3.3	0	0	0	0	0	0	15	9.3	0	0	0	0	0
3	zero	0	12	6	2	0	0	2	3	1	.2	0	0	0	0	15	9.2	2	0	0	0	2
3	zero	0	12	4.5	0	0	0	12	3.6	1	.2	0	0	0	0	25	8.3	0	0	0	0	0
3	LNOF	0	10	4.4	0	0	0	8	3.6	2	.4	0	0	0	0	20	8.4	0	0	0	0	0
3	LNOF	0	12	4.2	1	2	1.1	4	2.4	2	.4	0	0	0	0	20	8.1	1	0	3	0	0
3	LNOF	0	17	5.5	0	1	.2	6	5.4	1	.2	0	0	0	0	25	11.3	0	0	1	0	0
3	LNF	1	17	4.9	2	0	0	13	7.5	3	3.33	0	0	0	0	33	15.73	2	0	0	0	0

Appendix 27 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
3	LNF	1	13	4.4	1	0	0	9	2.7	4	4.44	0	0	0	0	26	11.54	1	0	1	0	0
3	LNF	1	7	1.4	0	1	.2	4	3.6	1	.36	0	1	.31	0	14	5.87	0	0	0	0	0
3	NOF	1	10	2	0	0	0	1	.3	0	0	0	0	0	0	11	2.3	0	0	0	0	0
3	NOF	1	12	4.8	0	1	.9	5	3.9	3	1.51	0	0	0	0	21	11.11	0	0	0	0	0
3	NOF	1	9	3	0	1	.2	6	3	3	.6	0	0	0	0	19	6.8	0	0	0	0	0
3	zero	1	4	1.4	0	0	0	3	2.4	0	0	0	1	.5	2	8	4.3	2	0	0	0	0
3	zero	1	3	.6	0	0	0	3	.9	1	1.11	0	0	0	2	7	2.61	2	0	0	0	0
3	zero	1	3	1.2	0	0	0	1	.3	2	1.31	0	0	0	0	6	2.81	0	0	0	0	0
3	NOL	1	10	7.4	0	1	.9	0	0	0	0	0	0	0	0	11	8.3	0	0	1	0	0
3	NOL	1	3	1.2	0	3	3.15	0	0	0	0	3	0	0	0	6	4.35	3	0	0	0	0
3	NOL	1	4	.8	0	0	0	0	0	1	1.11	0	0	0	0	5	1.91	0	0	0	0	0
1	LOF	1	22	10.4	2	11	2.2	8	2.4	0	1	0	3	2	0	44	3	1	1	0	0	0
1	LOF	1	2	.4	1	9	3.2	4	2.4	1	1.11	0	2	.62	0	18	7.73	1	0	0	0	0
1	LOF	1	11	4.6	0	7	1.4	5	2.7	0	0	0	3	1.73	0	26	10.43	0	0	0	0	0
1	NOF	0	21	6.6	0	4	2.9	10	3	0	0	1	0	0	0	35	12.5	1	0	0	0	0
1	NOF	0	5	2.2	0	7	1.4	9	7.5	2	.4	0	0	0	0	23	11.5	0	0	0	0	0
1	NOF	0	7	2.9	2	3	.6	8	6	3	.6	0	0	0	0	21	10.1	2	0	0	1	0
1	LOF	0	10	4.7	2	15	6.65	5	2.7	4	1.93	0	0	0	0	34	15.98	2	0	0	0	0
1	LOF	0	23	5.5	0	5	2.55	0	0	1	.2	2	0	0	0	29	8.25	2	0	0	0	0
1	LOF	0	10	3.8	0	3	2	6	1.8	2	.4	1	0	0	0	21	8	1	0	0	0	0
1	zero	1	14	5.8	0	0	0	2	.6	3	2.42	0	1	1.11	0	20	9.93	0	0	0	0	0
1	zero	1	6	2.4	0	0	0	4	1.2	1	1.11	0	0	0	0	11	4.71	0	0	0	0	0
1	zero	1	13	3.5	0	2	1.1	4	1.2	1	1.111	0	0	0	0	20	6.911	0	0	0	1	0
1	LNOF	1	21	7.2	0	4	.8	1	1.5	0	0	0	1	1.11	1	27	10.61	1	0	0	0	0
1	LNOF	1	15	4.5	0	15	5.25	2	3	0	0	0	0	0	0	32	12.75	0	0	0	0	0
1	LNOF	1	16	5	0	3	2.3	11	9.3	0	0	0	0	0	2	30	16.6	2	0	0	0	0
1	zero	0	9	2.4	0	2	1.1	2	.6	0	0	0	0	0	0	13	4.1	0	0	0	0	0
1	zero	0	6	1.8	0	0	0	4	1.2	1	.2	0	0	0	0	11	3.2	0	0	0	0	0
1	zero	0	9	3.6	1	4	2.9	3	.9	0	0	0	0	0	0	16	7.4	1	0	0	0	0
3	NOF	0	21	7.2	0	6	3.75	3	.9	0	0	0	0	0	0	30	11.85	0	0	0	0	0
3	NOF	0	28	9.5	0	4	2.9	1	1.5	0	0	0	0	0	0	33	13.9	0	0	0	0	0
3	NOF	0	11	2.2	5	11	3.6	7	3.3	0	0	0	0	0	0	29	9.1	5	0	0	0	0
3	NOL	0	14	6.4	0	5	3.55	3	.9	1	.2	0	0	0	0	23	11.05	0	0	0	0	0
3	NOL	0	16	5.5	0	5	1.7	0	0	1	.2	0	0	0	0	22	7.4	0	0	0	0	0
3	NOL	0	19	8.9	0	2	1.25	5	3.9	3	1.67	00	0	0	0	29	15.72	0	0	0	0	0
3	LNOF	1	5	1.9	1	4	1.5	3	.9	0	0	0	0	0	0	12	4.3	1	0	0	0	0
3	LNOF	1	14	4.6	0	8	3.3	0	0	0	0	0	1	1.11	0	23	9.01	0	0	0	0	0
3	LNOF	1	6	3.6	0	5	1.7	4	1.2	0	0	0	7	2.61	0	22	9.11	0	0	0	0	0
3	LNF	0	12	5.1	0	7	1.4	2	3	1	1.11	0	0	0	0	22	10.61	0	0	0	0	0
3	LNF	0	13	4.4	0	0	0	4	3.6	2	2.22	0	0	0	0	19	10.22	0	0	0	0	0
3	LNF	0	5	1.3	0	8	2.45	0	0	1	.2	0	0	0	0	14	3.95	0	0	0	0	0
3	LOF	1	9	1.8	0	2	.4	0	0	1	1.11	0	0	0	0	12	3.31	0	0	0	0	0
3	LOF	1	11	6.4	0	3	1.45	0	0	0	0	0	0	0	0	14	7.85	0	0	0	0	0
3	LOF	1	15	7.8	0	4	3.35	0	0	2	2.22	1	0	0	0	21	13.37	1	0	0	0	0

Appendix 27 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
3	LOF	0	11	4	0	5	2.55	0	0	2	1.31	0	0	0	0	18	7.86	0	0	0	0	0
3	LOF	0	16	5.9	0	4	1.65	1	.3	0	0	0	0	0	0	21	7.85	0	0	0	0	0
3	LOF	0	15	6.9	0	3	.6	1	.3	0	0	0	0	0	0	19	7.8	0	0	0	0	0
2	NOL	1	15	3	3	3	1.3	14	5.4	0	0	0	3	.93	0	35	10.63	3	0	2	0	0
2	NOL	1	17	7	2	1	.9	3	4.5	1	1.11	0	2	.62	0	24	14.13	2	0	0	0	0
2	NOL	1	6	4.8	1	0	0	16	9.6	2	1.31	0	0	0	3	24	15.71	4	0	0	0	0
2	NOF	0	8	5.8	0	5	2.55	10	4.2	0	0	0	0	0	0	23	12.55	0	0	0	0	0
2	NOF	0	5	4	0	5	2.7	10	6.6	0	0	0	0	0	0	20	13.3	0	0	0	0	0
2	NOF	0	14	5.2	0	2	1.1	5	1.5	0	0	0	0	0	0	21	7.8	0	0	0	0	0
2	LNOF	1	13	6.2	3	0	0	5	2.52	3	3.33	0	1	.31	0	22	12.36	3	0	0	0	0
2	LNOF	1	8	3.7	0	1	.9	4	2.4	0	0	0	0	0	0	13	7	0	0	0	0	0
2	LNOF	1	5	4	0	3	1.65	4	1.2	3	1.51	0	2	2.22	4	17	10.58	4	0	1	0	1
2	LNF	0	22	8.6	5	7	4.5	1	.3	0	0	0	0	0	0	30	13.4	5	0	0	0	2
2	LNF	0	15	5.4	0	0	0	3	1.8	1	.2	0	0	0	0	19	7.4	0	0	0	0	1
2	LNF	0	18	11.4	0	4	.8	2	3	0	0	0	0	0	0	24	15.2	0	0	0	1	0
2	LOF	1	3	1.8	0	1	.2	3	2.1	1	0	0	0	0	0	8	4.1	0	0	0	0	0
2	LOF	1	19	5	2	3	.6	6	5.35	0	0	0	0	0	0	28	10.95	2	0	0	0	2
2	LOF	1	14	4.9	0	3	2.15	6	5.4	0	0	0	1	.31	0	24	12.76	0	0	0	0	0
2	NOL	0	10	6	0	1	.9	7	6.9	0	0	0	0	0	0	18	13.8	0	0	0	0	0
2	NOL	0	2	1.6	0	0	0	5	1.5	1	.2	0	0	0	0	8	3.3	0	0	0	0	1
2	NOL	0	6	1.8	0	0	0	4	6	1	1.11	0	0	0	0	11	8.91	0	0	0	1	0
4	NOL	0	4	3.2	0	4	.8	12	6	0	0	0	1	.31	0	21	10.31	0	0	0	0	0
4	NOL	0	16	4.4	0	4	2.35	1	1.5	0	0	0	0	0	0	21	8.25	0	0	0	0	1
4	NOL	0	18	6	7	4	.8	0	0	1	.36	0	0	0	0	23	7.16	7	0	0	0	0
4	zero	1	10	3.2	0	0	0	1	.3	1	1.11	0	1	1.11	0	13	5.72	0	0	0	0	0
4	zero	1	9	2.4	4	0	0	2	.6	0	0	0	1	.31	1	12	3.31	5	0	1	0	0
4	zero	1	5	4	0	2	.4	7	3.3	1	1.11	0	0	0	0	15	8.81	0	0	1	0	0
4	LOF	1	4	3.2	0	4	.8	16	8.4	1	1.11	0	4	2.84	7	29	16.35	7	0	0	0	0
4	LOF	1	28	10.7	4	7	2.95	0	0	0	0	0	3	.93	0	38	14.58	4	0	0	0	1
4	LOF	1	20	5.2	1	3	2	1	.3	1	.36	0	0	0	0	25	7.86	1	0	0	0	0
4	LNOF	0	17	9.4	1	6	2.9	5	5.1	0	0	0	0	0	0	28	17.4	1	0	0	0	0
4	LNOF	0	17	9.7	0	1	.2	1	.3	00	0	0	3	.93	0	22	11.13	0	0	0	0	0
4	LNOF	0	8	3.4	4	9	3.35	2	1.8	0	0	0	0	0	0	19	8.55	4	0	0	0	0
4	NOF	1	2	.4	0	3	.6	3	.9	1	1.11	0	2	2.22	0	11	5.23	0	0	0	0	0
4	NOF	1	7	1.4	0	1	.2	3	2.1	0	0	0	2	1.42	1	13	5.12	1	0	0	0	0
4	NOF	1	6	1.8	0	3	.6	0	0	0	0	0	2	2.22	1	11	4.62	1	0	0	0	0
4	NOL	1	9	4.2	0	0	0	4	6	0	0	0	2	1.42	3	15	11.62	3	0	0	0	0
4	NOL	1	3	2.4	0	3	6	6	1.8	0	0	0	1	1.11	0	13	11.31	0	0	0	0	0
4	NOL	1	0	0	1	4	1.5	0	0	1	1.11	0	0	0	0	5	2.61	1	0	0	0	0
2	zero	0	6	2.4	0	1	.2	8	2.4	1	.2	0	0	0	0	16	5.2	0	0	0	0	0
2	zero	0	6	1.2	0	1	.2	9	2.7	1	.2	0	0	0	0	17	4.3	0	0	0	0	0
2	zero	0	10	4.4	1	2	1.1	6	1.8	0	0	0	0	0	0	18	7.3	1	0	0	0	0
2	LNOF	0	10	4.4	1	5	1	3	4.5	0	0	0	0	0	0	18	9.9	1	0	0	0	0
2	LNOF	0	6	3.6	2	0	0	4	2.4	2	.4	0	0	0	0	12	6.4	2	0	0	0	0

Appendix 27 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
2	LNOF	0	3	1.8	0	6	2.6	3	2.1	1	.36	0	0	0	0	13	6.86	0	0	0	0	0
2	LOF	0	5	2.2	0	1	1.05	8	8.4	0	0	0	0	0	0	14	11.65	0	0	0	0	0
2	LOF	0	16	5.6	4	0	0	8	3.3	1	1.11	0	0	0	0	25	10.01	4	0	0	0	0
2	LOF	0	9	7.2	2	2	1.1	6	4.2	0	0	0	0	0	0	17	12.5	2	0	0	0	1
2	NOF	1	11	3.4	3	0	0	0	0	0	0	0	1	1.11	1	12	4.51	4	0	0	0	1
2	NOF	1	12	2.4	0	4	.8	8	2.4	0	0	0	3	3.33	2	27	8.93	2	0	0	1	0
2	NOF	1	12	4.2	0	3	2.85	3	4.5	2	2.22	0	0	0	0	20	13.77	0	0	0	1	0
2	zero	1	16	7.4	2	0	0	5	1.5	0	0	0	0	0	1	21	8.9	3	0	0	0	0
2	zero	1	7	3.2	0	0	0	2	.6	0	0	0	0	0	1	9	3.8	1	0	0	0	0
2	zero	1	4	1.4	1	0	0	0	0	1	.2	0	0	0	0	5	1.6	1	0	0	0	0
2	LNF	1	14	3.4	1	2	.4	3	3	0	0	0	0	0	1	19	6.8	2	0	0	0	2
2	LNF	1	11	3.4	0	0	0	4	3.55	0	0	0	2	.62	2	17	7.57	2	0	0	0	0
2	LNF	1	6	2.4	0	5	1	6	1.8	0	0	0	0	0	0	17	5.2	0	0	0	0	0
4	LNOF	1	21	6	0	5	1	8	4.8	0	0	0	1	.31	2	35	12.11	2	0	0	0	2
4	LNOF	1	9	3.6	0	5	2.7	9	3.9	0	0	0	1	.75	0	24	10.95	0	0	0	0	0
4	LNOF	1	23	9.1	3	2	.4	5	3.9	0	0	0	2	2.22	4	32	15.62	7	0	0	0	0
4	LNF	0	18	4.8	0	1	.2	6	1.8	1	.36	0	0	0	0	26	7.16	0	0	0	0	0
4	LNF	0	18	6	0	3	2.15	1	.3	3	1.51	0	0	0	0	25	9.96	0	0	0	0	0
4	LNF	0	25	8	0	5	1	4	2.4	0	0	0	0	0	0	34	11.4	0	0	0	1	0
4	NOF	0	10	2	0	2	.4	8	2.4	0	0	0	0	0	0	20	4.8	0	0	0	0	0
4	NOF	0	11	2.8	0	2	.4	5	7.5	0	0	0	0	0	0	18	10.7	0	0	0	0	0
4	NOF	0	18	6.6	0	1	.9	8	3.6	1	.36	0	0	0	0	28	11.46	0	0	0	0	0
4	zero	0	7	3.2	0	2	2.1	1	.3	4	.8	0	0	0	0	14	6.4	0	0	0	0	0
4	zero	0	4	.8	0	1	.2	1	1.5	0	0	0	0	0	0	6	2.5	0	0	0	0	0
4	zero	0	7	2	0	0	0	2	3	1	.36	0	0	0	0	10	5.36	0	0	0	0	0
4	LNF	1	23	7	0	1	.2	6	3	3	1.51	0	0	0	1	33	11.71	1	0	0	0	0
4	LNF	1	10	3.8	0	1	.2	5	1.5	2	1.31	0	0	0	0	18	6.81	0	0	0	0	0
4	LNF	1	27	9.6	0	2	.4	3	.9	1	.2	0	0	0	0	33	11.1	0	0	0	0	0
4	LOF	0	2	1.6	1	5	1.85	8	6	0	0	0	0	0	0	15	9.45	1	0	0	0	0
4	LOF	0	51	13.8	0	31	13.65	7	3.3	1	1.11	0	0	0	0	90	31.86	0	0	1	0	0
4	LOF	0	7	8	0	0	0	2	.6	0	0	0	0	0	0	9	8.6	0	0	0	0	0

Appendix 28: Effect of treatment application and *A. longa* introduction on earthworm populations at Oatlands on 18-11-92
(*0- *A. longa* absent; 1- *A. longa* present; BHCg- black-headed cockchafer grubs; BHCa- .black-headed cockchafer adults; RHC- red-headed cockchafers).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
1	NOL	0	1	.2	0	0	0	0	0	0	0	0	0	0	0	1	.2	0	0	0	0	0
1	NOL	0	11	5.2	0	1	.9	3	1.69	0	0	0	0	0	0	15	7.79	0	0	0	1	0
1	NOL	0	1	.2	0	0	0	2	.64	0	0	0	0	0	0	3	.84	0	0	0	1	0
1	NOF	1	1	.8	1	0	0	0	0	0	0	0	0	0	0	1	.8	1	0	0	0	0
1	NOF	1	6	3.6	0	2	1.1	3	3.32	0	0	0	2	2.53	0	13	10.55	0	0	0	0	0
1	NOF	1	8	4	0	0	0	2	3	0	0	0	0	0	0	10	7	0	0	0	1	0
1	LNF	0	10	3.8	0	0	0	0	0	0	0	0	0	0	0	10	3.8	0	0	0	0	0
1	LNF	0	3	.6	0	0	0	0	0	0	0	0	0	0	0	3	.6	0	0	0	0	0
1	LNF	0	4	1.4	0	1	.9	0	0	0	0	0	0	0	0	5	2.3	0	0	0	0	0
1	NOL	1	2	.4	0	0	0	3	.96	0	0	0	3	.93	0	8	2.29	0	0	0	0	0
1	NOL	1	3	.6	1	1	1.05	1	.32	0	0	0	0	0	0	5	1.97	1	0	0	0	0
1	NOL	1	3	.6	0	1	.9	2	1.82	0	0	0	0	0	0	6	3.32	0	0	0	0	0
1	LNF	1	2	.4	0	2	2.1	0	0	0	0	0	0	0	3	4	2.5	3	0	0	0	0
1	LNF	1	0	0	0	0	0	1	1.5	0	0	0	0	0	0	1	1.5	0	0	0	0	0
1	LNF	1	2	.4	0	0	0	0	0	1	1.11	0	3	2.53	0	6	4.04	0	0	0	0	0
1	LNOF	0	2	.4	0	0	0	0	0	0	0	0	0	0	0	2	.4	0	0	0	0	0
1	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	LNOF	0	0	0	0	1	1.05	0	0	0	0	0	1	.5	0	2	1.55	0	0	0	0	0
3	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	zero	0	3	.6	0	0	0	1	.32	0	0	0	0	0	0	4	.92	0	0	0	0	0
3	zero	0	2	.4	0	0	0	0	0	0	0	0	0	0	0	2	.4	0	0	0	0	0
3	LNOF	0	0	0	0	0	0	0	0	2	.4	0	0	0	0	2	.4	0	0	0	0	0
3	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LNOF	0	3	.6	0	2	1.1	1	.32	0	0	0	0	0	0	6	2.02	0	0	0	0	0
3	LNF	1	1	.2	0	0	0	0	0	0	0	0	1	.75	0	2	.95	0	0	0	0	0
3	LNF	1	3	1.2	0	2	1.8	0	0	0	0	0	1	.75	2	6	3.75	2	0	0	0	0
3	LNF	1	3	1.2	0	0	0	2	.64	0	0	0	4	2.04	1	9	3.88	1	0	0	0	0
3	NOF	1	5	1	0	0	0	2	.64	0	0	0	0	0	0	7	1.64	0	0	0	0	0
3	NOF	1	2	1.2	0	1	.9	0	0	0	0	0	1	.75	0	4	2.85	0	0	0	0	0
3	NOF	1	7	1.4	0	1	.9	2	.64	0	0	0	0	0	1	10	2.94	1	0	0	0	0.
3	zero	1	4	.8	0	0	0	0	0	0	0	0	0	0	0	4	.8	0	0	0	0	0
3	zero	1	3	.6	0	0	0	0	0	0	0	0	0	0	0	3	.6	0	0	0	0	0
3	zero	1	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	0	0	0	0
3	NOL	1	3	.6	0	0	0	0	0	0	0	0	0	0	0	3	.6	0	0	0	0	0
3	NOL	1	3	.6	0	0	0	0	0	0	0	0	0	0	0	3	.6	0	0	0	0	0
3	NOL	1	4	.8	0	1	.9	0	0	0	0	0	1	.31	0	6	2.01	0	0	0	0	0
1	LOF	1	5	2.2	0	9	6.05	3	.96	0	0	0	0	0	4	17	3	1	0	0	0	0
1	LOF	1	5	2.8	0	5	2.4	1	1.5	1	1.11	0	0	0	0	12	7.81	0	0	0	0	0
1	LOF	1	0	0	0	1	.2	1	.32	0	0	0	0	0	0	2	.52	0	0	0	1	0
1	NOF	0	2	1.6	1	1	.2	2	3	0	0	0	0	0	0	5	4.8	1	0	0	0	0
1	NOF	0	2	.4	0	0	0	0	0	0	0	0	0	0	0	2	.4	0	0	0	0	0
1	NOF	0	6	1.2	0	2	2.1	0	0	0	0	0	0	0	0	8	3.3	0	0	0	0	2
1	LOF	0	3	1.7	0	0	0	0	0	0	0	0	0	0	0	3	1.7	0	0	0	0	0
1	LOF	0	10	5.6	0	1	.9	4	6	0	0	0	0	0	0	15	12.5	0	0	4	0	0

Appendix 28 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
1	LOF	0	5	2.8	0	3	1.3	3	.96	0	0	0	0	0	0	11	5.06	0	0	0	0	0
1	zero	1	2	1	0	1	1.05	0	0	0	0	0	0	0	0	3	2.05	0	0	0	2	0
1	zero	1	5	1.6	0	0	0	0	0	0	0	0	0	0	0	5	1.6	0	0	0	0	0
1	zero	1	4	1.4	0	0	0	1	.32	0	0	0	1	1.11	0	6	2.83	0	0	0	0	0
1	LNOF	1	5	1	0	3	.6	0	0	0	0	0	1	1.11	0	9	2.71	0	0	0	0	0
1	LNOF	1	13	3.2	2	3	.6	0	0	0	0	0	0	0	0	16	3.8	2	0	1	0	1
1	LNOF	1	4	.8	0	1	1.05	1	1.5	1	1.11	0	0	0	0	7	4.46	0	0	0	0	0
1	zero	0	18	7.8	1	1	.2	1	1.5	0	0	0	0	0	0	20	9.5	1	0	0	0	0
1	zero	0	5	1.6	1	0	0	0	.	0	0	0	0	0	0	5	1.6	1	0	0	0	0
1	zero	0	1	.8	0	0	0	0	0	0	0	0	0	0	0	1	.8	0	0	0	0	0
3	NOF	0	6	1.2	0	0	0	0	0	0	0	0	0	0	0	6	1.2	0	0	0	0	0
3	NOF	0	4	1.4	0	0	0	0	0	0	0	0	0	0	0	4	1.4	0	1	0	0	0
3	NOF	0	10	3.2	0	2	1.95	0	0	0	0	0	0	0	0	12	5.15	0	0	0	0	0
3	NOL	0	0	0	0	1	.2	0	0	0	0	0	0	0	0	1	.2	0	0	0	0	0
3	NOL	0	7	2.6	0	5	2.7	0	0	0	0	0	0	0	0	12	5.3	0	0	0	0	0
3	NOL	0	3	.6	0	4	3.6	0	0	1	1.11	0	0	0	0	8	5.31	0	0	0	0	0
3	LNOF	1	6	1.2	0	3	3.15	0	0	1	1.11	0	0	0	0	10	5.46	0	0	0	0	0
3	LNOF	1	5	1	0	10	7.1	1	.32	0	0	0	0	0	0	16	8.42	0	0	0	0	0
3	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LNF	0	3	.6	0	2	1.11	2	.64	0	0	0	0	0	0	7	2.35	0	0	0	0	0
3	LNF	0	7	1.4	0	1	.2	0	.0	0	0	0	0	0	0	8	1.6	0	0	0	0	0
3	LNF	0	4	.8	0	2	.4	1	.32	0	0	0	0	0	0	7	1.52	0	0	0	0	0
3	LOF	1	0	0	1	0	0	0	.	2	2.22	0	0	0	0	2	2.22	1	0	0	0	0
3	LOF	1	6	3	0	0	0	0	0	0	0	0	0	0	0	6	3	0	0	0	0	0
3	LOF	1	8	3.4	0	1	1.05	0	0	0	0	0	0	0	0	9	4.45	0	0	0	0	0
3	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LOF	0	5	1	0	1	.2	0	0	0	0	0	0	0	0	6	1.2	0	0	0	0	0
3	LOF	0	1	.2	0	0	0	0	0	2	2.22	0	0	0	0	3	2.42	0	0	0	0	0
2	NOL	1	3	1.2	0	0	0	1	1.5	1	.36	0	0	0	0	5	3.06	0	0	0	0	0
2	NOL	1	2	.4	0	2	2.1	0	0	0	0	0	0	0	6	4	2.5	6	0	0	0	0
2	NOL	1	0	0	0	4	3.35	0	0	0	0	0	0	0	0	4	3.35	0	0	0	0	0
2	NOF	0	13	8.6	0	1	.2	0	0	1	1.11	0	0	0	0	15	9.91	0	0	0	0	0
2	NOF	0	3	.6	0	0	0	0	0	0	0	0	0	0	0	3	.6	0	0	0	1	0
2	NOF	0	5	2.8	0	1	.2	0	0	0	0	0	0	0	0	6	3	0	0	2	0	0
2	LNOF	1	3	1.2	0	5	3.55	0	0	0	0	0	0	0	0	8	4.75	0	0	0	0	0
2	LNOF	1	6	3	0	0	0	1	.32	0	0	0	0	0	0	7	3.32	0	0	1	0	0
2	LNOF	1	6	3	0	0	0	2	.64	0	0	0	0	0	1	8	3.64	1	0	0	0	0
2	LNF	0	4	.8	0	0	0	2	.64	0	0	0	0	0	0	6	1.44	0	0	0	0	0
2	LNF	0	1	.2	0	0	0	0	0	0	0	0	0	0	0	1	.2	0	0	0	0	0
2	LNF	0	6	1.2	0	2	2.1	1	.32	0	0	0	0	0	0	9	3.62	0	0	0	0	0
2	LOF	1	5	1.6	1	5	3.25	1	1.5	0	0	0	0	0	0	11	6.35	1	0	0	0	0
2	LOF	1	9	3.6	0	0	0	0	0	0	0	0	1	.31	0	10	3.91	0	0	0	0	0
2	LOF	1	4	1.4	0	0	0	0	0	0	0	0	0	0	0	4	1.4	0	1	0	1	0
2	NOL	0	10	2	0	0	0	2	1.72	0	0	0	0	0	0	12	3.72	0	0	0	0	0

Appendix 28 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
2	NOL	0	5	2.2	0	2	1.8	1	.32	0	0	0	0	0	0	8	4.32	0	0	0	0	0
2	NOL	0	4	1.4	0	1	.2	0	0	0	0	0	0	0	0	5	1.6	0	0	1	1	0
4	NOL	0	2	.4	0	1	1.05	0	0	0	0	0	0	0	0	3	1.45	0	0	0	0	0
4	NOL	0	3	1.5	0	2	.4	0	0	0	0	0	0	0	0	5	1.9	0	0	0	0	0
4	NOL	0	0	0	0	2	1.25	0	0	0	0	0	0	0	0	2	1.25	0	0	2	0	0
4	zero	1	6	1.8	0	2	1.1	0	0	0	0	0	0	0	0	8	2.9	0	0	0	0	0
4	zero	1	11	3.4	0	0	0	0	0	0	0	0	0	0	0	11	3.4	0	0	0	0	0
4	zero	1	1	.2	0	1	.9	0	0	0	0	0	0	0	0	2	1.1	0	0	0	1	0
4	LOF	1	10	4.4	0	0	0	0	0	0	0	0	0	0	0	10	4.4	0	0	0	0	0
4	LOF	1	4	.8	0	0	0	0	0	0	0	0	0	0	0	4	.8	0	0	0	1	0
4	LOF	1	3	.6	0	0	0	0	0	0	0	0	0	0	0	3	.6	0	0	0	0	0
4	LNOF	0	3	.6	0	2	2.1	0	0	0	0	0	0	0	0	5	2.7	0	0	2	0	0
4	LNOF	0	7	3.2	0	1	1.05	1	1.5	0	0	0	0	0	0	9	5.75	0	0	0	0	0
4	LNOF	0	0	0	0	3	3.15	0	0	0	0	0	0	0	0	3	3.15	0	0	0	0	0
4	NOF	1	8	3.4	0	2	1.1	0	0	0	0	0	0	0	0	10	4.5	0	0	0	0	0
4	NOF	1	2	.4	0	1	1.05	0	0	0	0	0	0	0	0	3	1.45	0	0	0	0	0
4	NOF	1	3	.6	0	0	0	0	0	0	0	0	1	.31	0	4	.91	0	0	1	0	0
4	NOL	1	2	1	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
4	NOL	1	6	1.2	0	0	0	0	0	0	0	0	1	.31	0	7	1.51	0	0	0	0	0
4	NOL	1	0	0	0	4	.8	0	0	0	0	0	0	0	0	4	.8	0	0	0	0	0
2	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	zero	0	2	.4	0	0	0	1	.32	0	0	0	0	0	0	3	.72	0	0	0	0	0
2	zero	0	0	0	0	0	0	0	0	1	.2	0	0	0	0	1	.2	0	0	0	1	0
2	LNOF	0	6	1.2	0	2	.4	0	0	0	0	0	0	0	0	8	1.6	0	0	0	0	0
2	LNOF	0	3	.6	0	0	0	2	.64	2	1.31	.	0	0	0	7	2.55	0	0	0	0	0
2	LNOF	0	0	0	0	0	0	1	1.5	1	1.11	0	0	0	0	2	2.61	0	0	0	0	0
2	LOF	0	2	1.6	0	0	0	0	0	0	0	0	0	0	0	2	1.6	0	0	0	0	0
2	LOF	0	5	1	0	3	.6	0	0	1	.2	0	0	0	0	9	1.8	0	0	0	0	0
2	LOF	0	6	1.8	0	5	3.1	1	.32	0	0	0	0	0	0	12	5.22	0	0	0	0	0
2	NOF	1	5	1	0	3	.6	0	0	0	0	0	1	.5	0	9	2.1	0	0	0	0	0
2	NOF	1	11	5.2	0	0	0	0	0	0	0	0	2	1.42	0	13	6.62	0	0	0	0	0
2	NOF	1	7	3.2	0	4	3.75	0	0	0	0	0	0	0	0	11	6.95	0	0	0	0	0
2	zero	1	6	1.8	0	2	1.11	0	0	0	0	0	0	0	0	8	2.91	0	0	0	0	0
2	zero	1	5	1	0	1	.2	0	0	0	0	0	0	0	0	6	1.2	0	0	0	0	0
2	zero	1	0	0	0	1	.9	0	0	0	0	0	0	0	0	1	.9	0	0	0	0	0
2	LNF	1	4	1.4	0	4	1.65	0	0	0	0	0	0	0	0	8	3.05	0	0	0	0	0
2	LNF	1	8	1.6	0	1	.2	0	0	0	0	0	0	0	0	9	1.8	0	0	0	0	0
2	LNF	1	4	.8	0	3	2.7	0	0	0	0	0	0	0	0	7	3.5	0	0	0	0	0
4	LNOF	1	7	2	0	1	.2	0	0	1	.2	0	2	1.42	0	11	3.82	0	0	0	0	0
4	LNOF	1	6	1.2	0	0	0	0	0	0	0	0	0	0	0	6	1.2	0	0	0	0	0
4	LNOF	1	5	2.8	0	2	2.1	0	0	0	0	0	0	0	0	7	4.9	0	0	0	0	0
4	LNF	0	0	0	0	2	1.8	0	0	0	0	0	0	0	0	2	1.8	0	0	0	0	0
4	LNF	0	3	.6	0	0	0	0	0	0	0	0	0	0	0	3	.6	0	0	0	0	0
4	LNF	0	4	.8	0	0	0	0	0	0	0	0	0	0	0	4	.8	0	0	0	0	0

Appendix 28 (Continued).

Rep	Treat	Intro*	A. cal			L.rub		O.cya		A.trap			A.long			TNo.	TMass	TEggs	BHCg*	BHCa*	RHC*	Corby
			No.	Mass	Egg	No.	Mass	No.	Mass	No.	Mass	Egg	No.	Mass	Egg	No.	Mass	Egg	No.	No.	No.	No.
4	NOF	0	10	2.6	0	4	.8	0	0	0	0	0	0	0	0	14	3.4	0	0	0	0	2
4	NOF	0	2	.4	0	1	.2	0	0	0	0	0	0	0	0	3	.6	0	0	0	0	0
4	NOF	0	5	1.6	0	1	.2	0	0	0	0	0	0	0	0	6	1.8	0	0	0	0	0
4	zero	0	1	.2	0	2	1.1	1	.32	0	0	0	0	0	0	4	1.62	0	0	0	0	0
4	zero	0	9	4.8	0	0	0	0	0	0	0	0	0	0	0	9	4.8	0	0	0	0	0
4	zero	0	3	1.2	0	3	2.85	0	0	0	0	0	0	0	0	6	4.05	0	0	1	1	0
4	LNF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LNF	1	1	.8	1	1	1.05	0	0	0	0	0	0	0	1	2	1.85	2	0	0	0	0
4	LNF	1	2	.4	0	0	0	1	.32	0	0	0	1	.31	0	4	1.03	0	0	0	0	0
4	LOF	0	5	1.6	0	2	1.3	2	.64	0	0	0	0	0	0	9	3.54	0	0	0	0	0
4	LOF	0	0	0	0	1	1.05	0	0	0	0	0	0	0	0	1	1.05	0	0	0	0	0
4	LOF	0	11	4.6	0	2	1.1	0	0	1	.2	0	0	0	0	14	5.9	0	0	0	0	0

Appendix 29: Effect of treatment application and *A. longa* introduction on earthworm populations at Oatlands on 30-9-93
(*0- *A. longa* absent; 1- *A. longa* present; BHCg- black-headed cockchafer grubs; BHCa- .black-headed cockchafer adults; RHC- red-headed cockchafers).

Rep	treat	intro	A. cal			L.rub		O.cya		A.trap			A.long			TNo.	TMass	TEggs	BHCg	BHCa	RHC	Corby
			No.	Mass	Egg	No.	Mass	No.	Mass	No.	Mass	Egg	No.	Mass	Egg	No.	Mass	Egg	No.	No.	No.	No.
1	NOL	0	6	1.8	0	0	0	1	.32	0	0	0	0	0	0	7	2.12	0	0	0	0	0
1	NOL	0	8	1.6	0	1	1.1	1	1.19	1	0.2	0	0	0	0	11	4.04	0	0	0	0	0
1	NOL	0	5	1	0	0	0	4	4.82	0	0	0	0	0	0	9	5.82	0	0	0	0	0
1	NOF	1	2	1	0	0	0	2	1.8	0	0	0	0	0	0	4	2.8	0	0	0	9	0
1	NOF	1	12	3.6	0	1	1.1	0	0	1	0.42	0	0	0	0	14	5.075	0	0	0	0	0
1	NOF	1	16	4.1	0	1	0.2	1	1.5	0	0	0	0	0	0	18	5.6	0	0	0	0	0
1	LNF	0	20	4.6	0	1	0.2	4	4.8	0	0	0	0	0	0	25	9.6	0	0	0	0	0
1	LNF	0	5	1.4	0	0	0	4	4.72	0	0	0	0	0	0	9	6.12	0	0	0	0	0
1	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	NOL	1	8	2.2	0	1	0.2	0	0	0	0	0	0	0	1	9	3.4	1	0	0	0	0
1	NOL	1	13	5.9	0	1	1.1	3	3	1	1	0	0	0	0	18	10.3	0	0	0	0	0
1	NOL	1	10	2	0	0	0	4	2.46	1	0.36	0	1	1.11	3	16	5.57	3	0	0	5	0
1	LNF	1	9	3	0	2	1.8	1	1.19	0	0	0	1	.31	0	13	6.3	0	0	0	0	0
1	LNF	1	13	2.6	0	1	0.2	3	3.83	1	0.42	0	0	0	0	18	3.22	0	0	0	0	0
1	LNF	1	2	1.2	0	3	1.5	3	3.83	0	0	0	0	0	0	8	6.48	0	0	0	0	0
1	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	LNOF	0	2	0	0	0	0	0	0	1	0.2	0	0	0	0	0	0	0	0	0	0	0
1	LNOF	0	9	1.8	0	4	2.4	3	2.14	0	0	0	0	0	0	17	6.49	0	0	0	1	1
3	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LNOF	0	15	6.3	0	3	1.5	0	0	0	0	0	0	0	0	18	7.75	0	0	0	0	0
3	LNOF	0	11	2.2	0	10	2	0	0	1	0.42	0	0	0	0	22	4.62	0	0	0	0	0
3	LNF	1	13	2.6	0	2	1.1	0	0	0	0	0	1	.5	0	16	4.2	0	0	0	0	0

Appendix 29 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
3	LNF	1	7	1.4	0	0	0	1	1.19	0	0	0	0	0	0	8	2.59	0	0	0	0	0
3	LNF	1	21	4.8	0	0	0	3	.96	1	0.2	0	1	.31	0	26	6.27	0	0	0	0	0
3	NOF	1	10	3.2	0	2	1.1	1	.32	1	1.11	0	1	1.11	0	15	6.84	2	0	0	2	0
3	NOF	1	8	2.8	0	0	0	0	0	0	0	0	3	3.33	1	11	6.13	1	1	0	1	0
3	NOF	1	10	3.2	2	0	1	1	1.5	1	0.2	0	0	0	1	12	4.9	0	0	0	0	0.
3	zero	1	1	0.8	0	0	1	1	1.5	0	0	0	1	.31	0	3	2.61	0	0	0	0	0
3	zero	1	5	1	0	0	2	2	3	1	0.42	0	0	0	0	8	4.42	0	0	0	0	0
3	zero	1	3	1.2	0	0	1	1	1.5	0	0	0	1	1.11	0	5	3.81	0	0	0	0	0
3	NOL	1	5	2.8	0	0	0	0	0	0	0	0	1	1.11	1	6	3.91	1	0	0	0	0
3	NOL	1	5	1.6	0	0	0	0	0	1	0.2	0	0	0	0	6	1.8	0	0	0	0	0
3	NOL	1	2	1.6	0	1	.2	0	0	3	2.42	0	2	1.43	0	8	5.65	0	0	0	0	0
1	LOF	1	2	0.4	0	0	0	1	1.5	1	0.2	0	2	.62	4	6	2.72	1	0	0	0	0
1	LOF	1	5	1.8	0	1	.2	0	0	0	0	0	1	1.11	3	7	3.11	3	0	0	0	0
1	LOF	1	10	5	0	0	0	1	.32	0	0	0	2	.62	0	13	5.94	0	0	0	0	0
1	NOF	0	5	1.6	0	0	0	1	1.45	1	0.2	0	0	0	0	7	3.25	0	0	0	3	0
1	NOF	0	5	1.3	0	1	1.1	2	1.82	0	0	0	0	0	0	8	4.17	0	0	0	0	0
1	NOF	0	11	3.4	0	0	0	4	2.46	0	0	0	0	0	0	15	5.86	0	0	0	2	0
1	LOF	0	18	6.6	0	3	1.5	1	.32	5	1	0	0	0	0	27	9.37	0	0	0	2	0
1	LOF	0	15	3	0	1	1.1	2	1.82	2	0.62	0	0	0	0	20	6.49	0	0	0	0	0
1	LOF	0	8	1.9	0	0	0	0	0	5	1.16	0	0	0	0	13	3.06	0	0	0	0	0
1	zero	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	zero	1	8	2.2	0	0	0	1	1.5	1	0.2	0	1	.75	0	10	4.45	0	0	0	0	0
1	zero	1	12	4.2	0	1	1.1	2	.64	0	0	0	0	0	0	16	6.09	0	0	0	9	0
1	LNOF	1	4	0.8	0	1	0.2	0	0	1	0.42	0	3	.93	0	8	1.93	0	0	0	0	0
1	LNOF	1	10	3.2	0	1	0.9	1	.32	1	0.2	0	1	1.11	0	14	5.95	0	0	0	0	0
1	LNOF	1	10	2.6	0	0	0	0	0	0	0	0	2	.4	0	13	3.2	0	0	0	1	0
1	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	zero	0	0	0	0	0	0	0	0	1	0.2	0	0	0	0	0	0	0	0	0	0	0
3	NOF	0	5	1	0	0	0	0	0	0	0	0	0	0	0	6	1.2	0	0	0	5	0
3	NOF	0	11	4.6	0	0	0	1	1.5	0	0	0	0	0	0	12	6.1	0	0	0	0	0
3	NOF	0	9	2.1	0	1	1.1	1	.32	1	0.2	0	0	0	0	11	3.47	0	0	0	8	0
3	NOL	0	4	0.8	0	2	1.3	2	.64	0	0	0	0	0	0	9	2.89	0	0	0	0	0
3	NOL	0	8	2.2	0	1	0.2	0	0	2	0.6	0	0	0	0	9	2.4	0	0	0	0	0
3	NOL	0	14	3.1	0	1	0.2	0	0	1	0.31	0	0	0	0	18	3.91	0	0	0	0	0
3	LNOF	1	14	2.8	0	0	0	2	3	1	.2	0	6	1.86	0	24	8.97	0	0	0	0	0
3	LNOF	1	5	1	0	1	0.2	0	0	0	0	0	0	0	0	7	1.4	0	0	0	0	0
3	LNOF	1	3	0.6	0	1	1.1	1	1.45	0	0	0	2	.62	0	7	3.72	0	0	0	3	0
3	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	LOF	1	0	0	0	0	0	0	0	1	.2	0	0	0	0	0	0	0	0	0	0	0

Appendix 29 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
3	LOF	0	6	1.8	0	0	0	1	.32	0	0	0	0	0	0	8	2.32	0	0	0	0	0
3	LOF	0	4	1.4	0	0	0	0	0	0	0	0	2	1.42	0	6	2.82	0	0	0	0	0
3	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	NOL	1	5	1	0	0	0	2	1.43	1	.2	0	3	.93	0	10	3.36	0	0	0	0	0
2	NOL	1	1	0.2	0	0	0	5	1.6	0	0	0	4	1.24	6	11	3.24	0	0	0	2	0
2	NOL	1	12	3	0	0	0	3	.96	0	0	0	3	.93	0	18	4.89	0	0	0	2	0
2	NOF	0	0	0	0	0	0	0	0	2	.4	0	0	0	0	0	0	0	0	0	0	0
2	NOF	0	9	2.4	0	4	2.2	2	.64	0	0	0	0	0	0	17	5.59	0	0	0	2	0
2	NOF	0	7	1.4	0	1	.2	1	.32	0	0	0	0	0	0	9	1.92	0	0	0	1	0
2	LNOF	1	19	3.8	0	2	.4	8	2.8	0	0	0	1	1.11	0	30	8.11	0	0	0	0	0
2	LNOF	1	6	1.8	0	0	0	0	0	1	.2	0	2	.62	0	8	2.42	0	0	0	0	0
2	LNOF	1	13	3.8	0	0	0	3	.96	2	.4	0	1	1.11	1	18	6.07	0	0	0	1	0
2	LNF	0	7	1.4	0	2	1.3	1	1.5	0	0	0	0	0	0	12	4.55	0	0	0	0	0
2	LNF	0	24	5.4	0	2	.4	2	1.82	0	0	0	0	0	0	28	7.62	0	0	0	0	0
2	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	LOF	1	16	5	0	2	.4	0	0	1	.2	0	1	.31	0	20	5.91	0	0	0	1	0
2	LOF	1	6	1.2	0	2	1.3	0	0	0	0	0	0	0	0	8	2.45	0	0	0	0	0
2	NOL	0	6	2.4	0	0	0	0	0	0	0	0	0	0	0	6	2.4	0	0	0	1	0
2	NOL	0	14	4.6	0	1	.2	1	0	1	.36	0	0	0	0	17	5.16	0	0	0	1	0
2	NOL	0	5	2.2	0	0	0	0	0	2	.4	0	0	0	0	7	2.6	0	0	0	1	0
4	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	zero	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	zero	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	zero	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LOF	1	6	1.2	0	4	0.8	1	.32	0	0	0	2	2.22	0	13	4.54	0	0	0	1	0
4	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LOF	1	13	2.6	0	1	.9	0	0	0	0	0	1	.31	0	15	3.81	0	0	0	0	0
4	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOL	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOL	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOL	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	zero	0	6	2.1	0	0	0	5	3.1	0	0	0	0	0	0	11	5.2	0	0	0	3	0
2	zero	0	8	2.2	0	0	0	5	4.9	0	0	0	0	0	0	14	7.1	0	0	0	1	0
2	zero	0	8	1.6	0	0	0	3	2.14	3	.6	0	0	0	0	14	4.34	0	0	0	9	0
2	LNOF	0	4	0.8	0	0	0	0	0	0	0	0	1	.31	0	5	1.11	0	0	0	0	0
2	LNOF	0	10	3.2	0	0	0	3	3.32	1	0.36	0	0	0	0	14	6.88	0	0	0	1	0

Appendix 29 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
2	LNOF	0	12	4.2	0	0	0	0	0	0	0	0	0	0	0	12	4.2	0	0	0	0	0
2	LOF	0	9	1.8	0	0	0	0	0	0	0	0	0	0	0	9	1.8	0	0	0	0	0
2	LOF	0	9	2.1	0	4	2.4	1	1.5	1	0.36	0	0	0	0	15	6.31	0	0	0	0	0
2	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	NOF	1	11	2.5	0	0	0	1	1.45	2	0.4	0	0	0	0	14	4.35	0	0	0	0	0
2	NOF	1	12	2.4	0	0	0	1	1.5	0	0	0	0	0	0	13	3.9	0	0	0	0	0
2	NOF	1	8	1.6	0	0	0	0	0	0	0	0	0	0	0	8	1.6	0	0	0	0	0
2	zero	1	887	1.6	0	0	0	0	0	1	1.11	0	0	0	0	9	2.71	0	0	0	0	0
2	zero	1	2	2.2	0	0	0	0	0	0	0	0	1	1.11	0	9	3.31	0	0	0	0	0
2	zero	1	7	2.3	0	1	0.2	0	0	0	0	0	0	0	0	8	2.5	0	0	0	0	0
2	LNF	1	4	0.4	0	1	0.9	0	0	0	0	0	0	0	0	3	1.3	0	0	0	0	0
2	LNF	1	3	1.4	0	0	0	1	0.32	0	0	0	5	2.35	0	13	4.07	0	0	0	0	0
2	LNF	1	9	2.4	0	0	0	0	0	2	0.4	0	0	0	0	6	1.2	0	0	0	0	0
4	LNOF	1	0	0	0	0	0	0	0	2	2.22	0	5	3.95	0	10	6.77	0	0	0	0	0
4	LNOF	1	0	0	0	1	1.1	0	0	1	1.11	0	1	1.11	0	12	5.67	0	0	0	3	0
4	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
4	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
4	LNF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LNF	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0
4	LNF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Appendix 30: Effect of treatment application and *A. longa* introduction on earthworm populations at Perth on 29-9-92
(*0- *A. longa* absent; 1- *A. longa* present; BHCg- black-headed cockchafer grubs; BHCa- .black-headed cockchafer adults; RHC- red-headed cockchafers).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
1	NOL	0	1	.8	0	0	0	3	2.14	5	1.53	3	0	0	0	9	4.47	3	0	0	0	4
1	NOL	0	0	0	0	0	0	3	2.14	1	1.11	0	0	0	0	4	3.25	0	0	0	0	2.
1	NOL	0	0	0	0	0	0	1	1.5	0	0	0	0	0	0	1	1.5	0	0	0	0	3
1	NOF	1	0	0	0	0	0	1	1.5	0	0	0	2	2.22	0	3	3.72	0	0	0	0	3
1	NOF	1	0	0	0	0	0	1	1.5	0	0	0	0	0	0	1	1.5	0	0	0	0	5
1	NOF	1	0	0	0	0	0	1	1.5	0	0	0	0	0	1	1	1.5	1	0	1	0	5
1	LNF	0	0	0	0	0	0	0	0	2	1.31	0	0	0	0	2	1.31	0	0	0	0	0
1	LNF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	0	1	0	0
1	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
1	NOL	1	0	0	0	0	0	2	.64	0	0	0	2	2.22	0	4	2.86	0	0	0	0	5
1	NOL	1	0	0	0	0	0	0	0	0	0	0	1	.75	1	1	.75	1	0	2	0	4
1	NOL	1	0	0	0	0	0	0	0	2	2.22	0	0	0	0	2	2.22	0	0	0	0	1
1	LNF	1	0	0	0	0	0	1	.32	0	0	0	0	0	0	1	.32	0	0	0	0	1.
1	LNF	1	0	0	0	0	0	1	1.5	4	1.71	0	1	1.11	0	6	4.32	0	0	1	0	1
1	LNF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
1	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	3	1	0	3
1	LNOF	0	2	.4	0	0	0	1	1.5	1	1.11	0	0	0	0	4	3.01	0	0	0	0	4
1	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6
3	zero	0	0	0	0	0	0	0	0	0	0	0	1	1.11	0	1	1.11	0	2	0	0	2
3	zero	0	5	1	0	0	0	3	2.14	0	0	0	0	0	0	8	3.14	0	0	2	0	1
3	zero	0	1	.2	0	0	0	0	0	0	0	0	0	0	0	1	.2	0	0	0	0	2
3	LNOF	0	0	0	0	0	0	0	0	1	1.11	0	3	2.53	0	4	3.64	0	1	0	0	0
3	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	3
3	LNOF	0	0	0	0	0	0	7	3.42	0	0	0	1	.75	1	8	4.17	1	0	0	0	3
3	LNF	1	0	0	0	0	0	3	.96	0	0	0	1	1.11	0	4	2.07	0	0	0	0	3
3	LNF	1	0	0	0	0	0	0	0	0	0	0	1	1.11	3	1	1.11	3	0	1	0	2
3	LNF	1	3	.6	0	0	0	0	0	0	0	0	0	0	2	3	.6	2	0	0	0	0
3	NOF	1	0	0	0	0	0	0	0	2	2.22	0	4	2.92	0	6	5.14	0	0	2	0	2
3	NOF	1	0	0	0	0	0	1	1.5	0	0	0	1	1.11	0	2	2.61	0	0	1	0	0
3	NOF	1	0	0	0	0	0	1	.32	0	0	0	4	3.03	0	5	3.35	0	0	0	0	0.
3	zero	1	0	0	0	0	0	0	0	1	1.11	0	1	.31	1	2	1.42	1	0	0	0	1
3	zero	1	0	0	0	0	0	0	0	0	0	0	2	1.41	2	2	1.41	2	0	1	0	0
3	zero	1	0	0	0	0	0	1	1.5	0	0	0	0	0	1	1	1.5	1	0	1	0	0
3	NOL	1	0	0	0	0	0	0	0	0	0	0	2	.62	0	2	.62	0	1	0	0	6
3	NOL	1	0	0	0	0	0	0	0	1	.2	0	4	4.44	0	5	4.64	0	4	1	0	0
3	NOL	1	0	0	0	0	0	0	0	1	1.11	0	2	.62	0	3	1.73	0	0	0	0	2
1	LOF	1	0	0	0	0	0	0	0	1	1.11	0	3	3.33	1	4	4.44	1	0	0	0	0
1	LOF	1	0	0	0	0	0	1	1.5	0	0	0	2	2.22	1	3	3.72	1	0	0	0	2
1	LOF	1	0	0	0	0	0	0	0	0	0	0	1	1.11	1	1	1.11	1	0	0	0	2
1	NOF	0	0	0	0	0	0	0	0	1	.2	0	0	0	0	1	.2	0	0	0	0	4
1	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	2
1	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4
1	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2

Appendix 30 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
1	LOF	0	0	0	0	0	0	0	0	1	1.11	2	0	0	0	1	1.11	2	1	0	0	4
1	LOF	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	3	0	0
1	zero	1	0	0	0	0	0	0	0	0	0	0	3	3.33	1	3	3.33	1	0	0	0	1
1	zero	1	0	0	0	0	0	0	0	0	0	0	3	3.33	4	3	3.33	4	2	0	0	1
1	LNOF	1	0	0	0	0	0	0	0	0	0	0	2	2.22	1	2	2.22	1	2	0	0	3
1	LNOF	1	0	0	0	0	0	0	0	0	0	0	2	2.22	0	2	2.22	0	0	1	0	3
1	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	10
1	zero	0	0	0	0	0	0	0	0	1	1.11	1	2	2.22	1	3	3.33	2	6	3	0	0
1	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
3	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3	NOF	0	0	0	0	0	0	3	4.5	0	0	0	0	0	0	0	0	0	0	0	0	2
3	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	4.5	0	1	0	0	0
3	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	1	0	2
3	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	2
3	NOL	0	0	0	0	0	0	0	0	1	.2	1	0	0	0	1	.2	1	1	0	0	0
3	LNOF	1	0	0	0	0	0	0	0	1	1.11	1	0	0	0	1	1.11	1	2	0	0	1
3	LNOF	1	0	0	0	0	0	0	0	0	0	0	2	2.22	1	2	2.22	1	2	0	0	2
3	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	4	0	0
3	LNF	0	0	0	0	0	0	1	1.5	0	0	0	1	.5	0	1	.5	0	0	3	0	2
3	LNF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	2	2.61	0	0	0	0	0
3	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0
3	LOF	1	0	0	0	0	0	0	0	1	1.11	0	2	.62	1	3	1.73	1	0	0	0	2
3	LOF	1	0	0	0	0	0	0	0	2	2.22	1	0	0	1	2	2.22	2	4	0	0	0
3	LOF	0	0	0	0	0	0	0	0	6	5.75	1	2	2.22	4	8	7.97	5	0	1	0	0
3	LOF	0	0	0	0	0	0	0	0	4	3.53	4	0	0	0	4	3.53	4	0	2	0	0
3	LOF	0	0	0	0	0	0	2	3	2	2.22	0	0	0	0	2	2.22	0	1	4	0	0
2	NOL	1	0	0	0	0	0	2	3	0	0	0	0	0	0	2	3	0	1	1	0	4
2	NOL	1	0	0	0	0	0	0	0	1	1.11	0	2	2.22	0	5	6.33	0	0	3	0	0
2	NOL	1	0	0	0	0	0	2	3	2	1.31	2	0	0	0	2	1.31	2	0	0	0	0
2	NOF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	3	4.11	0	0	0	0	0
2	NOF	0	0	0	0	0	0	1	.32	0	0	0	0	0	0	0	0	0	0	0	0	0
2	NOF	0	1	.8	0	0	0	0	0	0	0	0	0	0	0	1	.32	0	0	0	0	0
2	LNOF	1	0	0	0	0	0	0	0	1	.2	0	0	0	0	2	1	0	0	0	0	0
2	LNOF	1	0	0	0	0	0	0	0	0	0	2	2	2.22	2	2	2.22	4	0	0	0	0
2	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	2
2	LNF	0	0	0	0	0	0	0	0	0	0	0	2	2.22	0	2	2.22	0	0	0	0	0
2	LNF	0	0	0	0	0	0	1	1.5	0	0	1	0	0	0	0	0	1	5	1	0	0
2	LNF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	2	2.61	0	2	2	0	0
2	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2
2	LOF	1	0	0	0	0	0	1	1.5	1	1.11	0	2	2.22	1	3	3.33	1	0	0	0	1
2	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1.5	0	4	1	0	1
2	NOL	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	1	3	0	4

Appendix 30 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
2	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
2	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
4	NOL	0	1	.2	0	0	0	0	0	2	2.22	0	0	0	0	2	2.22	0	1	0	0	6
4	NOL	0	0	0	0	0	0	0	0	1	.2	0	0	0	0	2	.4	0	3	3	0	0
4	zero	1	0	0	0	0	0	0	0	0	0	0	1	.31	1	1	.31	1	3	2	0	0
4	zero	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1
4	zero	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
4	LOF	1	0	0	0	0	0	0	0	0	0	0	2	2.22	0	2	2.22	0	0	1	0	0
4	LOF	1	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	0	1	0	0
4	LOF	1	1	.2	0	0	0	0	0	0	0	0	2	1.61	0	2	1.61	0	3	0	0	3
4	LNOF	0	0	0	0	0	0	0	0	1	.2	0	2	2.22	4	4	2.62	4	0	0	0	1
4	LNOF	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	2	1	3	0	2
4	LNOF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	2	0	1	2
4	NOF	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	2
4	NOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0
4	NOF	1	0	0	0	0	0	0	0	0	0	0	2	.81	0	2	.81	0	0	0	0	1
4	NOL	1	0	0	0	0	0	0	0	0	0	0	1	.5	0	1	.5	0	0	0	0	0
4	NOL	1	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	2
4	NOL	1	0	0	0	0	0	0	0	1	1.1	0	0	0	0	1	1.1	0	0	0	0	1
2	zero	0	0	0	0	0	0	0	0	2	2.22	2	0	0	0	2	2.22	2	2	3	0	0
2	zero	0	1	.2	0	0	0	0	0	1	.2	0	0	0	0	1	.2	0	2	2	0	1
2	zero	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	.2	1	0	0	0	0
2	LNOF	0	0	0	0	0	0	2	3	1	.2	0	0	0	0	1	.2	0	0	3	0	3
2	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	0	2	0	1
2	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4
2	LOF	0	0	0	0	0	0	0	0	2	.4	0	0	0	0	2	.4	0	0	2	0	1
2	LOF	0	0	0	0	0	0	0	0	3	3.33	0	0	0	0	3	3.33	0	0	3	0	3
2	LOF	0	0	0	0	0	0	3	3.32	2	2.22	0	0	0	0	2	2.22	0	1	3	0	3
2	NOF	1	0	0	0	0	0	1	1.5	2	2.22	0	0	0	0	5	5.54	0	0	0	0	2
2	NOF	1	0	0	0	0	0	1	1.5	0	0	2	2	2.22	1	3	3.72	3	0	0	0	4
2	NOF	1	0	0	0	0	0	0	0	1	1.11	0	0	0	0	2	2.61	0	0	2	0	3
2	zero	1	0	0	0	0	0	0	0	1	.2	0	1	1.11	0	2	1.31	0	0	0	0	3
2	zero	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
2	zero	1	0	0	0	0	0	0	0	0	0	0	2	2.22	4	2	2.22	4	3	0	0	0
2	LNF	1	0	0	0	0	0	0	0	0	0	0	1	1.11	1	1	1.11	1	3	0	1	0
2	LNF	1	0	0	0	0	0	0	0	1	1.11	0	1	1.11	1	2	2.22	1	1	1	0	0
2	LNF	1	0	0	0	0	0	0	0	1	1.11	0	0	0	2	1	1.11	2	1	1	0	0
4	LNOF	1	0	0	0	0	0	0	0	0	0	0	3	3.33	1	3	3.33	1	2	0	0	0
4	LNOF	1	0	0	0	0	0	0	0	1	1.11	1	0	0	1	1	1.11	2	1	2	0	0
4	LNOF	1	0	0	0	0	0	0	0	1	1.11	0	1	.31	2	2	1.42	2	3	2	0	0
4	LNF	0	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	0	2	0	0
4	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0
4	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0

Appendix 30 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
4	NOF	0	0	0	0	0	0	0	0	3	3.33	1	0	0	0	3	3.33	1	2	3	0	0
4	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	4
4	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0
4	zero	0	0	0	0	0	0	0	0	1	.2	0	0	0	0	1	.2	0	2	0	0	0
4	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
4	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0
4	LNF	1	0	0	0	0	0	0	0	0	0	1	1	1.11	1	1	1.11	2	0	2	0	0
4	LNF	1	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	4	1	0	0	0
4	LNF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1
4	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1
4	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1
4	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1

Appendix 31: Effect of treatment application and *A. longa* introduction on earthworm populations at Perth on 26-8-93
(*0- *A. longa* absent; 1- *A. longa* present; BHCg- black-headed cockchafer grubs; BHCa- .black-headed cockchafer adults; RHC- red-headed cockchafers)

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
1	NOL	0	0	0	0	0	0	1	1.50	4	2.62	0	0	0	0	5	4.12	0	0	0	3	0
1	NOL	0	0	0	0	0	0	1	1.50	0	0	0	4	1.68	0	5	3.18	0	3	0	2	0
1	NOL	0	0	0	0	0	0	0	0	0	0	0	1	.75	0	1	.75	0	2	0	1	0
1	NOF	1	1	1	0	0	0	1	1.50	0	0	0	0	0	0	2	2.5	0	0	0	1	0
1	NOF	1	0	0	0	0	0	0	0	0	0	0	2	1.42	0	2	1.42	0	0	0	2	0
1	NOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1	LNF	0	1	0.2	0	0	0	0	0	0	0	0	0	0	0	1	.2	0	0	0	0	0
1	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1	LNF	0	0	0	0	0	0	3	2.14	0	0	0	0	0	0	3	2.14	0	0	0	0	0
1	NOL	1	0	0	0	0	0	0	0	0	0	0	6	4.89	0	6	4.89	0	0	0	6	0
1	NOL	1	0	0	0	0	0	0	0	0	0	0	4	2.04	0	4	2.04	0	0	0	4	0
1	NOL	1	0	0	0	0	0	0	0	2	2.22	0	1	.31	0	3	2.53	0	0	0	2	0
1	LNF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
1	LNF	1	0	0	0	0	0	0	0	1	.42	0	1	.31	0	2	.73	0	0	0	4	0
1	LNF	1	0	0	0	0	0	0	0	0	0	0	4	3.28	0	4	3.28	0	0	0	4	0
1	LNOF	0	0	0	0	0	0	1	1.50	0	0	0	0	0	0	1	1.5	0	0	0	11	0
1	LNOF	0	0	0	0	0	0	0	0	1	.36	0	0	0	0	1	.36	0	0	0	4	0
1	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
3	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
3	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
3	zero	0	0	0	0	0	0	0	0	2	.78	0	0	0	0	2	.78	0	0	0	0	0
3	LNOF	0	0	0	0	0	0	0	0	2	.72	0	0	0	0	2	.72	0	0	0	5	0
3	LNOF	0	0	0	0	0	0	2	1.95	0	0	0	0	0	0	2	1.95	0	0	0	2	0
3	LNOF	0	0	0	0	0	0	0	0	3	1.51	0	0	0	0	3	1.51	0	2	0	1	0
3	LNF	1	0	0	0	0	0	1	1.50	0	0	0	1	.31	0	2	1.81	0	0	0	0	0
3	LNF	1	0	0	0	0	0	0	0	0	0	0	2	.62	0	2	.62	0	0	0	1	0

Appendix 31 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
3	LNF	1	0	0	0	0	0	1	1.50	0	0	0	3	1.37	0	4	2.87	0	0	0	5	0
3	NOF	1	0	0	0	0	0	0	0	0	0	0	7	3.43	1	7	3.43	1	0	0	2	0
3	NOF	1	0	0	0	0	0	0	0	0	0	0	3	1.92	0	3	1.92	0	0	0	4	0
3	NOF	1	0	0	0	0	0	1	.32	0	0	0	4	1.24	1	5	1.56	1	0	0	5	0
3	zero	1	0	0	0	0	0	2	1.82	0	0	0	3	1.92	0	5	3.74	0	0	0	3	0
3	zero	1	0	0	0	0	0	1	.32	0	0	0	2	.62	0	3	.94	0	0	0	0	0
3	zero	1	0	0	0	0	0	0	0	0	0	0	3	1.37	0	3	1.37	0	0	0	1	0
3	NOL	1	1	.2	0	0	0	0	0	0	0	0	1	.31	0	2	.51	0	0	0	0	0
3	NOL	1	0	0	0	0	0	0	0	0	0	0	6	2.30	0	6	2.3	0	0	0	1	0
3	NOL	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
1	LOF	1	1	.2	0	0	0	2	.64	2	2.22	0	2	1.06	0	7	4.12	0	1	0	0	0
1	LOF	1	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	3	0	0	0
1	LOF	1	0	0	0	0	0	1	.32	0	0	0	4	2.04	1	5	2.36	1	0	0	0	1
1	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
1	NOF	0	0	0	0	0	0	0	0	0	0	0	3	1.68	0	3	1.68	0	0	0	0	0
1	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
1	LOF	0	0	0	0	0	0	2	1.82	2	.56	0	0	0	0	4	2.38	0	0	0	5	0
1	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
1	LOF	0	0	0	0	0	0	0	0	0	0	0	2	.62	0	2	.62	0	0	0	7	0
1	zero	1	0	0	0	0	0	0	0	0	0	0	2	1.42	0	2	1.42	0	0	0	2	0
1	zero	1	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	1	0	2	0
1	zero	1	0	0	0	0	0	3	3.14	0	0	0	2	2.22	0	5	5.36	0	0	0	1	0
1	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
1	LNOF	1	0	0	0	0	0	1	.32	2	1.47	0	0	0	0	3	1.79	0	0	0	0	0
1	LNOF	1	0	0	0	0	0	0	0	2	.40	0	0	0	0	2	.4	0	0	0	2	0
1	zero	0	0	0	0	0	0	0	0	1	.36	0	0	0	0	1	.36	0	0	0	0	0
1	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0
1	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
3	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0
3	NOF	0	0	0	0	0	0	0	0	1	.20	0	0	0	0	1	.2	0	1	0	15	0
3	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	8	0
3	NOL	0	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	0	0	0	0
3	NOL	0	0	0	0	0	0	1	1.5	0	0	0	0	0	0	1	1.5	0	0	0	3	0
3	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0
3	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
3	LNOF	1	0	0	0	0	0	2	1.82	2	1.31	0	1	1.11	0	5	4.24	0	1	0	2	0
3	LNOF	1	0	0	0	0	0	0	0	1	1.11	0	1	.31	0	2	1.42	0	0	0	2	0
3	LNF	0	0	0	0	0	0	0	0	1	.36	0	0	0	0	1	.36	0	0	0	8	0
3	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
3	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
3	LOF	1	0	0	0	0	0	0	0	0	0	0	3	1.92	0	3	1.92	0	1	0	4	0
3	LOF	1	0	0	0	0	0	0	0	0	0	0	3	2.17	0	3	2.17	0	0	0	10	0
3	LOF	1	0	0	0	0	0	0	0	1	1.11	0	5	2.54	0	6	3.65	0	0	0	15	0
3	LOF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	0	0	5	0

Appendix 31 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
3	LOF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	0	0	4	0
3	LOF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	0	0	13	0
2	NOL	1	1	.2	0	0	0	0	0	0	0	0	6	1.86	0	7	2.06	0	0	0	2	0
2	NOL	1	0	0	0	0	0	2	1.82	0	0	0	0	0	0	2	1.82	0	0	0	0	0
2	NOL	1	0	0	0	0	0	1	1.50	0	0	0	4	2.04	0	5	3.54	0	2	0	1	0
2	NOF	0	0	0	0	0	0	0	0	1	.36	0	0	0	0	1	.36	0	0	0	0	0
2	NOF	0	0	0	0	0	0	1	1.50	0	0	0	0	0	0	1	1.5	0	0	0	0	0
2	NOF	0	0	0	0	0	0	0	0	1	.36	0	1	.31	0	2	.67	0	1	0	0	0
2	LNOF	1	0	0	0	0	0	0	0	0	0	1	1	.31	0	1	.31	1	0	0	0	0
2	LNOF	1	0	0	0	0	0	0	0	0	0	0	2	.62	0	2	.62	0	0	0	0	0
2	LNOF	1	0	0	0	0	0	0	0	0	0	0	2	1.42	1	2	1.42	1	0	0	0	0
2	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0
2	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
2	LNF	0	0	0	0	0	0	0	0	3	2.58	0	3	.93	0	6	3.51	0	0	0	9	0
2	LOF	1	0	0	0	0	0	0	0	0	0	0	2	1.42	0	2	1.42	0	0	0	0	0
2	LOF	1	0	0	0	0	0	0	0	1	1.11	0	3	1.73	0	4	2.84	0	2	0	2	0
2	LOF	1	1	.8	0	0	0	1	1.5	2	1.47	0	7	2.17	0	11	5.94	0	0	0	0	0
2	NOL	0	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	1	0	5	0
2	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
2	NOL	0	0	0	0	0	0	0	0	1	.36	0	0	0	0	1	.36	0	0	0	10	0
4	NOL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
4	NOL	0	0	0	0	0	0	0	0	1	.42	0	0	0	0	1	.42	0	1	0	2	0
4	NOL	0	0	0	0	0	0	0	0	2	.78	0	0	0	0	2	.78	0	2	0	5	0
4	zero	1	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	0	0	2	0
4	zero	1	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	0	0	2	0
4	zero	1	0	0	0	0	0	0	0	1	1.11	0	2	.62	0	3	1.73	0	0	0	8	0
4	LOF	1	1	.2	0	0	0	0	0	0	0	0	0	0	0	1	.2	0	0	0	6	0
4	LOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0
4	LOF	1	0	0	0	0	0	0	0	0	0	0	4	2.84	0	4	2.84	0	0	0	5	0
4	LNOF	0	0	0	0	0	0	0	0	1	.36	0	0	0	0	1	.36	0	0	0	11	0
4	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	0
4	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
4	NOF	1	0	0	0	0	0	0	0	0	0	0	2	1.42	0	2	1.42	0	0	0	5	0
4	NOF	1	0	0	0	0	0	0	0	0	0	0	1	1.11	0	1	1.11	0	0	0	3	0
4	NOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0
4	NOL	1	0	0	0	0	0	0	0	0	0	0	3	2.53	0	3	2.53	0	0	0	1	0
4	NOL	1	0	0	0	0	0	0	0	0	0	0	3	2.53	0	3	2.53	0	0	0	10	0
4	NOL	1	0	0	0	0	0	0	0	0	0	0	2	1.42	0	2	1.42	0	0	0	9	0
2	zero	0	0	0	0	0	0	0	0	1	.36	0	0	0	0	1	.36	0	1	0	2	0
2	zero	0	0	0	0	0	0	0	0	1	.20	0	0	0	0	1	.2	0	3	0	1	1
2	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0
2	LNOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
2	LNOF	0	0	0	0	0	0	1	1.5	3	3.33	0	0	0	0	4	4.83	0	2	0	16	0
2	LNOF	0	0	0	0	0	0	0	0	4	1.56	0	0	0	0	4	1.56	0	0	0	10	0

Appendix 31 (Continued).

Rep	Treat	Intro*	A. cal No.	Mass	Egg	L.rub No.	Mass	O.cya No.	Mass	A.trap No.	Mass	Egg	A.long No.	Mass	Egg	TNo. No.	TMass Mass	TEggs Egg	BHCg* No.	BHCa* No.	RHC* No.	Corby No.
2	LOF	0	0	0	0	0	0	0	0	2	.72	0	0	0	0	0	.72	0	2	0	3	0
2	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	LOF	0	0	0	0	0	0	1	1.50	0	0	0	1	.31	0	2	1.81	0	0	0	3	0
2	NOF	1	0	0	0	0	0	2	1.82	4	3.69	0	0	0	0	6	5.51	0	0	0	4	0
2	NOF	1	0	0	0	0	0	0	0	0	0	0	1	1.11	0	1	1.11	0	0	0	1	0
2	NOF	1	0	0	0	0	0	0	0	2	.56	0	2	2.22	0	4	2.78	0	0	0	0	0
2	zero	1	0	0	0	0	0	1	1.50	1	.36	0	2	1.06	0	4	2.92	0	0	0	3	0
2	zero	1	0	0	0	0	0	0	0	0	0	0	2	1.42	0	2	1.42	0	1	0	0	0
2	zero	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0
2	LNF	1	0	0	0	0	0	1	1.50	1	.36	0	0	0	0	2	1.86	0	0	0	7	0
2	LNF	1	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	1	0	4	0
2	LNF	1	0	0	0	0	0	1	.32	0	0	0	1	.31	0	2	.63	0	0	0	2	0
4	LNOF	1	0	0	0	0	0	0	0	0	0	0	1	.31	0	1	.31	0	0	0	2	0
4	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
4	LNOF	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
4	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	14	0
4	LNF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0
4	LNF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	0	0	2	0
4	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0
4	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0
4	NOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	16	0
4	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0
4	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0
4	zero	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	4	0
4	LNF	1	0	0	0	0	0	0	0	0	0	0	2	1.42	0	2	1.42	0	0	0	11	0
4	LNF	1	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	0	0	16	0
4	LNF	1	0	0	0	0	0	0	0	0	0	0	3	2.53	0	3	2.53	0	0	0	11	0
4	LOF	0	0	0	0	0	0	0	0	1	1.11	0	1	.31	0	2	1.42	0	0	0	17	0
4	LOF	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	12	0
4	LOF	0	0	0	0	0	0	0	0	1	1.11	0	0	0	0	1	1.11	0	0	0	12	0

Appendix 32: **Effect of treatment application and *A. longa* introduction on pasture production at Oatlands on 26-11-91 (*0- *A. longa* absent; 1- *A. longa* present).**

plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)	plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	1	0	37	5	1	c1	NOL	3	1	1	66.8	10	1
a1	NOL	1	2	0	29	5	1	c1	NOL	3	2	1	47.8	10	1
a1	NOL	1	3	0	51.8	10	1	c1	NOL	3	3	1	40	10	1
a2	NOF	1	1	1	65.1	20	5	c2	NOF	3	1	0	31.8	10	1
a2	NOF	1	2	1	62.1	10	5	c2	NOF	3	2	0	53.4	15	10
a2	NOF	1	3	1	47.7	7	5	c2	NOF	3	3	0	65.9	15	1
a3	LNF	1	1	0	49.4	25	5	c3	LNOF	3	1	1	96.4	20	5
a3	LNF	1	2	0	58.9	5	1	c3	LNOF	3	2	1	66.1	20	1
a3	LNF	1	3	0	27.4	5	10	c3	LNOF	3	3	1	12.7	5	5
a4	NOL	1	1	1	42.9	5	1	c4	LNF	3	1	0	111.3	15	1
a4	NOL	1	2	1	40.1	5	1	c4	LNF	3	2	0	59	10	1
a4	NOL	1	3	1	68.1	5	0	c4	LNF	3	3	0	92.5	5	2
a5	LNF	1	1	1	56.3	5	5	c5	LOF	3	1	1	28.6	10	1
a5	LNF	1	2	1	48.5	10	5	c5	LOF	3	2	1	35.6	10	1
a5	LNF	1	3	1	72.6	5	1	c5	LOF	3	3	1	50.2	30	5
a6	LNOF	1	1	1	77.8	10	1	c6	NOL	3	1	0	58.3	2	5
a6	LNOF	1	2	1	38.8	5	5	c6	NOL	3	2	0	42.4	1	5
a6	LNOF	1	3	1	39.5	3	5	c6	NOL	3	3	0	43.2	10	1
a7	zero	2	1	1	10.1	1	0	c7	NOL	4	1	0	39.5	10	5
a7	zero	2	2	1	20.1	1	1	c7	NOL	4	2	0	70.3	10	1
a7	zero	2	3	1	18.4	15	1	c7	NOL	4	3	0	35.2	10	1
a8	LNOF	2	1	0	17.4	20	1	c8	zero	4	1	1	27.5	10	0
a8	LNOF	2	2	0	27.3	30	5	c8	zero	4	2	1	20.2	25	5
a8	LNOF	2	3	0	28.3	25	5	c8	zero	4	3	1	42.4	15	2
a9	LNF	2	1	1	62.2	20	5	c9	LOF	4	1	1	33.7	5	1
a9	LNF	2	2	1	48.6	40	1	c9	LOF	4	2	1	46.9	15	1
a9	LNF	2	3	1	78.4	25	2	c9	LOF	4	3	1	36.7	15	1
a10	NOF	2	1	1	52.8	10	1	c10	LNOF	4	1	0	45.4	15	5
a10	NOF	2	2	1	54.6	10	5	c10	LNOF	4	2	0	48.9	5	1
a10	NOF	2	3	1	78	5	5	c10	LNOF	4	3	0	31.9	10	5
a11	zero	2	1	0	18.6	5	5	c11	NOF	4	1	1	54.5	15	1
a11	zero	2	2	0	22	20	10	c11	NOF	4	2	1	75.7	5	1
a11	zero	2	3	0	14	1	1	c11	NOF	4	3	1	66.2	10	5
a12	NOL	2	1	1	50.8	7	2	c12	NOL	4	1	1	53.8	15	5
a12	NOL	2	2	1	26.5	40	10	c12	NOL	4	2	1	69.2	1	0
a12	NOL	2	3	1	32.1	30	10	c12	NOL	4	3	1	52.9	10	1
b1	LOF	1	1	1	75.8	0	2	d1	zero	3	1	0	40.1	10	5
b1	LOF	1	2	1	63.4	15	1	d1	zero	3	2	0	53.8	10	5
b1	LOF	1	3	1	51.6	20	1	d1	zero	3	3	0	39.3	10	40
b2	NOF	1	1	0	104.1	5	0	d2	LNOF	3	1	0	63	5	1
b2	NOF	1	2	0	83.5	10	2	d2	LNOF	3	2	0	56.8	15	1
b2	NOF	1	3	0	55.4	2	1	d2	LNOF	3	3	0	71.6	15	5
b3	LOF	1	1	0	44.8	5	1	d3	LOF	3	1	0	70.1	15	1
b3	LOF	1	2	0	35.4	10	1	d3	LOF	3	2	0	44.5	40	1
b3	LOF	1	3	0	50.8	20	1	d3	LOF	3	3	0	52.7	8	1
b4	zero	1	1	1	35.4	15	5	d4	NOF	3	1	1	73.4	10	1
b4	zero	1	2	1	42	3	2	d4	NOF	3	2	1	61.9	15	1
b4	zero	1	3	1	25.2	5	0	d4	NOF	3	3	1	58.5	20	1
b5	LNOF	1	1	0	66.9	20	5	d5	zero	3	1	1	29.6	10	0
b5	LNOF	1	2	0	56.9	5	1	d5	zero	3	2	1	17.4	50	3
b5	LNOF	1	3	0	55.6	20	1	d5	zero	3	3	1	27.5	50	5
b6	zero	1	1	0	25.3	10	5	d6	LNF	3	1	1	64.3	30	2
b6	zero	1	2	0	3.8	0	10	d6	LNF	3	2	1	79.1	20	1
b6	zero	1	3	0	31.7	15	1	d6	LNF	3	3	1	77.8	30	5
b7	NOF	2	1	0	59.7	10	5	d7	LNOF	4	1	1	64.4	20	1
b7	NOF	2	2	0	47.1	15	1	d7	LNOF	4	2	1	48.2	20	2
b7	NOF	2	3	0	51.1	10	2	d7	LNOF	4	3	1	38.7	10	1
b8	NOL	2	1	0	51.7	5	10	d8	LNF	4	1	0	23.1	10	1
b8	NOL	2	2	0	36.7	5	5	d8	LNF	4	2	0	53.3	10	1
b8	NOL	2	3	0	34.1	10	1	d8	LNF	4	3	0	73.9	25	5
b9	LNOF	2	1	1	75.5	40	5	d9	NOF	4	1	0	83.1	20	5
b9	LNOF	2	2	1	37.4	40	1	d9	NOF	4	2	0	59.4	20	5
b9	LNOF	2	3	1	71	15	5	d9	NOF	4	3	0	57.5	25	1
b10	LNF	2	1	0	51.2	30	5	d10	zero	4	1	0	10.4	10	1
b10	LNF	2	2	0	34	15	2	d10	zero	4	2	0	29.3	30	5
b10	LNF	2	3	0	40.7	5	1	d10	zero	4	3	0	30.7	5	1
b11	LOF	2	1	1	41.6	30	1	d11	LNF	4	1	1	50.5	25	1
b11	LOF	2	2	1	36.2	20	0	d11	LNF	4	2	1	52.7	15	10
b11	LOF	2	3	1	43.1	10	5	d11	LNF	4	3	1	84.2	15	5
b12	LOF	2	1	0	39.52	25	1	d12	LOF	4	1	0	29.52	20	8
b12	LOF	2	2	0	29	20	2	d12	LOF	4	2	0	29.2	20	1
b12	LOF	2	3	0	33.4	25	1	d12	LOF	4	3	0	51.7	15	1

Appendix 33: Effect of treatment application and *A. longa* introduction on pasture production at Oatlands on 15-10-92 (three pasture samples combined; *0- *A. longa* absent; 1- *A. longa* present).

plot	treat	rep	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	0	31.9	30	30
a2	NOF	1	1	23.6	60	10
a3	LNF	1	0	68.1	50	5
a4	NOL	1	1	60	30	5
a5	LNF	1	1	130.7	50	2
a6	LNOF	1	0	62.3	40	2
a7	zero	2	0	47.4	55	15
a8	LNOF	2	0	56.1	70	5
a9	LNF	2	1	85	40	5
a10	NOF	2	1	64.4	35	5
a11	zero	2	1	20.7	15	20
a12	NOL	2	1	35.8	50	15
b1	LOF	1	1	103.7	80	2
b2	NOF	1	0	33.3	30	10
b3	LOF	1	0	69.1	65	5
b4	zero	1	1	139.3	30	5
b5	LNOF	1	1	111.8	50	0
b6	zero	1	0	51.4	50	0
b7	NOF	2	0	77.1	55	2
b8	NOL	2	0	76.6	65	5
b9	LNOF	2	1	48.7	65	2
b10	LNF	2	0	*	60	5
b11	LOF	2	1	38.4	90	0
b12	LOF	2	0	*	90	0
c1	NOL	3	1	46.9	15	20
c2	NOF	3	0	37.1	25	5
c3	LNOF	3	1	54	60	10
c4	LNF	3	0	53.2	30	15
c5	LOF	3	1	82.1	60	5
c6	NOL	3	0	48.8	65	1
c7	NOL	4	0	64.4	35	1
c8	zero	4	1	68.3	45	5
c9	LOF	4	1	59.8	70	5
c10	LNOF	4	0	59.9	55	10
c11	NOF	4	1	34.4	15	80
c12	NOL	4	1	52	55	2
d1	zero	3	0	58.8	20	20
d2	LNOF	3	0	96.8	70	0
d3	LOF	3	0	57.4	70	0
d4	NOF	3	1	66.6	60	0
d5	zero	3	1	69.6	60	2
d6	LNF	3	1	77.7	75	0
d7	LNOF	4	1	57.7	65	10
d8	LNF	4	0	71.52	65	5
d9	NOF	4	0	32.6	60	5
d10	zero	4	0	50.9	30	10
d11	LNF	4	1	95.5	65	5
d12	LOF	4	0	48.5	75	2

Appendix 34: Effect of treatment application and *A. longa* introduction on pasture production at Oatlands on 18-11-92 (*0- *A. longa* absent; 1- *A. longa* present).

plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)	plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	1	0	20.6	0	0	c1	NOL	3	1	1	25	0	0
a1	NOL	1	2	0	16.9	0	0	c1	NOL	3	2	1	29.3	0	0
a1	NOL	1	3	0	27	0	0	c1	NOL	3	3	1	34.8	0	0
a2	NOF	1	1	1	15.52	0	0	c2	NOF	3	1	0	36.1	0	0
a2	NOF	1	2	1	25	0	0	c2	NOF	3	2	0	32.4	0	0
a2	NOF	1	3	1	25.6	0	0	c2	NOF	3	3	0	30.5	0	0
a3	LNF	1	1	0	27.6	0	0	c3	LNOF	3	1	1	48.2	0	0
a3	LNF	1	2	0	17	0	0	c3	LNOF	3	2	1	26.4	0	0
a3	LNF	1	3	0	19.9	0	0	c3	LNOF	3	3	1	26.5	0	0
a4	NOL	1	1	1	26.2	0	0	c4	LNF	3	1	0	29.8	0	0
a4	NOL	1	2	1	22.8	0	0	c4	LNF	3	2	0	23.9	0	0
a4	NOL	1	3	1	26.4	0	0	c4	LNF	3	3	0	17.1	0	0
a5	LNF	1	1	1	48.4	0	0	c5	LOF	3	1	1	39.9	0	0
a5	LNF	1	2	1	35.8	0	0	c5	LOF	3	2	1	61.6	0	0
a5	LNF	1	3	1	36.9	0	0	c5	LOF	3	3	1	42	0	0
a6	LNOF	1	1	0	42.2	0	0	c6	NOL	3	1	0	31.4	0	0
a6	LNOF	1	2	0	31.1	0	0	c6	NOL	3	2	0	29.9	0	0
a6	LNOF	1	3	0	31.6	0	0	c6	NOL	3	3	0	30.8	0	0
a7	zero	2	1	0	7.4	0	0	c7	NOL	4	1	0	31.6	0	0
a7	zero	2	2	0	20.3	0	0	c7	NOL	4	2	0	45	0	0
a7	zero	2	3	0	21.8	0	0	c7	NOL	4	3	0	69.2	0	0
a8	LNOF	2	1	0	30.2	0	0	c8	zero	4	1	1	24.8	0	0
a8	LNOF	2	2	0	43.4	0	0	c8	zero	4	2	1	39.3	0	0
a8	LNOF	2	3	0	50.7	0	0	c8	zero	4	3	1	27.7	0	0
a9	LNF	2	1	1	35	0	0	c9	LOF	4	1	1	44.4	0	0
a9	LNF	2	2	1	38.1	0	0	c9	LOF	4	2	1	25.5	0	0
a9	LNF	2	3	1	34.8	0	0	c9	LOF	4	3	1	22.4	0	0
a10	NOF	2	1	1	37.6	0	0	c10	LNOF	4	1	0	49.7	0	0
a10	NOF	2	2	1	26.3	0	0	c10	LNOF	4	2	0	44.6	0	0
a10	NOF	2	3	1	25.1	0	0	c10	LNOF	4	3	0	39.52	0	0
a11	zero	2	1	1	18.4	0	0	c11	NOF	4	1	1	23.6	0	0
a11	zero	2	2	1	17.7	0	0	c11	NOF	4	2	1	30.8	0	0
a11	zero	2	3	1	11.4	0	0	c11	NOF	4	3	1	38.1	0	0
a12	NOL	2	1	1	12.4	0	0	c12	NOL	4	1	1	31.4	0	0
a12	NOL	2	2	1	16.2	0	0	c12	NOL	4	2	1	28.4	0	0
a12	NOL	2	3	1	13.6	0	0	c12	NOL	4	3	1	30.8	0	0
b1	LOF	1	1	1	57.3	0	0	d1	zero	3	1	0	69.6	0	0
b1	LOF	1	2	1	58.2	0	0	d1	zero	3	2	0	35.5	0	0
b1	LOF	1	3	1	52.4	0	0	d1	zero	3	3	0	32.7	0	0
b2	NOF	1	1	0	26.5	0	0	d2	LNOF	3	1	0	28.6	0	0
b2	NOF	1	2	0	25.2	0	0	d2	LNOF	3	2	0	32.7	0	0
b2	NOF	1	3	0	31.2	0	0	d2	LNOF	3	3	0	28	0	0
b3	LOF	1	1	0	53.4	0	0	d3	LOF	3	1	0	33.3	0	0
b3	LOF	1	2	0	49.2	0	0	d3	LOF	3	2	0	24.8	0	0
b3	LOF	1	3	0	26.8	0	0	d3	LOF	3	3	0	19.7	0	0
b4	zero	1	1	1	27.1	0	0	d4	NOF	3	1	1	31.9	0	0
b4	zero	1	2	1	24.9	0	0	d4	NOF	3	2	1	21.4	0	0
b4	zero	1	3	1	18	0	0	d4	NOF	3	3	1	20.8	0	0
b5	LNOF	1	1	1	44.9	0	0	d5	zero	3	1	1	46.1	0	0
b5	LNOF	1	2	1	58.2	0	0	d5	zero	3	2	1	40.5	0	0
b5	LNOF	1	3	1	41.3	0	0	d5	zero	3	3	1	32.6	0	0
b6	zero	1	1	0	33.1	0	0	d6	LNF	3	1	1	31.8	0	0
b6	zero	1	2	0	41.3	0	0	d6	LNF	3	2	1	35	0	0
b6	zero	1	3	0	24.7	0	0	d6	LNF	3	3	1	43.2	0	0
b7	NOF	2	1	0	51.9	0	0	d7	LNOF	4	1	1	40.4	0	0
b7	NOF	2	2	0	31.1	0	0	d7	LNOF	4	2	1	25.3	0	0
b7	NOF	2	3	0	37.7	0	0	d7	LNOF	4	3	1	55.6	0	0
b8	NOL	2	1	0	37.6	0	0	d8	LNF	4	1	0	45.8	0	0
b8	NOL	2	2	0	40.7	0	0	d8	LNF	4	2	0	56.2	0	0
b8	NOL	2	3	0	48.2	0	0	d8	LNF	4	3	0	54.2	0	0
b9	LNOF	2	1	1	68.2	0	0	d9	NOF	4	1	0	45.3	0	0
b9	LNOF	2	2	1	57.6	0	0	d9	NOF	4	2	0	30.7	0	0
b9	LNOF	2	3	1	51.8	0	0	d9	NOF	4	3	0	36.3	0	0
b10	LNF	2	1	0	35.5	0	0	d10	zero	4	1	0	40.2	0	0
b10	LNF	2	2	0	34.8	0	0	d10	zero	4	2	0	51.9	0	0
b10	LNF	2	3	0	23.4	0	0	d10	zero	4	3	0	43.7	0	0
b11	LOF	2	1	1	33.9	0	0	d11	LNF	4	1	1	45.1	0	0
b11	LOF	2	2	1	24.2	0	0	d11	LNF	4	2	1	51.4	0	0
b11	LOF	2	3	1	23.5	0	0	d11	LNF	4	3	1	51.9	0	0
b12	LOF	2	1	0	38.2	0	0	d12	LOF	4	1	0	68.1	0	0
b12	LOF	2	2	0	26.4	0	0	d12	LOF	4	2	0	72.7	0	0
b12	LOF	2	3	0	31.9	0	0	d12	LOF	4	3	0	52.5	0	0

Appendix 35: Effect of treatment application and *A. longa* introduction on pasture production at Oatlands on 30-3-93 (*0- *A. longa* absent; 1- *A. longa* present).

plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)	plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	1	0	15.3	30	6.67	c1	NOL	3	1	1	27.9	31.7	6.67
a1	NOL	1	2	0	24.5	30	6.67	c1	NOL	3	2	1	25.2	31.7	6.67
a1	NOL	1	3	0	12	30	6.67	c1	NOL	3	3	1	38.2	31.7	6.67
a2	NOF	1	1	1	13.20	35	5	c2	NOF	3	1	0	41.4	40	5
a2	NOF	1	2	1	21.10	35	5	c2	NOF	3	2	0	46.1	40	5
a2	NOF	1	3	1	23.10	35	5	c2	NOF	3	3	0	33.1	40	5
a3	LNF	1	1	0	28.9	40	5	c3	LNOF	3	1	1	49.2	46.7	5
a3	LNF	1	2	0	23.20	40	5	c3	LNOF	3	2	1	74.8	46.7	5
a3	LNF	1	3	0	44.1	40	5	c3	LNOF	3	3	1	41.1	46.7	5
a4	NOL	1	1	1	14.1	35	5	c4	LNF	3	1	0	21.8	40	5
a4	NOL	1	2	1	99.9	35	5	c4	LNF	3	2	0	78.4	40	5
a4	NOL	1	3	1	45	35	5	c4	LNF	3	3	0	32.3	40	5
a5	LNF	1	1	1	12.52	30	5	c5	LOF	3	1	1	31.6	45	5
a5	LNF	1	2	1	20.2	30	5	c5	LOF	3	2	1	66.8	45	5
a5	LNF	1	3	1	36.7	30	5	c5	LOF	3	3	1	59.4	45	5
a6	LNOF	1	1	0	52.8	35	5	c6	NOL	3	1	0	67.9	43	5
a6	LNOF	1	2	0	64.1	35	5	c6	NOL	3	2	0	92.1	43	5
a6	LNOF	1	3	0	16.9	35	5	c6	NOL	3	3	0	72.1	43	5
a7	zero	2	1	0	14.2	25	10	c7	NOL	4	1	0	67.7	38	5
a7	zero	2	2	0	53.5	25	10	c7	NOL	4	2	0	53.1	38	5
a7	zero	2	3	0	54	25	10	c7	NOL	4	3	0	60	38	5
a8	LNOF	2	1	0	33.3	30	5	c8	zero	4	1	1	40.5	26.7	5
a8	LNOF	2	2	0	37.4	30	5	c8	zero	4	2	1	35.9	26.7	5
a8	LNOF	2	3	0	45	30	5	c8	zero	4	3	1	27.3	26.7	5
a9	LNF	2	1	1	36.2	30	5	c9	LOF	4	1	1	36.3	48	5
a9	LNF	2	2	1	64.2	30	5	c9	LOF	4	2	1	33.7	48	5
a9	LNF	2	3	1	52.4	30	5	c9	LOF	4	3	1	27.8	48	5
a10	NOF	2	1	1	39.3	20	5	c10	LNOF	4	1	0	26.9	33	5
a10	NOF	2	2	1	34.2	20	5	c10	LNOF	4	2	0	26.4	33	5
a10	NOF	2	3	1	14.4	20	5	c10	LNOF	4	3	0	30.5	33	5
a11	zero	2	1	1	17.4	20	10	c11	NOF	4	1	1	25.8	40	5
a11	zero	2	2	1	8.4	20	10	c11	NOF	4	2	1	27.8	40	5
a11	zero	2	3	1	30.7	20	10	c11	NOF	4	3	1	51.9	40	5
a12	NOL	2	1	1	44	25	6.67	c12	NOL	4	1	1	22.1	45	5
a12	NOL	2	2	1	21.4	25	6.67	c12	NOL	4	2	1	30.8	45	5
a12	NOL	2	3	1	12.2	25	6.67	c12	NOL	4	3	1	53.2	45	5
b1	LOF	1	1	1	43.8	55	5	d1	zero	3	1	0	16.2	30	6.67
b1	LOF	1	2	1	23	55	5	d1	zero	3	2	0	34.3	30	6.67
b1	LOF	1	3	1	37	55	5	d1	zero	3	3	0	28.5	30	6.67
b2	NOF	1	1	0	28.1	36.7	5	d2	LNOF	3	1	0	26.9	40	5
b2	NOF	1	2	0	23.8	36.7	5	d2	LNOF	3	2	0	31.7	40	5
b2	NOF	1	3	0	44.4	36.7	5	d2	LNOF	3	3	0	35.8	40	5
b3	LOF	1	1	0	54.6	65	5	d3	LOF	3	1	0	34.5	46.7	5
b3	LOF	1	2	0	50.52	65	5	d3	LOF	3	2	0	39.9	46.7	5
b3	LOF	1	3	0	43.4	65	5	d3	LOF	3	3	0	34.2	46.7	5
b4	zero	1	1	1	37.1	41.2	5	d4	NOF	3	1	1	34.9	41.7	5
b4	zero	1	2	1	38.6	41.2	5	d4	NOF	3	2	1	51.8	41.7	5
b4	zero	1	3	1	29.2	41.2	5	d4	NOF	3	3	1	25.6	41.7	5
b5	LNOF	1	1	1	60.8	46.7	5	d5	zero	3	1	1	48.6	45	6.67
b5	LNOF	1	2	1	46	46.7	5	d5	zero	3	2	1	44.2	45	6.67
b5	LNOF	1	3	1	76.4	46.7	5	d5	zero	3	3	1	24.4	45	6.67
b6	zero	1	1	0	41.8	31.7	5	d6	LNF	3	1	1	49.3	45	5
b6	zero	1	2	0	65.7	31.7	5	d6	LNF	3	2	1	50.7	45	5
b6	zero	1	3	0	42	31.7	5	d6	LNF	3	3	1	52.5	45	5
b7	NOF	2	1	0	90.9	50	5	d7	LNOF	4	1	1	55.5	55	5
b7	NOF	2	2	0	50.6	50	5	d7	LNOF	4	2	1	53.8	55	5
b7	NOF	2	3	0	52.5	50	5	d7	LNOF	4	3	1	44.2	55	5
b8	NOL	2	1	0	51.4	45	5	d8	LNF	4	1	0	52	46.7	5
b8	NOL	2	2	0	48.2	45	5	d8	LNF	4	2	0	50.2	46.7	5
b8	NOL	2	3	0	64.9	45	5	d8	LNF	4	3	0	36.2	46.7	5
b9	LNOF	2	1	1	53.8	53	5	d9	NOF	4	1	0	28.1	45	5
b9	LNOF	2	2	1	43	53	5	d9	NOF	4	2	0	43.1	45	5
b9	LNOF	2	3	1	51.7	53	5	d9	NOF	4	3	0	34	45	5
b10	LNF	2	1	0	31	56.7	5	d10	zero	4	1	0	29.5	41.7	8.3
b10	LNF	2	2	0	28.3	56.7	5	d10	zero	4	2	0	31.2	41.7	8.3
b10	LNF	2	3	0	32.9	56.7	5	d10	zero	4	3	0	30.9	41.7	8.3
b11	LOF	2	1	1	39.9	50	5	d11	LNF	4	1	1	32.9	43	6.67
b11	LOF	2	2	1	45.8	50	5	d11	LNF	4	2	1	23.6	43	6.67
b11	LOF	2	3	1	31.5	50	5	d11	LNF	4	3	1	31.9	43	6.67
b12	LOF	2	1	0	10.4	58	5	d12	LOF	4	1	0	38.1	45	5
b12	LOF	2	2	0	46.1	58	5	d12	LOF	4	2	0	41.8	45	5
b12	LOF	2	3	0	7.9	58	5	d12	LOF	4	3	0	33.2	45	5

Appendix 36: Effect of treatment application and *A. longa* introduction on pasture production at Oatlands on 30-9-93 (*0- *A. longa* absent; 1- *A. longa* present).

plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)	plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	1	0	1.7	10	82.5	c1	NOL	3	1	1	15.2	25	70
a1	NOL	1	2	0	6.6	10	82.5	c1	NOL	3	2	1	5	25	70
a1	NOL	1	3	0	4.1	10	82.5	c1	NOL	3	3	1	5	25	70
a2	NOF	1	1	1	9.7	31.5	65	c2	NOF	3	1	0	19.6	40	57.5
a2	NOF	1	2	1	20	31.5	65	c2	NOF	3	2	0	12.1	40	57.5
a2	NOF	1	3	1	14.5	31.5	65	c2	NOF	3	3	0	14.7	40	57.5
a3	LNF	1	1	0	13.4	42.5	57.5	c3	LNOF	3	1	1	20.6	45	55
a3	LNF	1	2	0	19.1	42.5	57.5	c3	LNOF	3	2	1	16.1	45	55
a3	LNF	1	3	0	15.3	42.5	57.5	c3	LNOF	3	3	1	7.9	45	55
a4	NOL	1	1	1	7	40	55	c4	LNF	3	1	0	28.5	47.5	52.5
a4	NOL	1	2	1	13.3	40	55	c4	LNF	3	2	0	16.4	47.5	52.5
a4	NOL	1	3	1	9.4	40	55	c4	LNF	3	3	0	32.6	47.5	52.5
a5	LNF	1	1	1	24.7	40	55	c5	LOF	3	1	1	11.3	52.5	47.5
a5	LNF	1	2	1	26.2	40	55	c5	LOF	3	2	1	18.7	52.5	47.5
a5	LNF	1	3	1	22.7	40	55	c5	LOF	3	3	1	10.4	52.5	47.5
a6	LNOF	1	1	1	13.2	60	37.5	c6	NOL	3	1	0	23.9	42.5	57.5
a6	LNOF	1	2	1	12	60	37.5	c6	NOL	3	2	0	17.7	42.5	57.5
a6	LNOF	1	3	1	23.5	60	37.5	c6	NOL	3	3	0	20.1	42.5	57.5
a7	zero	2	1	1	1.2	0	0	c7	NOL	4	1	0	16.3	42.5	57.5
a7	zero	2	2	1	5.1	0	0	c7	NOL	4	2	0	12.8	42.5	57.5
a7	zero	2	3	1	9.9	0	0	c7	NOL	4	3	0	25	42.5	57.5
a8	LNOF	2	1	0	23.4	70	25	c8	zero	4	1	1	23.5	30	67.5
a8	LNOF	2	2	0	22.4	70	25	c8	zero	4	2	1	15.7	30	67.5
a8	LNOF	2	3	0	16.2	70	25	c8	zero	4	3	1	7.1	30	67.5
a9	LNF	2	1	1	21.5	67.5	30	c9	LOF	4	1	1	36.2	60	40
a9	LNF	2	2	1	25.2	67.5	30	c9	LOF	4	2	1	19.4	60	40
a9	LNF	2	3	1	17.6	67.5	30	c9	LOF	4	3	1	50.2	60	40
a10	NOF	2	1	1	8.1	57.5	40	c10	LNOF	4	1	0	43.4	62.5	37.5
a10	NOF	2	2	1	13.4	57.5	40	c10	LNOF	4	2	0	23.4	62.5	37.5
a10	NOF	2	3	1	6.2	57.5	40	c10	LNOF	4	3	0	28.4	62.5	37.5
a11	zero	2	1	0	2.7	45	47.5	c11	NOF	4	1	1	29.1	55	45
a11	zero	2	2	0	2.6	45	47.5	c11	NOF	4	2	1	29.9	55	45
a11	zero	2	3	0	8.9	45	47.5	c11	NOF	4	3	1	24.4	55	45
a12	NOL	2	1	1	8.4	50	42.5	c12	NOL	4	1	1	*	57.5	42.5
a12	NOL	2	2	1	3.2	50	42.5	c12	NOL	4	2	1	*	57.5	42.5
a12	NOL	2	3	1	2	50	42.5	c12	NOL	4	3	1	*	57.5	42.5
b1	LOF	1	1	1	18.9	60	40	d1	zero	3	1	0	8.9	40	60
b1	LOF	1	2	1	22.3	60	40	d1	zero	3	2	0	14.5	40	60
b1	LOF	1	3	1	9	60	40	d1	zero	3	3	0	13	40	60
b2	NOF	1	1	0	9.8	52.5	45	d2	LNOF	3	1	0	13.4	45	52.5
b2	NOF	1	2	0	16.8	52.5	45	d2	LNOF	3	2	0	13.4	45	52.5
b2	NOF	1	3	0	12.8	52.5	45	d2	LNOF	3	3	0	12	45	52.5
b3	LOF	1	1	0	40.7	57.5	42.5	d3	LOF	3	1	0	19.8	45	55
b3	LOF	1	2	0	21.2	57.5	42.5	d3	LOF	3	2	0	24.2	45	55
b3	LOF	1	3	0	27.9	57.5	42.5	d3	LOF	3	3	0	18.9	45	55
b4	zero	1	1	1	17.4	55	45	d4	NOF	3	1	1	33.5	45	55
b4	zero	1	2	1	16.8	55	45	d4	NOF	3	2	1	26.3	45	55
b4	zero	1	3	1	15.2	55	45	d4	NOF	3	3	1	15.8	45	55
b5	LNOF	1	1	0	19.8	57.5	42.5	d5	zero	3	1	1	9.3	45	55
b5	LNOF	1	2	0	24.2	57.5	42.5	d5	zero	3	2	1	8.9	45	55
b5	LNOF	1	3	0	18.8	57.5	42.5	d5	zero	3	3	1	2.3	45	55
b6	zero	1	1	0	15.3	57.5	42.5	d6	LNF	3	1	1	10.8	47.5	52.5
b6	zero	1	2	0	19	57.5	42.5	d6	LNF	3	2	1	9.8	47.5	52.5
b6	zero	1	3	0	12.5	57.5	42.5	d6	LNF	3	3	1	9.8	47.5	52.5
b7	NOF	2	1	0	29	60	40	d7	LNOF	4	1	1	9.4	50	50
b7	NOF	2	2	0	31.4	60	40	d7	LNOF	4	2	1	15.5	50	50
b7	NOF	2	3	0	24.6	60	40	d7	LNOF	4	3	1	27.4	50	50
b8	NOL	2	1	0	34.3	67.5	32.5	d8	LNF	4	1	0	31.1	47.5	52.5
b8	NOL	2	2	0	7.6	67.5	32.5	d8	LNF	4	2	0	28.9	47.5	52.5
b8	NOL	2	3	0	10.1	67.5	32.5	d8	LNF	4	3	0	10.5	47.5	52.5
b9	LNOF	2	1	1	33.6	72.5	27.5	d9	NOF	4	1	0	21	47.5	52.5
b9	LNOF	2	2	1	31.1	72.5	27.5	d9	NOF	4	2	0	18.1	47.5	52.5
b9	LNOF	2	3	1	21.3	72.5	27.5	d9	NOF	4	3	0	16.2	47.5	52.5
b10	LNF	2	1	0	30.3	72.5	27.5	d10	zero	4	1	0	15.2	47.5	52.5
b10	LNF	2	2	0	39.1	72.5	27.5	d10	zero	4	2	0	13.3	47.5	52.5
b10	LNF	2	3	0	40.7	72.5	27.5	d10	zero	4	3	0	13.1	47.5	52.5
b11	LOF	2	1	1	12.5	72.5	27.5	d11	LNF	4	1	1	23.1	55	45
b11	LOF	2	2	1	16.6	72.5	27.5	d11	LNF	4	2	1	24.1	55	45
b11	LOF	2	3	1	20.6	72.5	27.5	d11	LNF	4	3	1	33.1	55	45
b12	LOF	2	1	0	32.1	80	20	d12	LOF	4	1	0	29.1	55	45
b12	LOF	2	2	0	17.7	80	20	d12	LOF	4	2	0	44.1	55	45
b12	LOF	2	3	0	25.1	80	20	d12	LOF	4	3	0	32.6	55	45

Appendix 37: Effect of treatment application and *A. longa* introduction on pasture production at Perth on 27-11-91 (*0- *A. longa* absent; 1- *A. longa* present).

plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)	plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	1	0	24.9	5	0	c1	NOL	3	1	1	38.3	1	0
a1	NOL	1	2	0	44.7	1	0	c1	NOL	3	2	1	51.3	1	0
a1	NOL	1	3	0	34.7	1	10	c1	NOL	3	3	1	102.6	0	0
a2	NOF	1	1	1	73.2	1	0	c2	NOF	3	1	0	28	1	0
a2	NOF	1	2	1	57.8	1	0	c2	NOF	3	2	0	43.9	1	0
a2	NOF	1	3	1	68.8	5	1	c2	NOF	3	3	0	61.7	1	0
a3	LNF	1	1	0	75.3	1	0	c3	LNOF	3	1	1	28.1	1	0
a3	LNF	1	2	0	57.5	1	0	c3	LNOF	3	2	1	45.6	1	0
a3	LNF	1	3	0	60.8	15	0	c3	LNOF	3	3	1	33.4	5	0
a4	NOL	1	1	1	56.5	0	1	c4	LNF	3	1	0	51.3	10	1
a4	NOL	1	2	1	39.3	5	0	c4	LNF	3	2	0	68.7	5	5
a4	NOL	1	3	1	44.3	1	1	c4	LNF	3	3	0	63.1	5	0
a5	LNF	1	1	1	23	15	25	c5	LOF	3	1	1	56.7	5	3
a5	LNF	1	2	1	49.9	5	1	c5	LOF	3	2	1	67.1	3	0
a5	LNF	1	3	1	54.3	15	1	c5	LOF	3	3	1	42.8	5	1
a6	LNOF	1	1	1	40.9	10	1	c6	NOL	3	1	0	52.3	1	1
a6	LNOF	1	2	1	29.4	5	1	c6	NOL	3	2	0	55.2	10	1
a6	LNOF	1	3	1	43.7	1	1	c6	NOL	3	3	0	78.1	10	1
a7	zero	2	1	1	8.4	5	1	c7	NOL	4	1	0	62.2	10	5
a7	zero	2	2	1	8.3	1	1	c7	NOL	4	2	0	66.2	1	1
a7	zero	2	3	1	8.2	5	5	c7	NOL	4	3	0	69	5	1
a8	LNOF	2	1	0	31.1	5	0	c8	zero	4	1	1	54.7	5	5
a8	LNOF	2	2	0	33.9	5	1	c8	zero	4	2	1	50.2	5	0
a8	LNOF	2	3	0	78.1	10	1	c8	zero	4	3	1	54	0	0
a9	LNF	2	1	1	6.9	10	50	c9	LOF	4	1	1	43.5	10	5
a9	LNF	2	2	1	72.2	5	5	c9	LOF	4	2	1	27	5	10
a9	LNF	2	3	1	39.5	10	25	c9	LOF	4	3	1	63.3	1	1
a10	NOF	2	1	1	71.2	50	10	c10	LNOF	4	1	0	56.5	1	0
a10	NOF	2	2	1	82.4	1	0	c10	LNOF	4	2	0	30.6	5	3
a10	NOF	2	3	1	47.9	30	5	c10	LNOF	4	3	0	47.6	5	0
a11	zero	2	1	0	33.9	10	25	c11	NOF	4	1	1	33.1	25	0
a11	zero	2	2	0	35.8	15	0	c11	NOF	4	2	1	56.8	5	1
a11	zero	2	3	0	33.1	25	0	c11	NOF	4	3	1	51.5	10	1
a12	NOL	2	1	1	31.1	20	0	c12	NOL	4	1	1	69	1	10
a12	NOL	2	2	1	64.2	5	0	c12	NOL	4	2	1	71.5	1	2
a12	NOL	2	3	1	43.7	20	1	c12	NOL	4	3	1	84	1	0
b1	LOF	1	1	1	67.9	0	1	d1	zero	3	1	0	54.9	0	1
b1	LOF	1	2	1	21.52	0	0	d1	zero	3	2	0	46.4	0	1
b1	LOF	1	3	1	48.8	1	0	d1	zero	3	3	0	54.2	1	0
b2	NOF	1	1	0	38.4	0	0	d2	LNOF	3	1	0	67.6	0	0
b2	NOF	1	2	0	43.1	5	1	d2	LNOF	3	2	0	39.8	0	0
b2	NOF	1	3	0	76.3	1	0	d2	LNOF	3	3	0	48.7	1	0
b3	LOF	1	1	0	79	1	1	d3	LOF	3	1	0	25.5	0	5
b3	LOF	1	2	0	61.9	1	0	d3	LOF	3	2	0	17.7	10	0
b3	LOF	1	3	0	26.2	10	1	d3	LOF	3	3	0	28.7	1	0
b4	zero	1	1	1	29.3	1	0	d4	NOF	3	1	1	70.7	0	0
b4	zero	1	2	1	49.8	10	5	d4	NOF	3	2	1	48.7	0	0
b4	zero	1	3	1	41.1	10	20	d4	NOF	3	3	1	58.9	10	0
b5	LNOF	1	1	0	41.8	1	0	d5	zero	3	1	1	45.2	1	1
b5	LNOF	1	2	0	63.8	1	1	d5	zero	3	2	1	62.3	5	1
b5	LNOF	1	3	0	47.8	1	1	d5	zero	3	3	1	37.7	5	0
b6	zero	1	1	0	26.9	20	2	d6	LNF	3	1	1	53.8	1	0
b6	zero	1	2	0	47	1	1	d6	LNF	3	2	1	52.9	15	1
b6	zero	1	3	0	46.5	1	1	d6	LNF	3	3	1	77.2	1	5
b7	NOF	2	8	0	102.7	1	0	d7	LNOF	4	1	1	100.5	1	0
b7	NOF	2	2	0	30.3	5	1	d7	LNOF	4	2	1	78.9	5	1
b7	NOF	2	3	0	48.7	1	0	d7	LNOF	4	3	1	80.1	10	1
b8	NOL	2	1	0	46.7	15	0	d8	LNF	4	1	0	35	1	5
b8	NOL	2	2	0	48.8	5	0	d8	LNF	4	2	0	43.9	15	1
b8	NOL	2	3	0	59.9	1	0	d8	LNF	4	3	0	64.2	1	10
b9	LNOF	2	1	1	68.3	1	0	d9	NOF	4	1	0	61.4	5	15
b9	LNOF	2	2	1	35.2	5	20	d9	NOF	4	2	0	94.9	5	1
b9	LNOF	2	3	1	66.2	5	0	d9	NOF	4	3	0	62.3	5	8
b10	LNF	2	1	0	40.4	5	1	d10	zero	4	1	0	49.3	10	10
b10	LNF	2	2	0	37.9	5	15	d10	zero	4	2	0	38.5	0	15
b10	LNF	2	3	0	97.5	10	5	d10	zero	4	3	0	45.7	1	0
b11	LOF	2	1	1	59.7	1	1	d11	LNF	4	1	1	40.6	10	5
b11	LOF	2	2	1	31.2	0	0	d11	LNF	4	2	1	48.6	1	0
b11	LOF	2	3	1	39.9	1	1	d11	LNF	4	3	1	20.7	1	1
b12	LOF	2	1	0	66.4	5	1	d12	LOF	4	1	0	39.3	1	1
b12	LOF	2	2	0	36.9	10	1	d12	LOF	4	2	0	24.3	10	50
b12	LOF	2	3	0	75	10	5	d12	LOF	4	3	0	51.1	0	1

Appendix 38: Effect of treatment application and *A. longa* introduction on pasture production at Perth on 29-9-92 (three pasture samples combined; *0- *A. longa* absent; 1- *A. longa* present).

plot	treat	rep	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	0	50.1	5	2
a2	NOF	1	1	61.1	2	5
a3	LNF	1	0	95.4	20	0
a4	NOL	1	1	48.6	10	0
a5	LNF	1	1	68.6	30	0
a6	LNOF	1	0	36.4	20	0
a7	zero	2	0	26.7	20	0
a8	LNOF	2	0	35.8	10	2
a9	LNF	2	1	75.6	40	0
a10	NOF	2	1	*	20	5
a11	zero	2	1	77.3	0	0
a12	NOL	2	1	43.7	5	2
b1	LOF	1	1	70.9	2	0
b2	NOF	1	0	43.8	2	0
b3	LOF	1	0	47.3	5	2
b4	zero	1	1	50.8	10	0
b5	LNOF	1	1	43.5	5	0
b6	zero	1	0	65.5	10	10
b7	NOF	2	0	54.2	5	2
b8	NOL	2	0	35.1	10	0
b9	LNOF	2	1	55.7	5	2
b10	LNF	2	0	81.5	20	2
b11	LOF	2	1	55.4	20	2
b12	LOF	2	0	33.6	30	0
c1	NOL	3	1	72.7	1	0
c2	NOF	3	0	80.1	2	0
c3	LNOF	3	1	51	5	5
c4	LNF	3	0	65.6	10	0
c5	LOF	3	1	42.3	5	5
c6	NOL	3	0	*	5	5
c7	NOL	4	0	*	5	5
c8	zero	4	1	61.9	30	20
c9	LOF	4	1	50.3	20	30
c10	LNOF	4	0	36.7	5	10
c11	NOF	4	1	59	20	2
c12	NOL	4	1	70.7	10	5
d1	zero	3	0	75.6	5	2
d2	LNOF	3	0	40.2	2	2
d3	LOF	3	0	45.8	20	5
d4	NOF	3	1	60.7	5	2
d5	zero	3	1	*	20	2
d6	LNF	3	1	66.6	10	0
d7	LNOF	4	1	83.3	5	2
d8	LNF	4	0	80.3	5	5
d9	NOF	4	0	85.2	5	10
d10	zero	4	0	62.5	10	10
d11	LNF	4	1	74.1	5	5
d12	LOF	4	0	49.1	20	5

Appendix 39: Effect of treatment application and *A. longa* introduction on pasture production at Perth on 16-12-92 (*0- *A. longa* absent; 1- *A. longa* present).

plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)	plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	1	0	11.8	0	0	c1	NOL	3	1	1	23.2	0	0
a1	NOL	1	2	0	5.7	0	0	c1	NOL	3	2	1	9.5	0	0
a1	NOL	1	3	0	10.4	0	0	c1	NOL	3	3	1	12.2	0	0
a2	NOF	1	1	1	12.4	0	0	c2	NOF	3	1	0	19.52	0	0
a2	NOF	1	2	1	18	0	0	c2	NOF	3	2	0	20.1	0	0
a2	NOF	1	3	1	9.7	0	0	c2	NOF	3	3	0	11.8	0	0
a3	LNF	1	1	0	32.9	0	0	c3	LNOF	3	1	1	34.8	0	0
a3	LNF	1	2	0	23.4	0	0	c3	LNOF	3	2	1	25.1	0	0
a3	LNF	1	3	0	21.9	0	0	c3	LNOF	3	3	1	29.5	0	0
a4	NOL	1	1	1	27.5	0	0	c4	LNF	3	1	0	39.4	0	0
a4	NOL	1	2	1	23.4	0	0	c4	LNF	3	2	0	42.4	0	0
a4	NOL	1	3	1	30.4	0	0	c4	LNF	3	3	0	36.4	0	0
a5	LNF	1	1	1	36.5	0	0	c5	LOF	3	1	1	32	0	0
a5	LNF	1	2	1	29.1	0	0	c5	LOF	3	2	1	34.3	0	0
a5	LNF	1	3	1	53.1	0	0	c5	LOF	3	3	1	44.3	0	0
a6	LNOF	1	1	0	11.4	0	0	c6	NOL	3	1	0	40.6	0	0
a6	LNOF	1	2	0	12.4	0	0	c6	NOL	3	2	0	29	0	0
a6	LNOF	1	3	0	21.9	0	0	c6	NOL	3	3	0	39.5	0	0
a7	zero	2	1	0	23.3	0	0	c7	NOL	4	1	0	29.2	0	0
a7	zero	2	2	0	28.4	0	0	c7	NOL	4	2	0	16.2	0	0
a7	zero	2	3	0	27	0	0	c7	NOL	4	3	0	20.4	0	0
a8	LNOF	2	1	0	15.9	0	0	c8	zero	4	1	1	48.4	0	0
a8	LNOF	2	2	0	11.8	0	0	c8	zero	4	2	1	28.5	0	0
a8	LNOF	2	3	0	11.5	0	0	c8	zero	4	3	1	32.6	0	0
a9	LNF	2	1	1	39.1	0	0	c9	LOF	4	1	1	23.3	0	0
a9	LNF	2	2	1	27	0	0	c9	LOF	4	2	1	36.8	0	0
a9	LNF	2	3	1	23.8	0	0	c9	LOF	4	3	1	48	0	0
a10	NOF	2	1	1	17.6	0	0	c10	LNOF	4	1	0	13.3	0	0
a10	NOF	2	2	1	6.2	0	0	c10	LNOF	4	2	0	34.3	0	0
a10	NOF	2	3	1	13.5	0	0	c10	LNOF	4	3	0	32.5	0	0
a11	zero	2	1	1	17.4	0	0	c11	NOF	4	1	1	34.6	0	0
a11	zero	2	2	1	15.6	0	0	c11	NOF	4	2	1	32.4	0	0
a11	zero	2	3	1	13.5	0	0	c11	NOF	4	3	1	30.3	0	0
a12	NOL	2	1	1	24.9	0	0	c12	NOL	4	1	1	53.7	0	0
a12	NOL	2	2	1	21.1	0	0	c12	NOL	4	2	1	20.8	0	0
a12	NOL	2	3	1	27	0	0	c12	NOL	4	3	1	34.9	0	0
b1	LOF	1	1	1	23.6	0	0	d1	zero	3	1	0	16.4	0	0
b1	LOF	1	2	1	29.1	0	0	d1	zero	3	2	0	20.9	0	0
b1	LOF	1	3	1	0	0	0	d1	zero	3	3	0	19.1	0	0
b2	NOF	1	1	0	7.8	0	0	d2	LNOF	3	1	0	8.52	0	0
b2	NOF	1	2	0	16.4	0	0	d2	LNOF	3	2	0	18.9	0	0
b2	NOF	1	3	0	13.9	0	0	d2	LNOF	3	3	0	12.7	0	0
b3	LOF	1	1	0	18.4	0	0	d3	LOF	3	1	0	18	0	0
b3	LOF	1	2	0	24.1	0	0	d3	LOF	3	2	0	25.8	0	0
b3	LOF	1	3	0	19	0	0	d3	LOF	3	3	0	29.2	0	0
b4	zero	1	1	1	32.2	0	0	d4	NOF	3	1	1	23.4	0	0
b4	zero	1	2	1	21.8	0	0	d4	NOF	3	2	1	33.7	0	0
b4	zero	1	3	1	18.8	0	0	d4	NOF	3	3	1	39.6	0	0
b5	LNOF	1	1	1	27.7	0	0	d5	zero	3	1	1	25.1	0	0
b5	LNOF	1	2	1	16.9	0	0	d5	zero	3	2	1	28.3	0	0
b5	LNOF	1	3	1	26.6	0	0	d5	zero	3	3	1	37.9	0	0
b6	zero	1	1	0	40	0	0	d6	LNF	3	1	1	38.2	0	0
b6	zero	1	2	0	36.6	0	0	d6	LNF	3	2	1	34.6	0	0
b6	zero	1	3	0	47.52	0	0	d6	LNF	3	3	1	28.8	0	0
b7	NOF	2	1	0	23.8	0	0	d7	LNOF	4	1	1	39.6	0	0
b7	NOF	2	2	0	49.9	0	0	d7	LNOF	4	2	1	36	0	0
b7	NOF	2	3	0	31.6	0	0	d7	LNOF	4	3	1	45.1	0	0
b8	NOL	2	1	0	16.3	0	0	d8	LNF	4	1	0	41.9	0	0
b8	NOL	2	2	0	23.2	0	0	d8	LNF	4	2	0	43.52	0	0
b8	NOL	2	3	0	21	0	0	d8	LNF	4	3	0	42.3	0	0
b9	LNOF	2	1	1	29.8	0	0	d9	NOF	4	1	0	20.7	0	0
b9	LNOF	2	2	1	16.9	0	0	d9	NOF	4	2	0	31.2	0	0
b9	LNOF	2	3	1	36.6	0	0	d9	NOF	4	3	0	37.6	0	0
b10	LNF	2	1	0	37.2	0	0	d10	zero	4	1	0	35.1	0	0
b10	LNF	2	2	0	37.4	0	0	d10	zero	4	2	0	13.5	0	0
b10	LNF	2	3	0	29.9	0	0	d10	zero	4	3	0	24.5	0	0
b11	LOF	2	1	1	29.9	0	0	d11	LNF	4	1	1	33.1	0	0
b11	LOF	2	2	1	19.4	0	0	d11	LNF	4	2	1	32.4	0	0
b11	LOF	2	3	1	17.9	0	0	d11	LNF	4	3	1	34.9	0	0
b12	LOF	2	1	0	15.1	0	0	d12	LOF	4	1	0	15.1	0	0
b12	LOF	2	2	0	25.9	0	0	d12	LOF	4	2	0	32.3	0	0
b12	LOF	2	3	0	13.4	0	0	d12	LOF	4	3	0	28.3	0	0

Appendix 40: Effect of treatment application and *A. longa* introduction on pasture production at Perth on 26-8-93 (*0- *A. longa* absent; 1- *A. longa* present).

plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)	plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	1	0	15.3	0	0	c1	NOL	3	1	1	24.52	0	0
a1	NOL	1	2	0	16.2	0	0	c1	NOL	3	2	1	16.2	0	0
a1	NOL	1	3	0	7.2	0	0	c1	NOL	3	3	1	25.8	0	0
a2	NOF	1	1	1	15.5	0	0	c2	NOF	3	1	0	12	0	0
a2	NOF	1	2	1	5.4	0	0	c2	NOF	3	2	0	14.3	0	0
a2	NOF	1	3	1	8.3	0	0	c2	NOF	3	3	0	18.5	0	0
a3	LNF	1	1	0	11.52	0	0	c3	LNOF	3	1	1	12.1	0	0
a3	LNF	1	2	0	11.1	0	0	c3	LNOF	3	2	1	15.8	0	0
a3	LNF	1	3	0	3.7	0	0	c3	LNOF	3	3	1	10	0	0
a4	NOL	1	1	1	6.4	0	0	c4	LNF	3	1	0	7.4	0	0
a4	NOL	1	2	1	9.2	0	0	c4	LNF	3	2	0	9.52	0	0
a4	NOL	1	3	1	9.6	0	0	c4	LNF	3	3	0	20.5	0	0
a5	LNF	1	1	1	18.2	0	0	c5	LOF	3	1	1	15.7	0	0
a5	LNF	1	2	1	15.1	0	0	c5	LOF	3	2	1	22.3	0	0
a5	LNF	1	3	1	16.9	0	0	c5	LOF	3	3	1	15.3	0	0
a6	LNOF	1	1	1	6	0	0	c6	NOL	3	1	0	16.4	0	0
a6	LNOF	1	2	1	10	0	0	c6	NOL	3	2	0	9.4	0	0
a6	LNOF	1	3	1	18.1	0	0	c6	NOL	3	3	0	19.3	0	0
a7	zero	2	1	1	11	0	0	c7	NOL	4	1	0	12.8	0	0
a7	zero	2	2	1	0.7	0	0	c7	NOL	4	2	0	8.4	0	0
a7	zero	2	3	1	6.4	0	0	c7	NOL	4	3	0	17.7	0	0
a8	LNOF	2	1	0	20.9	0	0	c8	zero	4	1	1	9.2	0	0
a8	LNOF	2	2	0	11.3	0	0	c8	zero	4	2	1	8.3	0	0
a8	LNOF	2	3	0	7.2	0	0	c8	zero	4	3	1	14.9	0	0
a9	LNF	2	1	1	14.7	0	0	c9	LOF	4	1	1	32.4	0	0
a9	LNF	2	2	1	10.6	0	0	c9	LOF	4	2	1	21.5	0	0
a9	LNF	2	3	1	5.7	0	0	c9	LOF	4	3	1	25.52	0	0
a10	NOF	2	1	1	20.3	0	0	c10	LNOF	4	1	0	13.3	0	0
a10	NOF	2	2	1	16.5	0	0	c10	LNOF	4	2	0	17.2	0	0
a10	NOF	2	3	1	12.52	0	0	c10	LNOF	4	3	0	13.4	0	0
a11	zero	2	1	0	9.8	0	0	c11	NOF	4	1	1	20.9	0	0
a11	zero	2	2	0	14.9	0	0	c11	NOF	4	2	1	22.4	0	0
a11	zero	2	3	0	7.52	0	0	c11	NOF	4	3	1	22.4	0	0
a12	NOL	2	1	1	14.6	0	0	c12	NOL	4	1	1	30.6	0	0
a12	NOL	2	2	1	10.8	0	0	c12	NOL	4	2	1	22.3	0	0
a12	NOL	2	3	1	6.9	0	0	c12	NOL	4	3	1	12.7	0	0
b1	LOF	1	1	1	18.9	0	0	d1	zero	3	1	0	5.6	0	0
b1	LOF	1	2	1	11.4	0	0	d1	zero	3	2	0	7.5	0	0
b1	LOF	1	3	1	19.3	0	0	d1	zero	3	3	0	4.9	0	0
b2	NOF	1	1	0	8.3	0	0	d2	LNOF	3	1	0	16.6	0	0
b2	NOF	1	2	0	14.7	0	0	d2	LNOF	3	2	0	14.8	0	0
b2	NOF	1	3	0	14.3	0	0	d2	LNOF	3	3	0	19.9	0	0
b3	LOF	1	1	0	20.6	0	0	d3	LOF	3	1	0	15.7	0	0
b3	LOF	1	2	0	13	0	0	d3	LOF	3	2	0	16.7	0	0
b3	LOF	1	3	0	22.52	0	0	d3	LOF	3	3	0	9.7	0	0
b4	zero	1	1	1	30	0	0	d4	NOF	3	1	1	11.4	0	0
b4	zero	1	2	1	15.7	0	0	d4	NOF	3	2	1	5	0	0
b4	zero	1	3	1	12.4	0	0	d4	NOF	3	3	1	9.2	0	0
b5	LNOF	1	1	0	10.4	0	0	d5	zero	3	1	1	8	0	0
b5	LNOF	1	2	0	12.8	0	0	d5	zero	3	2	1	8.3	0	0
b5	LNOF	1	3	0	23.2	0	0	d5	zero	3	3	1	12.8	0	0
b6	zero	1	1	0	16.1	0	0	d6	LNF	3	1	1	10.3	0	0
b6	zero	1	2	0	9.3	0	0	d6	LNF	3	2	1	8.3	0	0
b6	zero	1	3	0	10.2	0	0	d6	LNF	3	3	1	21.1	0	0
b7	NOF	2	1	0	14.4	0	0	d7	LNOF	4	1	1	25.1	0	0
b7	NOF	2	2	0	9.4	0	0	d7	LNOF	4	2	1	16.8	0	0
b7	NOF	2	3	0	11.5	0	0	d7	LNOF	4	3	1	10.10	0	0
b8	NOL	2	1	0	10.5	0	0	d8	LNF	4	1	0	16.3	0	0
b8	NOL	2	2	0	9.4	0	0	d8	LNF	4	2	0	16.4	0	0
b8	NOL	2	3	0	15.5	0	0	d8	LNF	4	3	0	12.5	0	0
b9	LNOF	2	1	1	9.4	0	0	d9	NOF	4	1	0	15.4	0	0
b9	LNOF	2	2	1	7.6	0	0	d9	NOF	4	2	0	15	0	0
b9	LNOF	2	3	1	19.4	0	0	d9	NOF	4	3	0	14.6	0	0
b10	LNF	2	1	0	9.5	0	0	d10	zero	4	1	0	14.5	0	0
b10	LNF	2	2	0	13.3	0	0	d10	zero	4	2	0	7.1	0	0
b10	LNF	2	3	0	11.5	0	0	d10	zero	4	3	0	8.7	0	0
b11	LOF	2	1	1	12.2	0	0	d11	LNF	4	1	1	7	0	0
b11	LOF	2	2	1	11.4	0	0	d11	LNF	4	2	1	17.7	0	0
b11	LOF	2	3	1	12.9	0	0	d11	LNF	4	3	1	17.2	0	0
b12	LOF	2	1	0	8.3	0	0	d12	LOF	4	1	0	19.2	0	0
b12	LOF	2	2	0	10.7	0	0	d12	LOF	4	2	0	17.6	0	0
b12	LOF	2	3	0	9	0	0	d12	LOF	4	3	0	14.2	0	0

Appendix 41: Effect of treatment application and *A. longa* introduction on pasture production at Perth on 16-11-93 (*0- *A. longa* absent; 1- *A. longa* present).

plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)	plot	treat	rep	cut	intro*	weight (g)	clover (%)	weeds (%)
a1	NOL	1	1	0	40.8	10	85	c1	NOL	3	1	1	52.1	5	90
a1	NOL	1	2	0	49.9	10	85	c1	NOL	3	2	1	53	5	90
a1	NOL	1	3	0	37.4	10	85	c1	NOL	3	3	1	50.2	5	90
a2	NOF	1	1	1	56	4	90	c2	NOF	3	1	0	70.5	5	90
a2	NOF	1	2	1	41.05	4	90	c2	NOF	3	2	0	62.7	5	90
a2	NOF	1	3	1	105.2	4	90	c2	NOF	3	3	0	55	5	90
a3	LNF	1	1	0	58.7	15	70	c3	LNOF	3	1	1	64.7	5	90
a3	LNF	1	2	0	63.6	15	70	c3	LNOF	3	2	1	90.8	5	90
a3	LNF	1	3	0	57.2	15	70	c3	LNOF	3	3	1	106.5	5	90
a4	NOL	1	1	1	71.8	25	60	c4	LNF	3	1	0	60.6	5	90
a4	NOL	1	2	1	48.3	25	60	c4	LNF	3	2	0	39.2	5	90
a4	NOL	1	3	1	62.6	25	60	c4	LNF	3	3	0	62.2	5	90
a5	LNF	1	1	1	66.7	40	55	c5	LOF	3	1	1	59.9	5	90
a5	LNF	1	2	1	42.7	40	55	c5	LOF	3	2	1	72.3	5	90
a5	LNF	1	3	1	45.2	40	55	c5	LOF	3	3	1	58.5	5	90
a6	LNOF	1	1	1	55.7	30	65	c6	NOL	3	1	0	44.6	10	85
a6	LNOF	1	2	1	103.8	30	65	c6	NOL	3	2	0	42.2	10	85
a6	LNOF	1	3	1	54.2	30	65	c6	NOL	3	3	0	73.2	10	85
a7	zero	2	1	1	*	35	60	c7	NOL	4	1	0	41.8	5	90
a7	zero	2	2	1	*	35	60	c7	NOL	4	2	0	37.3	5	90
a7	zero	2	3	1	*	35	60	c7	NOL	4	3	0	22.8	5	90
a8	LNOF	2	1	0	49	30	60	c8	zero	4	1	1	58	15	80
a8	LNOF	2	2	0	67.3	30	60	c8	zero	4	2	1	37.2	15	80
a8	LNOF	2	3	0	53.1	30	60	c8	zero	4	3	1	39.6	15	80
a9	LNF	2	1	1	49.4	45	50	c9	LOF	4	1	1	56.1	15	80
a9	LNF	2	2	1	47.8	45	50	c9	LOF	4	2	1	52.5	15	80
a9	LNF	2	3	1	55.1	45	50	c9	LOF	4	3	1	57.1	15	80
a10	NOF	2	1	1	53.9	30	65	c10	LNOF	4	1	0	51.3	10	85
a10	NOF	2	2	1	46.1	30	65	c10	LNOF	4	2	0	31.6	10	85
a10	NOF	2	3	1	36.9	30	65	c10	LNOF	4	3	0	55.8	10	85
a11	zero	2	1	0	50.4	50	45	c11	NOF	4	1	1	27.3	10	85
a11	zero	2	2	0	44.8	50	45	c11	NOF	4	2	1	73.8	10	85
a11	zero	2	3	0	45.6	50	45	c11	NOF	4	3	1	51.2	10	85
a12	NOL	2	1	1	52.4	30	60	c12	NOL	4	1	1	65.2	10	85
a12	NOL	2	2	1	46	30	60	c12	NOL	4	2	1	40	10	85
a12	NOL	2	3	1	32	30	60	c12	NOL	4	3	1	57.1	10	85
b1	LOF	1	1	1	48.4	5	90	d1	zero	3	1	0	38.3	5	90
b1	LOF	1	2	1	43.6	5	90	d1	zero	3	2	0	100.6	5	90
b1	LOF	1	3	1	54.9	5	90	d1	zero	3	3	0	61.1	5	90
b2	NOF	1	1	0	80.7	5	90	d2	LNOF	3	1	0	49.6	5	90
b2	NOF	1	2	0	46.8	5	90	d2	LNOF	3	2	0	59.1	5	90
b2	NOF	1	3	0	72.8	5	90	d2	LNOF	3	3	0	47	5	90
b3	LOF	1	1	0	54.8	15	80	d3	LOF	3	1	0	40.9	10	85
b3	LOF	1	2	0	45.8	15	80	d3	LOF	3	2	0	61.6	10	85
b3	LOF	1	3	0	45.6	15	80	d3	LOF	3	3	0	53.9	10	85
b4	zero	1	1	1	51.5	15	80	d4	NOF	3	1	1	64.9	5	90
b4	zero	1	2	1	58.5	15	80	d4	NOF	3	2	1	50.2	5	90
b4	zero	1	3	1	54	15	80	d4	NOF	3	3	1	47.8	5	90
b5	LNOF	1	1	0	71.6	10	85	d5	zero	3	1	1	53.5	10	85
b5	LNOF	1	2	0	46.7	10	85	d5	zero	3	2	1	28.3	10	85
b5	LNOF	1	3	0	54.5	10	85	d5	zero	3	3	1	67.4	10	85
b6	zero	1	1	0	49.6	20	75	d6	LNF	3	1	1	24.1	25	70
b6	zero	1	2	0	93	20	75	d6	LNF	3	2	1	39.5	25	70
b6	zero	1	3	0	83.5	20	75	d6	LNF	3	3	1	41.8	25	70
b7	NOF	2	8	0	37.5	5	90	d7	LNOF	4	1	1	31.7	5	90
b7	NOF	2	2	0	46.8	5	90	d7	LNOF	4	2	1	41.5	5	90
b7	NOF	2	3	0	43.4	5	90	d7	LNOF	4	3	1	34.8	5	90
b8	NOL	2	1	0	36	10	85	d8	LNF	4	1	0	62	5	90
b8	NOL	2	2	0	37.5	10	85	d8	LNF	4	2	0	29.8	5	90
b8	NOL	2	3	0	40.8	10	85	d8	LNF	4	3	0	35.1	5	90
b9	LNOF	2	1	1	35.8	10	85	d9	NOF	4	1	0	48	10	85
b9	LNOF	2	2	1	55.5	10	85	d9	NOF	4	2	0	61.8	10	85
b9	LNOF	2	3	1	98.5	10	85	d9	NOF	4	3	0	47.6	10	85
b10	LNF	2	1	0	67.8	25	70	d10	zero	4	1	0	52.5	5	90
b10	LNF	2	2	0	93.9	25	70	d10	zero	4	2	0	38.6	5	90
b10	LNF	2	3	0	37.6	25	70	d10	zero	4	3	0	32.9	5	90
b11	LOF	2	1	1	47.3	25	70	d11	LNF	4	1	1	40.6	15	80
b11	LOF	2	2	1	46.8	25	70	d11	LNF	4	2	1	36.7	15	80
b11	LOF	2	3	1	41.2	25	70	d11	LNF	4	3	1	38.4	15	80
b12	LOF	2	1	0	53.8	20	65	d12	LOF	4	1	0	41.4	10	85
b12	LOF	2	2	0	28.6	20	65	d12	LOF	4	2	0	27.4	10	85
b12	LOF	2	3	0	52.2	20	65	d12	LOF	4	3	0	32.6	10	85

Appendix 42: Effect of treatment application and *A. longa* introduction on soil tests at Oatlands management trial (*0- *A. longa* absent; 1- .*A. longa* present).

Plot	Treatment	Intro*	pH (H2O)	EC (ds/m)	P (mg/kg)	K (mg/kg)	OC (g/100g)	N (%)
a1	NOL	0	6.8	0.11	32	98	4.6	0.22
a2	NOF	1	5.7	0.07	19	89	4.4	0.24
a3	LNF	0	6.6	0.12	19	108	4.1	0.22
a4	NOL	1	6.7	0.1	15	71	4.2	0.28
a5	LNF	1	6.5	0.08	15	108	4.6	0.24
a6	LNOF	0	6.1	0.11	21	208	4.4	0.24
a7	zero	0	5.6	0.08	17	186	4.8	0.23
a8	LNOF	0	6.4	0.09	15	103	4.6	0.22
a9	LNF	1	6.3	0.09	25	94	4.6	0.26
a10	NOF	1	5.6	0.07	25	163	4.6	0.28
a11	zero	1	6.1	0.1	26	182	6.4	0.37
a12	NOL	1	5.6	0.08	22	123	6.2	0.28
b1	LOF	1	6.6	0.11	26	91	5	0.26
b2	NOF	0	5.7	0.08	26	109	4.8	0.24
b3	LOF	0	6.9	0.1	29	82	4.2	0.23
b4	zero	1	5.7	0.12	33	136	4.2	0.24
b5	LNOF	1	6.5	0.14	38	164	4.2	0.29
b6	zero	0	5.7	0.07	26	77	4.4	0.21
b7	NOF	0	5.9	0.07	26	155	4.2	0.22
b8	NOL	0	6.3	0.09	26	91	4.6	0.24
b9	LNOF	1	6.4	0.09	21	82	4.6	0.24
b10	LNF	0	6.5	0.12	25	118	4.8	0.25
b11	LOF	1	6.6	0.15	34	145	4.2	0.28
b12	LOF	0	6.2	0.23	32	216	5.7	0.34
c1	NOL	1	6.7	0.1	14	91	3.3	0.28
c2	NOF	0	5.8	0.07	16	91	4.2	0.26
c3	LNOF	1	6.6	0.09	16	91	3.9	0.26
c4	LNF	0	6.8	0.12	21	100	4.8	0.24
c5	LOF	1	6.5	0.14	25	127	5.3	0.31
c6	NOL	0	6.9	0.13	21	145	4.6	0.28
c7	NOL	0	6.4	0.11	21	105	5	0.28
c8	zero	1	5.8	0.08	21	152	4.8	0.29
c9	LOF	1	6.7	0.23	25	307	9.2	0.31
c10	LNOF	0	6.4	0.11	21	152	7.9	0.24
c11	NOF	1	5.8	0.13	27	226	7.9	0.26
c12	NOL	1	6.5	0.14	21	165	8.8	0.26
d1	zero	0	6.2	0.06	13	64	6	0.21
d2	LNOF	0	6.7	0.1	13	87	5.7	0.24
d3	LOF	0	6.6	0.09	16	115	6.3	0.24
d4	NOF	1	6	0.09	16	119	6.9	0.25
d5	zero	1	5.9	0.06	15	138	7.4	0.27
d6	LNF	1	6.5	0.1	22	219	7.6	0.26
d7	LNOF	1	6.9	0.12	17	101	6.9	0.23
d8	LNF	0	6.6	0.12	26	138	6.9	0.25
d9	NOF	0	5.8	0.08	15	133	7.1	0.24
d10	zero	0	5.9	0.12	12	193	5.7	0.21
d11	LNF	1	6.9	0.14	19	239	6	0.21
d12	LOF	0	7.1	0.13	15	219	6.6	0.21

Appendix 43: Summary of the effect of treatment application on soil parameters at Oatlands (*significantly different from zero at 0.05 %).

Treatment	Sampling date	Soil test					
		pH (1:5 H_2O)	P (mg/kg)	K (mg/kg)	N (%)	OC (g/100g)	EC (dS/m)
zero#	20-10-91	6.0	19	89	-	4.41	0.09
zero	14-4-93	5.9	20	141	0.25	5.5	0.09
LNOF	14-4-93	6.5*	20	124	0.25	5.3	0.11*
LOF	14-4-93	6.7*	25	163	0.28	5.8	0.15*
NOF	14-4-93	5.8	21	136	0.25	5.5	0.08
LNF	14-4-93	6.6*	21	141	0.24	5.4	0.11*
NOL	14-4-93	6.5*	21	111	0.27	5.2	0.11*
LSD (P<0.05)	14-4-93	0.26	n.s.	n.s	n.s.	n.s.	0.029

prior to treatment application

Appendix 44: Effect of treatment application and *A. longa* introduction on soil tests at Perth management trial (*0- *A. longa* absent; 1- .*A. longa* present).

Plot	Treatment	Intro*	pH (H2O)	EC (ds/m)	P (mg/kg)	K (mg/kg)	OC (g/100g)	N (%)
a1	NOL	0	6.4	83	279	.10	.186	1.6
a2	NOF	1	5.8	69	362	.09	.189	2.3
a3	LNF	0	6.4	66	357	.08	.186	1.4
a4	NOL	1	6.6	46	343	.10	.200	2.8
a5	LNF	1	7.0	47	289	.11	.181	2.1
a6	LNOF	0	6.9	50	274	.09	.178	1.8
a7	zero	0	6.3	48	254	.07	.183	1.8
a8	LNOF	0	6.9	42	274	.07	.183	1.8
a9	LNF	1	6.8	54	293	.07	.222	1.8
a10	NOF	1	7.0	59	362	.10	.214	2.1
a11	zero	1	6.8	51	306	.07	.192	2.1
a12	NOL	1	6.2	42	261	.08	.208	2.1
b1	LOF	1	6.5	60	493	.13	.162	1.6
b2	NOF	0	5.6	85	296	.09	.186	1.8
b3	LOF	0	6.5	70	429	.13	.197	1.8
b4	zero	1	6.4	51	266	.09	.186	1.8
b5	LNOF	1	6.9	62	316	.10	.200	2.3
b6	zero	0	6.8	47	316	.07	.175	1.4
b7	NOF	0	5.8	56	261	.06	.181	1.4
b8	NOL	0	7.0	48	335	.08	.192	1.8
b9	LNOF	1	6.7	59	194	.08	.192	1.8
b10	LNF	0	6.3	48	267	.06	.197	2.1
b11	LOF	1	6.7	53	369	.12	.222	2.1
b12	LOF	0	6.5	68	256	.09	.222	2.1
c1	NOL	1	5.9	44	344	.13	.165	2.2
c2	NOF	0	6.7	27	349	.09	.141	2.0
c3	LNOF	1	6.3	37	308	.09	.162	1.8
c4	LNF	0	6.9	59	323	.09	.180	2.2
c5	LOF	1	7.1	46	369	.08	.139	1.8
c6	NOL	0	6.7	46	374	.10	.147	1.8
c7	NOL	0	7.2	59	236	.08	.183	2.6
c8	zero	1	6.2	48	155	.05	.180	3.2
c9	LOF	1	6.7	54	324	.08	.171	2.6
c10	LNOF	0	6.7	54	298	.08	.174	2.8
c11	NOF	1	5.9	45	293	.06	.183	2.4
c12	NOL	1	6.6	62	272	.09	.212	3.4
d1	zero	0	5.8	72	505	.09	.174	2.4
d2	LNOF	0	6.4	49	572	.20	.180	3.2
d3	LOF	0	6.4	50	484	.11	.174	2.6
d4	NOF	1	6.7	54	360	.11	.180	2.6
d5	zero	1	6.4	54	216	.05	.162	2.2
d6	LNF	1	6.2	45	272	.10	.156	2.6
d7	LNOF	1	7.0	45	231	.08	.165	2.2
d8	LNF	0	6.5	47	283	.08	.199	2.8
d9	NOF	0	5.8	59	226	.07	.199	2.4
d10	zero	0	5.8	46	226	.05	.180	2.8
d11	LNF	1	6.8	55	183	.08	.171	2.0
d12	LOF	0	6.5	52	309	.08	.180	2.4

Appendix 45: Summary of the effect of treatment application on soil parameters at Perth (*significantly different from zero at 0.05 %).

Treatment	Sampling date	Soil test					
		pH (1:5 H_2O)	P (mg/kg)	K (mg/kg)	N (%)	OC (g/100g)	EC (dS/m)
zero#	20-10-91	6.0	69	385	-	2.9	0.09
zero	4-6-93	6.3	52	281	0.18	2.2	0.07
LNOF	4-6-93	6.7*	50	308	0.18	2.2	0.10
LOF	4-6-93	6.6*	57	379	0.18	2.1	0.10
NOF	4-6-93	6.2	57	314	0.18	2.1	0.08
LNF	4-6-93	6.6*	53	283	0.19	2.1	0.08
NOL	4-6-93	6.6*	4	306	0.19	2.3	0.10
LSD (P<0.05)	4-6-93	0.37	n.s.	n.s	n.s.	n.s.	n.s.

prior to treatment application

Appendix 46: Effect of treatment application and *A. longa* introduction on soil bulk density at Oatlands management trial .(*0- *A. longa* absent; 1- *A. longa* present).

Plot	Treatment	Intro*	Rep	Dry weight + paper bag (g)	Bulk density (g/cm3)	Plot	Treatment	Intro*	Rep	Dry weight + paper bag (g)	Bulk density (g/cm3)
a1	NOL	0	1	509.3	1.2	c1	NOL	1	1	510.65	1.21
a1	NOL	0	2	478.37	1.13	c1	NOL	1	2	499.7	1.18
a2	NOF	1	1	467.73	1.1	c2	NOF	0	1	490.64	1.16
a2	NOF	1	2	496.98	1.17	c2	NOF	0	2	463.1	1.09
a3	LNF	0	1	475.11	1.12	c3	LNOF	1	1	463.39	1.09
a3	LNF	0	2	493.02	1.17	c3	LNOF	1	2	475.66	1.12
a4	NOL	1	1	479.64	1.13	c4	LNF	0	1	453.6	1.07
a4	NOL	1	2	478.9	1.13	c4	LNF	0	2	429.72	1.01
a5	LNF	1	1	475.88	1.12	c5	LOF	1	1	462.86	1.09
a5	LNF	1	2	490.02	1.16	c5	LOF	1	2	449.53	1.06
a6	LNOF	0	1	507.15	1.2	c6	NOL	0	1	467.53	1.1
a6	LNOF	0	2	491.53	1.16	c6	NOL	0	2	463.85	1.1
a7	zero	0	1	485.21	1.15	c7	NOL	0	1	447.86	1.06
a7	zero	0	2	454.39	1.07	c7	NOL	0	2	454.42	1.07
a8	LNOF	0	1	452.67	1.07	c8	zero	1	1	466.55	1.1
a8	LNOF	0	2	455.29	1.08	c8	zero	1	2	433.13	1.02
a9	LNF	1	1	432.34	1.02	c9	LOF	1	1	456.53	1.08
a9	LNF	1	2	447.75	1.06	c9	LOF	1	2	426.5	1.01
a10	NOF	1	1	428.28	1.01	c10	LNOF	0	1	412.28	0.97
a10	NOF	1	2	440.09	1.04	c10	LNOF	0	2	458.11	1.08
a11	zero	1	1	443.49	1.05	c11	NOF	1	1	408.3	0.96
a11	zero	1	2	432.28	1.02	c11	NOF	1	2	452.61	1.07
a12	NOL	1	1	433.85	1.02	c12	NOL	1	1	479.83	1.13
a12	NOL	1	2	417.61	0.99	c12	NOL	1	2	490.83	1.16
b1	LOF	1	1	465.06	1.1	d1	zero	0	1	534.76	
b1	LOF	1	2	450.6	1.06	d1	zero	0	2	507.2	1.26
b2	NOF	0	1	457.39	1.08	d2	LNOF	0	1	516.62	1.2
b2	NOF	0	2	468.52	1.11	d2	LNOF	0	2	496.23	1.22
b3	LOF	0	1	519.71	1.23	d3	LOF	0	1	501.51	1.17
b3	LOF	0	2	466.04	1.1	d3	LOF	0	2	475.68	1.19
b4	zero	1	1	484.31	1.14	d4	NOF	1	1	485.83	1.12
b4	zero	1	2	478.17	1.13	d4	NOF	1	2	494.64	1.15
b5	LNOF	1	1	444.44	1.05	d5	zero	1	1	475.99	1.17
b5	LNOF	1	2	481.28	1.14	d5	zero	1	2	490.23	1.12
b6	zero	0	1	491.63	1.16	d6	LNF	1	1	465.85	1.16
b6	zero	0	2	481.93	1.14	d6	LNF	1	2	451.13	1.1
b7	NOF	0	1	459.49	1.09	d7	LNOF	1	1	497.94	1.07
b7	NOF	0	2	452.34	1.07	d7	LNOF	1	2	460.79	1.18
b8	NOL	0	1	479.04	1.13	d8	LNF	0	1	450.31	1.09
b8	NOL	0	2	482.95	1.14	d8	LNF	0	2	469.49	1.06
b9	LNOF	1	1	473.46	1.12	d9	NOF	0	1	447.21	1.11
b9	LNOF	1	2	441.74	1.05	d9	NOF	0	2	498.81	1.06
b10	LNF	0	1	488.24	1.15	d10	zero	0	1	488.14	1.18
b10	LNF	0	2	432.07	1.02	d10	zero	0	2	490.93	1.15
b11	LOF	1	1	489.8	1.16	d11	LNF	1	1	539.43	1.16
b11	LOF	1	2	437.61	1.03	d11	LNF	1	2	495.83	1.28
b12	LOF	0	1	406.49	0.96	d12	LOF	0	1	468.94	1.17
b12	LOF	0	2	390.77	0.92	d12	LOF	0	2	525.61	1.11

Appendix 47: Effect of treatment application and *A. longa* introduction on soil bulk density at Perth management trial .(*0- *A. longa* absent; 1- *A. longa* present).

Plot	Treatment	Intro*	Rep	Dry weight + paper bag (g)	Bulk density (g/cm3)	Plot	Treatment	Intro*	Rep	Dry weight + paper bag (g)	Bulk density (g/cm3)
a1	NOL	0	1	574.31	1.36	c1	NOL	1	1	555.24	1.31
a1	NOL	0	2	585.85	1.39	c1	NOL	1	2	578.31	1.37
a2	NOF	1	1	512.52	1.21	c2	NOF	0	1	600.66	1.42
a2	NOF	1	2	549.24	1.30	c2	NOF	0	2	561.51	1.33
a3	LNF	0	1	586.9	1.39	c3	LNOF	1	1	564.69	1.34
a3	LNF	0	2	535.57	1.27	c3	LNOF	1	2	575.76	1.36
a4	NOL	1	1	555.58	1.31	c4	LNF	0	1	541.05	1.28
a4	NOL	1	2	563.78	1.33	c4	LNF	0	2	536.76	1.27
a5	LNF	1	1	571.86	1.35	c5	LOF	1	1	516.91	1.22
a5	LNF	1	2	561.22	1.33	c5	LOF	1	2	569.59	1.35
a6	LNOF	0	1	568.77	1.35	c6	NOL	0	1	589.51	1.40
a6	LNOF	0	2	574.3	1.36	c6	NOL	0	2	575.74	1.36
a7	zero	0	1	552.41	1.31	c7	NOL	0	1	536.96	1.27
a7	zero	0	2	552.37	1.31	c7	NOL	0	2	552.13	1.31
a8	LNOF	0	1	550.83	1.30	c8	zero	1	1	592.94	1.40
a8	LNOF	0	2	572.64	1.36	c8	zero	1	2	546.64	1.29
a9	LNF	1	1	553.67	1.31	c9	LOF	1	1	581.03	1.38
a9	LNF	1	2	547.03	1.29	c9	LOF	1	2	564.39	1.34
a10	NOF	1	1	558.58	1.32	c10	LNOF	0	1	546.17	1.29
a10	NOF	1	2	519.14	1.23	c10	LNOF	0	2	574.98	1.36
a11	zero	1	1	546.85	1.29	c11	NOF	1	1	567.8	1.34
a11	zero	1	2	533.87	1.26	c11	NOF	1	2	551.08	1.30
a12	NOL	1	1	512.26	1.21	c12	NOL	1	1	537.69	1.27
a12	NOL	1	2	511.93	1.21	c12	NOL	1	2	506.78	1.20
b1	LOF	1	1	575.21	1.36	d1	zero	0	1	578.4	1.37
b1	LOF	1	2	572.27	1.35	d1	zero	0	2	556.37	1.32
b2	NOF	0	1	579.6	1.37	d2	LNOF	0	1	529.56	1.25
b2	NOF	0	2	561.84	1.33	d2	LNOF	0	2	558.45	1.32
b3	LOF	0	1	555.89	1.32	d3	LOF	0	1	598.6	1.42
b3	LOF	0	2	575.3	1.36	d3	LOF	0	2	578.82	1.37
b4	zero	1	1	562.19	1.33	d4	NOF	1	1	590.5	1.40
b4	zero	1	2	600.91	1.42	d4	NOF	1	2	526.26	1.25
b5	LNOF	1	1	584.86	1.38	d5	zero	1	1	585.02	1.39
b5	LNOF	1	2	586.93	1.39	d5	zero	1	2	556.6	1.32
b6	zero	0	1	612.44	1.45	d6	LNF	1	1	60268	1.43
b6	zero	0	2	567.48	1.34	d6	LNF	1	2	575.56	1.36
b7	NOF	0	1	554.17	1.31	d7	LNOF	1	1	565.07	1.34
b7	NOF	0	2	572.74	1.36	d7	LNOF	1	2	534.51	1.26
b8	NOL	0	1	528.67	1.25	d8	LNF	0	1	539.37	1.28
b8	NOL	0	2	527.23	1.25	d8	LNF	0	2	543.44	1.29
b9	LNOF	1	1	522.89	1.24	d9	NOF	0	1	550.48	1.30
b9	LNOF	1	2	549.44	1.30	d9	NOF	0	2	573.72	1.36
b10	LNF	0	1	550.09	1.30	d10	zero	0	1	587.55	1.39
b10	LNF	0	2	549.93	1.30	d10	zero	0	2	536.01	1.27
b11	LOF	1	1	517.81	1.22	d11	LNF	1	1	571.68	1.35
b11	LOF	1	2	546.23	1.29	d11	LNF	1	2	575.46	1.36
b12	LOF	0	1	520.13	1.23	d12	LOF	0	1	562.53	1.33
b12	LOF	0	2	559.65	1.32	d12	LOF	0	2	558.03	1.32

Appendix 48: Summary of the effect of treatment application on bulk density at Oatlands and Perth in January 1994.

Treatment	Bulk density (g/cm^3)	
	Oatlands	Perth
zero	1.13	1.33
LNOF	1.13	1.33
LOF	1.09	1.32
NOF	1.10	1.32
LNF	1.09	1.32
NOL	1.15	1.29

Appendix 49: Summary of the effect of *A. longa* introduction on bulk density at Oatlands and Perth in January 1994.

Earthworm introduction	Bulk density (g/cm^3)	
	Oatlands	Perth
- A. longa	1.12	1.33
+A. longa	1.10	1.31

Appendix 50: Average masses calculated from life cycle data used to estimate earthworm biomass from management trial sites at Oatlands and Perth.

Stage	Earthworm species				
	A. caliginosa	A. trapezoides	A. longa	O. cyaneum	L. rubellus
j	0.2	0.2	0.31	0.32	0.2
a	0.2	0.42	0.5	1.19	0.9
b	0.5	0.36	0.75	1.45	0.9
c	0.8	1.11	1.11	1.50	1.05

Appendix 51: The effect of offering dung with ivermectin (I) and without ivermectin (C) on the growth of earthworm species.

week	species	rep	treatment	worm no.	mass (g)	week	species	rep	treatment	worm no.	mass (g)
0	cal	1	C	1	0.83	0	cal	1	I	1	0.6
0	cal	1	C	2	0.66	0	cal	1	I	2	0.66
0	cal	1	C	3	0.51	0	cal	1	I	3	0.58
0	cal	2	C	1	0.61	0	cal	2	I	1	0.76
0	cal	2	C	2	0.31	0	cal	2	I	2	0.82
0	cal	2	C	3	0.82	0	cal	2	I	3	0.62
0	cal	3	C	1	0.71	0	cal	3	I	1	0.44
0	cal	3	C	2	0.61	0	cal	3	I	2	0.74
0	cal	3	C	3	0.5	0	cal	3	I	3	0.56
0	cal	4	C	1	0.6	0	cal	4	I	1	0.69
0	cal	4	C	2	0.89	0	cal	4	I	2	0.68
0	cal	4	C	3	0.71	0	cal	4	I	3	0.73
0	trap	1	C	1	1.77	0	trap	1	I	1	1.19
0	trap	1	C	2	1	0	trap	1	I	2	1.16
0	trap	1	C	3	1.29	0	trap	1	I	3	0.76
0	trap	2	C	1	0.63	0	trap	2	I	1	1.34
0	trap	2	C	2	1.09	0	trap	2	I	2	0.91
0	trap	2	C	3	1.13	0	trap	2	I	3	1.02
0	trap	3	C	1	1.73	0	trap	3	I	1	1.23
0	trap	3	C	2	1.36	0	trap	3	I	2	1.16
0	trap	3	C	3	1.19	0	trap	3	I	3	0.89
0	trap	4	C	1	1.16	0	trap	4	I	1	1.42
0	trap	4	C	2	1.42	0	trap	4	I	2	0.96
0	trap	4	C	3	1.1	0	trap	4	I	3	0.74
0	rub	1	C	1	0.56	0	rub	1	I	1	0.83
0	rub	1	C	2	1.14	0	rub	1	I	2	1.38
0	rub	1	C	3	1.27	0	rub	1	I	3	0.84
0	rub	2	C	1	1.37	0	rub	2	I	1	0.89
0	rub	2	C	2	0.71	0	rub	2	I	2	1.1
0	rub	2	C	3	0.95	0	rub	2	I	3	1.35
0	rub	3	C	1	0.71	0	rub	3	I	1	1.47
0	rub	3	C	2	1.27	0	rub	3	I	2	0.97
0	rub	3	C	3	0.8	0	rub	3	I	3	1.21
0	rub	4	C	1	0.72	0	rub	4	I	1	0.66
0	rub	4	C	2	0.86	0	rub	4	I	2	0.86
0	rub	4	C	3	0.65	0	rub	4	I	3	0.98
0	longa	1	C	1	1.43	0	longa	1	I	1	2.08
0	longa	2	C	1	2.84	0	longa	2	I	1	1.9
0	longa	3	C	1	2.2	0	longa	3	I	1	1.87
0	longa	4	C	1	1.36	0	longa	4	I	1	2.4

Appendix 51 (Continued).

date	species	rep	treatment	worm no.	mass (g)	date	species	rep	treatment	worm no.	mass (g)
1	cal	1	C	1	0.89	1	cal	1	I	1	0.84
1	cal	1	C	2	0.92	1	cal	1	I	2	0.87
1	cal	1	C	3	1.12	1	cal	1	I	3	0.69
1	cal	2	C	1	0.54	1	cal	2	I	1	0.76
1	cal	2	C	2	0.98	1	cal	2	I	2	1
1	cal	2	C	3	1.06	1	cal	2	I	3	0.8
1	cal	3	C	1	0.93	1	cal	3	I	1	0.75
1	cal	3	C	2	0.92	1	cal	3	I	2	0.87
1	cal	3	C	3	0.65	1	cal	3	I	3	0.65
1	cal	4	C	1	1.02	1	cal	4	I	1	0.96
1	cal	4	C	2	0.92	1	cal	4	I	2	0.91
1	cal	4	C	3	1	1	cal	4	I	3	0.91
1	trap	1	C	1	1.91	1	trap	1	I	1	1.23
1	trap	1	C	2	2.04	1	trap	1	I	2	1.33
1	trap	1	C	3	1.45	1	trap	1	I	3	1.7
1	trap	2	C	1	1.3	1	trap	2	I	1	1.76
1	trap	2	C	2	1.12	1	trap	2	I	2	1.47
1	trap	2	C	3	1.82	1	trap	2	I	3	1.25
1	trap	3	C	1	2.2	1	trap	3	I	1	1.64
1	trap	3	C	2	1.83	1	trap	3	I	2	1.64
1	trap	3	C	3	1.43	1	trap	3	I	3	1.58
1	trap	4	C	1	1.49	1	trap	4	I	1	1.27
1	trap	4	C	2	1.84	1	trap	4	I	2	1.03
1	trap	4	C	3	1.4	1	trap	4	I	3	1.4
1	rub	1	C	1	1.75	1	rub	1	I	1	1.53
1	rub	1	C	2	0.86	1	rub	1	I	2	1.19
1	rub	1	C	3	1.58	1	rub	1	I	3	1.09
1	rub	2	C	1	1.7	1	rub	2	I	1	1.18
1	rub	2	C	2	0.95	1	rub	2	I	2	1.48
1	rub	2	C	3	1.26	1	rub	2	I	3	1.4
1	rub	3	C	1	1.24	1	rub	3	I	1	1.81
1	rub	3	C	2	1.67	1	rub	3	I	2	1.54
1	rub	3	C	3	1.07	1	rub	3	I	3	1.38
1	rub	4	C	1	0.84	1	rub	4	I	1	1.31
1	rub	4	C	2	0.98	1	rub	4	I	2	1.38
1	rub	4	C	3	1.26	1	rub	4	I	3	0.99
1	longa	1	C	1	2.31	1	longa	1	I	1	2.22
1	longa	2	C	1	3.33	1	longa	2	I	1	2.03
1	longa	3	C	1	3	1	longa	3	I	1	1.92
1	longa	4	C	1	1.87	1	longa	4	I	1	2.88

Appendix 51 (Continued).

date	species	rep	treatment	worm no.	mass (g)	date	species	rep	treatment	worm no.	mass (g)
2	cal	1	C	1	1.29	2	cal	1	I	1	0.87
2	cal	1	C	2	0.95	2	cal	1	I	2	0.85
2	cal	1	C	3	0.97	2	cal	1	I	3	0.79
2	cal	2	C	1	1.12	2	cal	2	I	1	0.97
2	cal	2	C	2	1.04	2	cal	2	I	2	1.01
2	cal	2	C	3	0.64	2	cal	2	I	3	1.23
2	cal	3	C	1	1.05	2	cal	3	I	1	0.76
2	cal	3	C	2	1.01	2	cal	3	I	2	0.72
2	cal	3	C	3	0.74	2	cal	3	I	3	1.03
2	cal	4	C	1	0.96	2	cal	4	I	1	0.84
2	cal	4	C	2	0.99	2	cal	4	I	2	0.61
2	cal	4	C	3	1.1	2	cal	4	I	3	*
2	trap	1	C	1	1.96	2	trap	1	I	1	1.3
2	trap	1	C	2	1.67	2	trap	1	I	2	1.92
2	trap	1	C	3	1.9	2	trap	1	I	3	1.39
2	trap	2	C	1	1.76	2	trap	2	I	1	1.36
2	trap	2	C	2	1.56	2	trap	2	I	2	1.84
2	trap	2	C	3	1.29	2	trap	2	I	3	1.53
2	trap	3	C	1	1.23	2	trap	3	I	1	1.48
2	trap	3	C	2	2.04	2	trap	3	I	2	1.71
2	trap	3	C	3	2.33	2	trap	3	I	3	1.66
2	trap	4	C	1	1.55	2	trap	4	I	1	1.14
2	trap	4	C	2	1.64	2	trap	4	I	2	1.26
2	trap	4	C	3	1.69	2	trap	4	I	3	1.3
2	rub	1	C	1	1.56	2	rub	1	I	1	1.22
2	rub	1	C	2	1.73	2	rub	1	I	2	1.08
2	rub	1	C	3	0.8	2	rub	1	I	3	1.34
2	rub	2	C	1	1.03	2	rub	2	I	1	1.67
2	rub	2	C	2	1.58	2	rub	2	I	2	1.33
2	rub	2	C	3	1.39	2	rub	2	I	3	1.26
2	rub	3	C	1	1.41	2	rub	3	I	1	1.94
2	rub	3	C	2	1.71	2	rub	3	I	2	1.38
2	rub	3	C	3	1.22	2	rub	3	I	3	1.42
2	rub	4	C	1	0.88	2	rub	4	I	1	1.72
2	rub	4	C	2	1.05	2	rub	4	I	2	1.12
2	rub	4	C	3	1.2	2	rub	4	I	3	1.49
2	longa	1	C	1	2.75	2	longa	1	I	1	2.95
2	longa	2	C	1	3.49	2	longa	2	I	1	1.83
2	longa	3	C	1	2.73	2	longa	3	I	1	1.8
2	longa	4	C	1	1.97	2	longa	4	I	1	2.25

Appendix 51 (Continued).

date	species	rep	treatment	worm no.	mass (g)	date	species	rep	treatment	worm no.	mass (g)
3	cal	1	C	1	1.09	3	cal	1	I	1	0.86
3	cal	1	C	2	1.12	3	cal	1	I	2	0.83
3	cal	1	C	3	1.25	3	cal	1	I	3	0.84
3	cal	2	C	1	1.12	3	cal	2	I	1	1.4
3	cal	2	C	2	1.21	3	cal	2	I	2	1.11
3	cal	2	C	3	0.72	3	cal	2	I	3	1.09
3	cal	3	C	1	0.82	3	cal	3	I	1	1.05
3	cal	3	C	2	1.06	3	cal	3	I	2	0.68
3	cal	3	C	3	1.04	3	cal	3	I	3	1.05
3	cal	4	C	1	0.89	3	cal	4	I	1	1.18
3	cal	4	C	2	*	3	cal	4	I	2	1.04
3	cal	4	C	3	0.87	3	cal	4	I	3	0.68
3	trap	1	C	1	1.74	3	trap	1	I	1	2.03
3	trap	1	C	2	2.16	3	trap	1	I	1	1.43
3	trap	1	C	3	2.13	3	trap	1	I	1	1.42
3	trap	2	C	1	1.65	3	trap	2	I	1	2.04
3	trap	2	C	2	2.01	3	trap	2	I	2	1.59
3	trap	2	C	3	1.44	3	trap	2	I	3	1.33
3	trap	3	C	1	1.23	3	trap	3	I	1	1.93
3	trap	3	C	2	2.62	3	trap	3	I	2	2.08
3	trap	3	C	3	1.91	3	trap	3	I	3	1.73
3	trap	4	C	1	1.76	3	trap	4	I	1	1.24
3	trap	4	C	2	1.58	3	trap	4	I	2	1.28
3	trap	4	C	3	*	3	trap	4	I	3	1.47
3	rub	1	C	1	0.89	3	rub	1	I	1	0.85
3	rub	1	C	2	1.56	3	rub	1	I	2	1.1
3	rub	1	C	3	1.78	3	rub	1	I	3	1.24
3	rub	2	C	1	1.46	3	rub	2	I	1	1.06
3	rub	2	C	2	1.38	3	rub	2	I	2	1.45
3	rub	2	C	3	0.92	3	rub	2	I	3	1.17
3	rub	3	C	1	*	3	rub	3	I	1	1.78
3	rub	3	C	2	*	3	rub	3	I	2	1.29
3	rub	3	C	3	*	3	rub	3	I	3	1.32
3	rub	4	C	1	1.43	3	rub	4	I	1	1.66
3	rub	4	C	2	1.11	3	rub	4	I	2	1.58
3	rub	4	C	3	*	3	rub	4	I	3	1.1
3	longa	1	C	1	2.51	3	longa	1	I	1	2.51
3	longa	2	C	1	3.65	3	longa	2	I	1	1.98
3	longa	3	C	1	2.99	3	longa	3	I	1	2.19
3	longa	4	C	1	1.83	3	longa	4	I	1	2.53

Appendix 51 (Continued).

date	species	rep	treatment	worm no.	mass (g)	date	species	rep	treatment	worm no.	mass (g)
4	cal	1	C	1	1.18	4	cal	1	I	1	0.98
4	cal	1	C	2	1.29	4	cal	1	I	2	0.89
4	cal	1	C	3	1.37	4	cal	1	I	3	0.93
4	cal	2	C	1	1.17	4	cal	2	I	1	1.16
4	cal	2	C	2	1.22	4	cal	2	I	2	1.33
4	cal	2	C	3	0.73	4	cal	2	I	3	1.11
4	cal	3	C	1	1.03	4	cal	3	I	1	0.87
4	cal	3	C	2	1.19	4	cal	3	I	2	1.12
4	cal	3	C	3	0.74	4	cal	3	I	3	0.63
4	cal	4	C	1	1.14	4	cal	4	I	1	1.16
4	cal	4	C	2	0.92	4	cal	4	I	2	1.23
4	cal	4	C	3	*	4	cal	4	I	3	0.83
4	trap	1	C	1	2.16	4	trap	1	I	1	1.53
4	trap	1	C	2	1.94	4	trap	1	I	2	1.94
4	trap	1	C	3	2.15	4	trap	1	I	3	1.5
4	trap	2	C	1	1.54	4	trap	2	I	1	1.7
4	trap	2	C	2	1.42	4	trap	2	I	2	1.51
4	trap	2	C	3	*	4	trap	2	I	3	1.82
4	trap	3	C	1	2.23	4	trap	3	I	1	1.7
4	trap	3	C	2	1.95	4	trap	3	I	2	1.87
4	trap	3	C	3	1.27	4	trap	3	I	3	2.08
4	trap	4	C	1	1.7	4	trap	4	I	1	1.67
4	trap	4	C	2	1.7	4	trap	4	I	2	1.12
4	trap	4	C	3	*	4	trap	4	I	3	1.08
4	rub	1	C	1	1.14	4	rub	1	I	1	1.39
4	rub	1	C	2	1.82	4	rub	1	I	2	1.29
4	rub	1	C	3	1.63	4	rub	1	I	3	1.17
4	rub	2	C	1	1.58	4	rub	2	I	1	1.32
4	rub	2	C	2	1.45	4	rub	2	I	2	1.14
4	rub	2	C	3	*	4	rub	2	I	3	0.95
4	rub	3	C	1	*	4	rub	3	I	1	2.12
4	rub	3	C	2	*	4	rub	3	I	2	1.5
4	rub	3	C	3	*	4	rub	3	I	3	1.37
4	rub	4	C	1	1.28	4	rub	4	I	1	1.66
4	rub	4	C	2	1.42	4	rub	4	I	2	1.6
4	rub	4	C	3	*	4	rub	4	I	3	1.14
4	longa	1	C	1	2.4	4	longa	1	I	1	2.34
4	longa	2	C	1	3.02	4	longa	2	I	1	2.1
4	longa	3	C	1	*	4	longa	3	I	1	2.6
4	longa	4	C	1	1.73	4	longa	4	I	1	2.7

Appendix 51 (Continued).

date	species	rep	treatment	worm no.	mass (g)	date	species	rep	treatment	worm no.	mass (g)
5	cal	1	C	1	1.56	5	cal	1	I	1	1.07
5	cal	1	C	2	1	5	cal	1	I	2	0.92
5	cal	1	C	3	1.29	5	cal	1	I	3	0.87
5	cal	2	C	1	0.76	5	cal	2	I	1	1.56
5	cal	2	C	2	1.26	5	cal	2	I	2	1.28
5	cal	2	C	3	1.04	5	cal	2	I	3	1.12
5	cal	3	C	1	1.12	5	cal	3	I	1	0.86
5	cal	3	C	2	0.63	5	cal	3	I	2	1.21
5	cal	3	C	3	1.33	5	cal	3	I	3	0.96
5	cal	4	C	1	1.11	5	cal	4	I	1	1.12
5	cal	4	C	2	0.95	5	cal	4	I	2	0.87
5	cal	4	C	3	*	5	cal	4	I	3	1.33
5	trap	1	C	1	2.12	5	trap	1	I	1	1.73
5	trap	1	C	2	2.08	5	trap	1	I	2	2.09
5	trap	1	C	3	2.02	5	trap	1	I	3	1.63
5	trap	2	C	1	1.55	5	trap	2	I	1	1.58
5	trap	2	C	2	*	5	trap	2	I	2	1.84
5	trap	2	C	3	*	5	trap	2	I	3	1.78
5	trap	3	C	1	2.12	5	trap	3	I	1	1.69
5	trap	3	C	2	1.48	5	trap	3	I	2	1.56
5	trap	3	C	3	*	5	trap	3	I	3	1.97
5	trap	4	C	1	2	5	trap	4	I	1	1.06
5	trap	4	C	2	1.9	5	trap	4	I	2	1.2
5	trap	4	C	3	*	5	trap	4	I	3	1.26
5	rub	1	C	1	1.78	5	rub	1	I	1	1.4
5	rub	1	C	2	2	5	rub	1	I	2	1.42
5	rub	1	C	3	1.14	5	rub	1	I	3	1.64
5	rub	2	C	1	1.38	5	rub	2	I	1	1.22
5	rub	2	C	2	1.63	5	rub	2	I	2	1.58
5	rub	2	C	3	*	5	rub	2	I	3	1.42
5	rub	3	C	1	*	5	rub	3	I	1	1.52
5	rub	3	C	2	*	5	rub	3	I	2	2.14
5	rub	3	C	3	*	5	rub	3	I	3	1.47
5	rub	4	C	1	1.7	5	rub	4	I	1	1.6
5	rub	4	C	2	1.37	5	rub	4	I	2	1.71
5	rub	4	C	3	*	5	rub	4	I	3	1.03
5	longa	1	C	1	2.76	5	longa	1	I	1	2.24
5	longa	2	C	1	3.95	5	longa	2	I	1	2.45
5	longa	3	C	1	*	5	longa	3	I	1	2.87
5	longa	4	C	1	1.72	5	longa	4	I	1	2.21

Appendix 52: The effect of offering dung with ivermectin (I) and without ivermectin (C) on cocoon production of earthworms.

species	rep	treatment	egg no.	species	rep	treatment	egg no.
cal	1	C	14	cal	1	I	10
cal	2	C	0	cal	2	I	11
cal	3	C	24	cal	3	I	12
cal	4	C	17	cal	4	I	6
trap	1	C	13	trap	1	I	18
trap	2	C	9	trap	2	I	14
trap	3	C	11	trap	3	I	21
trap	4	C	1	trap	4	I	6
rub	1	C	17	rub	1	I	15
rub	2	C	21	rub	2	I	18
rub	3	C	*	rub	3	I	28
rub	4	C	18	rub	4	I	7
longa	1	C	0	longa	1	I	0
longa	2	C	0	longa	2	I	0
longa	3	C	0	longa	3	I	0
longa	4	C	0	longa	4	I	0