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## **Waste-free: 'Vermicompost' to Improve Agricultural Soils**

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# Waste-free: 'Vermicompost' to improve Agricultural Soils

## Executive Summary

All urban areas in Australia face increasing difficulty in dealing with their solid wastes. More than 40% of these are organic and have the potential to be recycled through their agricultural use as soil ameliorants or fertilisers. Organic amendments, such as sludges, manures, and compost are well known to act as organic fertilisers whilst improving the chemical and physical properties of soils. Soil structure decline and the accumulation of phyto-toxic concentrations of aluminium accompanying soil acidification (a naturally occurring process accelerated by agriculture) are among the greatest limitations to agricultural productivity in Australia. Organic amendments offer the potential to arrest or reverse this degradation of the soil resource.

Composting or vermicomposting processes can be conducted at minimal cost in any location in Australia, and if the resulting product is of a consistent and high quality it should enable the waste resources of urban centres to be recycled to agricultural lands. However, the cost of transport of the product from its urban source to the point of use must be able to be shown to be offset by the value of the product to the user, so it is important to establish a benefit of compost addition. This project explored the effects on plant growth and on soil physical and chemical properties of the application vermicompost or compost to a crop (oats) and a pasture. The vermicompost and compost used were produced by the ACT Organic Waste Recycling unit from vegetable and garden waste.

The vermicompost and compost were analysed to determine their important chemical constituents. The concentrations of all elements that were measured were higher in the compost compared to those in the vermicompost. Carbon contents of both the vermicompost and compost were at the lower end of the range of values reported in the literature, similar to those for composted garden waste. Because carbon is the main indicator of nutrient availability it is therefore likely that the materials used in our trials will be less effective in improving soil conditions and plant growth than some other composted materials.

Standard agronomic practices were followed in establishing and managing the trials and determining growth response of the oats and pasture. As well as six rates of vermicompost (up to 20 t/ha) and two rates of compost (up to 20 t/ha), three rates of fertiliser application and control treatments were included. Conventional soil chemical and soil physical measurement techniques were used to determine the effect on a number of key soil properties, namely mineral nitrogen, mineralisation rate of soil organic nitrogen, pH and cation status, bulk density, soil water retention and soil aggregate stability.

One of the expected benefits of the application of composted organic waste is that it will contribute nitrogen to the soil. To be able to be taken up and used by plants, however, this nitrogen must be in inorganic form, as nitrate or ammonium. Monitoring showed that there were no increases in the concentration of inorganic N in the soil in response to vermicompost or compost addition. Measurements of the release of inorganic nitrogen (mineralisation) by

natural decomposition of organic matter also showed little effect of the addition of vermicompost or compost. Similarly, measurements of microbial biomass in the soil, an indicator of the rate of turnover of nutrients in the soil, showed no response to applications of vermicompost or compost.

Perhaps the most effective indicator of improved soil condition is improved crop growth. Increased growth and nitrogen accumulation under the fertiliser treatments showed that there was potential for a response at each site. However no significant effect on plant growth was observed for either the vermicompost or compost applications. Nor was there any increase in the accumulation of nitrogen in the plants in response to vermicompost or compost application, indicating that the nitrogen fertiliser value of the materials were low.

Beneficial trends of increased pH, decreased aluminium saturation and increased calcium saturation in the surface soil were observed following application of vermicompost or compost. No marked improvements in soil physical condition (bulk density, soil water retention, and aggregate stability) were observed, although there were indications of a trend to beneficial changes.

Comparison of the results from this study with those from the literature suggest that significant benefits are only likely to be produced by larger additions of vermicompost or compost, or by repeated additions of them. A greater beneficial effect of additions of composted materials may be able to be produced by increasing their organic carbon and nitrogen content or by increasing the amount of rapidly mineralised organic nitrogen. Co-composting with sewage sludge, or other material that has a higher organic N content, may achieve this.

## Introduction

All urban areas in Australia face increasing difficulty in dealing with their solid wastes. More than 40% of these are organic and cause the majority of management problems in landfill. Large proportions of organic wastes are suitable for recycling through their agricultural use as soil ameliorants or fertilisers. Such materials could be used either singularly or in conjunction with other urban wastes, and this has the potential to slow the degradation of agricultural soils. Organic amendments, such as sludges, manures, and spent mushroom compost have been shown to act as organic fertilisers whilst improving the physical properties of soils (Mays *et al.*, 1973; Gupta *et al.* 1973; Metzger and Yaron, 1987; Tester, 1990, Gusquiani *et al.* 1995). Composting or vermicomposting processes can be conducted at minimal cost in any location in Australia, and if the resulting product is of a consistent and high quality it should enable the waste resources of urban centres to be recycled to agricultural lands. However, the cost of transport of the product from its urban source to the point of use must be able to be shown to be offset by the value of the product to the user, so it is important to establish an economic benefit of compost addition.

Organic sludges, manures and compost, when applied at high rates, have been reported to raise soil pH, decrease soil bulk density, improve aggregate stability and increase the soil carbon content (Metzger and Yaron, 1987; Khaleel *et al.*, 1981; Serra-Wittling *et al.*, 1996; Stewart *et al.*, 1998). Large amounts of the nutrients nitrogen (N) and phosphorus (P) are generally applied in these types of materials and increased plant growth has been reported. Decay of the organic carbon, and the release of nutrients from the organic pool into a plant available pool, is characterised by an initially rapid phase followed by a slower rate of decline as the material appears to approach an "equilibrium value" (Metzger and Yaron, 1987). Heavy applications (>40 t/ha) of municipal compost, made by the composting garbage wastes and up to 20% sewage sludge, produced significant yield responses with sorghum, corn and bermudagrass (Mays *et al.* 1973). Incorporation of the compost increased soil pH, organic matter, calcium, and magnesium concentrations in the soil. In the above trials, the compost was applied at rates that ranged from 46 to 164 t/ha; the increases in soil pH varied from 0.8 to 1.1. Similar findings were reported by Stewart *et al.* (1998a), who measured an increase in soil pH of 0.7, 29 weeks after final application of spent mushroom compost. A total of 192 t/ha (dry-weight basis) was applied in four applications.

Soil structure decline and the accumulation of phyto-toxic concentrations of aluminium accompanying soil acidification (a naturally occurring process accelerated by agriculture) are among the greatest limitations to agricultural productivity. The central and southern slopes of NSW have the most serious and extensive problem. In other areas, although the problem is less severe, acidification will continue to develop because of the net export of basic cations in agricultural products (Helyar and Porter, 1989). The full extent of the problems and the cost in terms of lost production has only recently been realised. The Murray-Darling Basin Environmental Resource Study (1994) estimated the cost of soil structure decline within the Basin at \$144 M per year, whereas acidification in south eastern Australia is estimated to cost \$300 million/year.

Adding composted urban waste to soil, particularly at rates that result in increased soil organic matter contents, may offer a way of reversing soil structural decline, improving plant growth and counteracting trends of declining soil pH.

The objectives of the work reported here were to determine the effect of vermicompost or compost application on soil physical and chemical properties and plant growth under crop-

ping and pasture production, and to compare these effects with inorganic fertiliser. While the ultimate goal is increased productivity, improvement in soil chemical and physical conditions has a tangible benefit in reversing the degradation of the soil resource.

## **Material and methods**

### *Site*

The study investigated the effects of six rates of vermicompost, two rates of compost and three rates of fertiliser in a randomised block design with three replicates on acid soils sown to either pasture or crop. The rates selected were based on preliminary findings from pot and field trials undertaken by the ACT Organic Waste Recycling unit using similar vermicompost. The pasture site was located north of Yass on land owned by John Weatherstone. This site was selected after consultation with the Yass LandCare Coordinator (Annabel Kater). The cropping site was on land owned by Roger Clark near Boorowa, and was selected after consultation with the Boorowa LandCare Coordinator (Janelle Jenkins).

The Boorowa site had been sown to wheat and oat crops in the previous years. The stubble was grazed and burnt. The site was sprayed with herbicide and cultivated with a tine implement to a depth of 100 mm in late April 1998. Six rates of vermicompost (0, 1, 2, 5, 10 and 20 t/ha), two rates of compost (5 and 20 t/ha) and 3 rates of nitrogen fertiliser (25, 50 and 100 kg N/ha) were applied to plots (25 m by 2 m) on 6 May 98. The nitrogen fertiliser used was ammonium nitrate. Triphosphate (20.7 % P) was broadcast over all the plots at 25 kg P/ha, and the plots cultivated with a rotary power harrow (Lely Roter) to incorporate the compost and fertiliser in the surface 50 mm layer. Oats was sown in rows 150 mm apart at a seeding rate of 100 kg/ha on 7 May 1998. The oats were harvested for hay on 25 November 1998.

The Yass site had been managed under a grazed annual pasture for the past five years. The dominant species was annual rye grass. The site was cultivated in mid April with a tine implement. Six rates of vermicompost (0, 1, 2, 5, 10 and 20 t/ha), two rates of compost (5 and 20 t/ha) and 3 rates on potassium (10, 25 and 50 kg K/ha) were applied to plots (25 m by 2 m) on 6 May 98. Potassium was applied as Muriate Potash at Yass because pasture establishment and growth is generally improved by this element. The site was cultivated with a rotary harrow to incorporate the compost and fertiliser to a depth of about 50 mm and the pasture sown on 7 May 1998. The establishment of the pasture was poor due to the late break of season, and the site was re-sown on 14 July 1998. Species sown in the pasture were Victoria rye grass (2 kg/ha), Goulburn sub-clover (4 kg/ha), Goss sub-clover (4 kg/ha), Haifa white clover (2 kg/ha), Demeter tall fescue (8 kg/ha), and Currie cocksfoot (2 kg/ha). The pasture was harvest 25 November 1998.

### *Source and composition of the vermicompost and compost*

The compost used in this trial was made from organic wastes collected from the Fyshwick Markets, and a commercial vegetable wholesaler. This was mixed with shredded organic urban wastes (lawn clipping and tree pruning) and the compost converted to vermicompost at the worm farm operated by the ACT Organic Waste Recycling unit.

In order to understand the effects of compost additions to the soil, it is necessary to know their chemical composition, at least in relation to the major constituents that may contribute to improved soil chemical and physical condition.

The total sodium (Na), potassium (K), calcium (Ca) and magnesium (Mg), aluminium (Al) concentrations were determined by acid digestion in a microwave oven (USEPA method 3051) followed by ICP analysis. Total C and N were determined by direct combustion using a Leco CNS analyser (Model CNS-2000). Soluble carbon was determined by extracting the samples with water (1:5 soil to water extract) and analysing the carbon concentration on a Dohrmann DC-180. The total carbon content of the extract was determined by oxidation with UV/persulfate in acid solution. Inorganic carbon was determined by measuring the amount of carbon dioxide evolved when the sample was purged in an acid solution. Dissolved Organic Carbon was determined as the difference between the total carbon and inorganic C concentrations.

### ***Crop growth and nitrogen accumulation***

Perhaps the most effective indicator of improved soil condition is improved crop growth, so this is an important measure to demonstrate the benefit of soil amendments. Accumulation of nutrients in the plant material indicates the fertiliser value of the material.

Samples of plant material were taken at selected times throughout the year. Sampling consisted of cutting the plant material level with the soil surface from one location selected at random in each plot. Plant material was collected from 0.5-m sections of 3 adjacent rows in the oat crop, whereas all the material was cut from a quadrat (0.5 m<sup>2</sup>) in the pasture plots. The material was dried at 60°C and weighed to determine dry weight. The dried plant material was ground to pass a 0.42 mm sieve and retained for total N analysis.

At the final harvest, total biomass was determined by cutting all the aboveground plant material from an area of 5 to 6 m<sup>2</sup> in each plot. The material was dried at 60°C and weighed. A sub-sample was ground to pass a 0.42-mm sieve and total N content determined on a Leco CHS analyser (Model CNS-2000).

### ***Soil inorganic N***

Composted organic waste is expected to contain nitrogen. To be able to be taken up and used by plants, however, this nitrogen must be in inorganic form, as nitrate or ammonium. Consequently, monitoring the concentration of inorganic N in response to compost addition determines whether or not the soil's chemical fertility has been enhanced.

Cores (44 mm i.d.) were taken to a depth of 0.9 m in each plot the day after sowing and immediately after the final crop harvest. Cores were sectioned into 0-0.05, 0.05-0.10, 0.10-0.20, 0.20-0.30, 0.30-0.40, 0.40-0.50, 0.50-0.70, and 0.70-0.90 m depth intervals. After thorough mixing of the soil from each layer, NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> (including NO<sub>2</sub><sup>-</sup>) was extracted by shaking the equivalent of 10 g of dry soil with 100 cm<sup>3</sup> of 2 M KCl for 1 hour. The suspensions were filtered and the filtrate stored frozen until analysed. Ammonium was measured by reacting with hypochlorite liberated from dichlor-isocyanurate under alkaline conditions. The chloramine formed reacts under catalysis of nitroprusside with salicylate at a temperature of 37°C to form indophenol blue in an amount that is proportional to the ammonia concentration. The absorbance was measured at 660 nm. Nitrate was determined by quantitative reduction to nitrite by cadmium metal in a packed bed cadmium column using a segmented flow analyser. Gravimetric soil water content was measured by drying a sub-sample in an oven at 105°C.

### ***Net N mineralisation and microbial biomass***

While not immediately available to plants, nitrogen present in organic forms in the soil is transformed to the available inorganic forms as the organic matter decays, a process called mineralisation. Therefore, as well as knowing how much inorganic nitrogen is present in the soil at any time as a result of compost additions, it is important to know the rate at which the inorganic nitrogen is released from organic forms in the compost. This rate can be measured directly. Another useful indicator is microbial biomass, which regulates the turnover and storage of nutrients. It is the labile component of the soil organic matter, and the size and activity of the soil microbial biomass that determines the breakdown of organic matter and the release of nutrients. In addition, changes in microbial biomass can be used to monitor the toxicity of pollutants.

Net mineralisation rates were estimated by incubating soil (0-300 mm) in tubes (50 mm i.d.) driven into the soil (Raison *et al.*, 1987; Stein *et al.*, 1987). The mineralisation measurements were only carried out in the plots that received 0, 5, 10 and 20 t/ha of vermicompost or 5 or 20 t/ha of compost. The tubes were covered with a loose fitting container to prevent rainfall from leaching mineral N out of the tube. At 4 to 6 week intervals, two tubes were hammered into the soil in each plot; one tube was immediately removed, whereas the remaining tube was covered and incubated *in situ*.

After mixing of the soil from the tubes, ammonia ( $\text{NH}_4^+$ ) and nitrate ( $\text{NO}_3^-$ ; including  $\text{NO}_2^-$ ) was extracted by shaking the equivalent of 10 g of dry soil with 100 cm<sup>3</sup> of 2 M KCl for 1 hour (Keeney and Nelson, 1982). The suspensions were filtered and the filtrate stored frozen until analysed. The rate of net mineralisation was calculated from the accumulation of mineral N ( $\text{NH}_4^+$  plus  $\text{NO}_3^-$ ; including  $\text{NO}_2^-$ ) in the covered tubes:

$$\text{RNMIN} = [\text{N}_{(t+1)\text{cov}} - \text{N}_{t_0}] / (\Delta t) \quad (1)$$

where  $\text{N}_{\text{cov}}$  and  $\text{N}_{t_0}$  are the mineral N content of soil in the covered tube after incubation and soil at the beginning of the *in situ* incubation period. Microbial biomass N in the samples was determined using a fumigation/extraction method (Voroney *et al.*, 1993).

### ***Other soil chemical analyses***

Other chemical indicators of improved fertility in response to compost additions include soil pH, and soil exchangeable cation status. As described in the Introduction, many soils have become acidic as a result of agricultural practices and the low pH affects plant growth and productivity. An increase in soil pH as a result of compost addition would therefore be an indicator of a beneficial effect. Similarly a change in the composition of cations in the soil, and in particular an increase in the percentage of the total exchange capacity that is occupied by "basic" cations (Ca, Mg, Na, K) as opposed to "acidic" ones (H, Al), may indicate improved soil fertility.

Soil pH was measured in both water and 0.01 M  $\text{CaCl}_2$ . After the measurement of pH in water, 2.5 cm<sup>3</sup> of 0.21 M  $\text{CaCl}_2$  solution was added to the 50 cm<sup>3</sup> of suspension to obtain a 0.01 M  $\text{CaCl}_2$  solution (Method 4C2; Rayment and Higginson, 1992). The suspensions were immediately shaken for 15 minutes, allowed to settle for 20 to 30 minutes and the pH value recorded when a stable reading was obtained.

Exchangeable cations were determined by extracting 2.5 g of soil with 1M ammonium chloride ( $\text{NH}_4\text{Cl}$ ) after pre-treatment for soluble salts (Method 15B2; Rayment and Higginson,

1992). The concentration of exchangeable bases (Ca, Mg, Na and K) was measured in the  $\text{NH}_4\text{Cl}$  extracting solution. The cation exchange capacity of the soil was determined after leaching with 60% ethanol to remove any excess  $\text{NH}_4\text{Cl}$  solution from the soil and extractors. Ammonium held on the cation exchange sites was displaced by leaching with potassium nitrate and calcium nitrate solution. Data on exchangeable cations and cation exchange capacity are expressed as  $\text{cmol}(+)/\text{kg}$  of oven-dry soil. Aluminium and manganese were determined by extracting soil with 1M KCl for 1-hour using a 1:10 soil to solution ratio (Method 15G1; Rayment and Higginson, 1992).

### ***Soil physical properties***

Additions of compost and other organic materials are known to have effects on soil physical properties, including bulk density, soil water retention, hydraulic conductivity (permeability) and aggregate stability (Tester, 1990; Felton, 1995; Serra-Wittling et al., 1996; Abdel-Sabour, 1997; Stewart et al., 1998b). These properties determine the availability of water (and nutrients) to the plant directly as well as indirectly by affecting root growth. A decrease in bulk density, increase in soil water retention, increase in hydraulic conductivity and increase in aggregate stability would all be signs of improved soil physical conditions conducive to improved plant growth and productivity. Efforts in this study were concentrated on soil bulk density, water retention and aggregate stability. The effects of compost additions on hydraulic conductivity are very difficult to determine as a consequence of the large natural variability of this property (eg. Felton, 1995), so it was not measured in this study.

Natural variability of soil physical properties requires large numbers of measurements to be made to ensure statistical significance of any differences observed. Combined with the time consuming nature of the soil physical measurements, this required restriction of the number of treatments in which measurements were made to the control and the treatments with the largest additions of compost and vermicompost (20 t/ha) at each of the field sites.

Core samples for the soil physical measurements were collected in early November 1998 while the soil was still in a moist state after the spring rains. At the Boorowa site, three core samples were collected from each replicate of the control, 20 t/ha compost and 20 t/ha vermicompost treatments. At the Yass site, only replicates 2 and 3 were sampled because of the very different behaviour of replicate 1 observed from previous soil sampling. Five core samples were collected from replicate 2 and four from replicate 3, making a total of nine samples, as for the Boorowa site.

The samples were collected by driving thin-walled, stainless steel cores (75 mm diameter by 50 mm deep) into the soil, so that the top of the core was 10 mm below the soil surface. These were carefully excavated so as not to disturb the soil and transported to the laboratory where they were trimmed to length. The intact soil samples were then brought to saturation, following which they were equilibrated sequentially with soil water potentials of -10, -30, -50, -100, -340 and -600 cm of water. Weighing after each equilibration, and drying and weighing after the final equilibration enabled the determination of the soil bulk density and the soil water content at each of these soil water potentials.

A useful measure of soil aggregate stability is the water stable aggregate analysis (Kemper and Rosenau, 1986). This was carried on bulk soil samples collected at the time of sampling described above. Only one sample was collected in each of the treatment replicates sampled, from the top 20 mm of soil. The samples were sieved to obtain aggregates between 1 and 2 mm in diameter, a weighed sub-sample of which was shaken in water for 3 minutes. The per-

centage of the sub-sample that was retained on a 0.25-mm sieve after shaking was determined, and is a measure of the water stable aggregates.

### *Statistical analysis*

The changes in the soil properties were analysed by analysis of variance using Genstat 5 (Payne 1993), and means separated using least significant differences (l.s.d.,  $P=0.05$ ). Skew data were log-transformed before statistical analysis, and the untransformed means are presented.

**Table 1.** Chemical composition of the vermicompost and compost.

|              | Total C | Total N | Dissolved<br>organic C | Al                | Ca    | Mg   | K    | Na  | P    | S    |
|--------------|---------|---------|------------------------|-------------------|-------|------|------|-----|------|------|
|              | %       | %       | mg/L                   | ----- mg/kg ----- |       |      |      |     |      |      |
| Vermicompost | 5.47    | 0.51    | 78                     | 19900             | 7960  | 3050 | 7780 | 570 | 1350 | 820  |
| Compost      | 9.60    | 0.80    | 454                    | 16500             | 17070 | 4670 | 9740 | 740 | 1990 | 1240 |

**Table 2.** Element loading for the vermicompost and compost treatments.

| Loading             | tonne/ha         | 1                                  | 2    | 5    | 10   | 20   | 1                            | 2   | 5   | 10   | 20   |
|---------------------|------------------|------------------------------------|------|------|------|------|------------------------------|-----|-----|------|------|
|                     | g/m <sup>2</sup> | 100                                | 200  | 500  | 1000 | 2000 | 100                          | 200 | 500 | 1000 | 2000 |
| Element             | Concentration    |                                    |      |      |      |      |                              |     |     |      |      |
| <i>Vermicompost</i> |                  | ----- g N/m <sup>2</sup> -----     |      |      |      |      | ----- mg N/kg soil* -----    |     |     |      |      |
| Total C (%)         | 5.47             | 5.47                               | 10.9 | 27.4 | 55   | 109  | 84                           | 168 | 421 | 842  | 1683 |
| Total N (%)         | 0.51             | 0.51                               | 1.02 | 2.55 | 5.1  | 10.2 | 7.9                          | 16  | 39  | 78   | 157  |
|                     |                  | ----- mmol(+)/m <sup>2</sup> ----- |      |      |      |      | ----- mmol(+)/kg soil* ----- |     |     |      |      |
| Ca (mg/kg)          | 7960             | 39.8                               | 79.6 | 199  | 398  | 796  | 0.6                          | 1.2 | 3.1 | 6.1  | 12   |
| Mg (mg/kg)          | 3050             | 25.1                               | 50.2 | 126  | 251  | 502  | 0.4                          | 0.8 | 1.9 | 3.9  | 7.7  |
| K (mg/kg)           | 7780             | 19.9                               | 39.9 | 100  | 200  | 399  | 0.3                          | 0.6 | 1.5 | 3.1  | 6.1  |
| Na (mg/kg)          | 570              | 2.5                                | 5.0  | 12   | 25   | 50   | 0.04                         | 0.1 | 0.2 | 0.4  | 0.8  |
| <i>Compost</i>      |                  | ----- g N/m <sup>2</sup> -----     |      |      |      |      | ----- mg N/kg soil* -----    |     |     |      |      |
| Total C (%)         | 9.6              |                                    |      | 48   |      | 192  |                              |     | 738 |      | 2954 |
| Total N (%)         | 0.80             |                                    |      | 4    |      | 16   |                              |     | 62  |      | 246  |
|                     |                  | ----- mmol(+)/m <sup>2</sup> ----- |      |      |      |      | ----- mmol(+)/kg soil* ----- |     |     |      |      |
| Ca (mg/kg)          | 17070            |                                    |      | 427  |      | 1707 |                              |     | 6.6 |      | 26   |
| Mg (mg/kg)          | 4670             |                                    |      | 192  |      | 768  |                              |     | 3.0 |      | 12   |
| K (mg/kg)           | 9740             |                                    |      | 125  |      | 500  |                              |     | 1.9 |      | 7.7  |
| Na (mg/kg)          | 740              |                                    |      | 16   |      | 65   |                              |     | 0.3 |      | 1.0  |

\* Loading rate calculated assuming that the material is mixed throughout the upper 50 mm of soil with a bulk density of 1300 kg/m<sup>3</sup>.

## Results and Discussion

### *Chemical composition of vermicompost and compost*

The chemical composition of the compost and vermicompost used in the trial is shown in Table 1. The concentrations of the elements were higher in the compost compared to that measured in the vermicompost. Carbon (C) contents of the vermicompost and compost were at the lower end of the range of values reported for compost collected in northern Italy (Corti *et al.*, 1998), which ranged from 8% to 48%. The lowest values reported were measured in compost produced from garden waste, similar to the compost used in our study. Calcium and potassium were the major basic cations found in both the vermicompost and compost, and both had high total aluminium concentrations.

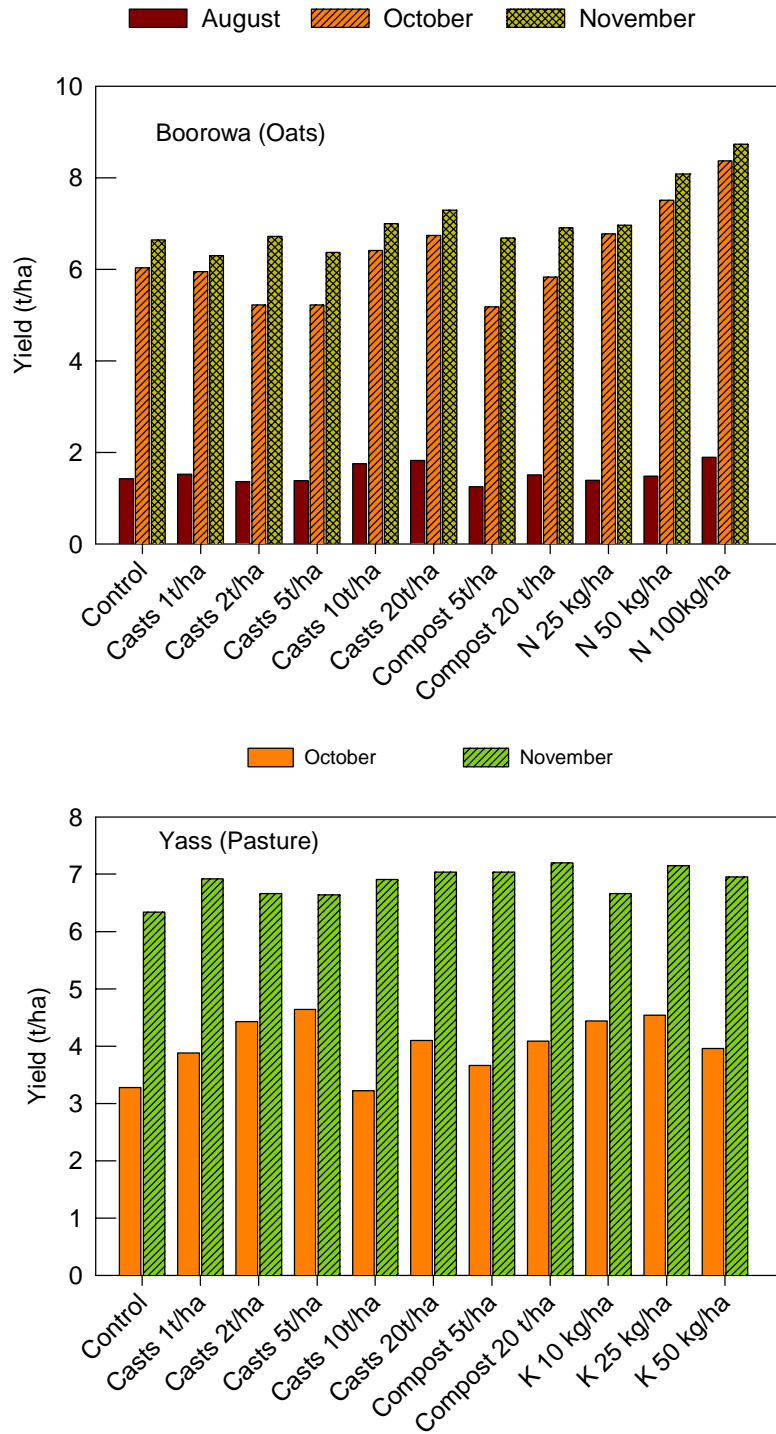
The composition in Table 1 can be used to calculate the amounts of each element added to the soil for each application rate. This is referred to as the loading. The loadings for selected elements are shown in Table 2, expressed both as an amount per square meter and as an effective concentration per unit mass of soil assuming that the materials were uniformly mixed throughout the surface 50 mm of soil. A maximum of 10 and 16 g N/m<sup>2</sup> (equivalent to 100 and 160 kgN/ha, respectively) was added to the soil when the vermicompost or compost was applied at 20 t/ha (equivalent to 2000 g/m<sup>2</sup>). This corresponds to increases in N concentration in the soil of 156 and 246 mg N/kg for the vermicompost and compost, respectively. The equivalent of 12 or 26 mmol(+)/kg of Ca was applied with the application of 20 t/ha of vermicompost or compost, respectively (Table 2). The above loading rates for carbon, nitrogen and basic cations (Ca, Mg, Na and K) are significant less than the amount applied in spent mushroom compost by Stewart *et al.*, 1998. For example, their spent mushroom compost had C and N contents of 31.6 and 1.8%, respectively. If this material were applied at 20 t/ha (dry weight basis), 6320 kg C/ha (632 g C/m<sup>2</sup>) and 360 kg N/ha (36 g N/m<sup>2</sup>) would be added to the soil.

### *Crop growth and nitrogen accumulation*

The biomass measured for the oats and pasture are shown in Fig. 1a and b. There was rapid growth of the oats and pasture between August and November. For the oats, there was a significant ( $P < 0.05$ ) increase in biomass due to the addition of fertiliser at the October and November 1998 sampling. The highest yield was measured on the treatment fertilised with 100 kg N/ha. However, there was no difference ( $P < 0.05$ ) between the yields of the other treatments. Furthermore, there was no difference in the establishment of the oats for different treatments (data not shown). At the pasture site, there were no yield differences between any of the treatments.

The accumulation of N in the biomass increased ( $P < 0.01$ ) with time at both sites (data not shown). With the exception of the N fertiliser treatments, there was no difference between the N accumulation in the oats or the pasture for the vermicompost or compost treatments ( $P < 0.05$ ). In November, the average N accumulation for these treatments was  $3.7 \pm 0.28$  and  $9.2 \pm 0.7$  g N/m<sup>2</sup> for oats and pasture, respectively.

We conclude that the vermicompost and compost applications did not result in improved plant growth and nutrient accumulation, although the results from the fertiliser treatments showed that there was potential for improved growth in response to increased plant available nitrogen. At Boorowa, mineral N limited growth of the oats, and neither compost nor vermicompost increased the mineral N values at the rates applied.



**Fig. 1.** Biomass at (a) Boorowa in August, October and November 1998, and (b) Yass in October and November 1998. Vertical bars represent l.s.d. ( $P=0.05$ ) appropriate to comparisons between the means in (a) August, (b) October and (c) November.

### ***Soil inorganic N***

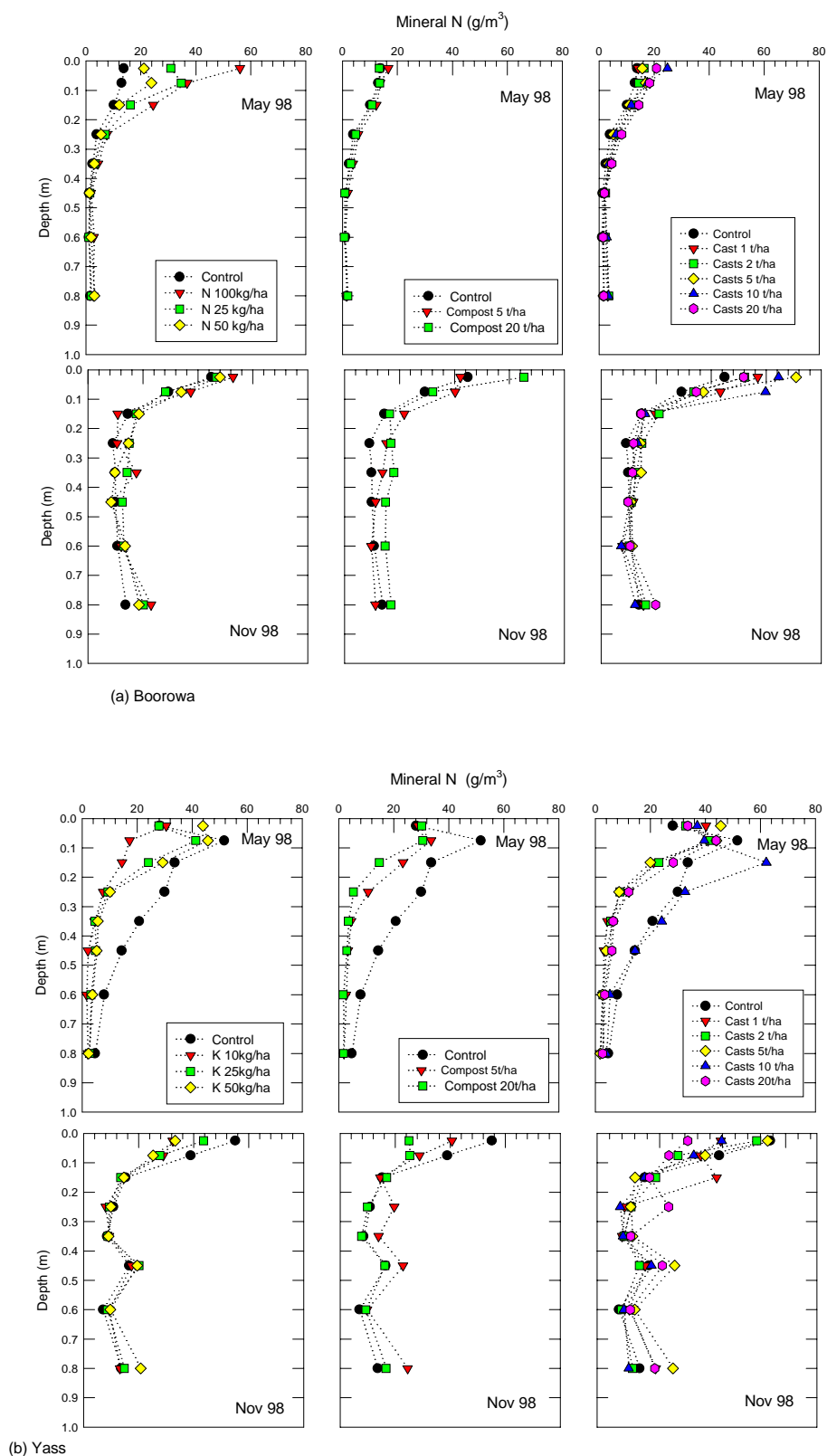
The addition of vermicompost or compost had no effect on mineral N values in the surface 0.4 m of soil at sowing (May), and the values were significantly less ( $P < 0.05$ ) than those measured following the addition of N fertiliser (Fig. 2a, b). The N fertiliser application significantly increased mineral N concentrations in the surface 100 mm in May. Twenty tonnes per ha of vermicompost added  $10 \text{ g N/m}^2$  to the soil, whereas the compost added  $16 \text{ g N/m}^2$  (Table 2). The lack of an increase in mineral N concentrations in the soil of the vermicompost and compost treatments suggests that the N added was mainly in the organic form. Mineral N values were highest in the surface soils and decreased with depth in the soil profile ( $P < 0.001$ ).

At Boorowa, mineral N concentrations were higher in November than in May. This suggests that the amount of inorganic nitrogen produced from the mineralisation of organic N during the season (see below) exceeded crop requirements for nitrogen. In November, there was no difference ( $P < 0.05$ ) in mineral N values between the control and the N fertiliser treatments, although some values tended ( $P = 0.1$ ) to be higher in the treatments that received high rates of vermicompost and compost. At Yass, there was a similar increase ( $P < 0.001$ ) in mineral N values between May and November, and the values also decreased with depth. Furthermore, there was no trend of increasing mineral N values with increasing rate of compost or vermicompost; rather the values tended to decrease with increasing rates of compost or vermicompost application (Fig. 2b).

The lack of consistent and significant changes in mineral N values following the application of compost is consistent with the findings of others (Stewart et al., 1998; Maher, 1994). Stewart et al. (1998) reported no differences in soil nitrate-N concentration 89 days after the application of 80 t/ha of wet spent mushroom compost; equivalent to a total N application of about  $88 \text{ g N/m}^2$ . Maher (1994) reported that application up to 400 t/ha of spent mushroom compost had little effect on soil nitrate-N concentrations. Because carbon is the main indicator of nitrogen availability, and the low amount of carbon added by both the vermicompost and compost, we are unlikely to see an effect on soil mineral N.

### ***Net N mineralisation and microbial biomass***

At Boorowa, the application of vermicompost or compost had no significant effect on cumulative net N mineralisation, whereas the application of vermicompost at 5 t/ha tended to increase net N mineralisation at Yass (Fig. 3a and b). There may have been some net immobilisation in the 10 and 20 t/ha vermicompost treatments at Yass, as the net N mineralisation was negative between the 28 May and 2 July 1998. Furthermore, there was a trend of less cumulative N mineralisation with increasing rates of vermicompost or compost. Net N mineralisation did increase during the spring, presumably as the soil temperatures increased. These results are consistent with the findings of Stewart et al. (1998c). These researchers reported that N tended to be immobilised when applied at low rates (20 and 40 t/ha; equivalent to 360 or 720 kg N/ha) followed by slow net mineralisation. The slow release of mineral N from the compost or vermicompost presumably reflects that only the large complex organic C and N remain in the material, making it relatively unavailable. Smaller and readily available organic N molecules would be consumed during the composting and vermicomposting process, thus little rapidly mineralised organic nitrogen would remain in the material.



**Fig. 2.** Mineral N (ammonium plus nitrate) in the 0-90 cm soil layer in May 1998 and November 1998 at Boorowa (a) and Yass (b). Horizontal bars represent the 1.s.d. ( $P=0.05$ ) appropriate to comparisons between means.

Microbial biomass was lowest in the winter (July), and increased in the spring, however there was no difference between treatments at either site (Fig. 3a and b). The lack of any significant differences between the treatments is consistent with the net N mineralisation. This also indicates that there were no toxic or inhibitory effects associated with additions of compost or vermicompost. Similarly, Stewart et al. (1998a) reported no effect on microbial biomass 40 weeks after the addition of 80 t/ha of wet compost (equivalent to 48 t/ha of dry material). However, microbial biomass was increased following the addition of 320 t/ha of compost (192 t/ha dry material). These findings suggest the possibility of improved nutrient availability after repeated or larger additions of these materials.

### ***Other soil chemical analyses***

Soil pH profiles at the Yass and Boorowa sites are shown in Fig 4a and b, respectively. There was a significant effect of soil depth and time on soil pH values at both sites. Soil pH decreased to a minimum value in the 100 to 200 mm depth layers, and then increased with increasing depth in the soil profile. Soil pH values were higher ( $P < 0.001$ ) in the samples collected 1 day after the application of the treatment, compared to those measured on samples collected at the end of the growing season. There was no effect ( $P < 0.05$ ) of vermicompost or compost on soil pH at the Yass site (Fig. 4b). At Boorowa, however, the soil pH of the surface 200 mm depth layer tended ( $P < 0.15$ ) to increase with increasing rates of application of vermicompost.

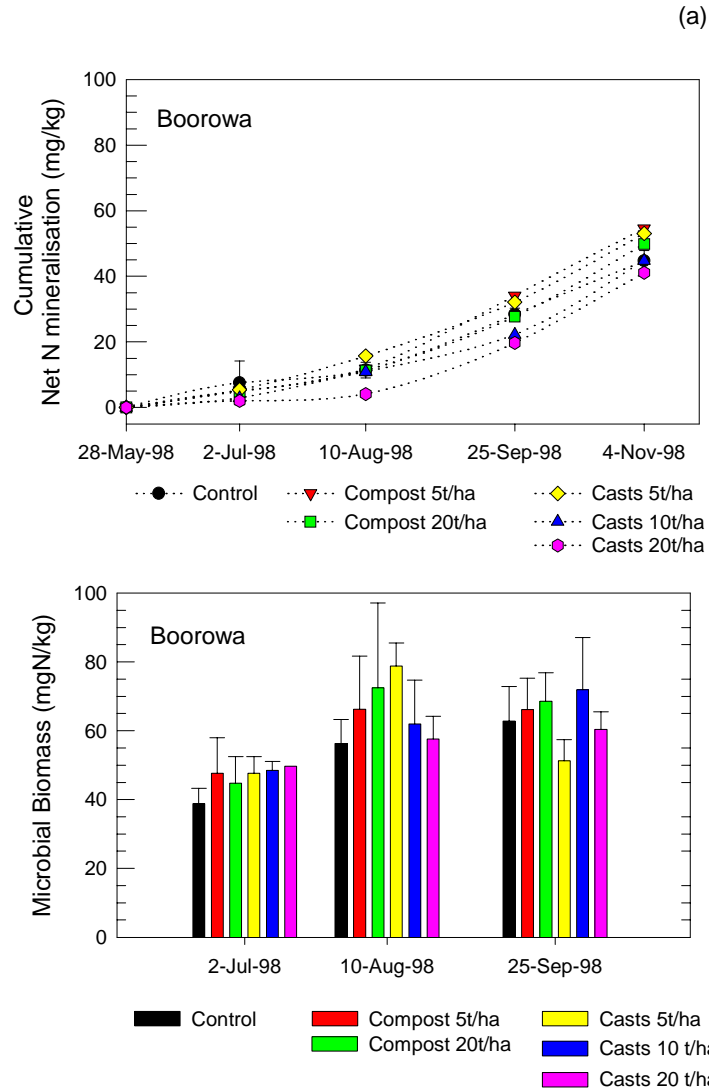
Exchangeable calcium and base saturation of the soils were increased in the surface 200 mm of soil by the application of vermicompost at both the Boorowa and Yass sites (Fig. 5a and b). Vermicompost was more effective than compost in increasing exchangeable Ca values, although the compost contained significantly more Ca than the vermicompost (Table 1). Aluminium saturation of the soil was low ( $< 1\%$ ) in the surface 5 cm layer of the soil, and the values increased with depth in the soil profile as the soil pH decreased below 4.8. The addition of compost and vermicompost decreased ( $P < 0.05$ ) the aluminium saturation of the soil in the upper 20-cm soil layers at the Boorowa site (Fig. 5a).

These results indicate positive effects of compost and vermicompost applications. The tendencies for increased pH and decreased aluminium saturation in the surface soil suggest the possibility of improved soil chemical fertility after repeated or larger additions of these materials.

### ***Soil physical properties***

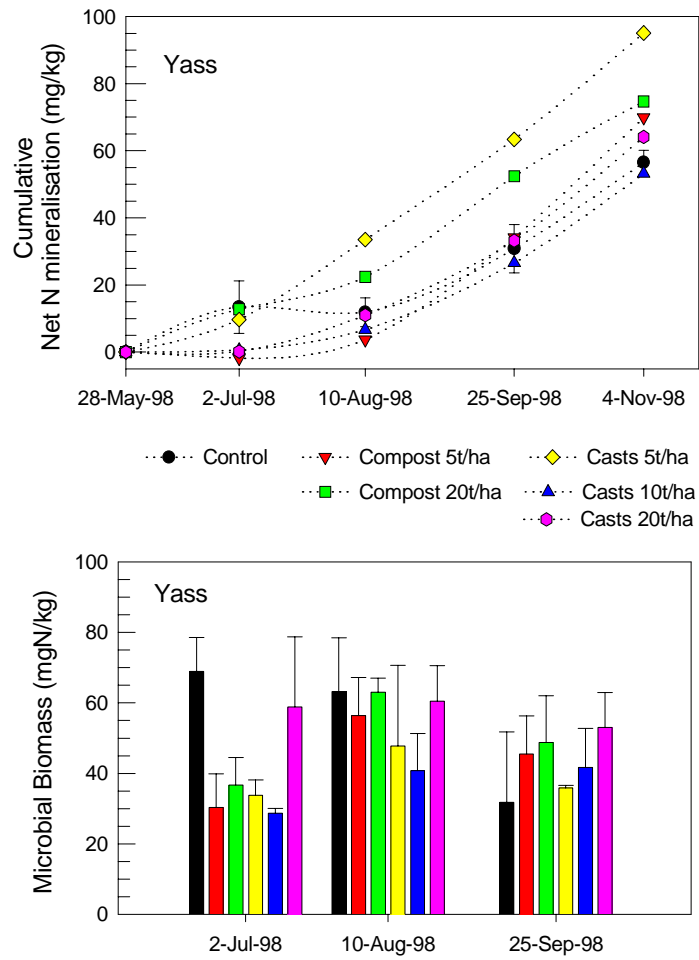
Results of the measurements of soil bulk density, soil water retention and water stable aggregation are presented in Table 3. The soil bulk density tended to be decreased by additions of both compost and vermicompost. Only at Boorowa was this decrease significant, however. No consistent or significant effects on soil water retention were observed at any value of soil water potential. There was also no significant effect on aggregate stability. There was a suggestion that compost addition produced increased stability at both the Boorowa and Yass field sites. Although vermicompost produced increased stability at Yass, at Boorowa the stability decreased. It should be noted that the aggregate stability at both sites was quite high, and that a more marked effect of the addition of compost might be produced at sites with soils having poorer stability initially.

Although there were not marked improvements in soil physical condition following addition of composted materials, there were indications that positive changes may be induced. Repeated applications or applications of larger amounts may be required to produce significant improvements.

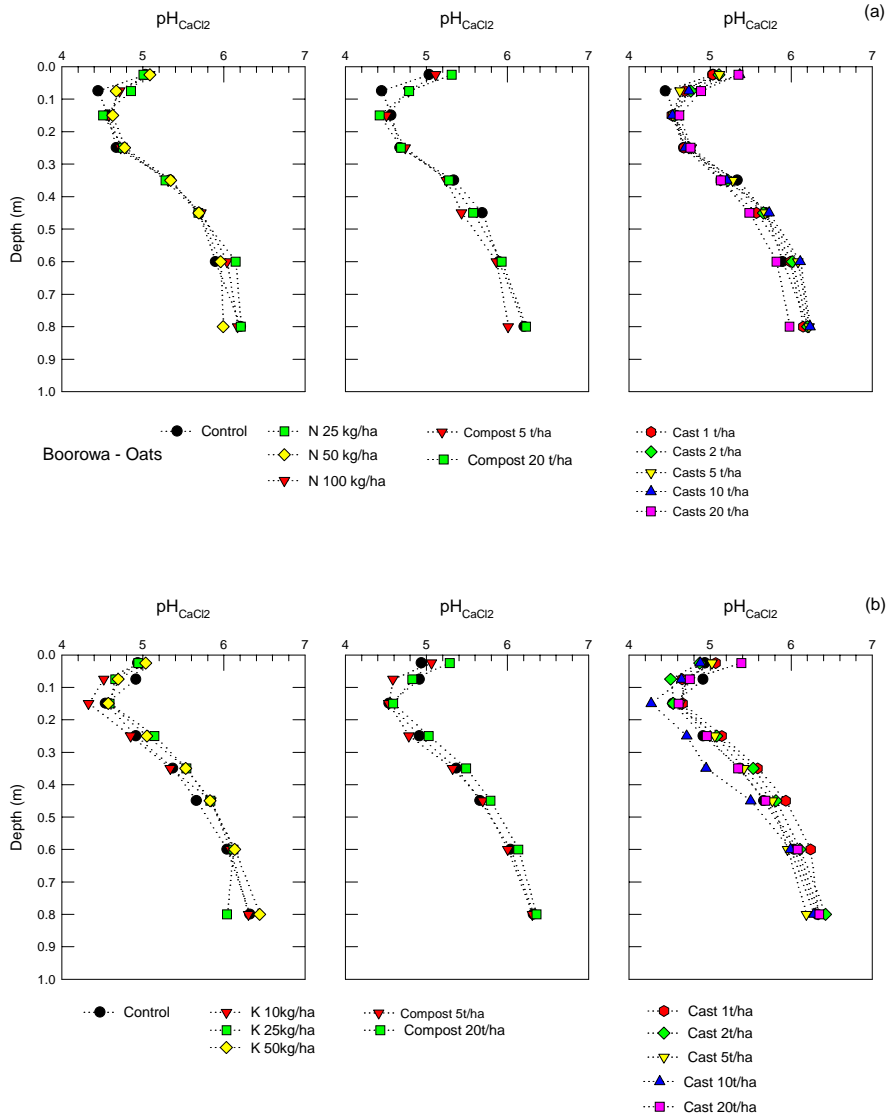


**Fig. 3.** (a) Cumulative net mineralisation measured from the accumulation of mineral N in covered tubes, and microbial biomass N at Boorowa.

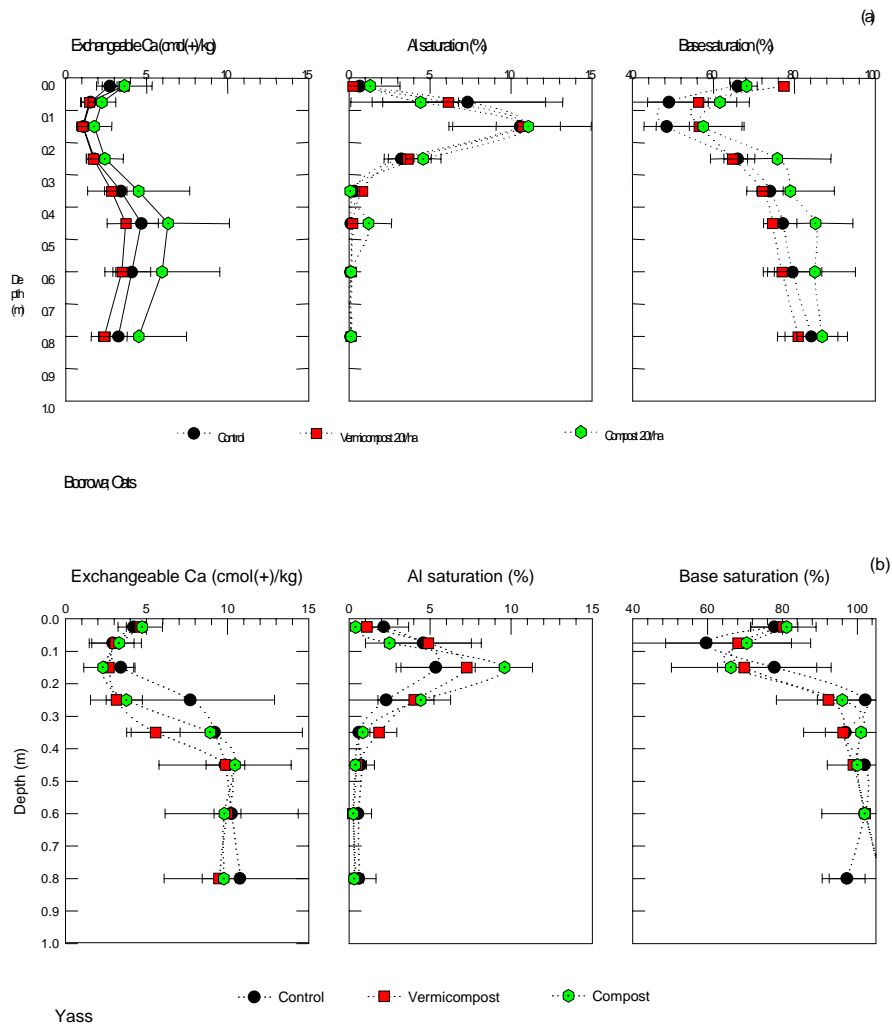
(b)



**Fig. 3.** (b) Cumulative net mineralisation measured from the accumulation of mineral N in covered tubes, and microbial biomass N at Yass.



**Fig. 4.** Average soil  $pH_{CaCl_2}$  for the treatments at (a) Boorowa and (b) Yass in November 1998. Horizontal bars represent l.s.d. ( $P=0.05$ ) appropriate to comparisons between means.



**Fig. 5.** Exchangeable Ca, aluminium saturation (%) and base saturation for the control, and 20t/ha (dry weight basis) of compost and vermicompost treatments at (a) Boorowa and (b) Yass in November 1998. Horizontal bars represent l.s.d. ( $P=0.05$ ) appropriate to comparisons between means.

Table 3. Bulk density, water retention and water stable aggregates measured in three treatments at each of the field sites; mean and standard deviation.

|   | Boorowa |                              |                    |       | Yass    |                              |                    |       |
|---|---------|------------------------------|--------------------|-------|---------|------------------------------|--------------------|-------|
|   | control | Vermi-<br>compost<br>20 t/ha | Compost<br>20 t/ha | lsd   | control | Vermi-<br>compost<br>20 t/ha | Compost<br>20 t/ha | lsd   |
| Bulk density (g/cm <sup>3</sup> )                   | 1.37    | 1.31 *                       | 1.30 *             | 0.056 | 1.33    | 1.31                         | 1.26               | 0.100 |
| Water retention (cm <sup>3</sup> /cm <sup>3</sup> ) |         |                              |                    |       |         |                              |                    |       |
| -10 cm  | 0.41    | 0.41                         | 0.41               | 0.016 | 0.40    | 0.41                         | 0.42               | 0.028 |
| -30 cm  | 0.38    | 0.37                         | 0.36               | 0.020 | 0.36    | 0.37                         | 0.37               | 0.022 |
| -50 cm  | 0.37    | 0.36                         | 0.35               | 0.020 | 0.34    | 0.35                         | 0.36               | 0.023 |
| -100 cm   | 0.34    | 0.33                         | 0.33               | 0.019 | 0.31    | 0.33                         | 0.33               | 0.024 |
| -340 cm   | 0.26    | 0.26                         | 0.26               | 0.016 | 0.26    | 0.28                         | 0.29               | 0.020 |
| -600 cm   | 0.22    | 0.22                         | 0.22               | 0.013 | 0.23    | 0.24                         | 0.25               | 0.018 |
| Water stable aggregates (%)                         | 72.9    | 71.0                         | 77.4               | 10.0  | 79.4    | 86.3                         | 87.1               | 12.0  |

\*vermicompost at 20t/ha and compost at 20 t/ha are significantly different from control,  $P < 0.05$

### Implications

Additions of vermicompost or compost at rates up to 20 t/ha did not increase the yield or nitrogen accumulation in the biomass. This was consistent with the observations that their application also did not significantly improve the chemical or physical environment of the soil. However, there were trends in the data to suggest beneficial effects on soil physical and chemical properties. Comparison of the results here with those from the literature indicate that significant benefits are only likely to be produced by larger additions of these materials, or by repeated additions.

A greater beneficial effect of additions of composted materials, in terms of improved crop growth, may be able to be produced by increasing their organic carbon and nitrogen content or by increasing the amount of rapidly mineralised organic nitrogen. Co-composting with sewage sludge, or other material that has a higher organic N content, may achieve this.

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