Chapter Four

Effect of organic amendments on soil properties and growth of irrigated cotton grown in a self-mulching Vertosol

4.1 Introduction

In Australia, cotton is grown on about 550,000 ha and the major soil types used in cotton production systems are cracking clay soils (black earths and grey brown clays) (McKenzie 1998; NLWRA 2002) or Vertosols (Isbell 1996a) as these are relatively fertile soils which can have clay contents above 50%. However, some of these soils can be sodic at depth.

While there are many indicators of soil quality, SOM is considered to be of central importance to it. It plays an important role in influencing a soil's different physical, chemical and biological properties. These properties, along with soil C, N and P, are considered critical indicators for the health and quality of soil. One management technique whereby SOM content can be increased is the addition of organic waste materials from various sources (Reynolds 1930). Some examples of locally available organic wastes are feedlot manure, vermicast or vermicompost, which is produced from the worm-composting of organic residues from animals and plants, and "cotton gin trash", a waste product of the cotton ginning process. Substantial quantities of cotton processing wastes are presently stored in a large stockpiles and left to degrade around the gins. Cotton-producers have recognized this waste as a potential source of organic matter and nutrients which could be used to improve soil conditions.

But detailed information regarding the benefits of using different organic inputs to improve and maintain soil quality is not readily available for the cotton growers farming on Vertosols. It is also not known whether any economic benefits occur by using these organic soil amendments, and how these benefits compare with those resulting from the application of cheaper inorganic amendments such as gypsum. In spite of the general paucity of information on the effects of organic amendments on soil properties of alkaline, swelling soils, in which approximately 75-80% of Australian cotton is grown, many commercial organisations have been promoting the sale and distribution of organic fertilizers and amendments based on data from acidic, non-swelling soils. This extrapolation may well be invalid, prompting many cotton growers to experiment with organic amendments such as feedlot manure, vermicompost and composted cotton gin trash.

Nonetheless, the limited research data that are available does suggest that organic C and K availability could be improved by organic amendments. Research in India and Canada suggests that applying feedlot manure at rates of 12-16 t/ha significantly enhanced K availability in Vertosols (Singh *et al.* 2002). At the same time laboratory studies have indicated that pelletised mixtures of sewage sludge and cotton gin trash had limited effects on soil physical properties of Vertosols, decreased pH and ESP, and increased organic C and $EC_{1:5}$ (Hulugalle 1996).

In this study, the environmental value of some of the locally available organic amendments such as cattle manure, cotton gin trash and vermicompost was assessed. The objective was to investigate whether there was any short-term effect of using these organic amendments along with inorganic fertilizer on soil quality and cotton production on a self-mulching Vertosol. We also compared our results with a large scale farmer's experiment which used cotton gin trash compost as an organic amendment.

4.2 Materials and Methods

4.2.1 Description of experimental field sites

Site 1 - Narrabri

A two year field experiment was conducted at the Australian Cotton Research Institute (ACRI), near Narrabri, north-western New South Wales, Australia (150°E, 30°S) which has a semi-arid climate. The experimental site experiences four distinct seasons with a mild winter and a hot summer. Figure 4.1 shows the total monthly rainfall and maximum and minimum average daily temperatures for the study period (August 2004 to May 2006). The surface soil (0-0.10 m depth) of the experimental site was a deep uniform grey cracking clay and was classified as a Grey Vertosol (Isbell 1996a) or Typic Haplustert (Soil Survey Staff 2006). The pH of the soil was alkaline (pH_{CaCl2} 7.25–7.56). $EC_{1:5}$ ranges from 0.24-0.25 dS/m and the organic C content was 0.83 g/100 g. X-ray diffraction analysis of the clay fraction showed that the soil at the surface was dominated by the illite (49%) with minor amounts of kaolinite (34%) and smectite (14%) also present. Particle size distribution (using hydrometer method by Gee and Bauder 1986) in the 0-0.10 m depth was 59 g/100 g clay (less than 2 μm), 17 g/100 g silt (2-20 μm) and 24 g/100 g sand (20 μm - 2 mm).

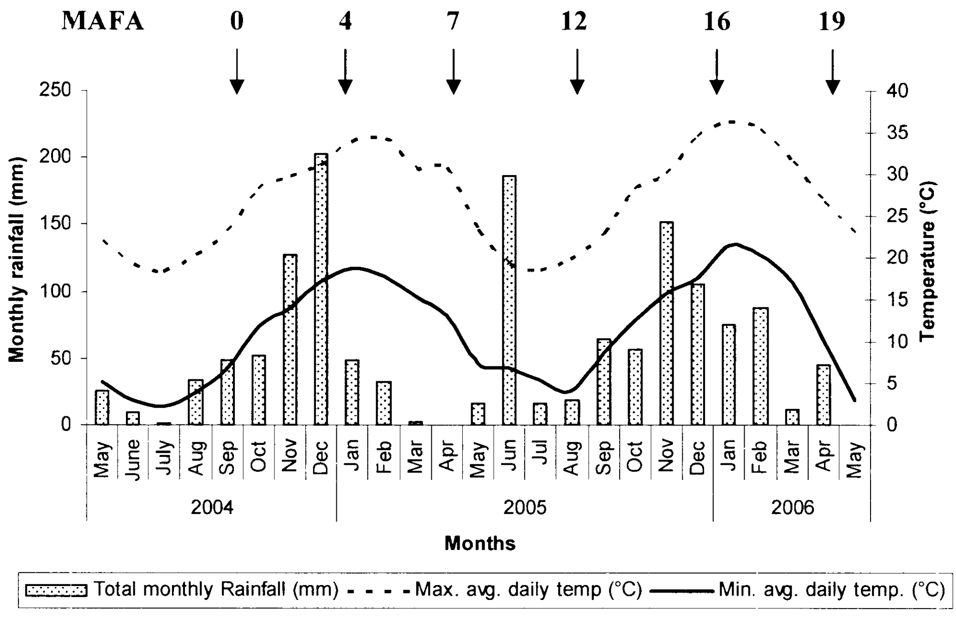

Figure 4.1 Monthly rainfall and mean daily minimum and maximum temperature at the experimental site during two years experiment. Sampling dates are also shown as months after first application of the amendments (MAFA)

4.2.2 Experimental design and treatments

The experiment was laid out in a randomized block design (Figure 4.2 and 4.3) with four replicate plots (9 m x 6 m) of four treatments. The experimental treatments were Narrabri cattle manure (dry weight 10 t/ha), composted cotton gin trash (dry weight 7.5 t/ha) and a commercial vermicast/vermicompost liquid (50 L/ha) and a control. Urea (60 Kg N/ha) was applied to each plot. The rates of the organic amendments were based on typical farmers' practice in this area and vermicast was applied as per the manufacturer's recommended rate. Surface application of the organic amendments (cattle manure and cotton gin trash) was done before sowing of the 1st year crop and then incorporated into the soil. Cattle manure and cotton gin trash were applied once in two years and only vermicast was applied in both years.

The nutrient contents of the amendments are presented in Table 4.1. The amounts of each nutrient added to the soil from the amendments are shown in Table 4.2.

The field was irrigated 6 times in a growing season. Winter vetch was grown over the winter, sprayed and incorporated into the soil before sowing of the first year cotton crop, but the site was in fallow in all following winters. Cotton residues were incorporated before sowing of the second year crop.

4.2.3 Collection of samples

A bulk soil sample of about 2 kg was taken at random from each plot from the 0-0.10 m depth prior to, and at 4, 7, 12, 16 and 19 months after the first application (MAFA) of the organic inputs. The soils were fairly moist when collected during the active growth stage of cotton (4 and 16 MAFA) as compare to sampling during the harvest (7 and 19 MAFA). Figure 4.1 shows the sampling dates in relation to climate and timing of application of organic amendments. Whole plants above the ground level were sampled during the active growth stage of cotton in each year. Treatment effects were also assessed non-destructively by recording physiological data (such as height, number of flowers, squares, nodes and bolls per plant, biomass as dry weight) of the cotton plants during that period. Lint yield was also measured each year. Stages of growth of cotton crop are illustrated in Plate 4.1.

4.2.4 Important dates of events

20.09.2004- 25.09.2004	:	Lay out of the field, application of treatments and collection of soil samples
18.01.2005:	:	Taking physiological observations, collection of soil and plant samples
23.04.2005	:	Measuring lint yield, cotton picking and collection of soil samples
26.08.2005	:	Collection of soil samples before sowing of 2^{nd} year cotton
15.01.2006	:	Taking physiological observations, collection of soil and plant samples
28.04.2006	:	Measuring lint yield, cotton picking and collection of soil samples

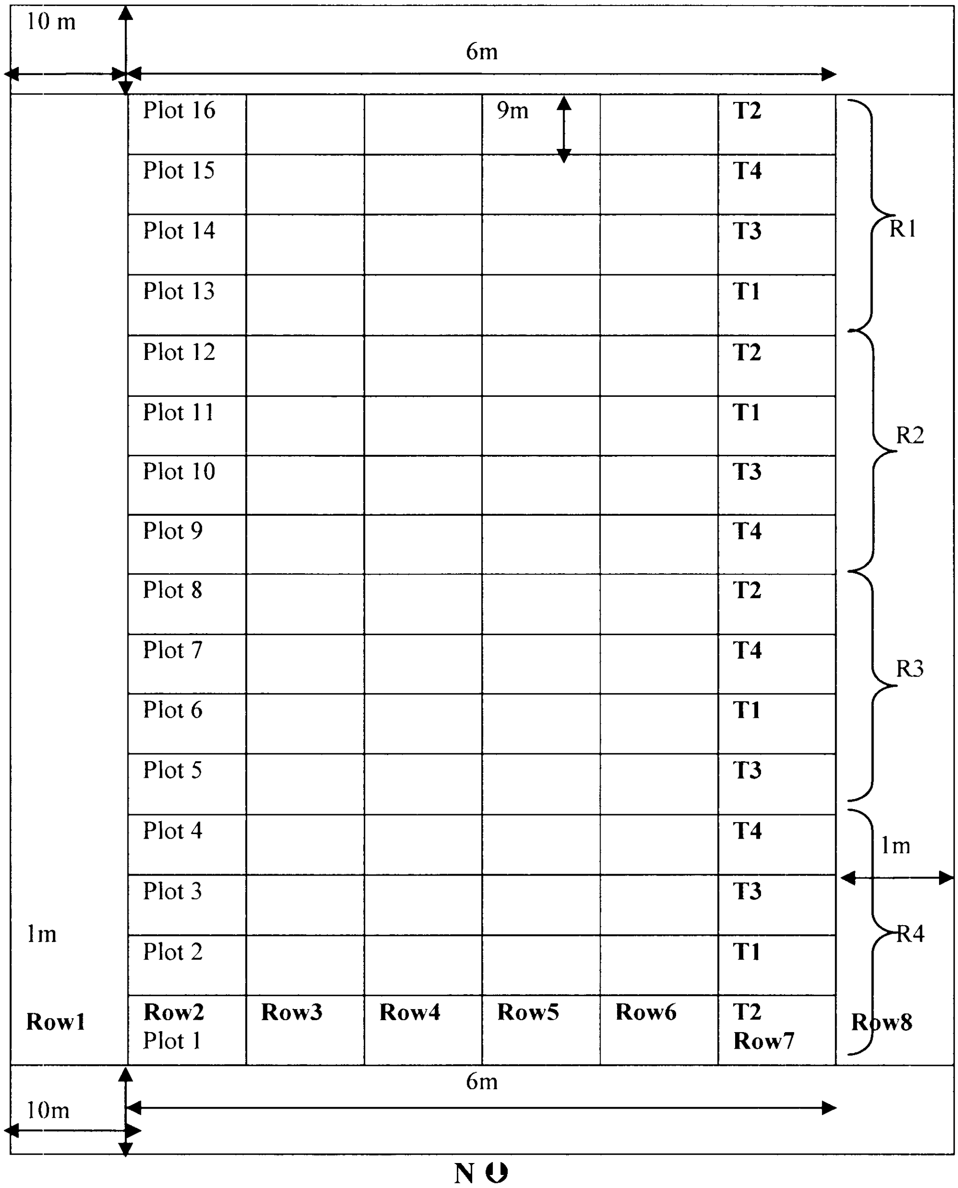

Fig. 4.2 Lay out of the ACRI field

T1 = Control (Plot No. 2, 6, 11, 13) (R1-R4 = Block)

T2 = Cotton Gin trash (Plot No. 1, 8, 12, 16)

T3 = Cattle manure (Plot No. 3, 5, 10, 14)

T4 = Commercial vermicast (Plot No. 4, 7, 9, 15)

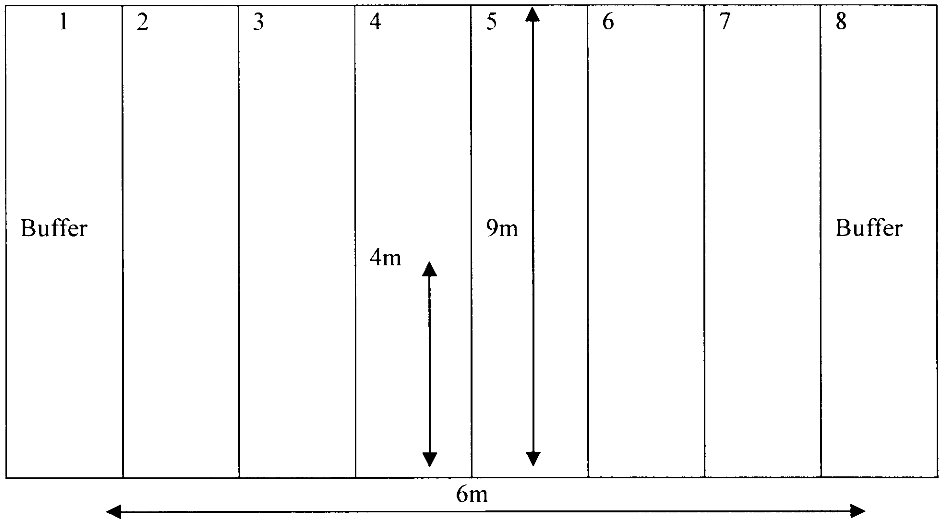

Fig. 4.3 Layout of each plot

Surface application of the organic amendments (cattle manure and cotton gin trash) was done on 9th November, 2004 and the after the 1st sampling before sowing of the crop. Cattle manure and cotton gin trash were applied once in two years and only vermicast was applied in the 2nd year. Vermicast was applied two times in each year and the first application was on 24 November, 2004.

The cotton variety used was Sicala V2RR.

4.2.5 Soil microbiological and chemical analyses

Approximately 50 g fresh samples were used to analyse the microbiological properties measured as microbial biomass and basal respiration using the method already described in Chapter 3.

Air-dried soil samples were passed through < 2 mm sieve and chemical analyses performed in the laboratory of University of New England, Armidale, NSW as described in Chapter 3.

4.2.6 Plant analyses

Plant samples were collected during the active growth period of cotton. All plant samples were dried at 70°C in a fan-forced dehydrator. The dry weights were recorded and the whole plant samples were coarsely ground and thoroughly mixed. A sub-sample of this coarsely ground plant material was finely ground and sieved (< 2 mm) and stored for nutrient analysis.

Plant samples having immature seed-cotton were removed from the developing bolls, weighed, dried and ginned. After ginning, the fuzzy seeds were returned to the dried plant material and ground. The weight of the lint was recorded and subtracted from the dry weights so that total nutrient uptake was not over-estimated. The lint samples were not analysed for nutrient concentration.

The concentration of P, S, K, Ca, Mg, Na and micronutrients in the plant samples were determined using the Sealed Chamber Digestion method described by Anderson and Henderson (1986): 0.2 g of finely ground plant material was weighed into a pre-weighed empty 50 ml glass bottle and pre-digested with 2 ml of a 7:3 70% $HClO_4$/30% H_2O_2 solution for a minimum of two hours. 1 ml of H_2O_2 was added to the samples, which were then tightly capped and digested for 30 minutes at 80°C in a warming oven. Once cool, 1 ml of H_2O_2 was added to the bottle and the samples were digested for 1 hour. Two further additions of H_2O_2 were made, although the time of digestion was reduced to 30 minutes. The solutions were made to an approximate final volume of 25 ml with distilled deionized water and left to stand overnight. The final of extract was determined gravimetrically, by weighing the completed digest and subtracting the weight of the empty bottle. The samples were filtered through a Whatman No. 1 filter paper into a glass vial and analysed using ICP-AES.

The nutrient concentration in the sample was weight and volume corrected and expressed as a percentage (%) for macronutrients and μg/g for the micronutrients. Nutrient uptake and removal were multiplying the nutrient concentration by the dry matter yield.

4.2.7 Organic amendment analyses

Chemical analyses of the organic amendments were performed in the Plant Nutrition Laboratory of University of New England, Armidale, NSW. The concentrations of P, S, K, Ca, Mg and Na in the amendments were determined using the Sealed Chamber Digestion method described by Anderson and Henderson (1986) and the vermicompost was analysed commercially, as described in Chapter 3.

Site 2 (Farmer's trial) - Goondiwindi

Another set of soil samples were collected from a long-term (about 6 years) farmer's trial at Goondiwindi, Queensland, Australia (150°E, 28°S). The surface soil (0-0.10

m) of this site was also a deep uniform grey cracking clay and was classified as a Grey Vertosol (Isbell 1996a) or Typic Haplustert (Soil Survey Staff 2006). The pH of the soil was alkaline (pH_{CaCl2} 6.9–7.2). $EC_{1:5}$ ranged from 0.098-0.11 dS/m. Particle size distribution in the 0-0.10 m depth was 55 g/100 g clay (less than 2 μm), 16 g/100 g silt (2-20 μm) and 29 g/100 g sand (20 μm - 2 mm). The area was 155 ha and the treatments (control and the compost amendment) were laid out in two blocks. Compost (7.5 t/ha) was applied a year (2003) before sampling in the 2004-05 growing season. Soil samples were collected at 0-0.10 m depth on two occasions from the field: before sowing cotton and during picking. All the samples were air dried and then passed through a < 2 mm sieve and then analyzed for selected microbiological and chemical properties as for the ACRI, Narrabri (Site 1) samples described above.

Table 4.1 Elemental composition of the organic amendments used at the field experiment

Treatment	Moisture content (g/100g)	C (g/100g)	N (g/100g)	K (g/100g)	P (g/100g)	Ca (g/100g)	Mg (g/100g)	Na (μg/g)
Gin trash	5.2	12.02	1.31	1.37	0.34	3.29	0.76	640
Manure	7.1	24.15	2.33	2.26	1.05	3.03	0.97	4010
Vermicast	liquefied	16.79	16.61	10.28	3.47	1.17	0.24	4555

Table 4.2 Nutrient added to the surface soil (0-0.1m) from the amendments

Treatment	C (kg/ha)	N (kg/ha)	K (kg/ha)	P (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Na (kg/ha)
Gin trash	900	100	100	25	240	59	4.8
Manure	2400	233	226	105	303	97	40
Vermicast	2.97	2.94	1.82	0.61	0.21	0.04	0.08

4.2.8 Statistical Analyses

Effects of amendment treatment at each sampling time were evaluated by analysis of variance (ANOVA) with treatment and block as factors. Where significant treatment effects were found, pair-wise comparisons (P = 0.05) between the control and other organic inputs were made. To evaluate the effect of time at Site 1, an ANOVA was carried out comparing plant and soil properties between 2004 and 2005 at the active growth stage. Another set of ANOVA was performed with pooled five sampling data analysed after application of the organic amendments at Site 1 and the treatment comparison was made using the contrasts (P = 0.05). For all analyses, variances were checked by plotting residual vs. fitted values to confirm the homogeneity of the data. No transformations were necessary. The results are presented as means and their standard errors (Webster and Payne 2002). All statistical analyses were carried out using R 2.5.0 (R Development Core Team 2006).

A

B

C

D

Plate 4.1 Stages of growth of cotton crop. A. Harvesting; B. ACRI field at full grown stage; C. Collection of physiological data; D. Cotton ready for picking.

4.3 Results

4.3.1 Site 1- Narrabri

The summary of the statistical analyses is presented below in Table 4.3.

Table 4.3 Results of analysis of variance and pair-wise comparison between control and other treatments for the selected chemical properties of the Vertosol

	Sampling time (months)	Nitrate-N	Phosphate-P	Exch. K	Na
Significance of ANOVA	0	ns	ns	ns	ns
	4	ns	ns	ns	ns
	7	*	ns	*	*
	12	*	***	ns	*
	16	ns	ns	ns	ns
	19	ns	ns	ns	ns
	4-19 (pooled)	**	***	*	*
Treatment (pair-wise comparison from control at $P = 0.05$)					
Cotton gin trash	7	↑	na	ns	ns
	12	ns	↑	na	ns
	4-19 (pooled)	↑	↑	ns	ns
Cattle manure	7	↑	na	↑	↑
	12	↑	↑	na	ns
	4-19 (pooled)	↑	↑	↑	↑
Vermicast	7	↑	na	ns	ns
	12	↑	ns	na	ns
	4-19 (pooled)	↑	↑	ns	ns

[Significant codes: '***' 0.001 '**' 0.01 '*' 0.05, na = not applicable, ns = not significant, ↑ = significant increase at $P = 0.05$, ↓ = significant decrease at $P = 0.05$]

4.3.2 Effect on soil properties

4.3.2.1 Soil microbiological properties

Neither microbial biomass nor respiration was affected by the treatments, but they varied with time. In comparison with the first year, microbial biomass in all treatments was lower during the 2nd year (Figure 4.3) with the values at 16 and 19 months after first application (MAFA) about half that at the start of the experiment (0 MAFA). Microbial respiration was markedly higher at 7 MAFA than at any other sampling time (Figure 4.4).

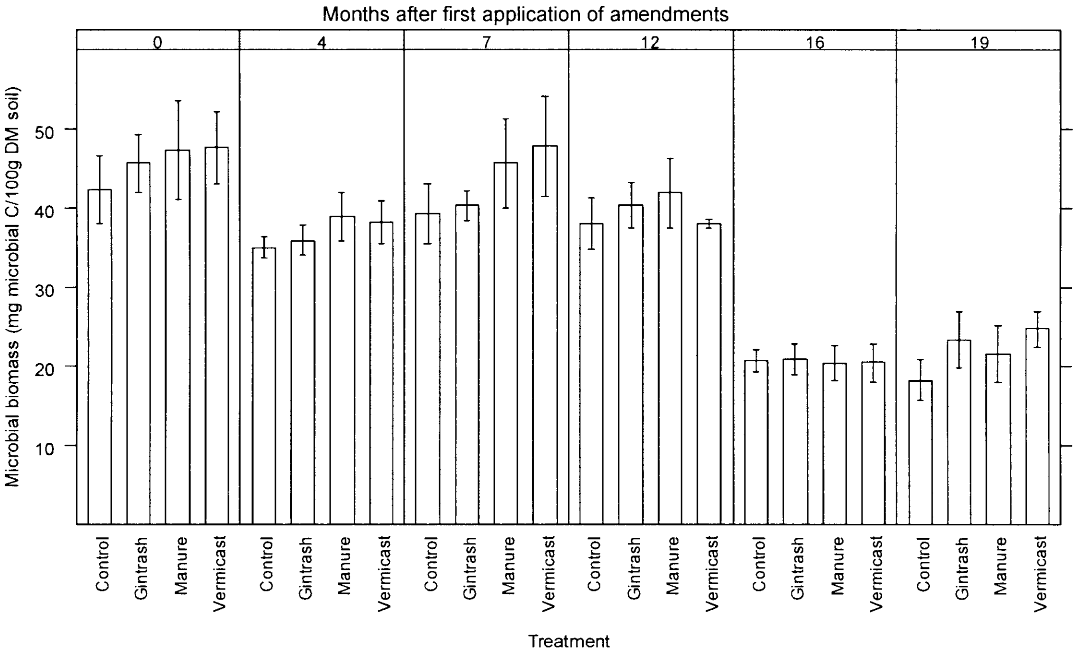

Figure 4.3 Changes in the microbial biomass C in two years due to application of organic amendments at Site 1. Vertical bars indicate the standard error of the means.

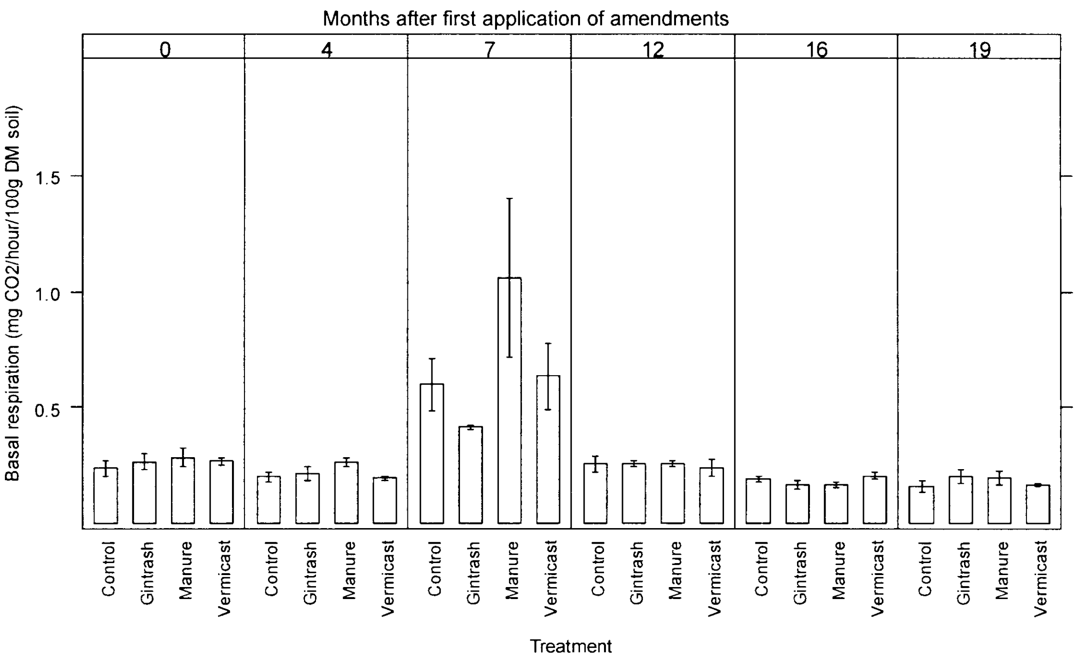

Figure 4.4 Effect of three different organic inputs on microbial respiration over two years at Site 1. Vertical bars are the standard error of the means.

4.3.2.2 Soil chemical properties

Before applying the organic amendments, there was no significant difference in particulate organic matter (free light fraction) among the treatments and the values ranged between 0.20-0.25 g/100 g (Figure 4.5). A significant treatment difference ($P < 0.05$) was observed at the active growth stage in both years. However, the contrast ($P < 0.05$) did not show any significant treatment difference at 4 MAFA, but a significant decrease was observed in the plots amended with the commercial vermicast which was below that of the control plots at 16 MAFA. No occluded fraction of organic matter was recorded.

Effects of treatments on soil chemical properties were only seen at 7 and 12 MAFA (Table 4.3). Table 4.3 also indicates that application of organic amendments resulted in a significant increase ($P < 0.05$) in nitrate-N in soil over the control after two years. At 7 MAFA, the organic residues of amended soils showed significant increases in nitrate-N concentration compared to control plots. The increase was highest in the cotton gin trash (68%) treatment, followed by vermicast (57%) and cattle manure (38%). At 12 MAFA, there was a significantly higher concentration of nitrate-N in manure and vermicast-amended plots. Before application of the treatments (0 MAFA), the nitrate-N content of the soil was high (159-187 µg/g), but it declined to 68-80 µg/g during the active growth stage of cotton at 4 MAFA (Figure 4.6). Nitrate-N concentration tended to be lower in the 2nd year than in the 1st year.

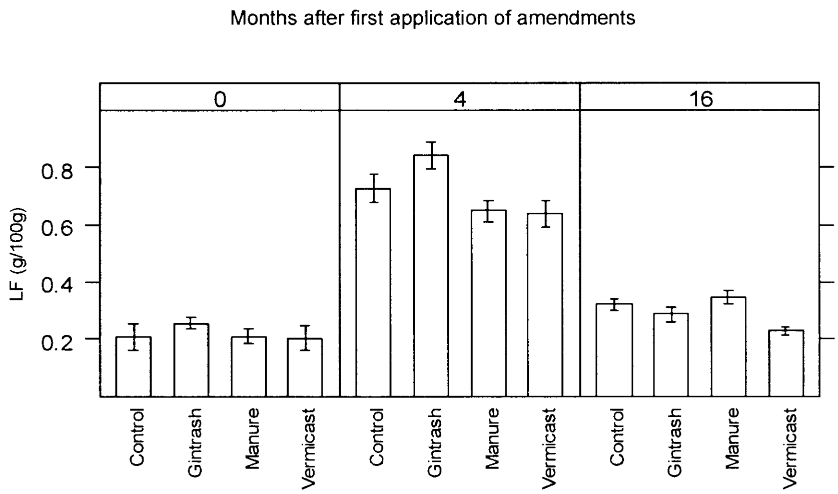

Figure 4.5 Light fractions (LF) of organic matter as affected by the application of three different organic amendments. Vertical bars represent the standard error of the means.

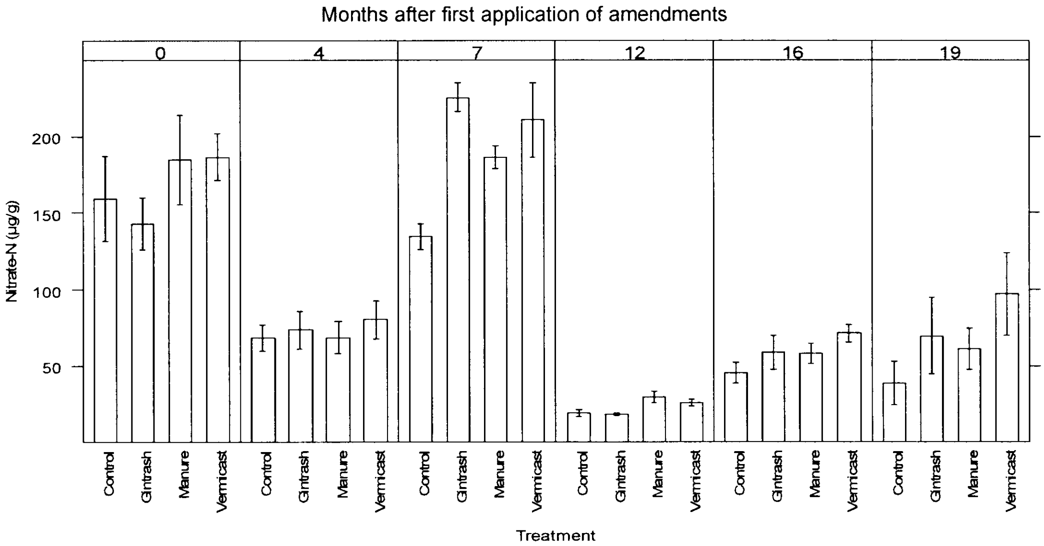

Figure 4.6 Changes in the nitrate-N content due to application of organic amendments at Site 1. Vertical bars indicate the standard error of the means.

A significant increase in phosphate-P ($P < 0.001$) was observed after two years of experiment due to addition of organic inputs (Table 4.3). The phosphate-P concentration differed significantly between the treatments ($P < 0.001$) only at 12 MAFA: cattle manure and gin trash applications resulted in a significant increases (115 and 55% respectively) in phosphate-P over the unamended control plots (Table 4.3, Figure 4.7). Phosphate-P concentration was lower at active growth stage and harvest in the 2nd year compared to the 1st year for all the treatments.

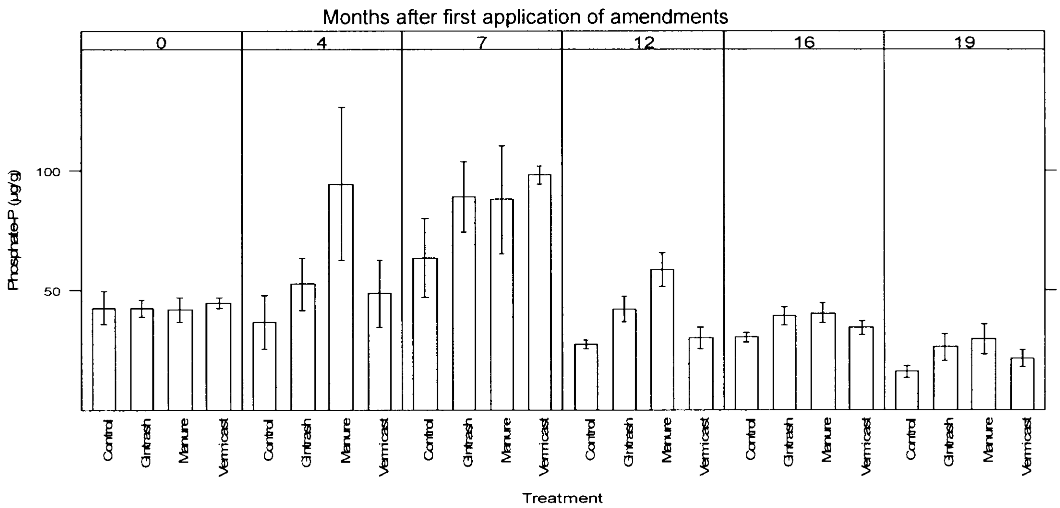

Figure 4.7 Effect of application of three different organic amendments on phosphate-P concentration at Narrabri (Site 1). Vertical bars are the standard error of the means.

Exchangeable K concentration differed significantly among treatments only once during the experiment; viz. at 7 MAFA during the 1st year active growth stage of cotton ($P < 0.05$) (Table 4.3, Figure 4.8). However, ANOVA with pooled data from 4-19 MAFA showed a significant treatment difference ($P < 0.05$) and the contrast showed that only cattle manure increased the exchangeable K significantly over two years (Table 4.3). At 7 MAFA, application of cattle manure resulted in significantly higher values than in the control (28%). There was a decreasing trend in exchangeable K concentration in the 2nd year across all the treatments measured after 12 MAFA.

Exchangeable Na concentration differed significantly ($P < 0.05$) among the treatments at 7 and 12 MAFA (Table 4.3). A significant increase in exchangeable Na over the control was observed with cattle manure with pooled 4-19 sampling data (Table 4.3). Cattle manure resulted in a significant 7% increase over unamended control at 7 MAFA and an overall increase of 8% was observed after two years of experiment. An increasing trend of exchangeable Na concentration over time was observed across all the treatments in the 2nd year (Table 4.4).

No significant differences among the treatments were found for exchangeable Ca and Mg concentrations (Table 4.4).

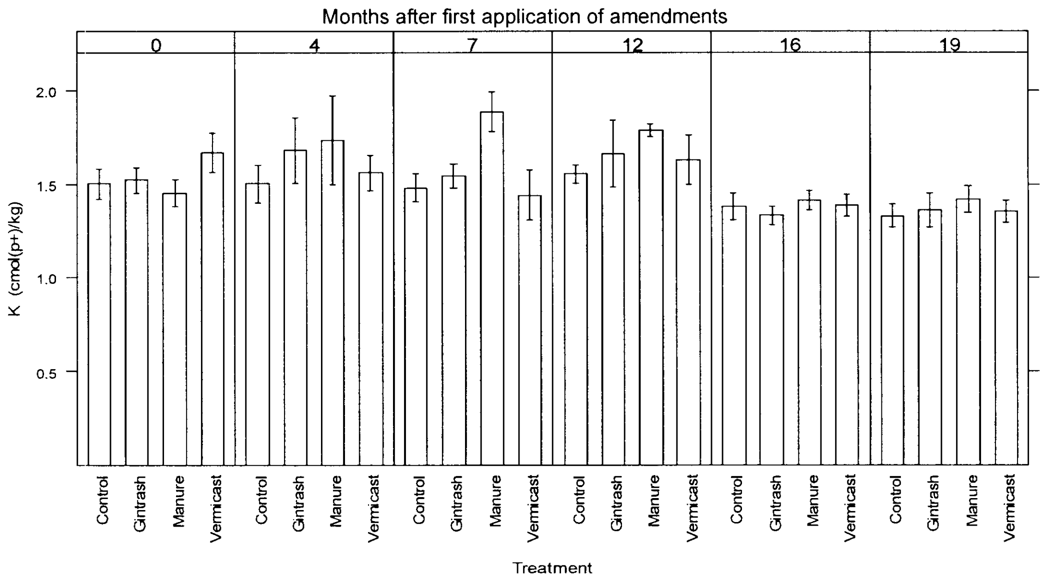

Figure 4.8 Effect of organic amendments on exchangeable K concentration in two years at Narrabri (Site 1). Vertical bars indicate the standard error of the means.

Table 4.4 Changes in the other soil properties due to addition of organic amendments at Narrabri (Site 1).

Treatment	Na (cmol(p$^+$)/kg)					
	0	4	7	12	16	19
Control	0.74	0.68	0.66	0.44	0.68	0.85
Gin trash	0.75	0.73	0.70	0.40	0.63	0.75
Manure	0.70	0.79	0.82	0.48	0.65	0.83
Vermicast	0.74	0.67	0.73	0.44	0.64	0.78
SE[a]	0.07	0.05	0.04	0.02	0.02	0.04
	Ca (cmol(p$^+$)/kg)					
Control	23.7	22.9	22.0	25.6	25.1	25.2
Gin trash	23.2	22.2	21.7	25.6	24.0	24.6
Manure	22.8	22.9	21.2	24.9	25.1	25.2
Vermicast	23.0	22.4	21.6	25.3	25.3	25.2
SE[a]	0.80	0.52	0.44	0.47	0.68	0.48
	Mg (cmol(p$^+$)/kg)					
Control	12.1	12.3	11.1	12.1	11.6	11.6
Gin trash	12.1	12.4	11.4	12.2	11.3	11.6
Manure	11.7	12.0	11.2	11.5	11.9	11.5
Vermicast	11.8	11.8	11.3	12.1	11.7	11.4
SE[a]	0.34	0.28	0.35	0.55	0.40	0.49

[a]: Standard error of treatment means

4.3.3 Effect on cotton

4.3.3.1 Nutrient uptake

The plant analysis of cotton in its active growth stage for the two years (Table 4.5; Figure 4.9, 4.10) showed that above-ground nutrient accumulation by cotton plants was generally higher in the 2005-06 growing season than in 2004-05. P uptake did not differ significantly among the treatments in both years (Figure 4.9), and there was almost a 93% increase in P uptake from 1st year to 2nd year.

Treatments had significant effects ($P < 0.05$) on the plant K uptake. Application of cattle manure increased the plant K uptake significantly over the untreated control and other treatments (Figure 4.9) in the 1st year. There was an increase in K uptake by cotton in all the treatments from 1st year to 2nd year.

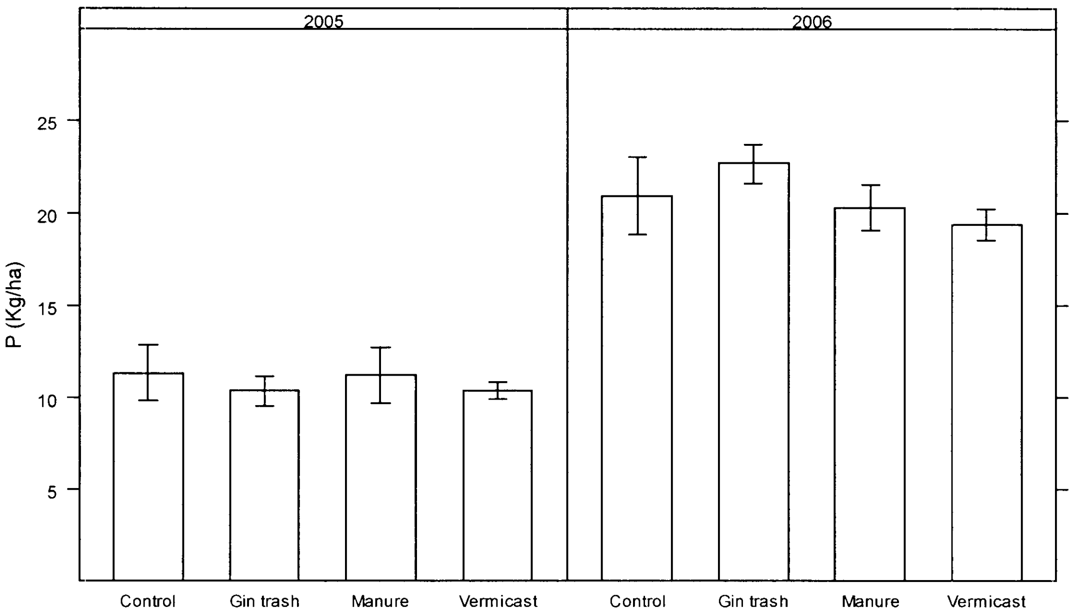

Figure 4.9 Effect of different organic inputs on P uptake by cotton at Site 1. Vertical bars represent the standard error of the means.

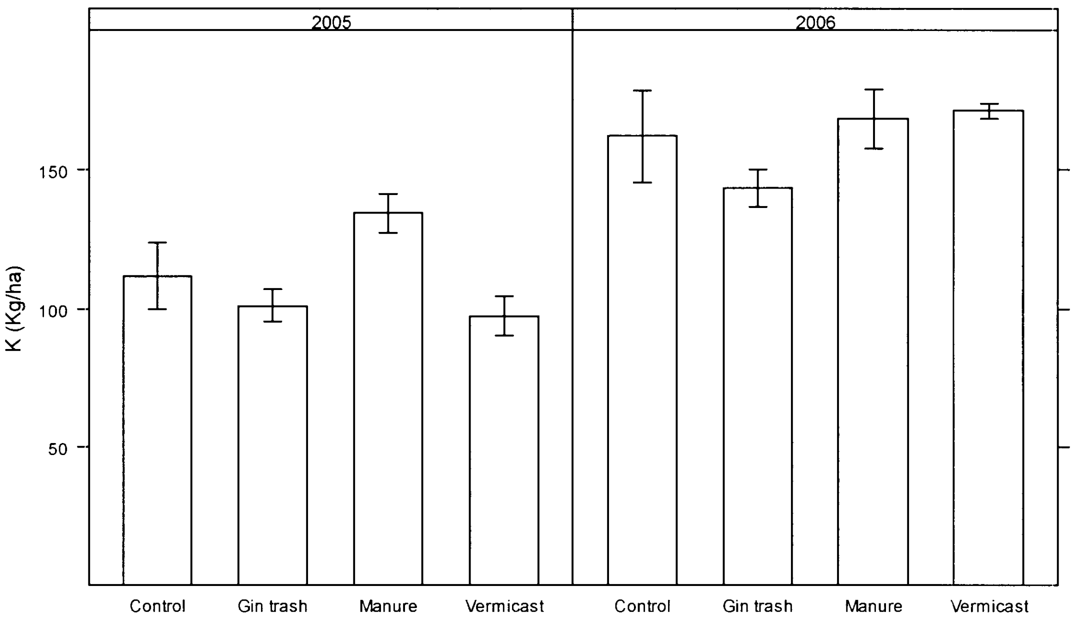

Figure 4.10 K uptake of cotton as affected by addition of organic amendments at Site 1. Vertical bars are the standard error of the means.

There was a considerable increase in Na, Ca and Mg (Table 4.5) concentrations in cotton from 1st year to 2nd year, but values did not differ significantly among treatments in both years. The increase in these nutrients from 1st year to 2nd year was highest in cotton gin trash (126% for Na, 137% for Ca and 71% for Mg) followed by the commercial vermicast (84% for Na, 130% for Ca and 70% for Mg), control (75% for Na, 111% for Ca and 50% for Mg) and cattle manure (64% for Na, 107% for Ca and 48% for Mg).

For the micronutrients, the concentrations differed from 1st year to 2nd year across all the treatments. Application of vermicast resulted in a significant (150%) increase in Zn concentration (Table 4.5) in cotton from 1st year to 2nd year followed by cattle manure (143%), cotton gin trash (129%) and control (88%). There were also significant increases in Fe, Cu and Mn concentrations (Table 4.5) in cotton in 2nd year. Application of cattle manure resulted in a higher Cu (113%) and Mn (72%) concentrations.

Table 4.5 Uptake of macro- and micro nutrients by mature cotton (at 7 and 19 MAFA) as affected by addition of organic amendments. Means and standard errors are presented.

2005	Nutrient uptake (kg/ha)							
Treatment	Na	Ca	Mg	Zn	Mn	Fe	Cu	S
Control	6.53±0.29	88.1±8.6	31.2±2.3	0.08±0.00	0.26±0.03	0.25±0.02	0.02±0.00	23.3±2.8
Gin trash	6.17±0.33	74.8±6.0	30.1±2.0	0.07±0.00	0.24±0.02	0.23±0.03	0.02±0.00	19.6±1.2
Manure	7.98±1.47	86.8±10.6	34.1±3.7	0.07±0.01	0.25±0.03	0.25±0.02	0.02±0.00	24.6±3.0
Vermicast	6.34±0.93	76.9±4.8	29.4±2.1	0.06±0.00	0.25±0.02	0.24±0.03	0.02±0.00	19.7±1.3
2006								
Treatment	Na	Ca	Mg	Zn	Mn	Fe	Cu	S
Control	11.4±1.58	185.5±10.4	46.8±7.0	0.15±0.01	0.39±0.07	0.32±0.05	0.04±0.00	38.8±6.7
Gin trash	14.0±1.74	177.3±24.6	51.4±5.3	0.16±0.01	0.44±0.05	0.29±0.05	0.04±0.00	45.1±5.8
Manure	13.1±1.35	179.4±19.4	50.5±2.3	0.17±0.01	0.42±0.06	0.32±0.04	0.05±0.00	45.3±3.8
Vermicast	11.6±0.75	177.0±20.5	50.0±2.9	0.15±0.01	0.44±0.03	0.25±0.01	0.04±0.00	44.5±4.0

4.3.3.2 Cotton growth and yield

Cotton physiological characteristics measured at active growth stage in each year also did not have any significant difference among the treatments (Table 4.6).

Figure 4.11 describes the lint yield in three years as affected by the addition of different organic amendments. ANOVA did not show any treatment significant differences in any year for the lint yield, although there was a significant decrease ($P < 0.001$) in yield in 2nd and 3rd year as compared with 1st year across all the treatments.

Table 4.6 Changes in physiological characteristics of cotton due to addition of organic amendments at Narrabri (Site 1). Means and standard errors are presented.

Treatment	Plant height (cm)	No. of plants	No. of flowers/plant	No. of squares/plant	No. of nodes/plant	No. of bolls/plant	Dry weight (t/ha)
			2005 (7 MAFA)				
Control	57.3±1.24	10.7±0.81	0.88±0.13	5.4±0.63	12.0±0.29	2.9±0.88	4.9±0.34
Gin trash	57.3±2.13	9.6±0.72	0.78±0.25	6.2±0.60	11.9±0.58	2.2±0.62	4.5±0.33
Manure	57.3±1.68	11.7±1.28	0.88±0.21	5.6±0.44	12.1±0.41	2.7±0.31	5.3±0.46
Vermicast	55.3±1.07	9.8±0.87	0.98±0.21	5.5±0.75	11.2±0.59	2.6±0.35	4.4±0.33
			2006 (19 MAFA)				
Control	57.9±2.00	17.1±1.58	1.03±0.18	3.6±0.35	13.1±0.24	3.9±0.41	7.7±0.75
Gin trash	56.3±0.71	16.7±0.93	1.20±0.13	4.3±0.28	13.0±0.31	3.9±0.19	7.5±0.59
Manure	57.3±1.10	16.3±0.92	1.15±0.10	3.9±0.41	13.8±0.63	4.8±0.74	7.9±0.25
Vermicast	58.5±1.46	16.0±0.57	1.28±0.12	3.9±0.40	13.6±0.33	4.3±0.59	7.4±0.30

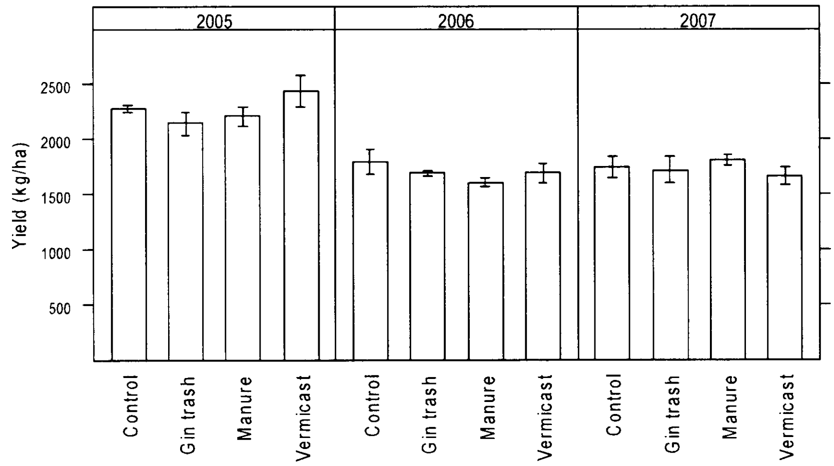

Figure 4.11 Effect of organic amendments on cotton lint yield at Site 1 over three years. Means and standard errors are presented as vertical bars.

4.3.3.3 Cotton leaf nutrient concentration

Fig. 4.12 describes the leaf concentrations of K and P in cotton in the full grown stage in the 2nd year. ANOVA showed that there was a significant treatment difference ($P < 0.05$) in the leaf K content. Plots amended with cotton gin trash and vermicast caused a significant decrease in the leaf K content from the control. The treatments did not have any significant effect on leaf P concentration.

ANOVA showed that the there was a significant treatment difference in leaf B ($P < 0.05$) and S ($P < 0.05$) concentrations. Application of cattle manure showed a significant increase in leaf B and S concentrations in the full grown cotton plants as compared to control (Fig. 4.13). There was a significant 4.1% increase and a 2.1%

decrease in leaf S concentration in vermicast and cotton gin trash amended plots respectively as compared to control.

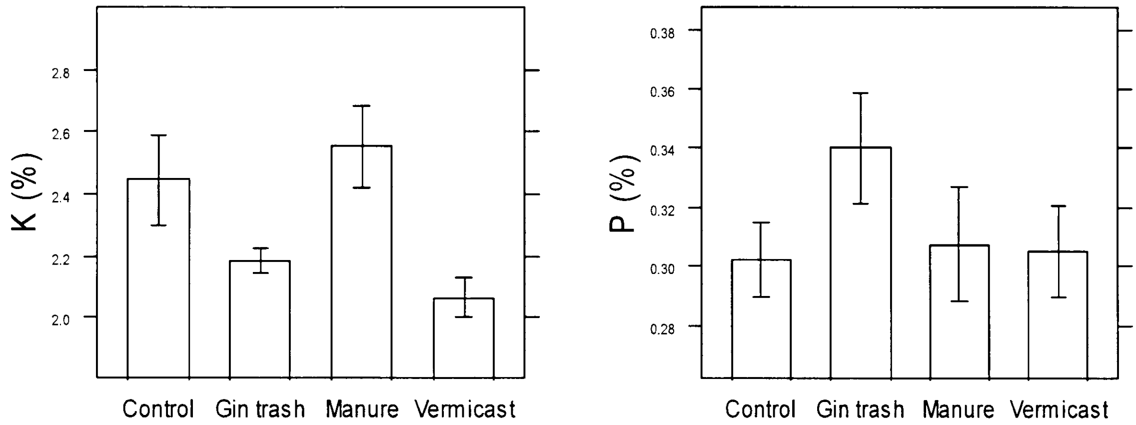

Fig. 4.12 Leaf concentration of K and P by cotton after addition of organic amendments at Site 1. Vertical bars are the standard error of the means.

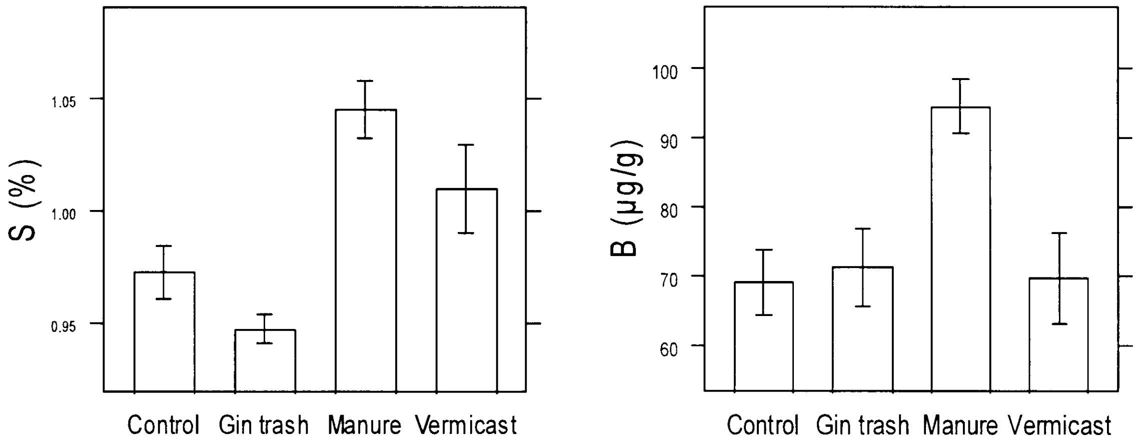

Fig. 4.13 Leaf concentration of S and B by cotton after addition of organic amendments at Site 1. Vertical bars are the standard error of the means.

Analysis of leaf concentrations of other macro- and micro-nutrients showed that the plots amended with cattle manure resulted in a significant increase in leaf Al and Mo content. However, the treatments did not differ significantly for the Ca, Na, Zn, Cu and Fe concentrations (Table 4.7). The significant increase in Mg concentration in the cotton leaves was observed in vermicast amended plots. Application of cotton gin trash resulted in significant increase in leaf Mn concentrations over the control plants.

Table 4.7 Leaf concentrations of other macro- and micro-nutrients by cotton after application of organic amendments at Site 1. Means and standard errors are presented.

Treatment	Ca (g/100 g)	Mg (g/100 g)	Na (mg/g)	Zn (μg/g)	Mn (μg/g)	Fe (μg/g)	Cu (μg/g)	Mo (μg/g)
Control	4.05±0.04	0.84±0.01	2.09±0.24	25.5±2.2	106.2±3.3	55.1±2.4	6.1±0.39	1.49±0.32
Cotton gin trash	3.89±0.11	0.85±0.02	1.98±0.18	27.0±1.8	121.4±2.4	61.5±5.2	6.9±0.46	1.65±0.28
Cattle manure	3.90±0.05	0.84±0.01	1.64±0.06	33.1±4.5	105.4±3.7	57.7±1.5	7.2±0.70	3.02±0.46
Vermicast	3.89±0.07	0.88±0.00	1.92±0.24	25.9±1.7	109.7±5.0	68.3±9.1	6.2±0.28	1.66±0.20

4.3.4 Site 2 (Farmer's trial) – Goondiwindi

Results from the farmer's trial are presented in Table 4.8. The results from the farmer's trial are similar to our research field's (Site 1) results, except with respect to the microbiological properties. Data suggested that the application of compost significantly increased ($P < 0.05$) the microbial biomass only during the final harvest. There was a general increase in microbial respiration during the final harvest, although it was not affected by the application of the organic inputs at any of the sampling times.

Among the nutrients, exchangeable-K content was increased significantly due to application of compost at both times; all other nutrients were not affected by the addition of amendments (Table 4.8). However, there was a significant increase ($P < 0.001$) in sulphate-S and phosphate-P and a significant decrease ($P < 0.01$) in exchangeable Ca and Mg concentrations with time.

Table 4.8 Changes in soil properties due to application of compost at Goondiwindi (Site 2). Samples were taken in November 2004 and May 2005. Means and standard errors are presented.

Treatment	Microbial biomass (mg microbial C/100 g DM soil)		Respiration (mg CO_2/hour/100 g DM soil)		Nitrate-N (μg/g)		Phosphate-P (μg/g)	
	Nov	May	Nov	May	Nov	May	Nov	May
Control	23.0±2.2	23.1±2.0	0.18±0.03	0.29±0.05	47.1±7.8	48.7±11.0	34.8±4.1	57.7±9.5
Compost	27.3±3.2	38.3±2.3	0.18±0.02	0.36±0.04	55.1±6.7	59.5±12.5	30.7±2.3	64.1±9.2
	Exchangeable-K (μg/g)		Sulphate-S (μg/g)		Ca (cmol(p^+)/kg)		Mg (cmol(p^+)/kg)	
	Nov	May	Nov	May	Nov	May	Nov	May
Control	0.87±0.07	0.65±0.05	20.7±1.6	91.0±35.9	20.2±0.55	18.2±0.43	10.3±0.12	9.7±0.11
Compost	1.05±0.03	0.93±0.07	24.8±1.9	96.3±34.3	22.2±0.14	18.6±0.25	11.1±0.15	9.9±0.19

**November sampling was before sowing and May sampling during harvest

4.4 Discussion

4.4.1 Effect on soil quality

The level of microbial biomass and its activity in a soil is usually determined by soil moisture, temperature and the amount and quality of SOM (Guidi *et al.* 1988; Fauci and Dick 1994). Any inorganic nutrient additions to soil ecosystems which may be limited by resources such as metabolizable C and available nutrients would also influence the soil microbial population (Wardle 1992). If organic materials are composted for any length of time, nutrients may also be lost through leaching and volatilisation from the compositing pile, and the quality of those organic materials as sources of plant nutrients to crops may be reduced. Thus it is not easy to predict how long any positive effects of organic amendments might last.

In Site 1, the soil microbial biomass did not respond to the addition of any of the organic amendments over two years. The intention in this study was to use similar rates of amendments to those in current use by cotton farmers (7.5 t/ha of cotton gin trash and 10 t/ha of cattle manure). If higher rates had been used, there may have been a response by soil microbial biomass. Hunt (inHunt 1998) found an increase of 50% in microbial biomass between control and soil amended with 60 t/ha cattle manure, but found no effect with 20 t/ha in a coarse sandy loam cropping soil at Armidale, NSW. The higher microbial activity during the 1st year can be attributed to the high rainfall during the winter of 2004 (Figure 4.1), and hence the microbial activity might have peaked at periods between the sampling times. Leaf senescence and addition of nutrients and C to the soil might be the reason for the increase in microbial biomass in the later stage of growth in both years. However, other researchers (Press *et al.* 1996) found no change in microbial biomass using organic by-products though they did find a change in types of bacteria present from gram positive to gram negative. The decline between year 1 and year 2 (4 and 16 MAFA) in particulate organic matter light fraction reflects the labile nature of this organic matter fraction. Gupta *et al.* (1994) found that an increase in microbial activity resulted in a rapid decomposition of particulate organic matter and labile fractions of plant residues. This would also seem to be the case in the present study where lower levels of microbial biomass were associated with lower levels of light fraction of particulate organic matter. The increase in microbial biomass due to compost addition in Site 2 is similar to the findings of Mabuhay *et al.* (2006) who also reported an increase in soil microbial biomass with both poultry manure (20 t/ha) and inorganic fertilizer in eroded soils. The quality of the compost used at Site 2 may have been better than that of the manure and cotton gin trash used in Site 1, as in the former site a microbial response was seen although the application rates were similar.

The higher respiration at the research field (Site 1) during the final harvest in the 1st year might can be explained by the heavy rains during the winter of 2005 (Figure 4.1), irrigation and hot summer conditions which lead to warm, wet soil, stimulating the microbial activity. Again, the decline in microbial biomass in the 2nd year resulted in lower respiration during that year. Microbial respiration is often stimulated after cultivation (Rastogi *et al.* 2002). The soil was cultivated in all treatments, including the control, after the first baseline sampling and C would have been respired over 1st year because of higher microbial activity, leaving the soil depleted of C, with subsequent declines in microbial populations and their activity. The vetch crop also added an additional 4-5 t/ha of residues, during the 1st year in addition to cotton stubble, whereas in the 2nd year only cotton stubbles were present. The marked decline by around 50% in the light organic fraction over one year between 4 and 16 MAFA in all the treatments would seem to support these conclusions.

'Light fraction' is the labile component of SOM (Magid *et al.* 1996) which is readily oxidizable by a mild oxidizing agent. The incorporation of previous residues and application of organic amendments resulted in a significant increase in the light fraction during the active growth stage in 1st year at Site 1. The significant decrease in the 2nd year might be attributed to the decomposition of these residues over a year. Cultivation is known to increase soil organic C mineralization and CO_2 emissions (Roberts and Chan 1990). Similarly, decomposition of these residues over a year caused a significant decrease in the light fraction after one year in all the treatments: 51, 61.5, 48.5 and 60.8% from 1st year to 2nd year in control, cotton gin trash, cattle manure and vermicast treatments respectively. The rate of breakdown of organic matter is often more important than the rate of addition (Nardi *et al.* 1996). In their native state, soils are in equilibrium and tend to have characteristic SOM content. The field was farmed for several years, so the native state may have changed, but we observed a similar value for the light fraction in our first measurement when no amendments were applied (Figure 4.5). This equilibrium is disturbed when the soils are brought into cultivation by the reduced accumulation of fresh material and acceleration of SOM breakdown (Conteh *et al.* 1997). The mineralization of the organic matter due the activity of the microorganisms present in the vermicast caused a significant increase in soil available N and P and a decrease in light fraction of organic matter. Given optimal time and soil conditions, the labile components can be rapidly and completely mineralized and the non-labile components accumulate. The higher light fractions in all the plots including the control as compared to the first measurement when amendments were not applied may be due to the residual effect of 1st year incorporation of residues and addition of organic amendments.

The decrease in nitrate-N content during the active growth stage at 4 MAFA at Site 1 is consistent with the higher growth rate and high nutrient uptake at that time. Mineralization of N from the amendments because of their low C/N ratio (Table 4.1) might cause the increase of nitrate-N over the control during 3rd sampling time (7 MAFA). Denitrification or leaching of nitrate due to heavy rainfall during winter of 2005 (Figure 4.1) might be the reason for decrease in its concentration at 12 MAFA, and then again mineralization of the residues incorporated caused an increase at 16 and 19 MAFA. The higher biomass of cotton in 2nd year (Table 4.6) reflected the high nutrient uptake by cotton leading to lower soil nitrate-N concentration at the 2006 harvest than the 2005 harvest. Although the residues were incorporated (a vetch crop was incorporated before sowing of 1st year cotton), the amendments (except vermicast) were applied only once in two years, and slower decomposition of previous cotton residues (Felton *et al.* 2000) resulted in a decrease in nitrate-N in the 2nd year. Stubble incorporation leads to a rapid increase in microbial decomposition, N-use and immobilization (Russel 1973). The 2nd year application of vermicast increased the plant available N during the final harvest in that growing season. Unpublished results from laboratory incubations of the soil indicate that vermicast, although it adds insignificant amounts of N to the soil, is able to stimulate the production of soil nitrate which might be because of the microorganisms present in the amendment which stimulated the mineralization of organic matter and resulted in a significant increase in soil available N.

In Site 1, among the applied organic amendments, cattle manure contributed a large amount of P (105 kg/ha) (Table 4.2), leading to a significant increase in available P content in the soil at 12 MAFA. This is supported by the findings of Motavalli and Miles (2002) where the addition of manures significantly increased resin P among all cropping systems compared with the unfertilized controls. The decline in P content in the 2nd year may be attributed to one or more of the following factors: P transformation and transport involving the process of microbial immobilization, soil P sorption, and crop uptake (Kwabiah *et al.* 2003). High crop uptake at 16 MAFA in 2nd year resulted in a decrease in P concentration over the fallow. Paul and Voroney (1984) and Stewart and Tiessen (1987) suggested that inorganic P uptake into microbial cells is energy dependent, and is affected by C quality and concentration. The absence of adequate C to match the available P will preclude significant immobilization of inorganic P by soil microbes. There was a decline in labile C in 2nd year. Thus it seems likely that the decline in phosphate-P in 2nd year was caused by soil fixation and also the higher P uptake by the cotton plants in the 2nd year as compared to 1st year (Figure 4.7). Nguluu *et al.*(1996) noted a decrease in extractable P over time due to an increased P sorption by the soil over time. Added phosphate might become progressively more strongly adsorbed over time, but in our study, Vertosols have had similar P inputs and outputs over many years (at least for the control). Various mechanisms have been proposed to explain how decomposing organic inputs could affect P availability (Cole *et al.* 1977). These include (1) enhanced solution P due to competitive advantage of organic anions formed by decomposing organic inputs for adsorption sites over P in the native soil (Iyamuremye and Dick 1996), (2) changes in the rate of diffusion of inorganic P to the microbial biomass (Harrison 1982) and, (3) changes in the equilibrium between inorganic P in soil solution and adsorption of the soil (Nguluu *et al.* 1996). Overall, our result with manure amended plots was supported by the findings of Blaise *et al.* (2006) who also observed that available P content in soil was greater in the manure treatments than the treatments without manure. The mineralization of the organic matter due to application of vermicast also resulted in an overall increase in available P in the soil.

The decline in K content during the active growth stage and final harvest (16 and 19 MAFA) in the 2nd year at Site 1 was similar to the findings of Singh *et al.* (2002) who found that the application of cattle manure resulted in relatively larger decline in native K due to higher uptake by crop. Goulding and Talibudeen (1984) also observed a considerable decrease in K preference of FYM-treated soils. The treatments did not differ significantly in exchangeable K except during the final harvest in 1st year when manure increased exchangeable K which is similar to the findings of Johnston and Addiscott (1971). They evaluated the effect of long-term FYM application and observed that the quantity:intensity parameters of FYM-treated and control soils were identical. The increase in exchangeable K content as a result of manure addition at 7 MAFA may be due the extra exchangeable K (226 kg/ha) added by the manure treatment and also the dominance of illitic type of clay in the experimental soil. The 14% increase in exchangeable K in soil after two years of experiment at Site 1 is similar to the findings of Bernal *et al.* (1993) who also observed that the addition of pig slurry caused a linear increase in exchangeable K content of soil mainly with illitic clay. The result at Site 1 was supported by our farmer's trial where we also found an increase in exchangeable-K content due to application of compost (Table 4.8).

Among the organic amendments applied at Site 1, cattle manure added highest exchangeable Na (40 kg/ha) into the surface soil which might be the reason for higher exchangeable Na in the manure amended plots. The high rainfall in the winter of 2005 (Figure 4.1) may have resulted in leaching of salt from the surface layer which in turn may have decreased exchangeable Na during the 2nd year. Hulugalle and Finlay (2003) suggested that build-up of SOM and microbial activity in Vertosol could reduce their tendency towards dispersion.

In our study, significant differences did not occur among treatments with respect to exchangeable Ca and Mg content of soil for both the sites (Tables 4.4, 4.8), but their concentrations differed with the sampling time.

4.4.2 Effect on lint yield and nutrient uptake

Cotton lint yield did not change significantly between the treatments, however, higher lint yield was observed in the 1st year as compared to the 2nd and 3rd year. In 2004, Reddy *et al.* reported that the application of poultry litter generally gave lower or similar cotton lint yield compared with ammonium nitrate at the same rate whereas Blaise *et al.* (2006) observed that the organic manure applied plots yielded better than the inorganic fertilizer plots. However, a significant decrease in yield in 2005-06 probably occurred because of slower mineralization of nutrients and thus may have not met the crop nutrient demand as the organic amendments except the vermicast were applied only in the 1st year. The other reason might be the infestation of boll worm (*Helicoverpa* spp.) in that year in later stages of growth. Dawe *et al.* (2000)

noticed significant yield declines at some locations in the intensive irrigated cropping systems. Another reason could be the high year-to-year climatic variability in the present study. Rainfall distribution can have a significant effect on cotton lint yields (Reddy *et al.* 2004). The high rainfall and low temperature in the 2nd year might also be the reason for lower lint yield. The early season rainfall may have resulted in nutrient leaching. It also resulted in extensive off-field weed and plant growth which can function as hosts for *Helcoverpa* moths, thereby causing large increases in regional moth populations.

Responses to application of manure have been distinct in irrigated cotton (Das *et al.* 2004), but this was based on the results of short-term experiments. In our study, the whole plant analysis at their full grown stage revealed that high amounts of K present in cattle manure resulted in higher K uptake by cotton plants in the 1st year, which is also evident from our soil available K result (Figure 4.8). However, the plant uptake of the nutrients is significantly higher in the 2005-06 growing season as compared to the previous year. This might be related to the high insect activity in the 2nd year which damaged the apical meristems leading to extensive branching and more vegetative growth and thus less nutrients being transferred to the lint. The difference in plant uptake of nutrients between the two years can also be related to the dry matter. The high dry matter of cotton in the 2nd year as compared to 1st year might be the reason for higher nutrient uptake in the 2nd year. The study by Sadras (1996) supported our findings, where he found that the insect-damaged cotton plants had more vegetative biomass than controls.

Study by Rochester (2007) suggested that cotton accumulated averages of 27, 167, 41, 160, 36 and 7 kg/ha for P, K, S, Ca, Mg and Na; these values are quite similar to the 2nd year data in the present study. The micronutrient uptake was quite low as compared to Rochester's (2007) findings. Mullins and Burmester (1990) observed 28, 626, 388 and 103 g/ha for Cu, Fe, Mn and Zn uptake respectively for the cotton grown in acid soils of Alabama; these values were also similar to our data except for the Fe and Mn, which may be due to the higher availability of these two micronutrients in acid soils. Constable *et al.* (1988) reported mean values of 20, 600, 450 and 60 g/ha for Cu, Fe, Mn and Zn uptake, respectively, for 35 cotton crops grown on alkaline soils of northern NSW, Australia; in contrast we found much lower values for Fe and Mn.

The lower uptake in the 1st year may be attributed to low rate of mineralization of the nutrients which became available in the 2nd year and higher uptake by cotton made the soil deficient in those nutrients which is quite clear from our 2nd year soil data. Although S, K, Mo, Cu or Mn did not improve cotton growth in the field, these nutrients may become deficient in future with continued intensive cropping (Hibberd *et al.* 1990).

4.5 Conclusions and future research

The organic amendments at these rates did not have a substantial short-term influence on Vertosol quality. Variable responses were observed only with time over two years. However, cattle manure-amended plots showed higher phosphate-P and exchangeable K concentration over two years. Only microbial biomass and exchangeable-K content was significantly increased due to application of the compost at Site 2. The microorganisms present in the vermicompost might enhance the mineralization of organic matter and resulted in increased soil available N and P, but it would cause the quick depletion of SOM. As some cotton farmers in Australia are using the vermicomposts in order to achieve a higher yield, using this amendment might need more investigation in order to maintain the soil quality. Cotton cropping is driven strongly by management based on soil C (with variable lability), high inputs of N, irrigation and the application of herbicides and pesticides. The changes to the soil microbial community due to such management practices would be many and variable and based mainly on labile C and soil nutrients and this would need to be examined further. Further work will also be required to examine potential longer term effects of these amendments, use of other different organic amendments, and the influence of application rates.

Chapter Five

Short-term effect of different organic amendments on soil properties of a Vertosol

5.1 Introduction

Improved management of soil organic matter (SOM) in arable soils is essential to sustain agricultural lands and the urban and natural ecosystems with which they interact. It influences a wide range of physical, chemical and biological properties of soil and is considered the most important indicator of soil quality (Carter *et al.* 1999). With the exception of fertilizers, SOM provides the largest pool of macronutrients with > 95% of N and S and 20-75% of P found in SOM (Duxbury *et al.* 1989). Organic amendments as a source of SOM and nutrients have a long history in agriculture; on the other hand, inorganic amendments have gained popularity because they are easier to manage, handle and apply (McLaughlin *et al.* 2002). It is also easier to synchronize the release of nutrients and plant uptake with inorganic fertilizer than is the case with organic amendments, as inorganic fertilizer is released into the soil solution often immediately. Application of NPK fertilizers is a common global practice which also affects soil quality.

Organic and inorganic fertilizer amendments are used mainly to increase the availability of nutrients to plants, but they can also affect soil microorganisms (Marschner *et al.* 2003). Soils amended with manures that do not contain toxic elements (e.g. heavy metals) generally have higher biological activity than those managed with mineral fertilizers (Dick 1992). The addition of biosolids increased organic C and available nutrients. Similarly, hydrolytic enzymes such as urease, alakaline phosphatase, arylsulfatase activities were increased by biosolids application (Kizilkaya and Hepsen 2004). Poultry litter is a relatively inexpensive source of both macronutrients and micronutrients and has been reported to increase soil organic C and enhance soil microbial activity (Nyakatawa *et al.* 2001). Edwards and Neuhauser (1988) report increased plant growth in potting-media enhanced with vermicompost derived from animal manures. Numerous studies from both overseas and Australia (Brechin and McDonald 1994; Kliese *et al.* 2005) have identified the potential of animal manures and urine to act as fertilizers, due to their high N and P content, whilst also noting potential undesirable environmental contamination issues (Carey *et* *al.* 1997; Philips 2004). While the addition of organic matter is generally regarded as beneficial, it is also necessary to consider the possible negative effects of applying manures.

Vertosols are clay textured soils with shrink-swell properties that exhibit strong cracking when dry (Isbell 1996a). These soils are structurally unstable, tend to slake easily on wetting and are easily compacted. However, they are very resilient and can develop a good structure after only a few cycles of wetting and drying (Wenke and Grant 1994). Soil structural stability in cracking clay soils with low SOM content is positively related to the frequency of intensive wetting and drying cycles (Sarmah *et al.* 1996; Pillai and McGarry 1999). SOM and fertility commonly decline with cropping on Vertosols (Chan 1997; Dalal and Chan 2001). Cultivated Vertosols in New South Wales have reduced organic matter (up to 40% less), greater pH, less extractable P, and reduced structural stability and biological activity (Chan *et al.* 1988). The P deficiency problems could partially be relieved by an informed decision on the part of farmers to return to the soil high quality organic materials which are locally available but are often ignored. Many landholders have been investigating options of using recycled organic material to improve soil properties with a view to partially or fully replacing inorganic fertilizers. However, information on the effects of organic waste products on quality of Vertosol used for irrigated cotton production systems in Australia is sparse.

In this study, we examined the effects of a wide range of easily accessible organic amendments on Vertosol quality. Application rates of amendments used in this study were those which reflected current practice among cotton farmers in the district under study. If application of these materials proves beneficial, it will benefit not only cotton farmers but will also offer an economic and environmentally acceptable means of waste disposal.

5.2 Materials and Methods

5.2.1 Experimental details

An incubation study was conducted for four weeks in a temperature controlled growth chamber in the Department of Agronomy and Soil Science, University of New England, Armidale, NSW. The experiment was conducted in a controlled temperature room where the temperature was maintained at 30°C. The soil used, a well structured grey cracking clay soil classified as Grey Vertosol (Isbell 1996a) or Typic Haplustert (Soil Survey Staff 2006), was collected from the 0-0.10 m depth of a field at the Australian Cotton Research Institute (ACRI), near Narrabri, NSW (150°E, 30°S). The pH of the soil was alkaline and the $EC_{1:5}$ ranges from 0.24-0.25 dS/m. The organic C content was 0.83%. X-ray diffraction (XRD) results showed that this soil is dominated by the illitic type of clay. Particle size distribution in the 0-0.10 m depth was 59 g/100 g clay (less than 2 μm), 17 g/100 g silt (2-20 μm) and 24 g/100 g sand (20 μm - 2 mm).

5.2.2 Experimental design and treatments

The soil was amended with twelve different organic amendments, which were obtained locally, regionally and from commercial suppliers. Among the twelve organic amendments, there were three cotton gin trashes of different origins; viz. one from the AUSCOTT cotton gin, near Narrabri (147°E, 31°S) and another two from the McIntyre farm, Goondiwindi (150°E, 28°S). Green waste compost and biosolids were collected from Armidale, NSW (151°E, 30°S). Biosolids were fairly wet as they were collected on the shore of a pond at the Armidale Council, NSW. The manures, obtained locally, were cattle manure from Narrabri and feedlot manure from Tullimba research feedlot (151°E, 30°S). The composted and fresh chicken manure were collected from the Department of Animal Science, University of New England, Armidale, NSW. The vermicomposts and pelletized chicken manure 'Dynamic Lifter®' were the commercial products used in this experiment as amendment.

Six hundred grams of air-dried soil were placed in 100 mm diameter pots filling them to a depth of 10 cm. The amendments were mixed thoroughly with the soil. The rate of application of the amendments was determined according to local farmer practice or the manufacturer's recommended application rate. No plants were grown in the pots.

The treatments were laid in a randomized block design with three replications. Water was added once a week to maintain the moisture level of the soil near field capacity (gravimetric soil water content of ~ 42 g/100 g). The treatments and their rate are summarized in Table 5.1.

5.2.3 Soil analyses

5.2.3.1 Microbiological properties

Approximately 50 g fresh samples were used to analyse the microbiological properties measured by microbial biomass and basal respiration using the method already described in Chapter 3.

Table 5.1 Soil amendments and their application rate

	Treatment	Abbreviation	Application rate
1.	Control		
2.	Narrabri cotton gin trash	CGT(N)	10 t/ha (dry weight)
3.	Goondiwindi cotton gin trash	CGT(G)	10 t/ha (dry weight)
4.	Cotton gin trash + lime	CGT+L	10 t/ha (dry weight)
5.	Green waste compost	GWC	10 t/ha (dry weight)
6.	Cattle manure	Manure	10 t/ha (dry weight)
7.	Tullimba Feedlot manure	FM(T)	10 t/ha (dry weight)
8.	Fresh chicken manure	FCM	3 t/ha (dry weight)
9.	Composted chicken manure	CM	3 t/ha (dry weight)
10.	Chicken manure (Dynamic Lifter®)	CDL	3 t/ha (dry weight)
11.	Biosolids	BS	10 t/ha (dry weight)
12.	Commercial vermicast1	Vermicast1	50 L/ha in 400 L/ha of water
13.	Commercial vermicast2	Vermicast2	combined application of two different vermicomposts @50 L/ha and 30 L/ha in 400 L/ha of water for soil

5.2.3.2 Physical properties

Air-dried soil samples were used to analyse the aggregate stability and dispersion index of the soil. The aggregate stability of the samples was determined by measuring the mean weight diameter (MWD) of the soil through dry sieving. The air-dried split samples (approximately 75 g) were placed in a stack of sieves from 9.5 mm up to 0.6 mm at amplitude 2 for 2 minutes. The soil aggregates retained by the individual sieves were then weighed and the mean weight diameter was calculated using the following formula.

$$MWD = \sum_{i=1}^{n} x_i w_i$$

Where, x_i is the mean diameter of any particular size range of aggregates separated by sieving, and w_i is the weight of the aggregates in that size range as a fraction of the total dry weight of the sample analysed.

The dispersion index (DI) of small aggregates was measured by using a method derived from Blackmore (1956) and Mason *et al.* (1984) where

$$DI = 100 \times (clay + silt)_{m.d.} / (clay + silt)_{f.d.}$$

Where m.d. refers to mild dispersion and f.d. is full dispersion. The denominator comes from the particle size analysis and the numerator was determined by using measurements on 25 g of 0.25-2.00 mm aggregates. These were added to water in sedimentation cylinders, allowed to soak for 16 hours and then stirred for 1 minute by using a hand plunger. The proportion of clay and silt was measured with a hydrometer.

5.2.3.3 Chemical properties

The soil samples were air dried, passed through < 2 mm sieve and then analysed for selected chemical properties as described in Chapter 3.

5.2.4 Organic amendment analyses

Chemical analyses of the organic amendments were performed in the Plant Nutrition Laboratory of University of New England, Armidale, NSW. The concentration of P, S, K, Ca, Mg and Na in the amendments were determined using the Sealed Chamber Digestion method described by Anderson and Henderson (1986) and the vermicompost was analysed commercially, as described in Chapter 3.

The chemical composition of the amendments is presented in Table 5.2. Table 5.3 showed the amount of nutrient added by the amendments into the soil.

Table 5.2 Elemental composition of the organic amendments

Treatment	Moisture content (g/100g)	C (g/100g)	N (g/100g)	P (g/100g)	K (g/100g)	Na (μg/g)	Ca (g/100g)	Mg (g/100g)
CGT(N)	5.2	12.0	1.3	0.34	1.3	640	3.3	0.76
CGT(G)	35.8	13.0	1.3	0.28	1.0	562	2.6	0.52
CGT+L	55.2	14.8	1.7	0.30	0.9	565	2.7	0.54
GWC	0.5	34.7	0.7	0.06	0.3	333	0.8	0.18
Manure	7.1	24.2	2.3	1.05	2.3	4010	3.0	0.97
FM(T)	77.6	19.9	1.9	0.86	0.8	1336	2.2	0.87
FCM	278.1	35.0	2.6	1.89	3.7	2856	4.0	0.95
CM	20.3	20.9	2.9	4.39	1.9	4378	17.6	0.97
CDL	34.4	32.1	4.4	2.83	2.4	6013	4.2	0.75
BS	219.4	21.8	2.2	1.35	0.1	724	4.7	0.30
Vermicast1	liquefied	12.5	0.3	0.07	0.3	5220	27.7	0.90
Vermicast2	liquefied	16.8	16.6	3.47	10.3	4555	1.2	0.24

Table 5.3 Nutrient added to each pot from the amendments

Treatment	C mg/pot	N mg/pot	P mg/pot	K mg/pot	Na mg/pot	Ca mg/pot	Mg mg/pot
CGT(N)	944	100	26.9	108	5.0	258	60
CGT(G)	1019	100	21.6	78	4.4	202	41
CGT+L	1161	130	23.4	69	4.4	212	43
GWC	2723	50	5.0	26	2.6	64	14
Manure	1896	180	82.3	177	31.5	238	76
FM(T)	1566	150	67.3	62	10.5	172	68
FCM	826	60	44.7	87	6.7	95	22
CM	493	70	103.6	45	10.3	416	23
CDL	758	100	66.8	56	14.2	98	18
BS	1709	170	105.8	9.0	5.7	368	24
Vermicast1	1.74	0.05	0.01	0.05	0.09	4.7	0.15
Vermicast2	2.84	2.31	0.48	1.43	0.06	0.16	0.03

5.2.5 Statistical analyses

Results were analysed in R 2.5.0 (R Development Core Team 2006) using fixed effects one-way analysis of variance (ANOVA) with treatment and block as factors. Where significant treatment effects were found, pair-wise comparisons (P = 0.05) between the control and organic inputs were made using contrasts. Variances were checked by plotting residual vs. fitted values to confirm the homogeneity of the data. No transformations were necessary.

5.3 Results

The summary of the statistical analyses are presented below in Table 5.4 and 5.5.

Table 5.4 Results of ANOVA and pair-wise comparison between control and other treatments for the microbiological and some physico-chemical properties of a Vertosol

	Microbial biomass	Microbial respiration	Mean weight diameter	Dispersion index	Light fractions	ESP
Significance	ns	**	***	***	**	***
Treatment (pair-wise comparison from control at $P = 0.05$)						
CGT(N)	na	ns	ns	ns	↑	↑
CGT(G)	na	ns	ns	ns	ns	↑
CGT+L	na	ns	ns	↑	↑	↑
GWC	na	ns	ns	ns	ns	↑
Manure	na	ns	ns	↑	↑	↑
FM(T)	na	ns	ns	↑	ns	↑
FCM	na	ns	ns	ns	↑	↑
CM	na	ns	↑	ns	ns	↑
CDL	na	ns	↑	ns	ns	↑
BS	na	↑	↓	ns	ns	↑
Vermicast1	na	ns	↑	↑	ns	↑
Vermicast2	na	ns	↑	↑	ns	↑

[Significance levels: (***) $P < 0.001$; (**) $P < 0.01$; (*) $P < 0.05$; ns = not significant, na = not applicable, ↑ = significant increase at $P = 0.05$, ↓ = significant decrease at $P = 0.05$]

Table 5.5 Results of ANOVA and pair-wise comparison between control and other treatments for the selected chemical properties of a Vertosol

	pH	EC	Phosphate-P	Nitrate-N	Exch. K	Exch. Ca	Exch. Mg	Exch. Na
Significance	***	***	***	***	***	*	**	***
Treatment (pair-wise comparison from control at $P = 0.05$)								
CGT(N)	ns	↑	ns	ns	ns	ns	ns	↑
CGT(G)	↑	↑	ns	ns	↑	↑	ns	↑
CGT+L	↑	↑	↑	↑	ns	ns	ns	↑
GWC	↑	↓	ns	↓	ns	ns	ns	↑
Manure	↑	↑	↑	ns	↑	ns	ns	↑
FM(T)	↑	↑	↑	↑	ns	ns	↑	↑
FCM	↑	↑	ns	↑	↑	↑	↑	↑
CM	↑	↑	↑	↑	ns	ns	↑	↑
CDL	↑	↑	ns	↑	ns	ns	↑	↑
BS	↑	↑	↑	↑	ns	↑	ns	↑
Vermicast1	↑	ns	ns	ns	ns	↑	↑	↑
Vermicast2	↑	↓	ns	ns	ns	ns	ns	↑

[Significance levels: (***) $P < 0.001$; (**) $P < 0.01$; (*) $P < 0.05$; ns = not significant, na = not applicable, ↑ = significant increase at $P = 0.05$, ↓ = significant decrease at $P = 0.05$]

5.3.1 Effect on microbiological properties

Microbial biomass was not affected by the short-term application of organic amendments, but a significant treatment difference ($P < 0.01$) was observed for basal respiration (Table 5.4, Figure 5.1). Only biosolid amended soil produced a significant (80%) increase in microbial respiration over control (Figure 5.2).

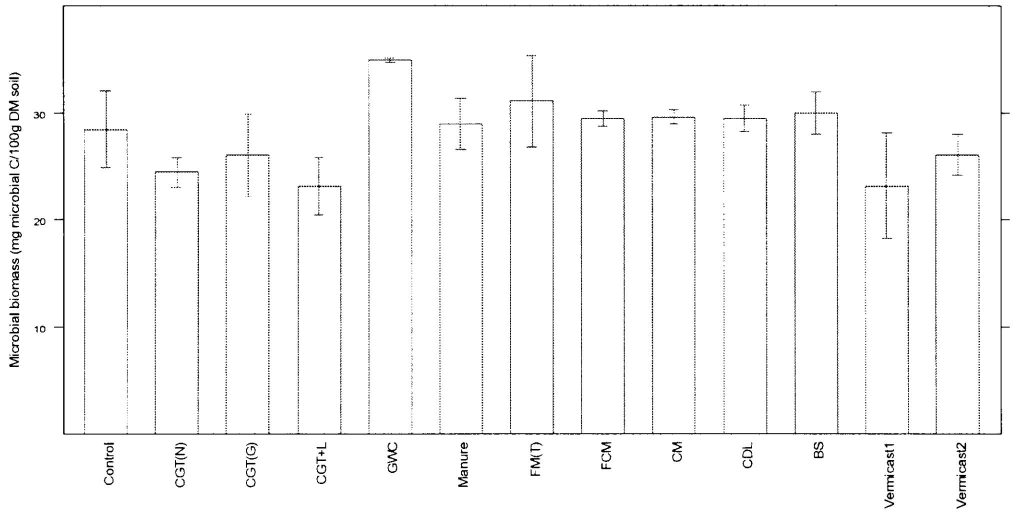

Figure 5.1 Effect of organic amendments on microbial biomass C. Vertical bars represent the standard error of the means.

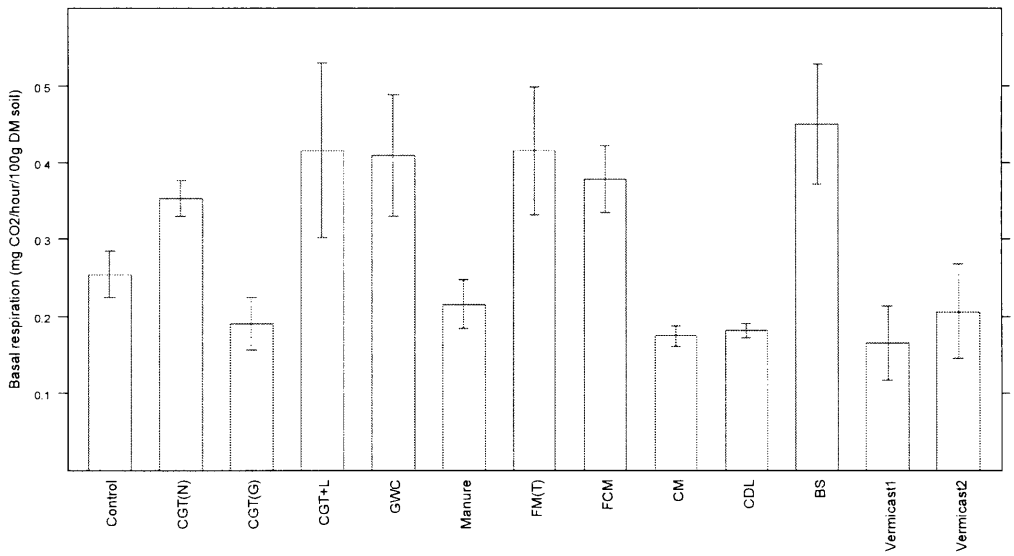

Figure 5.2 Effect of organic amendments on microbial respiration. Vertical bars indicate the standard error of the means.

5.3.2 Effect on physico-chemical properties

The treatments had a significant effect ($P < 0.001$) on the light fractions of organic matter (Table 5.4). Contrast ($P < 0.05$) showed that only four organic inputs resulted in a significant increase in the light fractions over the control treatment. The treatments are Narrabri cattle manure (442%), cotton gin trash + lime (183%), Narrabri cotton gin trash (176%) and fresh chicken manure (163%) (Figure 5.3).

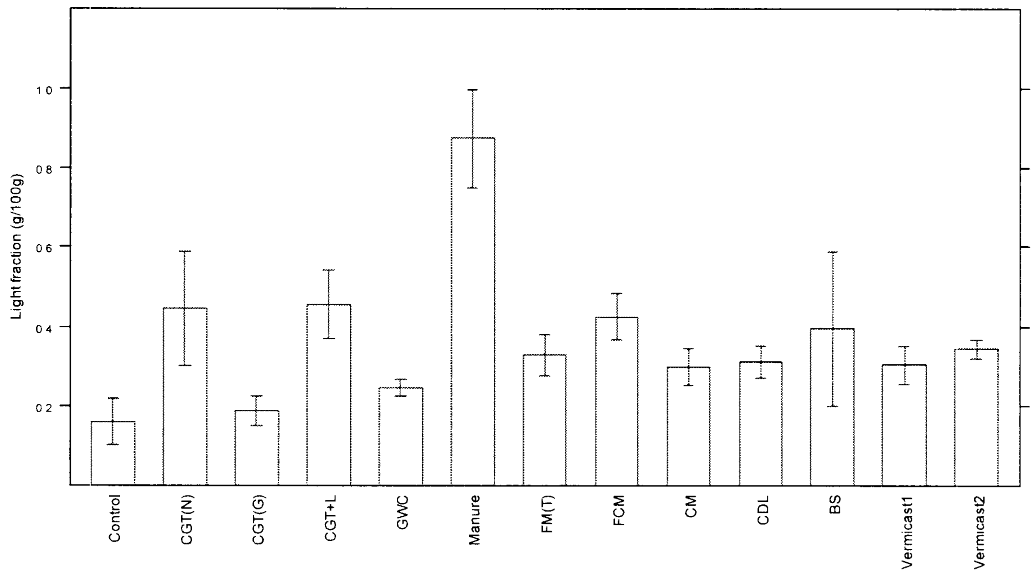

Figure 5.3 Effect of organic amendments on light fractions of organic matter. Vertical bars are the standard error of the means.

Mean weight diameter of aggregates was significantly affected by the application of organic amendments ($P < 0.01$) (Table 5.4). Contrast ($P < 0.05$) showed that the MWD significantly increased by the addition composted chicken manure, chicken 'Dynamic Lifter®' and the vermicasts; however, biosolids-amended soil showed a significant decrease over the control. There was a significant increase of 37, 31 and 25% in MWD for vermicast2, composted chicken manure and vermicast1 treatments respectively, whereas biosolids resulted in a significant 32.9% decrease over the control (Figure 5.4).

The treatments differed significantly ($P < 0.001$) for the DI of the Vertosol (Table 5.4). Contrast ($P < 0.05$) showed significant increase in DI by the application of cotton gin trash + lime, Tullimba feedlot manure, Narrabri cattle manure and both the vermicasts over the control. The increase in DI was highest due to surface application of cotton gin trash + lime (35%) followed by Tullimba feedlot manure (34%), vermicast2 (33%), Narrabri cattle manure (32%) and vermicast1 (25%) (Figure 5.5).

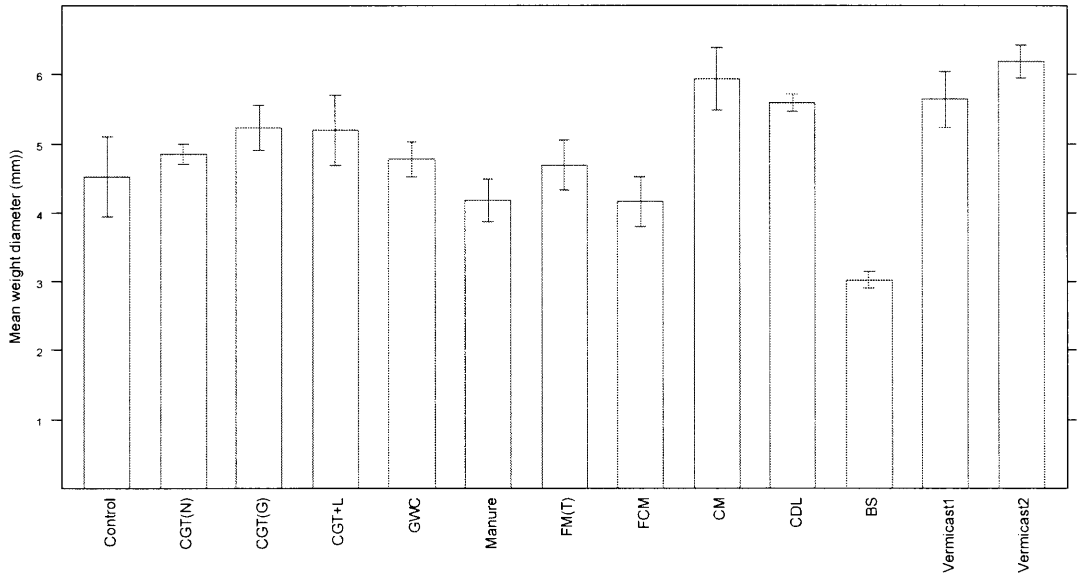

Figure 5.4 Effect of organic amendments on aggregate stability (mean weight diameter). Vertical bars indicate the standard error of the means.

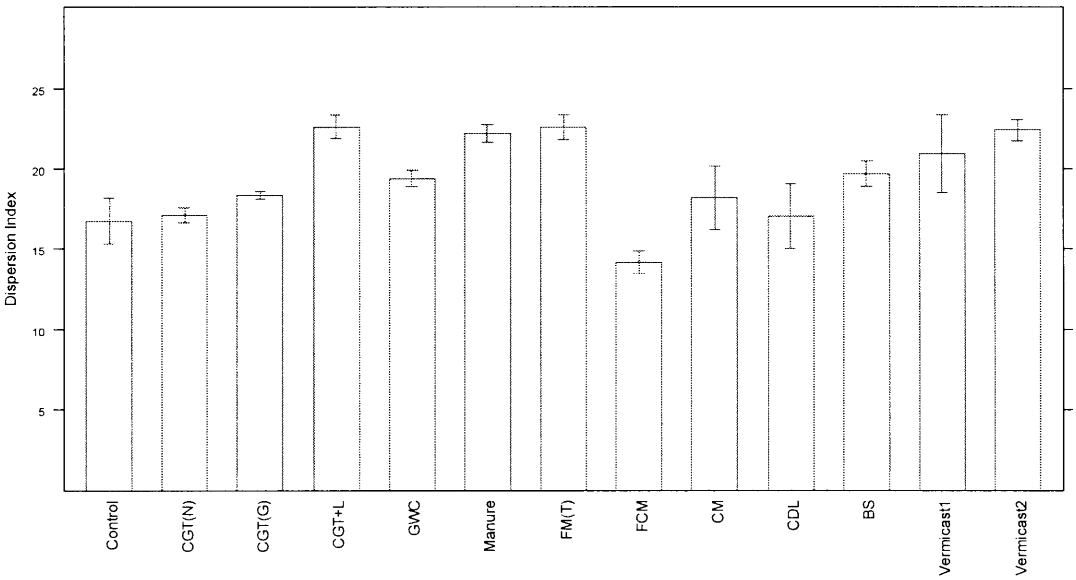

Figure 5.5 Effect of organic amendments on dispersion index of the Vertosol. Vertical bars represent the standard error of the means.

The pH of the Vertosol differed significantly among the treatments ($P < 0.001$) (Table 5.5). The contrast ($P < 0.05$) also showed a significant effect of the organic amendments on soil pH over control. Except Narrabri cotton gin trash, application of all other organic amendments significantly increased the soil pH relative to the control. The initial soil pH was 7.3, whereas it increased up to 8.1 due to addition of vermicast2 and green waste compost (Table 5.6).

A significant treatment difference ($P < 0.001$) was observed for the electrical conductivity (EC) of the Vertosol (Table 5.5). The contrast ($P < 0.05$) showed that except the vermicast1, all other organic inputs significantly affected the Vertosol EC over the control treatment. A significant decrease (15 and 11%) in soil EC was observed due to application of green waste compost and vermicast2 respectively as compared with control (Table 5.6). Among the organic inputs, the highest increase in EC was due to addition of fresh chicken manure (109%), followed by biosolids (87%), chicken 'Dynamic Lifter®' (71%), Narrabri cattle manure (62%), Tullimba feedlot manure (39%), composted chicken manure (38%), Goondiwindi cotton gin trash (29%), cotton gin trash from Narrabri (26%) and cotton gin trash + lime (24%).

Table 5.5 showed a significant treatment ($P < 0.001$) difference for the nitrate-N content of the Vertosol. Among the twelve organic inputs, addition of green waste compost resulted in a significant decrease ($P < 0.05$) in nitrate-N content compared with the control, whereas a significant increase in the nitrate level of the Vertosol was observed due to application of different types of chicken manures viz., fresh chicken manure (226%), chicken 'Dynamic Lifter®' (77%) and composted chicken manure (75%). Application of Tullimba feedlot manure (68%), biosolids (39%) and cotton gin trash + lime (29%) also increased the nitrate-N content of the Vertosol more than the unamended control (Figure 5.6).

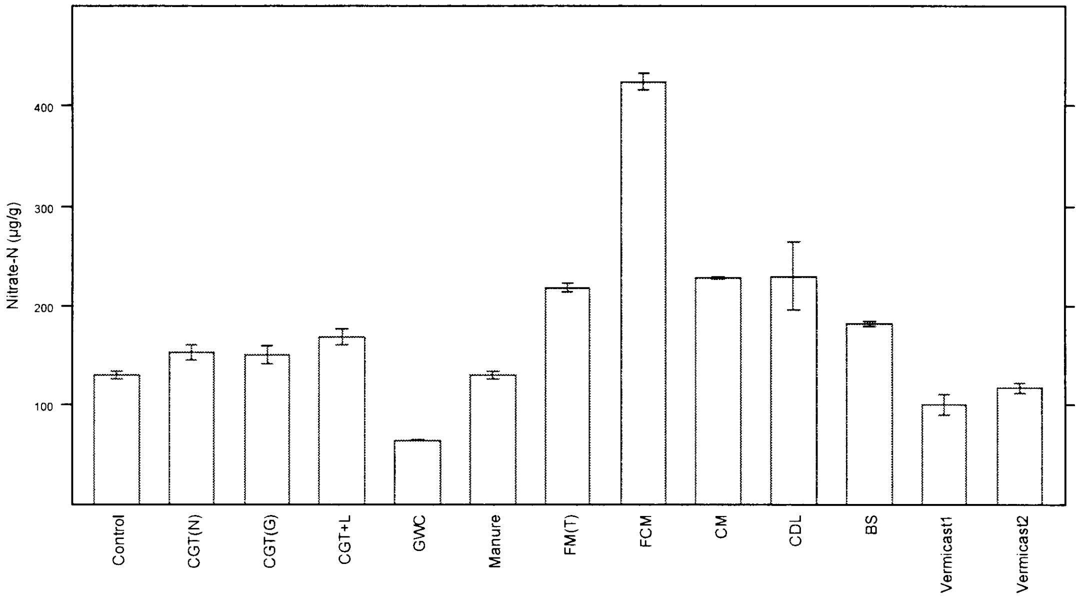

Figure 5.6 Effect of organic amendments on nitrate-N concentration of soil. Vertical bars indicate the standard error of the means.

The phosphate-P concentration of the Vertosol differed significantly between the treatments (P < 0.001) (Table 5.5). The contrast (P < 0.05) also showed the significant effect of the organic amendments over the control treatment. Among the different organic inputs, only biosolids, cotton gin trash + lime, composted chicken manure, Tullimba feedlot manure and cattle manure from Narrabri significantly increased the phosphate-P content of the soil. Figure 5.7 showed that there were 115, 108, 101, 86 and 67% significant increases in the phosphate-P content over the control soil due to Narrabri cattle manure, composted chicken manure, Tullimba feedlot manure, cotton gin trash + lime and biosolids respectively.

ANOVA showed a significant treatment difference (P < 0.001) for the exchangeable K concentration of the Vertosol (Table 5.5). Among the different organic inputs, only three; viz. Narrabri cattle manure, Goondiwindi cotton gin trash and fresh chicken manure caused a significant increase (P < 0.05) in exchangeable K concentration of the Vertosol as compared with the control. The exchangeable K content of the control soil was 1.57 cmol(p^+)/kg, whereas application of Narrabri cattle manure increased it by 22%, Goondiwindi cotton gin trash by 13% and fresh chicken manure by 9% (Figure 5.8).

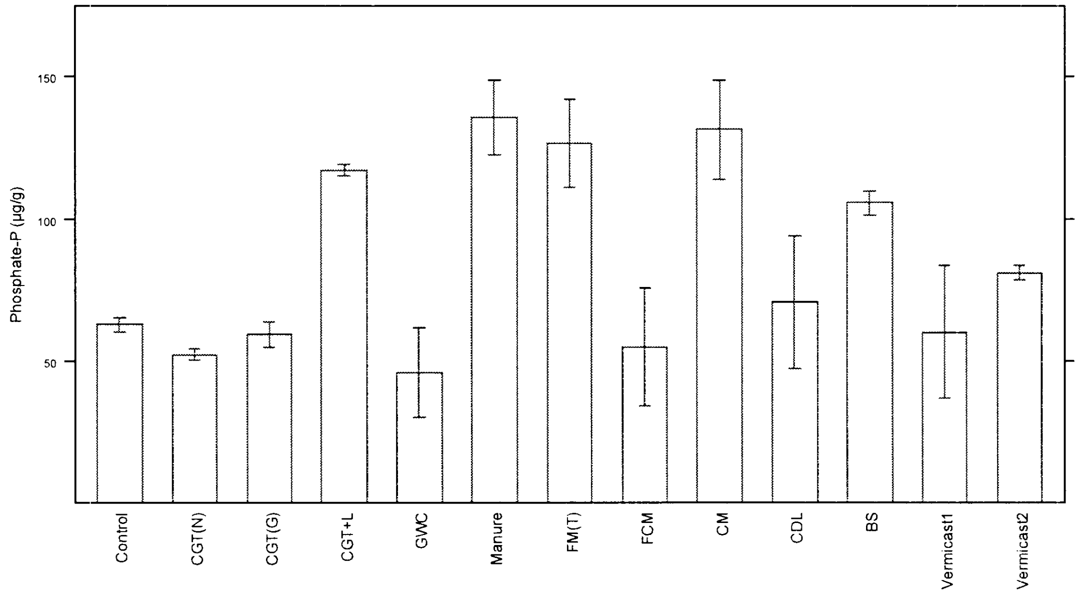

Figure 5.7 Effect of organic amendments on phosphate-P concentration of soil. Vertical bars are the standard error of the means.

The exchangeable Na content varied significantly ($P < 0.001$) with the treatments (Table 5.5). The contrast ($P < 0.05$) also showed a significant increase in its content due to addition of all organic amendments. The exchangeable Na content of the Vertosol was 0.85 cmol(p^+)/kg and it increased significantly up to 1.17 cmol(p^+)/kg due application of Narrabri cattle manure (Table 5.6).

A significant treatment difference ($P < 0.01$) was observed for the exchangeable Ca concentration (Table 5.5). Contrast ($P < 0.05$) also showed the significant increase in exchangeable Ca over control for biosolids, Goondiwindi cotton gin trash, fresh chicken manure and the vermicast1 treatments. The highest increase was observed due to surface application of fresh chicken manure (6.1%) followed by biosolids (5.5%), Goondiwindi cotton gin trash (5.4%) and vermicast1 (4.6%) (Table 5.6).

ANOVA showed a significant treatment difference ($P < 0.001$) for the exchangeable Mg content of the Vertosol (Table 5.5). Application of three different types of chicken manure resulted in a significant increase in its content as compared to control. Significant increases were also observed due to vermicast1 and Tullimba feedlot manure. The highest increase (9%) in the exchangeable Mg content than the control was found in fresh chicken manure-amended soil (Table 5.6).

We observed a significant treatment difference ($P < 0.001$) for the exchangeable sodium percentage (ESP) of the soil (Table 5.4). Organic inputs amended treatments resulted in a significant increase ($P < 0.05$) in the ESP of the Vertosol compared with the unamended control (Table 5.6).

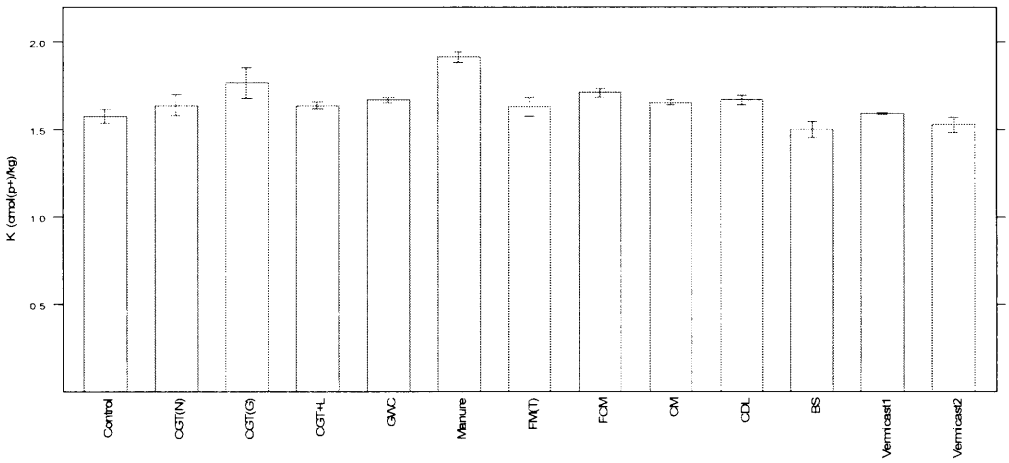

Figure 5.8 Effect of organic amendments on exchangeable-K concentration of soil. Vertical bars indicate the standard error of the means.

Table 5.6 Effect of organic amendments on some chemical properties of a Vertosol

	pH	EC (dS/m)	Exch. Ca (cmol(p^+)/kg)	Exch. Mg (cmol(p^+)/kg)	Exch. Na (cmol(p^+)/kg)	ESP
Control	7.30	0.22	24.7	11.7	0.85	2.19
CGT(N)	7.23	0.28	25.2	11.7	0.91	2.30
CGT(G)	7.45	0.29	26.0	12.1	0.98	2.39
CGT+L	7.61	0.28	25.6	11.7	0.90	2.27
GWC	8.05	0.19	25.4	12.1	0.98	2.43
Manure	7.89	0.36	24.6	12.1	1.17	2.95
FM(T)	7.74	0.31	25.1	12.2	0.99	2.47
FCM	7.58	0.47	26.2	12.8	1.06	2.54
CM	7.79	0.31	25.3	12.2	1.01	2.51
CDL	7.61	0.38	25.2	12.3	1.08	2.67
BS	7.59	0.42	26.1	11.7	0.94	2.33
Vermicast1	8.01	0.20	25.8	12.4	1.05	2.57
Vermicast2	8.08	0.20	24.9	12.1	0.99	2.52
SE[a]	0.097	0.012	0.44	0.25	0.023	0.038

[a]: Standard error of treatment means

5.4 Discussion

5.4.1 Microbial properties

The value of microbial biomass C is usually affected by organic and inorganic additions in soil ecosystems with limited resources such as metabolisable C and available nutrients (Wardle 1992). Mendham *et al.* (2002) found that microbial biomass was strongly influenced by soil texture across a range of soils in south-western Australia. In our study, organic amendments had no significant effect on microbiological biomass (Table 5.4) on fine textured clay Vertosol. Soil microbial biomass is generally correlated with the amounts of compost or other organic matter added to the soil (Guidi *et al.* 1988; Fauci and Dick 1994) and its quality. Press *et al.* (1996), in a short-term composting study, found that microbial biomass was related to the C/N ratio of the applied organic by-products. Our experiment was carried out under controlled conditions with same moisture and temperature regimes across all treatments and while the amendments have low C/N ratios (below 14), apart from green waste compost and the vermicast1, there was still no effect on microbiological properties. Although decomposition of the amendments by microorganisms would have been rapid, a measurable effect on microbiological properties was not detected, probably because of low application rates of the amendments. Similarly, Entry *et al.* (1997) did not find any significant effects of municipal or agricultural by-products applied at low rates (13.9 t/ha) on microbial biomass. Hunt (inHunt 1998) found an increase of 50% in microbial biomass between control soil and soil only when amended at high rates (60 t/ha) of cattle manure but not with rates of 20 t/ha in cropping soil at Armidale, NSW. In contrast, Tejada *et al.* (2006) observed an increase in microbial biomass with addition of 10 t/ha of organic residues (cotton gin crushed compost and poultry manure). The difference in quality of the organic amendments (Guidi *et al.* 1988; Fauci and Dick 1994) might be the reason for this contradiction. The higher water content in the biosolids prior to application may have influenced the microbial activity such that there was an increase in the short-term soil respiration but not microbial biomass.

5.4.2 Physico-chemical properties

Increasing the level of total or 'active' SOM content typically improves overall soil quality (Herrick and Wander 1997). The active pool is the smallest and youngest pool of organic matter and has a very short resident time in soil (Crater 1996). The increase in light fraction was related with the high C input from the amendments (Table 5.2). Cattle manure contributed about 24.2 g/100 g of total C into the soil, only 3.6% came into the labile pool. Although fresh chicken manure added the highest amount of C to the soil (34.9 g/100 g), its contribution into the labile pool was only 1.2%. The increase in free light fractions due to the organic amendments was supported by the findings of Wander *et al.* (1994) and Paustian *et al.* (1997). Aoyama *et al.* (1999a) also observed an increase in particulate organic matter (POM) with manure applications. Organic matter present in the cracking clay soils used for cotton production is highly decomposed, and most of it is concentrated in the microaggregates of the soil (Conteh and Blair 1998). Labile organic C has also been reported to be present between and on the surfaces of microaggregates (Tisdall 1996). The low application rates of the organic amendments may be responsible for the inconsistent increase in labile organic C fractions.

Soil aggregates are the basic unit of soil structure and organic matter is considered a major binding agent that stabilizes soil aggregates (Haynes *et al.* 1991). The significant increase in dry sieved aggregates was observed over the unamended control soil due to application of composted chicken manure and the vermicast2. The high Ca and Mg concentrations of these amendments (Table 5.2) might help to produce higher physical bonds for MWD. In addition, chicken manure and the vermicast2 decomposed more rapidly than the composted amendments during one month period of incubation. The increase in dry-sieved aggregates due to the vermicasts might also be a short-term effect because some polysaccharide glue may have come from that liquefied amendment. Ferreras *et al.* (2006) observed a significant increase in water stable aggregates with application of 20 Mg/ha of vermicompost and chicken manure. In 2002, Whalen and Chang observed that long-term application of manures can shift the aggregate size distribution from larger to smaller (< 2 mm) dry-sieved aggregates. They also found that dry-sieved aggregate fractions from soils with manure contained more total C, N and P than unamended soils. Similarly, we observed a higher nitrate-N and phosphate-P concentration in the composted chicken manure amended soil (Figure 5.6 and 5.7). However, we also observed a significant decrease (33%) in MWD due to biosolids application which contrasts with the findings of other researchers. Tsadilas *et al.* (2005) observed a significant decrease in bulk density and a significant increase in organic matter content, water retention capacity, available water and aggregate stability after three years of biosolids application on a clay loam soil. In our incubation study, biosolids did not have any significant effect on microbial properties as well as on the labile C pool, so the short-term decrease was probably caused by its relatively low application rate. The decrease in dry-sieved aggregate fractions due to biosolid application does not imply the poor physical condition of soil until there was a decrease in other physical properties such as DI.

The vermicasts, cattle manure, feedlot manure and cotton gin trash+lime treatments showed a significant increase in DI as compared to control. The cations accompanying Na on soil exchange sites have a significant impact on the dispersion of soils. The increase in DI of the Vertosol due to these amendments was consistent with the high Na level of these amendments (Table 5.2 and 5.3). Our results with vermicasts support the findings of Coughlan (1984) who observed that soils with large dry aggregates were susceptible to dispersion on wetting and input of mechanical energy. Although the Na concentration of the cotton gin trashes was almost similar (Table 5.2), only the gin trash + lime had a negative effect on DI which was probably due to the presumed poor quality of the amendment and presence of impurities. The negative effect of application of lime was also reported by Bolan *et al.* (2003).

The mineralization of N due to high N content of the organic inputs resulted in significantly higher nitrate-N content of the soil. Organic amendments with low N and high C/N ratio (vermicast1 and green waste compost) did not have a negative effect, on available N (Table 5.3). Traditionally, it has been suggested that C/N ratio greater than 30:1 will immobilize N. We observed that green waste compost contained lowest total N and highest C/N ratio (55:1) which might cause the significant decrease in nitrate-N from the control. The significant increase of nitrate-N up to 424 mg/kg due to fresh chicken manure was similar to the findings of Sistani *et al.* (2004) who also observed an increase in soil available N (Sistani *et al.* 2004) due to addition of poultry litter at 2.24 Mg/ha. Lee (2004) observed an increased nitrate-N content in the surface soil due to application of sewage sludge.

There are several interrelated factors influencing the P availability in soil such as composition of the organic amendment (Nziguheba *et al.* 1998), the rate of application (Reddy *et al.* 1980) and the soil type (Pote *et al.* 1999). In our incubation study, some organic amendments have been shown to increase resin P availability, thus expanding their potential to increase the availability of soil P. With the exception of chicken 'Dynamic Lifter®' and cotton gin trash +lime, the amendments with high (greater than about 60 mg/pot) P input, increased the soil available P (Table 5.3). Approximate proportion of resin-P for feedlot manure was 57%, the recovery for cattle manure was 53% and for chicken manure it was 39%. The presence of soluble P in cotton gin trash + lime might be the reason for the significant increase in phosphate-P by this amendment; the opposite was true for chicken 'Dynamic Lifter®' which contributed 111 mg/kg of P, but this might be in an insoluble form, and therefore did not reflect in the available pool. Our results agree with the findings of Motavalli and Miles (2002), who observed a significant increase in resin-P due to application of 13.4 Mg/ha of horse manure over the unfertilized control. Cooper (2005b) also observed a significant increase in total P and Bray-P at 0-10 cm depth due to addition of 4.5 Mg/ha of biosolids. Increased availability of native soil P due to added organic material is poorly defined as studies using organic materials as P sources have often emphasized differences in quality, such as total P content, C/P and N/P ratios of the materials as best predictors for release (Kwabiah *et al.* 2001).

High values of K added by cattle manure and fresh chicken manure (0.76 cmol(p^+)/kg and 0.37 cmol(p^+)/kg) might be the reason for the significant increase in exchangeable K by these organic inputs (Table 5.3). Among the other organic inputs, Goondiwindi cotton gin trash added 0.33 cmol(p^+)/kg of K and resulted in a significant increase in its value in soil up to 1.77 cmol(p^+)/kg. Soil K occurs in solution, exchangeable, non-exchangeable (fixed), and mineral (structural) forms (Sparks and Huang 1985). Most of the added K (51%) for Goondiwindi cotton gin trash came into the exchangeable pool, whereas the recovery in the exchangeable K-pool for cattle manure and fresh chicken manure was 41 and 30% respectively. Because of the dominance of the illitic type of clay, a substantial amount of applied K^+ by the organic materials at this low rate was retained, and did not come into the soil solution. Bernal *et al.* (1993) reported that addition of pig slurry to a soil dominant with illitic clay caused a linear increase in exchangeable K as the rates of slurry application increased. Organic amendments significantly increased the exchangeable-Na content over the unamended control. Cattle manure added the highest amount (Table 5.3) of Na into the soil, and resulted in a highest increase in its content (1.17 cmol(p^+)/kg) over control (0.85 cmol(p^+)/kg). The higher amount of exchangeable Na caused the small increase in DI of soil by this amendment (Table 5.4). Application of treated sewage sludge increased the exchangeable Na content in all depths (Hulugalle *et al.* 2006). Increase in exchangeable Na due to the organic amendment treatments reflected the significant increase in ESP of the soil (Table 5.4). Although vermicasts did not add significant amount of Na into the soil, but there was a significantl increase in ESP and consequently increase in DI. There was no methodological error in analyzing the Na concentration, therefore future work is needed to identify the mechanisms of increasing ESP due to application of vermicast.

Increase in exchangeable Ca content due to the organic materials (Goondiwindi cotton gin trash, fresh chicken manure, biosolids and vermicast1) might be attributed to their high Ca contents (Table 5.3). Biosolids added 3.1 cmol(p^+)/kg of exchangeable Ca and resulted in a significant increase in its content in soil up to 26.1 cmol(p^+)/kg over the control (24.7 cmol(p^+)/kg). The higher amount of Ca from other amendments (Table 5.2) might be in insoluble form and might be precipitated as carbonate and phosphate, and therefore did not show any increase in the exchangeable pool. Mean exchangeable Mg was 11.7 cmol(p^+)/kg in the control treatment and it was significantly increased by the addition of chicken manures, feedlot manure and vermicast1 which might be attributed to their contribution into the soil.

5.5 Conclusions

The organic amendments had both beneficial and detrimental short-term effects on Vertosol quality.

Cotton gin trash: Cotton gin trash can potentially increase short-term nutrient availability in Vertosols.

Manures: Application of manures may improve Vertosol quality by increasing the nutrient availability, although concurrent increases in exchangeable Na and DI, especially in the case of cattle manure needs further investigation.

Green waste compost: This amendment did not seem to have any short-term influence on Vertosol quality, and a significant decrease in nitrate content was also caused by this amendment due to its higher C/N ratio.

Biosolids: Biosolids affect the soil physical condition by reducing the size of dry-sieved aggregates, but did not affect the DI. Its application increased the N, P and Ca contents of the soil.

Vermicasts: Application of these amendments resulted in poor soil physical condition as they increased the soil dispersion.

Issues which require further investigation are the potential of the amendments to increase exchangeable Na content and their ability to meet crop nutrient demand. Farmers wishing to meet soil P requirements from organic inputs need information on choosing the correct materials and rates to maintain the soil quality, while concurrently increasing yield. However, the optimal application rates of the various amendments are unknown. The following chapter reports results from an experiment which investigated varying application rates of potential organic materials identified in this experiment with respect to enhancing soil fertility, quality and productivity of Vertosols.