Chapter Six

Short-term effect of application rates of organic amendments on Vertosol

6.1 Introduction

Continuous cultivation, which involves soil disturbance and vegetation removal, results in losses of soil nutrients, particularly SOM which is an indication of widespread soil degradation. Currently, land use practices are of much interest in replenishing such soil nutrient losses. These practices include greater cropping frequency, reduced tillage and application of organic amendments (Sommerfeldt *et al.* 1988). Application of FYM onto agricultural soil has been a global practice for thousands of years as a means of disposing of small quantities of waste and as a fertilizer for plant growth (Unger and Stewart 1974) and can result in increased concentrations of soil nutrients (Chang *et al.* 1991; Eghball 2002). Residual effects of organic materials on soil properties can contribute to improvement in soil quality for several years after application ceases (Ginting *et al.* 2003). Additional physical effects of adding organic amendments include higher soil water-holding capacity, increased hydraulic conductivity and increased aggregation (Khaleel *et al.* 1981). Meek *et al.* (1982) reported that high rates (180 t/ha every two years over a nine-year period) of cattle manure applications to a silty clay soil led to large losses of N, increased levels of K and increased availability of P. Chang *et al.* (1991) observed that application of cattle feedlot manure resulted in increase in total N from about 6 Mg/ha to 8.2 Mg/ha by 90 Mg/ha manure application to the nonirrigated soil, and from 6 to 12 Mg/ha by the 180 Mg/ha manure application to the irrigated soil. Three annual applications of dairy cattle manure at varying rates of 22.5, 45, 90, 180 and 270 Mg/ha increased the total N and NO_3-N in the surface soil (Mugwira 1979). In a 16 week incubation experiment, Qian and Schoenau (2000) observed an increase in soil P from 708 mg/kg to 738 mg/kg due to addition of liquid hog manure.

Substantial quantities of cotton processing waste, previously used as a cattle-feed substitute during drought, is presently dumped and left to degrade in stockpiles 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. 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). The recycling of municipal sewage sludge (biosolids) to agricultural land is of strategic importance to the water industry (Hill 2005). Biosolids are now widely accepted as an agricultural fertilizer in many countries in Europe and North America (Hillman *et al.* 2003) as they return plant nutrients to the soil, improve physical properties, and are relatively energy-efficient compared with conventional fertilizer options (Smith 1996). Worm-composting organic residues from animal and plant processing produce a finely-divided organic material, vermicompost, which is reputed to produce superior growth responses in plants. Edwards and Neuhauser (1988) report increased plant growth in potting-media enhanced with vermicompost derived from animal manures.

In this study, we used five, potentially useful and easily accessible organic amendments viz., cotton gin trash, cattle manure, biosolids, composted chicken manure and a liquefied vermicompost. These amendments were applied at various application rates from low to higher possible (and economically feasibile) rates including local farmers' practice. Our objective was to determine the optimal (most favourable) rate of these amendments which could improve the soil quality of a Vertosol and could be recommended for broadacre farming. The use of the 'optimal' rates in this study relates to the rates which is practically feasible.

6.2 Materials and Methods

6.2.1 Experimental details

An incubation study was conducted over four weeks in a temperature controlled growth chamber set at 30°C in the Department of Agronomy and Soil Science, University of New England, Armidale, NSW. The soil used was collected from 0-0.10 m depth of a field at the Australian Cotton Research Institute (ACRI), near Narrabri, NSW. It was a well structured grey cracking clay soil 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). $EC_{1:5}$ ranged from 0.24-0.25 dS/m and the organic C content was 0.83 g/100 g.

The soil was amended with five different organic amendments at six different rates. The choice of organic amendments was based on previous experimental results (Chapter 5). No plants were grown in the pots.

6.2.2 Experimental design and treatments

Six hundred grams of air-dried soil was placed in 100 mm diameter pots filling them to a depth of 10 cm. The organic inputs were mixed thoroughly with the soil. The treatments were laid in a randomized block design with two 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 are summarized in Table 6.1. After four weeks of incubation, microbiological, physical and chemical properties of the soil in the pots were evaluated as outlined below.

6.2.3 Soil analyses

6.2.3.1 Microbiological properties

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

Table 6.1 Soil amendments and their application rate

	Treatment	Rate
1.	Cotton gin trash	0, 7.5, 15, 30, 60 and 120 t/ha (dry weight)
2.	Cattle manure	0, 7.5, 15, 30, 60 and 120 t/ha (dry weight)
3.	Biosolids	0, 7.5, 15, 30, 60 and 120 t/ha (dry weight)
4.	Composted chicken manure	0, 2.25, 4.5, 9, 18 and 36 t/ha (dry weight)
5.	Commercial vermicompost	0, 60, 120, 240, 480 and 960 L/ha

6.2.3.2 Physical properties

A soil physical property measured was aggregate stability and it was measured by evaluating the MWD of the soil through dry sieving using the method described in Chapter 5.

6.2.3.3 Chemical properties

The soil samples were air dried, passed through < 2 mm sieve and then analysed for 0.5M NH_4Cl/0.5M $BaCl_2$ extractable cations and resin-extractable anions as described in Chapter 3 and chemical composition of the organic amendments were determined as described in Chapter 5. The amount of nutrient contribution from the organic inputs is summarized in Table 6.2.

6.2.4 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 for each organic input. Where significant treatment effects were found, pair-wise comparisons ($P = 0.05$) between the control and other application rates of the organic amendments were made using contrasts. Variances were checked by plotting residual vs. fitted values to confirm the homogeneity of the data. No transformations were necessary.

Because of anaerobic conditions, we did not get any nitrate-N in some of the treatments, so those values were deleted from the statistical analysis.

The analysis of organic amendments was also performed in the Plant Nutrition Laboratory following the method as discussed in Chapter 3. The amount of nutrient contribution from the organic inputs is summarized in Table 6.2.

Table 6.2 Nutrient added to every pot from the amendments

Treatment	Rate	C	N	P	K	Na	Ca	Mg
	t/ha	mg/pot	mg/pot	mg/pot	mg/pot	mg/pot	mg/pot	mg/pot
Cotton gin trash	7.5	7	77	20	81	3.8	194	45
	15	14	154	40	161	7.5	388	90
	30	28	308	80	323	15	775	179
	60	56	617	160	646	30	1550	358
	120	113	1235	320	1291	60	3100	716
Cattle manure	7.5	14	137	62	133	24	178	57
	15	28	274	124	266	47	357	114
	30	57	549	247	532	94	714	228
	60	114	1098	495	1065	189	1428	457
	120	228	2196	990	2130	378	2855	914
Biosolids	7.5	13	128	79	6.5	4.3	276	18
	15	26	257	159	13	8	552	35
	30	51	514	318	26	17	1105	71
	60	103	1027	636	52	34	2210	141
	120	205	2054	1272	104	68	4420	283
Chicken manure	2.25	3.7	52	78	34	7.8	312	17
	4.5	7.4	103	155	68	15	624	34
	9	15	207	311	137	31	1248	69
	18	30	413	622	273	62	2495	137
	36	59	827	1243	546	124	4990	275
	L/ha							
Vermicompost (liquefied)	60	1.8	1.7	0.4	1.1	0.05	0.12	0.02
	120	3.5	3.5	0.7	2.1	0.09	0.24	0.05
	240	7.0	6.9	1.4	4.3	0.19	0.49	0.10
	480	14.0	13.8	2.9	8.6	0.38	0.97	0.20
	960	28.0	27.6	5.8	17.1	0.76	1.95	0.40

6.3 Results

6.3.1 Cotton gin trash

6.3.1.1 Microbiological properties

The microbial biomass C varied significantly among the application rates ($P < 0.05$). There was a significant increase (70%) in microbial biomass when cotton gin trash was applied at 120 t/ha rate as compared with control (no amendment) (Figure 6.1).

Microbial respiration was not affected by the short-term application of gin trash at different rates (Figure 6.1).

6.3.1.2 Physical and chemical properties

ANOVA did not show any significant difference between the application rates for MWD. However, a substantial increase in MWD was observed up to 30 t/ha, after which, it decreased (Figure 6.1).

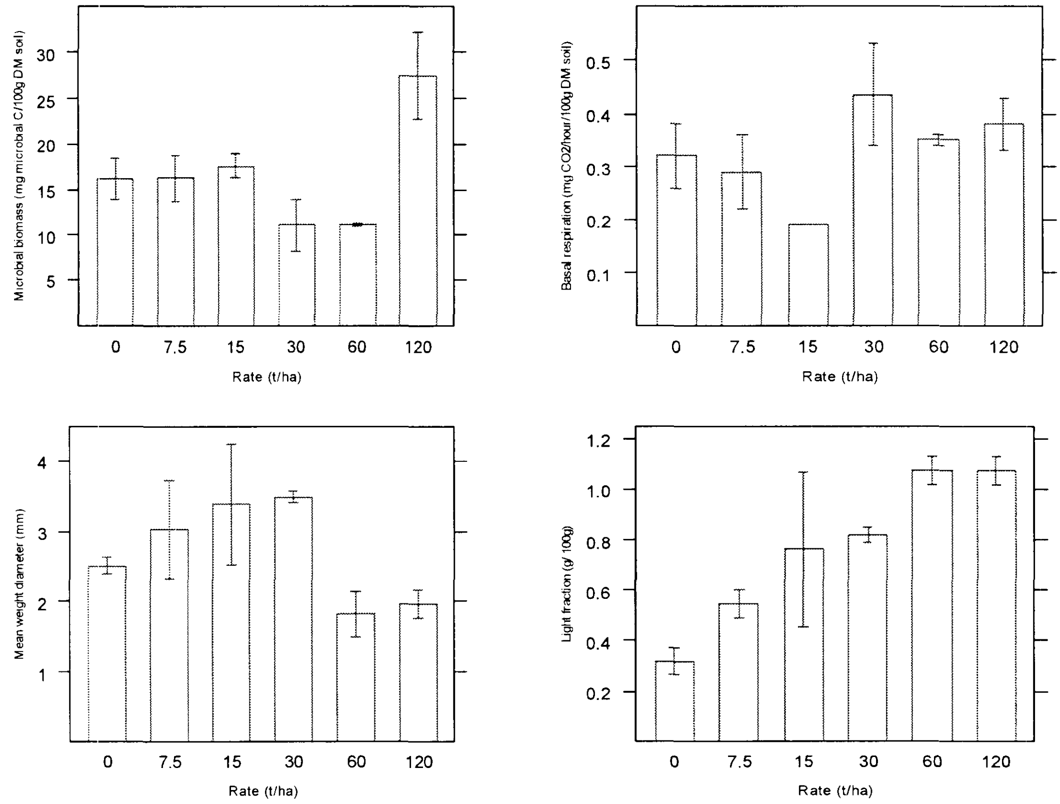


Figure 6.1 Effect of application rates of cotton gin trash on soil properties. Vertical bars are the standard errors of the means.

The light fraction of organic matter increased significantly with increasing application rate ($P < 0.01$) (Figure 6.1). Contrast ($P < 0.05$) showed that the increase over the control was significant with increasing rates except at 7.5 t/ha. There was a 137, 156, 237 and 237% increase in light fraction over the control when applied at 15, 30, 60 and 120 t/ha rates respectively.

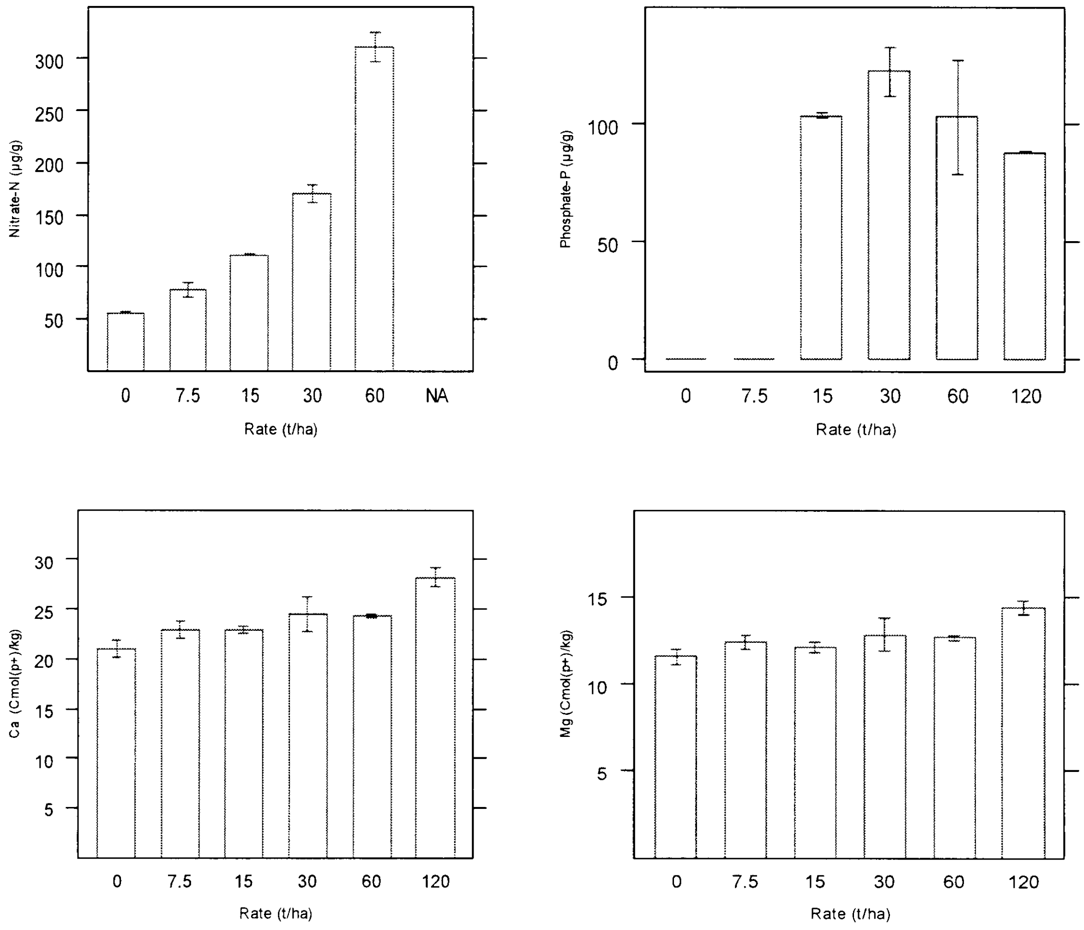


Figure 6.2 Effect of cotton gin trash on soil chemical properties. Vertical bars indicate the standard error of the means.

The nitrate-N content significantly differed among the application rates ($P < 0.001$). A significant increase ($P < 0.05$) in nitrate-N content was observed with the increase in application rates as compared with unamended control. Higher application rates (60 t/ha) resulted in the highest increase (456%) in nitrate-N over the control. A significant treatment difference ($P < 0.001$) was observed for the phosphate-P concentration of the soil. The increasing trend in phosphate-P content from the control was observed up to the application rate of 30 t/ha (Figure 6.2). Contrast ($P < 0.05$) also showed a significant increase in the phosphate-P content of the soil over control with the increase of application rate. The highest increase in its content over the control was observed when the input was applied at 30 t/ha followed by 15, 60 and 120 t/ha application rates.

ANOVA showed a significant difference ($P < 0.01$) among the application rates for exchangeable Ca concentration of the soil. The significant increase ($P < 0.05$) was observed when the input was applied at 30, 60 and 120 t/ha rates as compared to when no gin trash was applied. Highest application rate of the amendment (120 t/ha) showed the highest increase (34%) in exchangeable Ca followed by a 17 and 16% increase due to the 30 and 60 t/ha rates respectively.

Application rates differed significantly ($P < 0.05$) for the exchangeable Mg concentration of the soil. Contrast showed that the significant increase ($P < 0.05$) in exchangeable Mg over the unamended control was observed when gin trash was applied at 120 t/ha. This rate resulted in a 24% increase in exchangeable Mg content over the control.

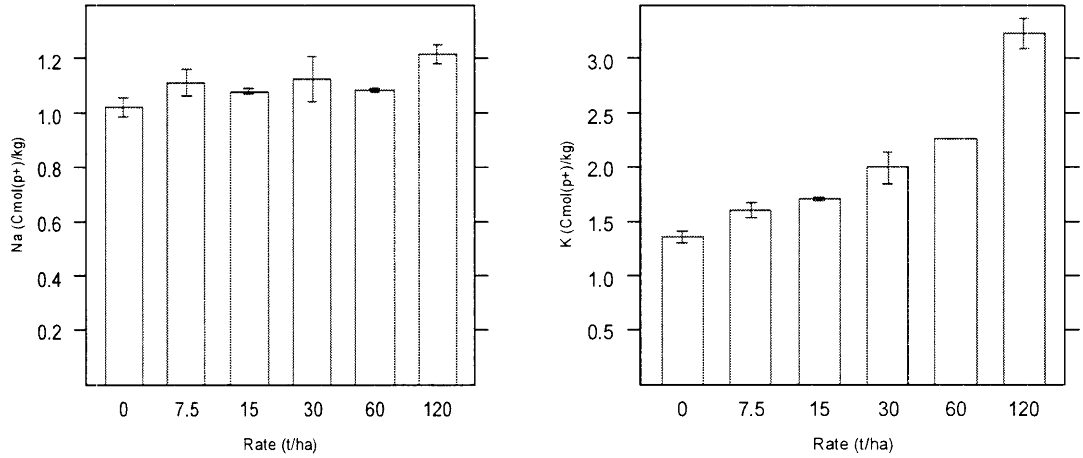


Figure 6.3 Changes in exchangeable Na and K concentration due application of cotton gin trash at different rates. Vertical bars are the standard errors of the means.

ANOVA did not show any significant effect of application rates for the exchangeable Na concentration; however, we observed a significant effect ($P < 0.001$) of the rates on the exchangeable K content. An increasing trend was observed with the increase in application rate (Figure 6.3). Contrast ($P < 0.05$) showed that except for the 7.5 t/ha rate, other higher rates resulted in a significant increase in exchangeable K content of the soil. Application of cotton gin trash at 15, 30, 60 and 120 t/ha rates increased by 21, 43, 64 and 128% respectively over the exchangeable K content of the unamended control.

6.3.2 Cattle manure

6.3.2.1 Microbiological properties

Microbial biomass C differed significantly ($P < 0.001$) at different application rates for the cattle manure. Figure 6.4 shows an increasing trend in microbial biomass from the control to higher application levels. However, a significant increase ($P < 0.05$) in microbial biomass over the control was observed only when the amendment was applied at 60 and 120 t/ha.

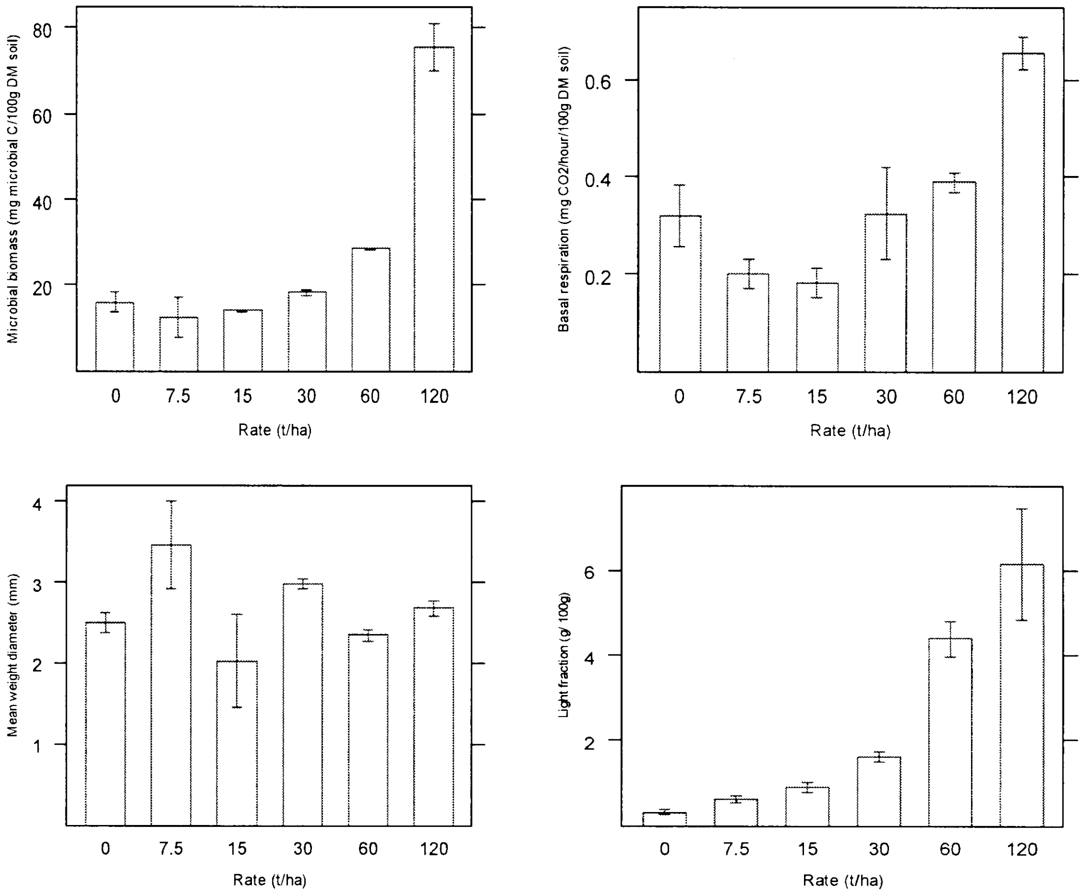


Figure 6.4 Effect of cattle manure with different application rates on selected soil properties. Vertical bars show the standard error of means.

A significant treatment difference was also observed for microbial respiration ($P < 0.05$). It was increased significantly ($P < 0.05$) as compared with control only when the input was applied at 120 t/ha.

6.3.2.2 Physical and chemical properties

The dry-sieved MWD was not affected by the application rates, although a higher MWD than the control was observed when cattle manure was applied at 7.5 and 30 t/ha (Figure 6.4).

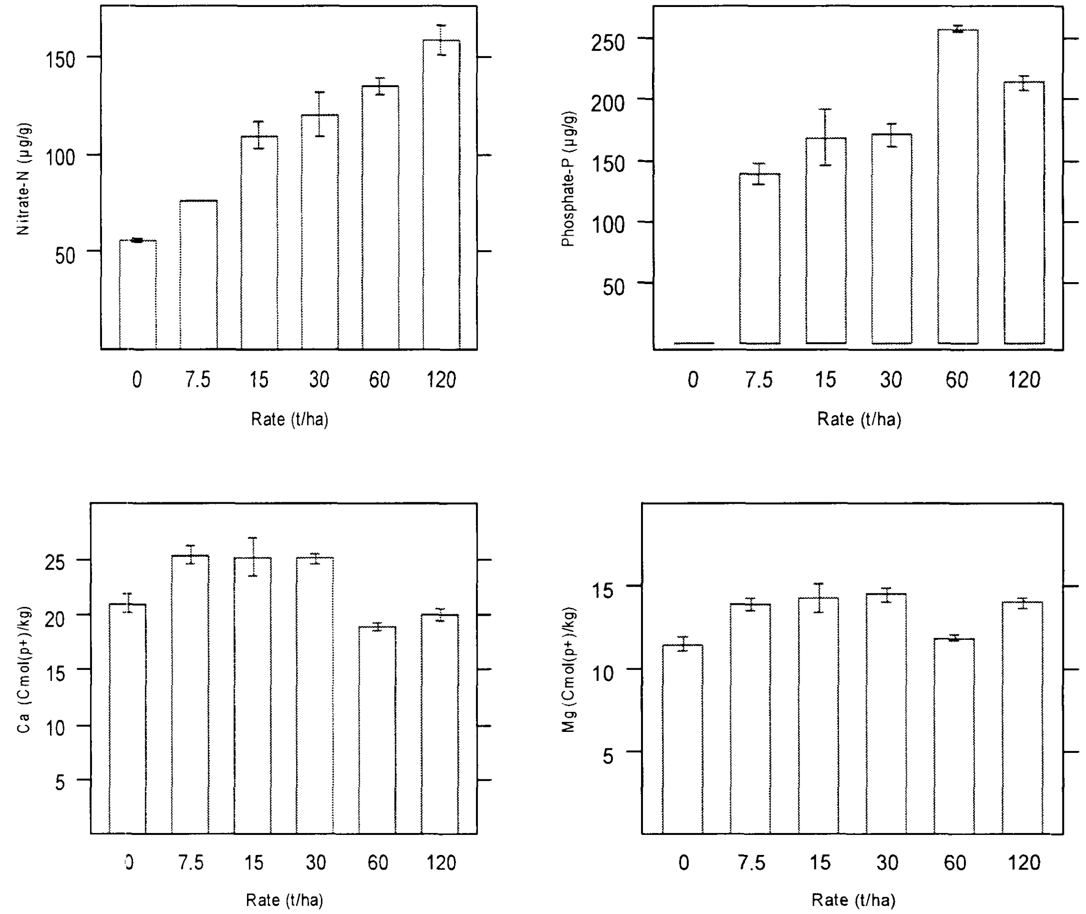


Figure 6.5 Changes in the nutrient concentration after addition of cattle manure with variable rates. Means and standard errors are presented as vertical bars.

ANOVA showed a significant difference ($P < 0.001$) among the treatments for the light fraction of organic matter. An increasing trend in light fraction can be seen with the increase in application rates (Figure 6.4). However, only higher application rates (60 and 120 t/ha) resulted in a significant increase ($P < 0.05$) in light fraction over the unamended control.

The nitrate-N content differed significantly ($P < 0.001$) with the application rates. Figure 6.5 shows an increasing trend of the nitrate-N from the control. Contrast ($P < 0.05$) also showed that the increase was significant ($P < 0.05$) from the lower rate (7.5 t/ha) up to the highest application rate (120 t/ha) as compared with control.

A significant increase ($P < 0.001$) in phosphate-P concentration of the Vertosol was observed with the increase in application rates of cattle manure. Soils in pots without the organic amendment did not contain any phosphate-P, but the concentration was increased significantly ($P < 0.05$) with the higher rates (Figure 6.5). The highest increase (141%) over the control was observed with 60 t/ha application rate.

ANOVA showed a significant treatment difference ($P < 0.01$) for the exchangeable Ca concentration of the soil. The higher rates did not change its content significantly, whereas the significant increase ($P < 0.05$) from 21 cmol(p^+)/kg up to 25 cmol(p^+)/kg was observed with lower rates (7.5, 15 and 30 t/ha).

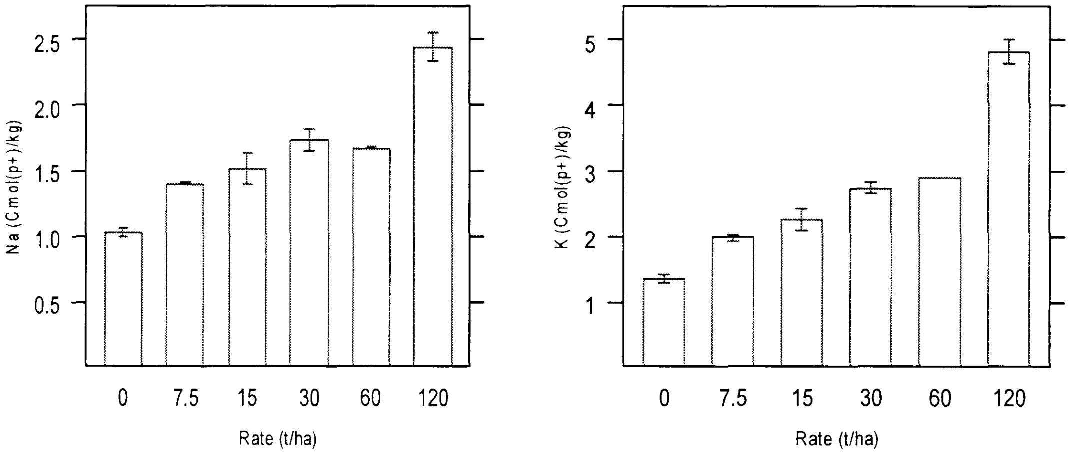


Figure 6.6 Effect of application rates of cattle manure on exchangeable Na and K content of soil. Vertical bars represent the standard errors of the means.

The application rates differed significantly among themselves ($P < 0.01$) for the exchangeable Mg content of the soil. Contrast ($P < 0.05$) showed that, except 60 t/ha, other rates resulted in a significant increase in exchangeable Mg content over unamended control. The highest increase (25%) over control in exchangeable Mg was observed when cattle manure was applied at 30 t/ha.

Significant treatment differences ($P < 0.001$) were observed for the exchangeable Na and K concentration of the soil. With the increase in application rates, positive trends can be seen for these exchangeable cations (Figure 6.6). Contrast ($P < 0.05$) also showed significant increases ($P < 0.05$) in exchangeable Na and K concentration as compared with control from lower rate to higher rates.

6.3.3 Biosolids

6.3.3.1 Microbiological properties

The microbial biomass C was significantly ($P < 0.001$) affected by the application rates of biosolids (Figure 6.7). Contrast ($P < 0.05$) showed that there was a significant decrease in microbial biomass at 7.5 t/ha, but a significant ($P < 0.05$) increase in microbial biomass was observed when the amendment was applied at 120 t/ha.

The application rates did not have any significant effect on the microbial respiration of soil (Figure 6.7).

6.3.3.2 Physical and chemical properties

A significant treatment difference ($P < 0.01$) was observed for MWD of the soil. There was a significant increase ($P < 0.05$) in MWD at 7.5 t/ha, but a significant reduction in MWD was caused by the higher rates (60 and 120 t/ha). The MWD of the soil was 2.51 mm, and addition of biosolids at 7.5 t/ha resulted in a 32% increase up to 3.30 mm, whereas a significant decrease of 30 and 28% was found due to 60 and 120 t/ha application rates respectively (Figure 6.7).

The light fraction of organic matter differed significantly ($P < 0.01$) among the treatments. Contrast ($P < 0.05$) showed that only higher application rates (60 and 120 t/ha) resulted in a significant increase in light fraction over the control (Figure 6.7).

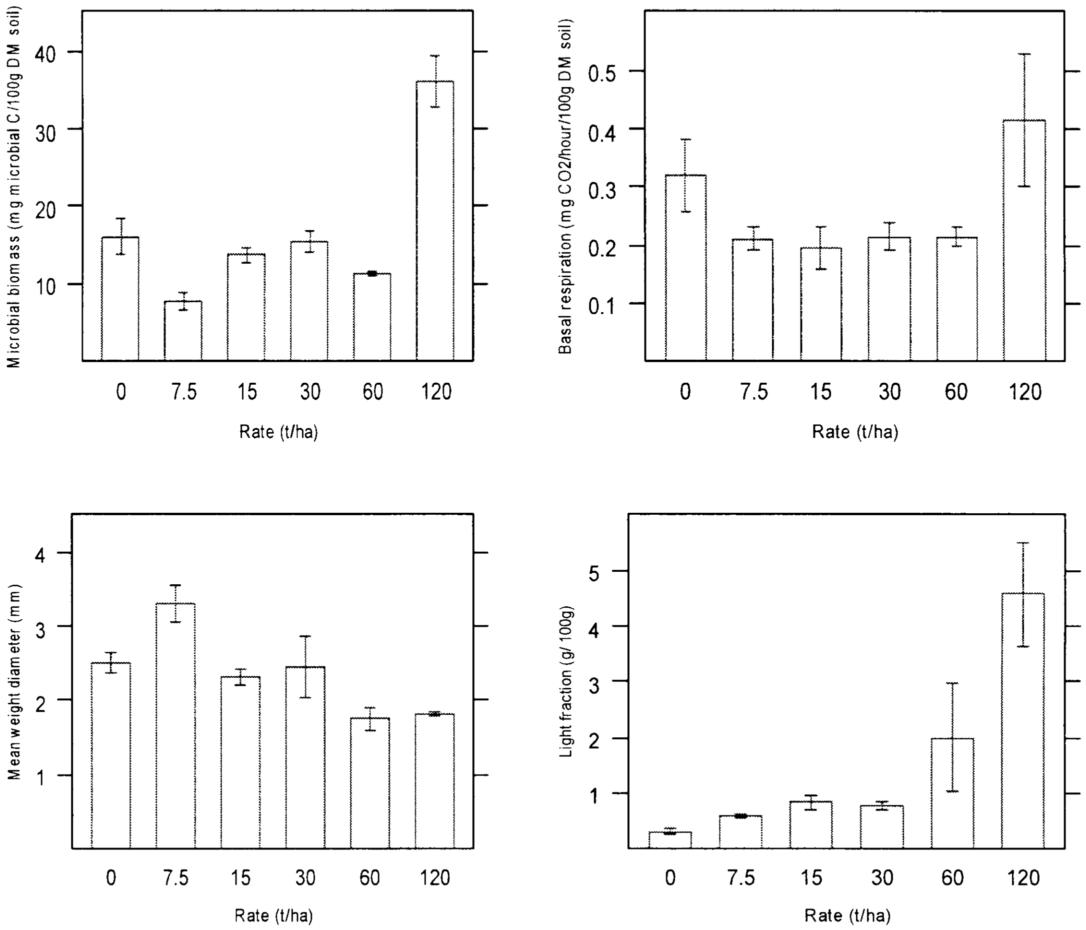


Figure 6.7 Effect of biosolids at variable application rate on microbiological and selected physical and chemical properties of a Vertosol. Means and standard errors are presented as vertical bars.

Due to anaerobic conditions in the pots, higher rates did not produce any nitrate-N. However, an increasing trend of nitrate-N was observed up to 30 t/ha (Figure 6.8). ANOVA showed that the application rates varied significantly ($P < 0.001$) for the nitrate-N content of the soil. Contrast ($P < 0.05$) also showed the significant increase in its content over the control with 7.5 and 30 t/ha.

The phosphate-P content of the soil was significantly ($P < 0.001$) affected by the application rates of biosolids. Except for 7.5 t/ha, all other rates significantly increased ($P < 0.05$) available P in soil. The highest increase in available P was observed due to 30 t/ha (Figure 6.8).

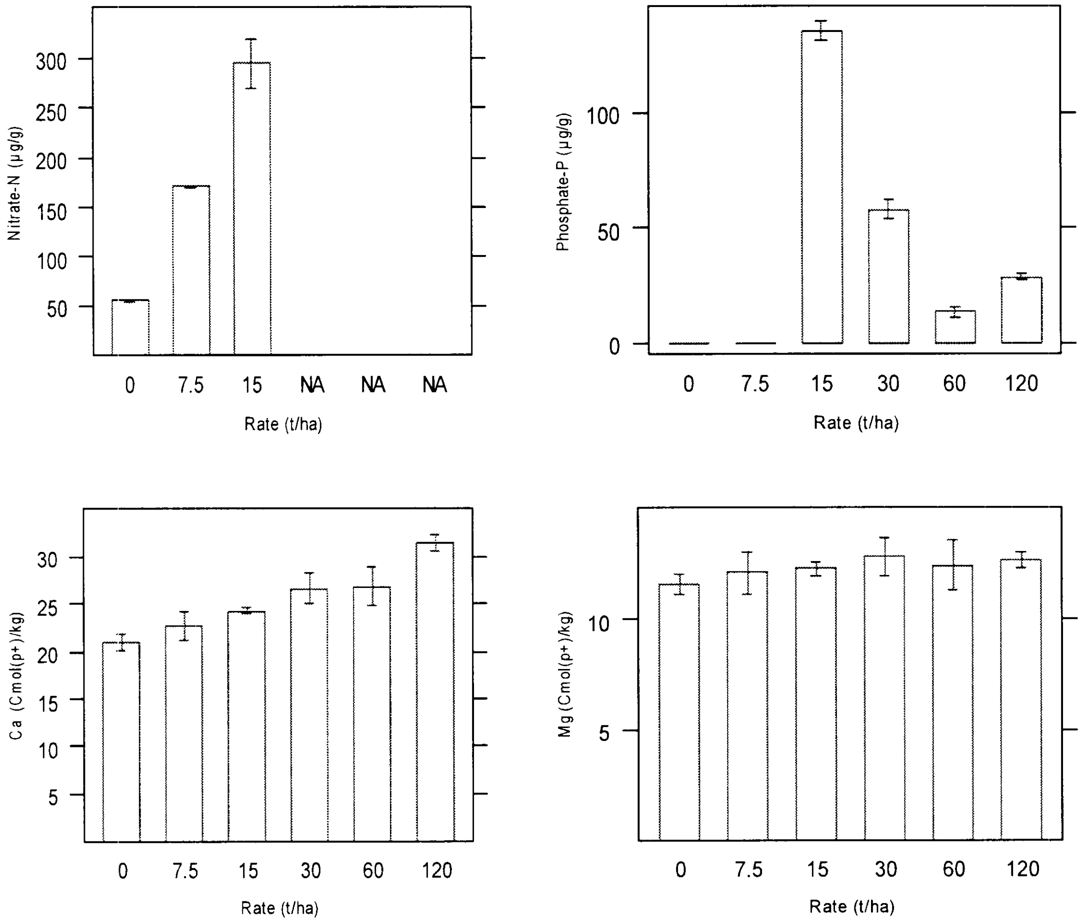


Figure 6.8 Effect of application rates of biosolids on soil chemical properties. Vertical bars are the standard errors of the means.

ANOVA showed that the exchangeable Ca concentration differed significantly ($P < 0.01$) among the application rates. An increasing trend in exchangeable Ca was observed with the increase in application rates (Figure 6.8). The higher rates (30, 60 and 120 t/ha) significantly increased ($P < 0.05$) its content as compared to when there was no amendment.

There was no significant effect of the application rates on the exchangeable Mg content of the soil (Figure 6.8).

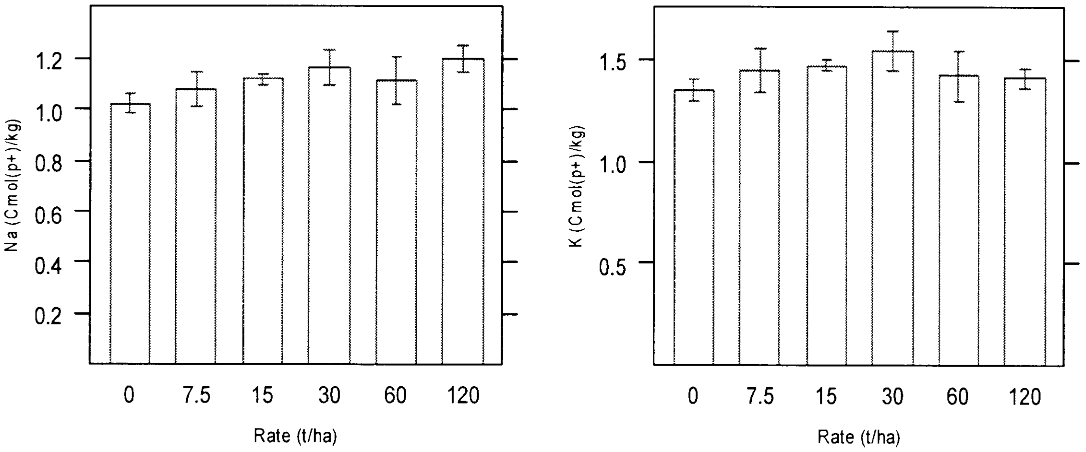


Figure 6.9 Exchangeable Na and K concentrations of a Vertosol as affected by variable application rates of biosolids. Vertical bars indicate the standard errors of the means.

Exchangeable Na and K concentrations were not significantly affected by the application of biosolids at different rates (Figure 6.9).

6.3.4 Chicken manure

6.3.4.1 Microbiological properties

ANOVA showed a significant ($P < 0.001$) treatment difference for the microbial biomass C of the soil. With the higher application rates (18 and 36 t/ha) of the amendment, an increasing trend of microbial biomass can be seen (Figure 6.10). Contrast ($P < 0.05$) also showed the significant increase with 18 and 36 t/ha rates over the unamended control.

Microbial respiration significantly varied ($P < 0.01$) among the treatments. There was significant increase ($P < 0.05$) in basal respiration at 18 t/ha, whereas a significant decrease was noticed when the amendment was applied at 9 t/ha (Figure 6.10).

6.3.4.2 Physical and chemical properties

MWD of the soil differed significantly ($P < 0.01$) among the treatments. It increased up to 9 t/ha, then slightly decreased with 18 and 36 t/ha application rates (Figure 6.10). The significant increase in MWD over the control was observed with the increase in application rates except with 36 t/ha. The highest increase (63%) was caused by the 9 t/ha rate.

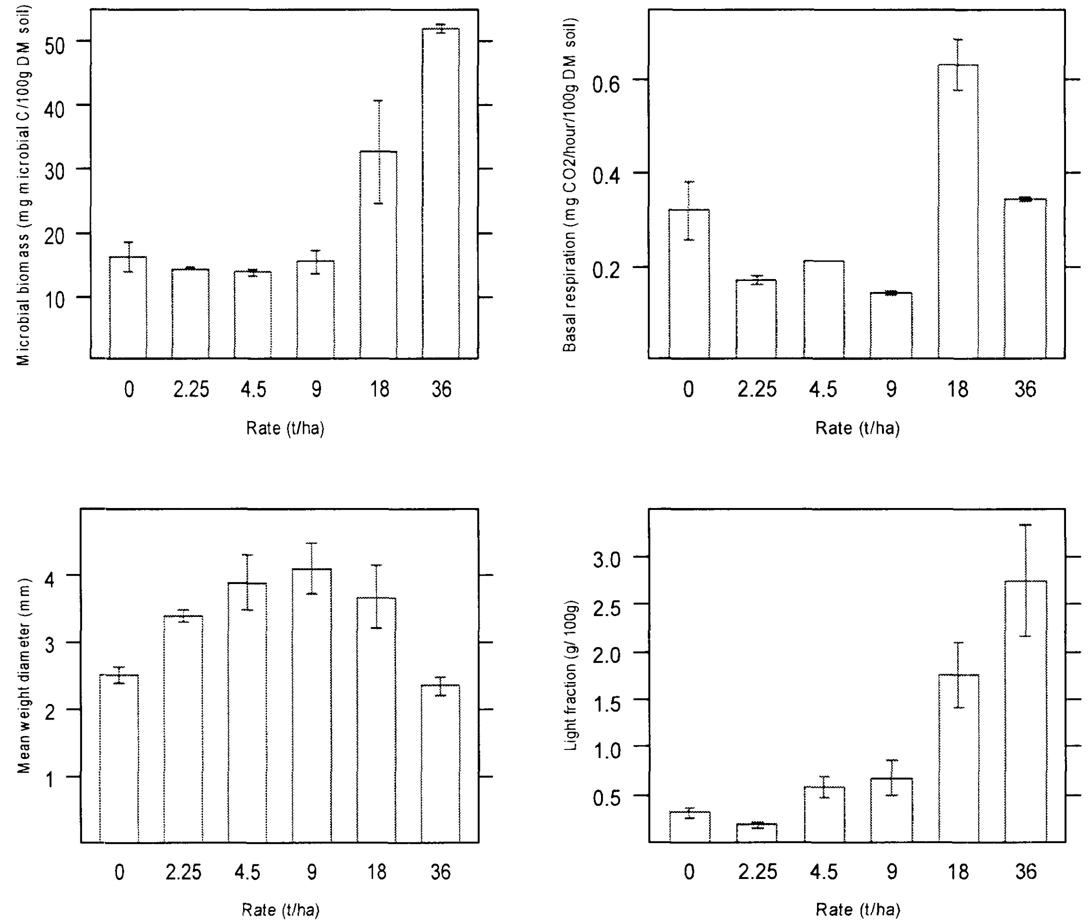


Figure 6.10 Effect of varying application rates of chicken manure on soil microbiological and some physico-chemical properties. Means and standard errors are presented as vertical bars.

There was a significant treatment difference (*P* < 0.001) for the light fraction of organic matter. Figure 6.10 shows that from the unamended control, the light fraction showed an increasing trend with the higher rates. The increase was significant (*P* < 0.05) due to 18 and 36 t/ha application rates.

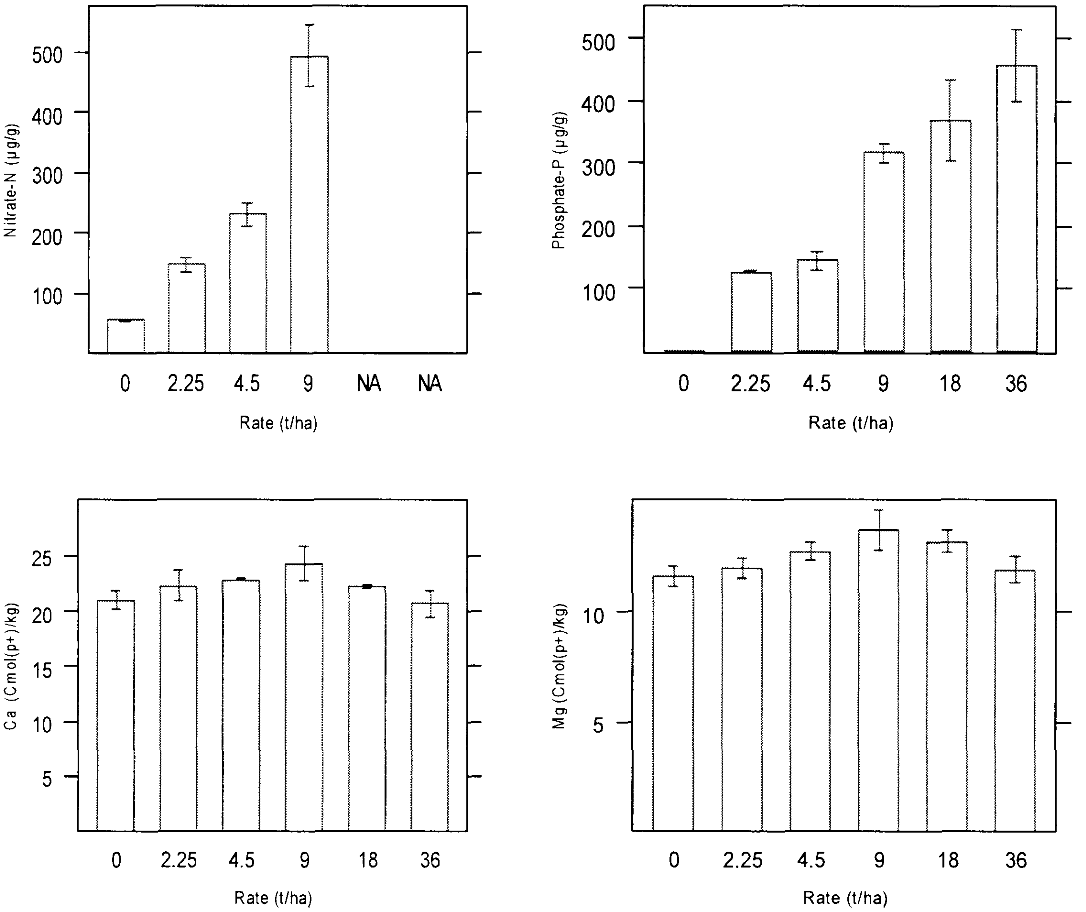


Figure 6.11 Effect of application rates of chicken manure on soil chemical properties. Vertical bars represent standard errors of means.

Application rates had significant effects ($P < 0.001$) on nitrate-N content of the soil. There was an increase in its content up to 9 t/ha (Figure 6.11) and the increase was significant ($P < 0.05$).

The phosphate-P content of the soil differed significantly ($P < 0.001$) among the application rates. With the increase in rates, an increasing trend in available P can be noticed (Figure 6.11). Contrast ($P < 0.05$) showed that there was a significant increase in available P with all the five application rates as compared with unamended control.

Application of chicken manure at five different rates did not have any significant effect on the exchangeable Ca and Mg concentrations of the Vertosol.

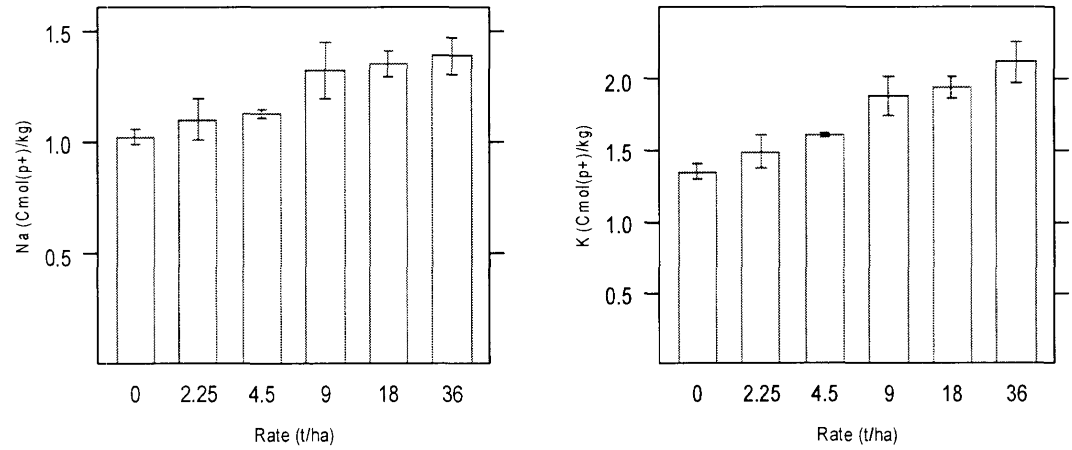


Figure 6.12 Effect of chicken manure applied at different rates on exchangeable Na and K concentration of soil. Vertical bars represent the standard errors of means.

The exchangeable Na concentration of the soil differed significantly (*P* < 0.05) among the treatments. Lower rates up to 4.5 t/ha did not increase the exchangeable Na content significantly, whereas a significant increase (*P* < 0.05) was observed with higher rates (9, 18 and 36 t/ha). The higher rates resulted in a 29-32 % increase in exchangeable Na concentration in the soil (Figure 6.12).

ANOVA showed a significant (*P* < 0.01) treatment difference for the exchangeable K content of the soil. Without the amendment, the exchangeable K content was 1.35 cmol(p^+)/kg, but it increased up to 2.12 cmol(p^+)/kg with 36 t/ha (Figure). However, the significant increase (*P* < 0.05) over the control was observed with the higher rates (9, 18 and 36 t/ha) (Figure 6.12).

6.3.5 Vermicompost

6.3.5.1 Microbiological properties

Neither microbial biomass nor respiration was significantly affected by application of vermicompost at different rates. However, a decreasing trend can be seen for both the microbiological properties at higher rates of application (Figure 6.13).

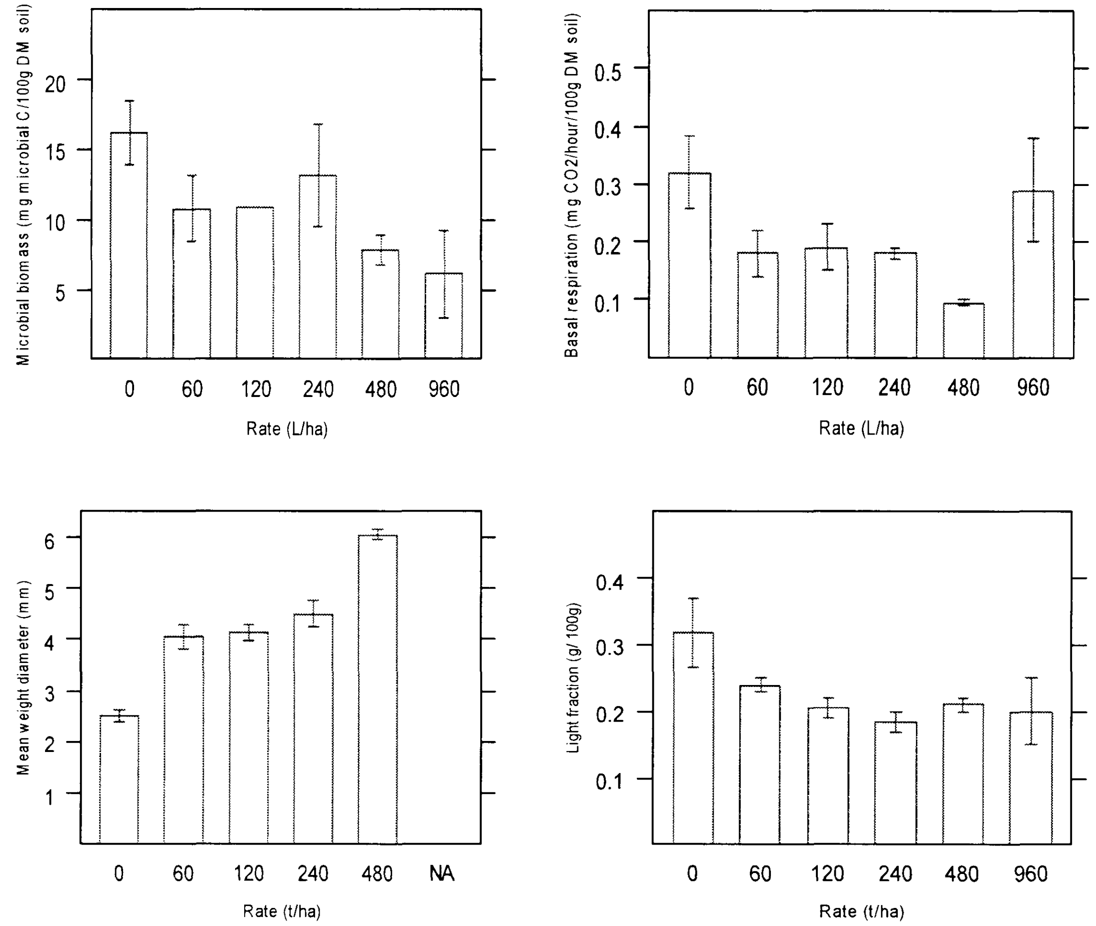


Figure 6.13 Effect of application rates of vermicast on some soil properties. Means and standard error are presented as vertical bars.

6.3.5.2 Physical and chemical properties

A significant treatment difference ($P < 0.001$) was observed for the MWD of the soil. With the increase in application rates, the MWD was increased from 2.51 mm to 6.05 mm with 480 L/ha. Contrast ($P < 0.05$) showed that all the rates significantly increased the MWD of the soil (Figure 6.13).

The light fraction of organic matter did not change significantly between the treatments, although a decreasing trend can be noticed from unamended control to 960 L/ha (Figure 6.13).

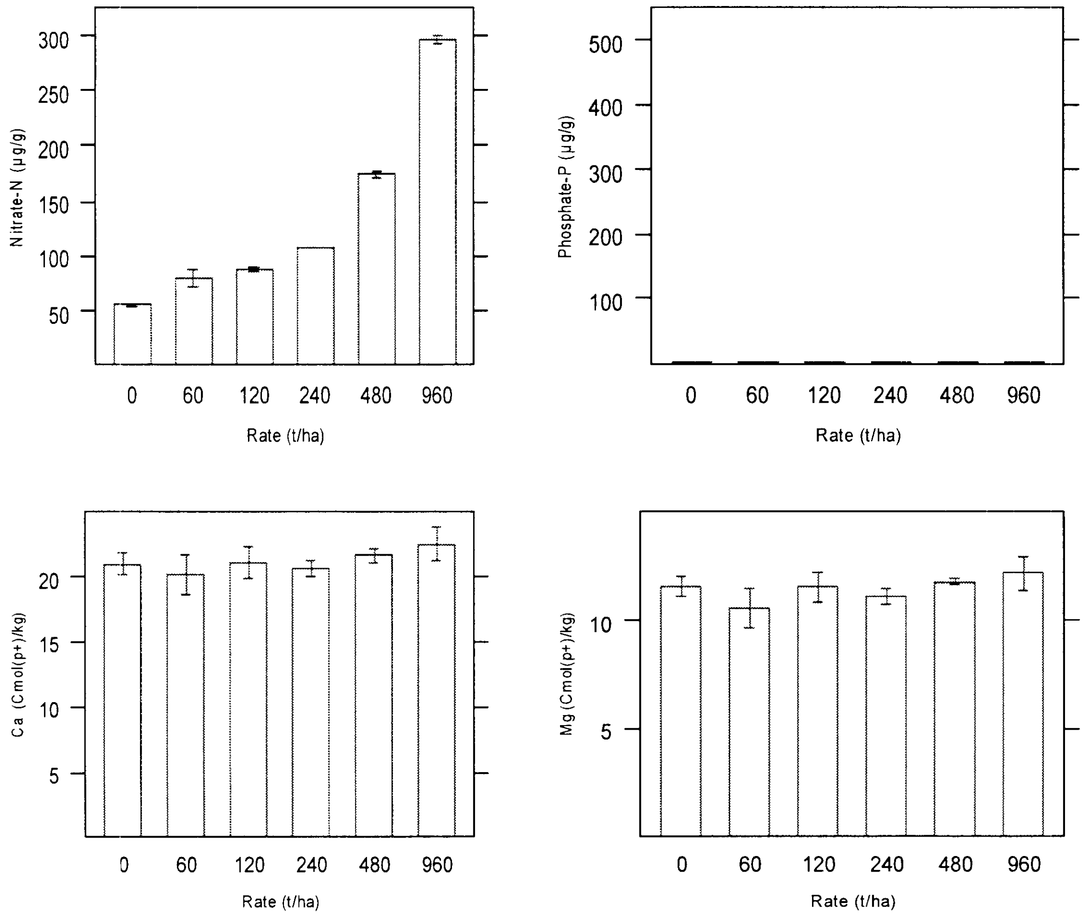


Figure 6.14 Effect of vermicast at different rates on soil chemical properties. Vertical bars indicate the standard errors of means.

ANOVA showed a significant treatment difference ($P < 0.001$) for the nitrate-N content of the soil. An increasing trend in available N can be seen in Figure 6.14. The increase in available N from the control was significant ($P < 0.05$) in all the five rates. There were 43, 58, 93, 214 and 429% increases over the control due to 60, 120, 240, 480 and 960 L/ha rates respectively.

We did not get any phosphate-P in the soil (Figure 6.14).

Application of vermicompost/vermicast at five different rates did not have any significant effect on exchangeable Ca, Mg, Na and K concentrations of the soil (Figure 6.14 and 6.15).

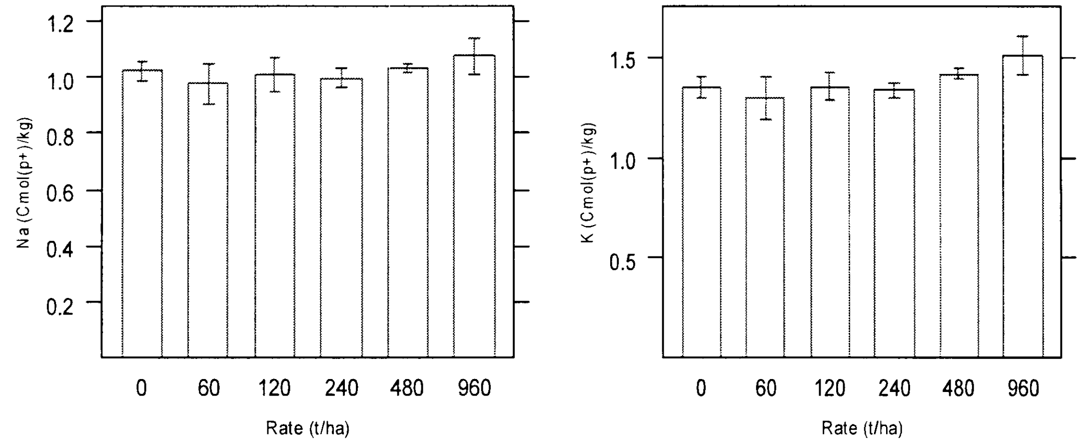


Figure 6.15 Changes in the exchangeable Na and K concentration after addition of vermicast with variable rates. Means and standard errors are presented as vertical bars.

Table 6.3 Effect of application rates of the organic amendments on the effective cation exchange capacity (ECEC) and ESP of the soil

	Treatment				
	Cotton gin trash	Cattle manure	Biosolids	Chicken manure	Vermicompost
ECEC	**	**	*	ns	ns
Rate 1	35	35	35	35	35
Rate 2	38	43	37	37	33
Rate 3	38	43	39	38	35
Rate 4	40	44	42	41	34
Rate 5	40	35	42	39	36
Rate 6	47	41	47	36	37
SE[a]	2.12	2.10	2.68	-	-
ESP	***	***	***	***	*
Rate 1	2.93	2.93	2.93	2.93	2.93
Rate 2	2.92	3.19	2.90	2.98	2.96
Rate 3	2.86	3.50	2.87	2.96	2.89
Rate 4	2.78	3.93	2.77	3.21	2.92
Rate 5	2.69	4.72	2.67	3.49	2.89
Rate 6	2.58	5.92	2.57	3.84	2.89
SE[a]	0.022	0.072	0.026	0.080	0.016

Significance levels: (***) $P < 0.001$; (**) $P < 0.01$; (*) $P < 0.05$; ns = not significant.
Rate 1, 2, 3, 4, 5 and 6 represents the application rates of the amendments
[a]: Standard error of treatment means

6.4 Discussion

6.4.1 Microbial properties

The supply of readily metabolisable C in the organic waste products is likely to have been the most influential factor contributing to the increase in microbial biomass C. Soil microbial biomass responds rapidly to additions of readily available C with increasing application rates of all amendments except the vermicompost which would not have provided significant amounts of organic C. The positive effect on microbial biomass observed in the soils amended with solid organic wastes is due to a direct effect on microbial growth by these byproducts (Pascual *et al.*, 1998). The amendments made little difference to the microbial biomass except at the highest rates. The increases in nitrate concentration with increased amendment rate and the onset of anoxia in some incubation containers demonstrate that there were increases in microbial activity associated with residue decomposition. The higher microbial biomass due to application of the cotton gin trash, cattle manure, biosolids and chicken manure was observed only at higher rates which might be due to the greater labile fraction of organic matter in those amendments at higher rates. In addition, the nutrient content (N and P) was higher in these amendments at higher rates (Table 6.2), and these nutrients might have increased the abundance and activity of microorganisms. So, the availability of a high quantity and quality of biodegradable substrates (which is in agreement with the higher content of labile C observed in those treatments) most probably caused a positive response in microbial activity. Our results are supported by the findings of Tejada *et al.* (2006) who also observed a higher microbial biomass and respiration in poultry manure (10 t/ha) amended soil due to availability of higher labile C.

Soil basal respiration is considered to reflect the availability of C for microbial maintenance and is a measure of basic turnover rates in soil (Insam *et al.* 1991). High amounts of readily available C in cattle manure and chicken manure at their high application rates might be responsible for the significant increase in soil respiration which was also associated with significantly higher microbial biomass in those treatments at that rate. Soils with a lower input of labile organic matter, as we observed for the vermicast treatments, even at higher rates, did not show high potential microbial activity because the labile organic matter fractions express the ecosystem's potential to support an energy load sufficient for microbial activity (Van Veen *et al.* 1985).

6.4.2 Physical and chemical properties

Dry soil aggregation has been used in clay soils to study the process of slaking, dispersion and self-mulching (Coughlan 1984; Wenke and Grant 1994) and to assess aggregate size in seed beds (Coughlan and Loch 1984). Very high amounts of organic matter were required to produce significant differences in the mechanical strength of aggregates and it is very difficult to improve aggregate stability in Vertosols by organic matter input (Coughlan 1984). In our study, composted cotton gin trash and cattle manure did not have any influence on MWD even at higher rates. A good soil structure depends on the content and nature of the organic matter added as the organic matter promotes flocculation of clay minerals, which is an essential condition for the aggregation of soil particles. The enhancement of soil structure at higher rates of chicken manure application was probably due to the different chemical composition of the amendment, especially high Ca and Mg concentrations which helped to produce higher physical bonds for MWD. The increase in dry-sieved aggregates due to vermicast might be a short-term effect and because some polysaccharide glue may have come from that liquefied amendment. However, Coughlan (1984) observed that soils with large dry aggregates were susceptible to dispersion on wetting and input of mechanical energy. Our result with vermicasts supported his findings. In addition, as observed in Chapter 5, the application of both the vermicasts improved the MWD as well as increased the DI of the Vertosol. Aoyama *et al.* (1999a) observed an increase in SOM with addition of manure and consequently the formation of slaking-resistant macroaggregates (250-1000 µm diameter).

The free light fraction of the organic matter pool as measured here corresponds to organic residues that are relatively undecomposed and not bonded to mineral soil particles. It represents a labile pool of organic matter closely connected to recent plant residue inputs. The light fraction is often thought to act as a nucleus for aggregation as its decomposition products are involved in binding soil particles together (Golchin *et al.* 1998). It is also known to be more sensitive than the total organic matter (Gregorich and Janzen 1996) as it is an important source of labile C. Substantial increases in the light fraction with increasing amendment rate were seen for all amendments except vermicompost. This might be due to high C input (Table 6.2) from those amendments as there is a highly significant positive correlation between light fraction and C mineralization (Janzen *et al.* 1992; Bremer *et al.* 1994). All amendments stimulated nitrate production in the soil, with the nitrate-N at the end of the incubation rising as amendment application rate increased. For cotton gin trash, biosolids and chicken manure, no nitrate was detected at high application rates. This was attributed to anoxic conditions developing in the incubation containers as a result of high microbial respiration rates and consequent denitrification. This raises the question as to whether high amendment rates might also encourage denitrification in the field. If so, this would set an upper limit on feasible application rates. Field trials are needed to evaluate this. Despite adding only small amounts of N to the soil, vermicompost produced high concentrations of nitrate-N. For example at the highest application rate of 960 L/ha, only 50 mg/kg N was added, but about 250 mg/kg of nitrate-N was produced. This implies that the vermicompost was stimulating mineralization and nitrification of organic N already present in the soil. This could either be due to the input of microorganisms with the vermicompost, or alternatively a result of nutrients added in the vermicompost. The latter seems less likely as vermicompost inputs of C, P, etc were low. Since the nitrate comes from the soil organic pool and is not an input, the results suggest that high application rates of vermicompost could hasten the decline of organic N in inadequately fertilized cropping systems. Chicken manure may also have stimulated nitrate production with about 450 mg/kg N being produced at the 9 t/ha rate, with a N input of only 375 mg/kg, although the lower application rates of 2.25 and 4.5 t/ha produced about the same amount of nitrate-N as the N inputs (94 and 188 mg/kg). For the other treatments, a substantial proportion of the applied N was recovered as nitrate. For example, at a rate of 15 t/ha, recovery for cotton gin trash was 50/280 = 18%, for cattle manure was 60/499 = 12%, and for biosolids was 240/467 = 51%. All the amendments, apart from vermicompost, are good sources of mineralisable N if adequate application rates are used.

Increase in soil inorganic N at 0-10 cm depth due to addition of 16 Mg/ha of poultry litter was also observed by Motavalli *et al.* (2003). Lee (2004) found a higher soil nitrate-N with the application of 50 Mg/ha of sewage sludge. The higher amount of nitrate-N with higher rates was possibly associated with the higher soil organic C at those rates (Slattery *et al.* 2002).

Resin extractable phosphate-P was low in the unamended soil, but was generally increased by the organic amendments (Table 6.2). Vermicompost was an exception with low detectable resin P at all application rates, an observation which is consistent with the low P input from this source. As with N, a substantial proportion of the added P was present as resin extractable (and therefore available) P at the end of the incubation. Approximate proportions for the 30 t/ha rate are for cotton gin trash 120/146 = 82%, for cattle manure 170/450 = 38%, and for biosolids 60/578 = 10%. For chicken manure at 9 t/ha the proportion was 300/564 = 53%. For biosolids the maximum resin-P concentration occurred at 15 t/ha, with a substantial decline being observed for higher application rates. Phosphate can be removed from solution and rendered unavailable by several mechanisms including adsorption onto colloid surfaces, precipitation as insoluble phosphate salts and immobilisation via uptake into the microbial biomass. In this incubation the soil became anaerobic when amended with biosolids at rates above 15 t/ha. If Fe and Mn were reduced and dissolved in the anoxic environment and then subsequently oxidized as the soils were dried for analysis, there would be the possibility of Fe and Mn phosphates precipitating or phosphate sorption onto Fe and Mn oxides.

Although resin P tended to increase with increasing amendment rate for cattle manure and chicken manure, above a certain rate the increases were less than might be expected from the additional P inputs. For cotton gin trash, there was little gain in resin P above 15 t/ha, for cattle manure above 7.5 t/ha and for chicken manure above 9 t/ha. In other studies, it has been observed that large applications of P in dairy effluent (Murphy *et al.* 1973) and in fresh manure (Pratt and Lagg 1981) significantly increased soil extractable P levels. Similarly, Pu *et al.* (2004) observed that biosolids applied at different rates increased the nitrate level and total P in soil.

All amendments apart from vermicompost provided substantial inputs of Ca (Table 6.2). At the highest amendment rates, all provided more Ca than the soil exchangeable + soluble Ca pool (21 $\mathrm{cmol_c/kg}$). However, the amendments had relatively little effect on Ca extracted at the end of the incubation, with increases generally less than 5 $\mathrm{cmol_c/kg}$. Chicken manure provided the highest Ca inputs (45 $\mathrm{cmol_c/kg}$ at 36 t/ha), yet yielded no increase in Ca extracted from the soil. There are two possibilities to explain this: either the added Ca was in an insoluble, unavailable form, or it was removed from the soluble pool once in the soil. For example, Ca in plant material can be in cell walls as insoluble pectates or it might be present as poorly soluble salts such as carbonates and phosphates in soil. The high pH of this soil may prevent calcium carbonate and phosphates dissolving.

We also observed a significant increase in ECEC (Table 6.3) associated with the increase in exchangeable Ca by these amendments in higher application rates and the part of the increases in ECEC is also due to increases in other cations, particularly K e.g. in the case of cattle manure (Fig. 6.6). The response of the soil to Mg inputs was similar to that for Ca. Despite inputs of up to 10.7 $cmol_c$/kg from cotton gin trash and 13.6 $cmol_c$/kg from cattle manure, increases in exchangeable + soluble Mg were relatively small, suggesting low availability of the Mg in the amendments. The lack of an effect of vermicompost on soil Mg was expected, given the insignificant input. Our result is supported by Slattery *et al.* (2002) who also observed a significant increase in exchangeable Ca and Mg with the application of 109 t/ha of composted feedlot manure. Murphy *et al.* (1973) showed an increase in levels of Ca and Mg leading to large accumulations in soil where there had been a prolonged application of manure over several years

The greatest response of the soil exchangeable + soluble Na pool to Na input was found for cattle manure at 120 t/ha with an increase if about 1.5 $cmol_c$/kg, and corresponded to an input of 3 $cmol_c$/kg. This corresponds to in increase in ESP from 2.9% to 5.9% (Table 6.3), a level at which the soil may be considered only marginally sodic. The proportion of Na in the amendment which was extracted at the end of the incubation for the highest application rates ranged from about 30% for chicken manure to 50% for cattle manure. This indicates that the Na in the amendments had a higher availability than was found for Ca or Mg, which is expected as Na salts tend to be more soluble than those of Ca and Mg, and Na is not immobilized in organic compounds. The increase in exchangeable Na may result in the dispersion of soil colloids, destroying the ability of clay particles to aggregate resulting in loss of soil structure (Rengasamy and Churchman 1999). Although the amendments and rates used in this study did not result in substantial increases in sodicity, repeated applications may do so, particularly when one considers the apparent higher solubility of Na relative to Ca.

As with Na, some major changes to the exchangeable + soluble K pool occurred after application of some of the organic amendments. For the highest application rates about 30% of the K added in cotton gin trash, cattle manure and chicken manure was recovered at the end of the incubation. For these amendments the amount of K recovered tended to increase with application rate, but not in proportion to the extra amount of K added. This suggests some buffering of soluble K pool, possibly by the non-exchangeable K pool. If that is the case, then the extra K may become slowly available as crops deplete the soluble pool. A significant increase in exchangeable K due to application of composted feedlot manure (109 t/ha) was also observed by Slattery *et al.* (2002). Singh *et al.* (2002) found an increased soil available K due to application of 16 t/ha of farm yard manure.

6.5 Conclusions

Application of the organic amendments at higher rates changed the soil properties of a Vertosol. Considering the results of this experiment, cotton gin trash applied at 30 t/ha significantly affects the Vertosol properties. For the cattle manure, 30 or 60 t/ha application rates might be appropriate to have an effect on Vertosol properties. Biosolids could have an effect on Vertosol if they were applied at 60 t/ha rate. Application of 18 t/ha of chicken manure would have the potential to improve the Vertosol quality. Vermicompost did not have much effect on soil properties, although higher application rates could affect the microbial properties and increase the soil available N. However, significant increases in exchangeable Na with the higher rates of cattle manure and chicken manure resulted in increased sodicity of the soil which needs more investigation.

Chapter Seven

Short-term effect of organic amendments on properties of sodic Vertosols

7.1 Introduction

Sodic soils are of increasing importance worldwide as they can affect agricultural production in several ways. In Australia, approximately 23% of the landmass and 80% of the irrigated agricultural area is affected by sodic soils (Rengasamy and Olsson 1993). A study by the Cooperative Research Centre for Soil and Land Management in 1997 estimated that in Australia, soil sodicity reduced farmers' incomes by \$1.3 billion (Watson *et al.* 2000). Sodic soils are characterized by their poor structural stability in water. Structural stability in sodic soils, usually measured as dispersion, is said to be determined mainly by the levels of exchangeable Na (Rengasamy and Olsson 1991; McKenzie 1998; Rengasamy and Churchman 1999). Dispersion involves the breakdown of soil aggregates resulting in separation of clay particles < 2 μm, which then diffuse through the dispersing solution (Churchman *et al.* 1993). These can affect water and air movement in soil, water holding capacity, root penetration, seedling emergence, runoff and erosion as well as making tillage and sowing operations more difficult (Oster and Jayawardane 1998). The dispersion of clay particles is also strongly dependent on the electrolyte concentration in the soil solution (Rengasamy *et al.* 1984; Quirk 2001).

Sodic soils generally have low organic matter contents, due to their relatively low productivity and associated organic matter inputs and their relatively high losses of organic matter in erosion and leaching events (Nelson and Oades 1998b). Micaceous minerals frequently occur in several sodic soils where large amount of K^+ are usually available (Gupta and Abrol 1990). In Australian sodic soils, K^+ is a growth-limiting nutrient (Ford *et al.* 1993), but the K^+ uptake by the plants can be markedly suppressed by an increase in soil Na^+ levels. Traditionally, sodic soil amelioration and management has aimed to displace excess Na^+ from the cation exchange sites and to leach out the Na and thus reduce soil salinity and sodicity to levels that do not limit production and permit high levels of crop productivity. Various amendments applied to the sodic soil have been shown to affect the availability of soil nutrients in a variety of ways during the amelioration process.

In Australia, surface and/or the subsoils of the majority of cotton growing regions are sodic (Northcote and Skene 1972; McKenzie 1998) and dispersion directly affects the hydraulic conductivity, and consequently crop water uptake and water logging potential in Vertosols (So and Aylmore 1993). It is widely accepted that organic matter has a positive effect on the physical properties of soils. Different types of organic matter act at different scales within the soil structure. Sometimes it may enhance dispersion, but their general effect is to bind the soil particles together (Nelson and Oades 1998b). Organic anions enhance dispersion by increasing the negative charge on clay particles and by complexing Ca^{2+} and other polyvalent cations such as those of Al, thereby reducing their activity in solution. On the other hand, large organic polyanions can bind clay particles together into stable macroaggregates (Greenland 1965a; 1965b). In the last decade, organic wastes such as animal manure (Haynes and Naidu 1998), sewage sludge (Albiach *et al.* 2001), city refuse (Giusquiani *et al.* 1995; Eriksen *et al.* 1999), compost (Sikora and Enkiri 1999), crop residues (De Neve and Hofman 2000), and industrial byproducts (Madejon *et al.* 2001; Tejada and Gonzalez 2004) have been applied in an effort to reclaim degraded soils. Tejada *et al.* (2006) observed a significant decrease in exchangeable sodium percentage (ESP) due to application of cotton gin crushed compost and poultry manure. Adding organic amendments such as compost made from plant materials or municipal solid waste compost may help in the exchange of the adsorbed Na^+ by Ca^{2+} and in the displacement of Na^+ (Somani 1990). However, studies in regard to the processes involved on effect of organic amendments on properties of sodic Vertosols are sparse. Therefore, the present study was initiated with an aim to determine how organic amendments applied at higher rates could influence the Vertosol properties with different levels of sodicity.

7.2 Materials and Methods

7.2.1 Experimental details

No universally accepted critical ESP for sodic soils exists. In Australia, Northcote and Skene (1972) assigned soils to three classes of sodicity; non-sodic (ESP < 6%), sodic (ESP 6%-15%) and strongly sodic (ESP > 15%). In the Australian Vertosols used for cotton production McKenzie (1998) suggests the use of an ESP of 5% to delineate sodic soils, because ESPs as low as 2 can have detrimental effects on the structure of these soils under conditions of low electrical conductivity (Cook *et al.*

1992). Soil variability such as clay mineralogy, soil texture, nutrient status, salinity and organic matter content between different sites and down the profile makes it difficult to use naturally-occurring soils of varying ESP values in experiments requiring this. In order to understand the processes involved between the organic amendments and sodicity, it is necessary to produce soils of varying ESP from one soil, minimising the risk of other soil properties confounding the experiment. To overcome these problems we used an artificial sodification method to change the sodicity level of the Vertosols such that they could be grouped into non-sodic, moderately sodic and strongly sodic with their EC's adjusted to < 4 dS/m.

7.2.1.1 Collection of soil samples

The soils used in this experiment were collected from two different sites at 0-0.1 m depth in order to compare their behaviour on application of organic amendments at varying levels of sodicity. One soil was collected from a cotton field at the Australian Cotton Research Institute (ACRI), Myall Vale, NSW (150°E, 30°S), where it had been used for irrigated cotton and wheat cropping for approximately 25 years. The other soil was collected from a cotton field near Dalby, Queensland (149°E, 27°S) which was characterized by low K content. Both the soils were dark grayish brown cracking clays, classified as Grey Vertosols (Isbell 1996a; b). X-ray diffraction results showed that the ACRI soil was dominated by illitic type (49%) of clay, whereas montmorillonitic clay (48%) dominated in Dalby soil. Relative proportion of other clay minerals present in ACRI soil was montmorillonite (14%), kaolinite (34%) and other (1%). For Dalby soil, 14% illite, 27% kaolinite and 11% other clay minerals were present. 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) for ACRI soil and the distribution for Dalby soil was 50 g/100 g clay, 21 g/100 g silt and 29 g/100 g sand.

7.2.1.2 Soil sodification

Soil sodicity is generally defined in terms of ESP:

$$\mathrm{ESP}\ (\%) = \frac{\mathrm{ExNa}}{\mathrm{ExNa} + \mathrm{ExCa} + \mathrm{ExMg} + \mathrm{ExK}} \times 100$$

Where, Ex denotes the concentration of the exchangeable cation in $\mathrm{cmol_c/kg}$ soil.

Richards (1954) described the relationship between solution SAR and soil ESP as follows;

$$\mathrm{ESP}\,(\%) = \frac{100 \times (-0.0126 + 0.01475 \times \mathrm{SAR})}{1 + (-0.0126 + 0.01475 \times \mathrm{SAR})}$$

The initial sodification method employed was a modified version (Dodd 2007) of the method of Patruno *et al.* (2002). To produce soils with three levels of sodicity, approximately 1000 kg of soil was air-dried, passed through a 10 mm sieve to remove large particles of organic matter and separated into four equal portions. For each sodification treatment, a 250 kg portion was then divided between several calico lined stainless steel trays (30×80×7.5 cm) with perforated bases, each filled to a depth of approximately 5 cm (Plate 7.1). The trays were designed to allow treatment solution but not soil material to pass through the base. The soil trays were immersed into treatment solutions placed in large stainless steel trays, such that approximately 1 cm of treatment solution covered the soil surface. Each tray was immersed for 4 h, allowed to drain for 1 h and then partially dried in a fan-forced oven at 40°C overnight (~ 12 h). The immersion, drainage and drying cycle was repeated six times. The major cations used were Ca, Na, Mg and K and were included as their Cl salts.

Table 7.1 The SARs, cation concentrations and soil ESP values of the equilibrating solutions

Treatment	Solution SAR	Na (mM)	Ca (mM)	Mg (mM)	K (mM)	Target ESP
Non-sodic	2	0	0.0	0.00	0.00	< 6
Moderate sodicity	21	12.0	0.0	0.32	0.07	6-15
Strong sodicity	200	121.5	0.0	0.37	0.08	> 15

Following equilibration with the three different SAR solutions (Table 7.1), the salinity of the soils was adjusted to a level < 4 dS/m. At this $\mathrm{EC_e}$ value soils are considered non-saline and the growth of moderately salt-tolerant plants is not affected (Richards 1954). Consequently, salt was added to some treatments and removed from others. Treated soil was immersed in solutions containing the same K and Mg concentrations as the equilibrating solutions, but using solution Ca and Na concentrations as outlined in Table 7.2. Each soil was submerged six times, for 5 mins and allowed to drain for 1 h between each immersion. This process was repeated four times. The Ca and Na concentrations required to obtain this $\mathrm{EC_e}$ in the other treatments were determined by analysing small amounts of the soil. The $\mathrm{EC_{1:5}}$ values were converted to the electrical conductivity of the saturated extract (EC_e) using a conversion factor for heavy clays of 5.8 (Slavich and Petterson 1993).

Table 7.2 The cation concentrations of the solutions used to adjust the electrical conductivity of the soils

Treatment	Na (mM)	Ca (mM)	Mg (mM)	K (mM)
Non-sodic	0	14.0	0.32	0.07
Moderate sodicity	10.0	0.0	0.32	0.07
Strong sodicity	0.0	0.0	0.37	0.08

Table 7.3 The resultant exchangeable cations, electrical conductivity and ESP of the sodic Vertosols after the sodification

	Na ($cmol_c/kg$)	Ca ($cmol_c/kg$)	Mg ($cmol_c/kg$)	K ($cmol_c/kg$)	EC_e (dS/m)	ESP
ACRI soil						
Non-sodic	0.75	29.1	10.8	1.8	3.8	1.8
Moderate sodicity	2.17	23.1	11.7	1.7	2.9	5.6
Strong sodicity	7.72	21.9	9.9	1.6	3.9	18.8
Dalby soil						
Non-sodic	0.32	27.0	6.7	0.46	2.6	0.9
Moderate sodicity	2.25	22.0	7.4	0.50	3.4	7.0
Strong sodicity	4.99	20.3	6.3	0.50	3.7	15.6

7.2.2 Experimental design and treatments

The soil was amended with three different organic amendments at high application rates. The choice of organic amendments was based on previous experimental results (Chapter 5). No plants were grown in the pots. The organic amendments were cotton gin trash, cattle manure and composted chicken manure. Cotton gin trash and cattle manure were applied at 60 t/ha and for chicken manure, the rate was 18 t/ha.

Six hundred grams of air-dried soil was placed in 100 mm diameter pots filling them to a depth of 10 cm. The organic inputs were mixed thoroughly with the soil. Then the soils were incubated over four weeks in a temperature controlled growth chamber set at 30°C in the Department of Agronomy and Soil Science, University of New England, Armidale, NSW. 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). After four weeks of incubation, the soil in the pots was analysed for selected physical and chemical properties.

7.2.3 Soil analyses

7.2.3.1 Physical properties

Air-dried soil samples were used to analyse the dispersion index of the soil. The dispersion index (DI) of small aggregates was measured by using a method derived from Blackmore (1956) and Mason *et al.* (1984), where

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

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.

7.2.3.2 Chemical properties

The soil samples were air dried, passed through < 2 mm sieve and then analysed for pH, $EC_{1:5}$, 0.5M NH_4Cl/0.5M $BaCl_2$ extractable cations and resin-extractable anions. The chemical analyses were performed using the methods as described in Chapter 3.

With the increase in EC, there is a decrease in soil dispersion regardless of how sodic the soil is. McKenzie (1998) suggested calculating the 'electrochemical stability index' (ESI) ($EC_{1:5}$/ESP), along with ESP, for a better understanding of soil dispersion. A tentative critical ESI value for Australian cotton soil is 0.05. An economically viable response of the amendment can be expected if ESI values are below this level. ESI was also calculated in this study.

Air-dried soil samples were also used to determine the non-exchangeable K content by measuring the nitric acid (HNO_3) extractable K. HNO_3-extractable K was measured using the method described by Helmke and Sparks (1996). 2.5 g air-dry soil samples were gently boiled in 25 ml of 1M HNO_3 at 115°C for 15 min and the final volume made up to 100 ml with deionised water. Then the non-exchangeable K was calculated by subtracting exchangeable K from the HNO_3-extractable K.

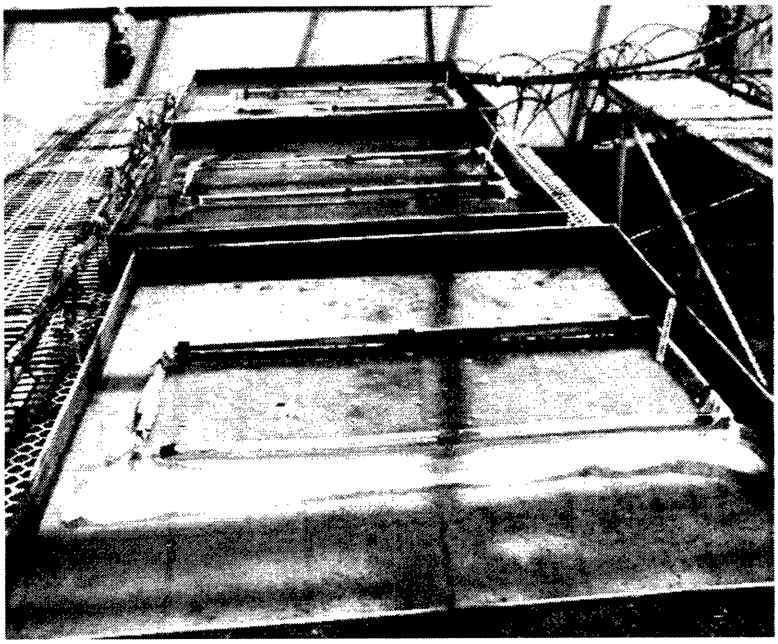
The analysis of organic amendments was also performed following the method as described in Chapter 3. The amount of nutrient contribution from the organic inputs is summarized in Table 7.4.

Table 7.4 Nutrient added to every pot from the amendments

Treatment	Rate	C	N	P	K	Na	Ca	Mg
	t/ha	mg/pot	mg/pot	mg/pot	mg/pot	mg/pot	mg/pot	mg/pot
Cotton gin trash	60	56	617	160	646	30	1550	358
Cattle manure	60	114	1098	495	1065	189	1428	457
Chicken manure	18	30	413	622	273	62	2495	137

7.2.4 Statistical analyses

Results were analysed using the analysis of variance (ANOVA) function of R 2.5.0 (R Development Core Team 2006) and *P* values < 0.05 were considered significant. Variances were checked by plotting residual vs. fitted values to confirm the homogeneity of the data. No transformations were necessary. Means for significant treatment effects were separated based on standard errors (SE). The treatment combination means presented for a variable are based on the highest order of factorial combination that is significant in the ANOVA. Where there is less than the factorial combination, the data have been generated by pooling the data across the nonsignificant factors.



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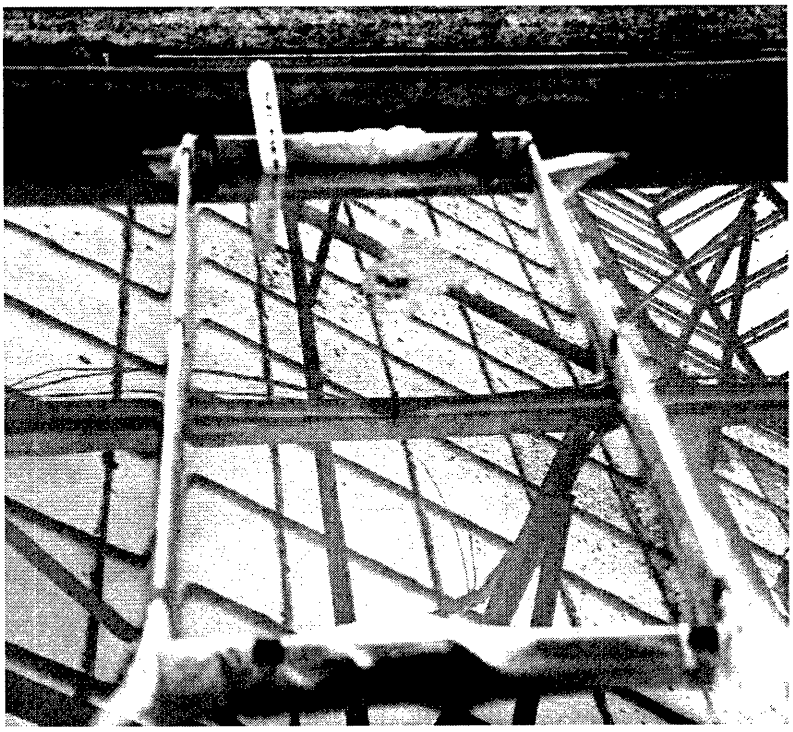

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Plate 7.1 A. Method of soil sodification; B. Method of leaching of salts

7.3 Results

The summary of the statistical analyses are presented below in Table 7.5.

Table 7.5 Significance levels[a] in two-way ANOVA of the effect of organic amendments (cotton gin trash, cattle manure and composted chicken manure) and sodicity levels (non sodic, moderately sodic and strongly sodic) on selected soil properties of two Vertosols

Terms	pH	EC	NO_3-N	PO_4-P	Exch. K	Nonex. K	Exch. Ca	Exch. Mg	Exch. Na	ESP	ECEC	DI	ESI
ACRI soil													
T	***	***	***	***	***	***	***	*	***	***	***	**	***
SL	***	***	ns	***	ns	ns	***	***	***	***	***	*	***
T × SL	***	ns	***	***	ns	ns	ns	*	***	***	ns	ns	***
Dalby soil													
T	***	***	***	***	***	***	**	***	***	**	***	***	***
SL	***	***	ns	***	ns	**	***	***	***	***	**	***	***
T × SL	**	ns	**	***	ns	ns	ns	ns	ns	ns	ns	***	***

[a](***) $P < 0.001$; (**) $P < 0.01$; (*) $P < 0.05$, ns = not significant

[T = treatment, SL = sodicity level; ESP = exchangeable sodium percentage, ECEC = effective cation exchange capacity; DI = dispersion index, EC = electrical conductivity, ESI = electrochemical stability index]

7.3.1 Effect on physical properties

The DI of ACRI soil was not affected by the two-way interaction between treatment and sodicity level ($P \geq 0.05$), but the interaction was highly significant ($P < 0.001$) for Dalby soil (Table 7.5). Application of cotton gin trash and cattle manure resulted in a significant decrease in DI of ACRI soil as compared to control. A significantly higher DI was also observed in the strongly sodic ACRI soil compared with the two lower sodicity levels (Table 7.6). A significant decrease in DI was observed in moderately and strongly sodic Dalby soil due to application of organic amendments. Cotton gin trash caused the highest decrease (29%) in DI over the control at the moderate sodicity level, whereas in strongly sodic Dalby soil, the lowest DI was observed due to application of chicken manure (Table 7.6).

Table 7.6 Changes in dispersion index of the Vertosols with varying sodicity level due to application of organic amendments

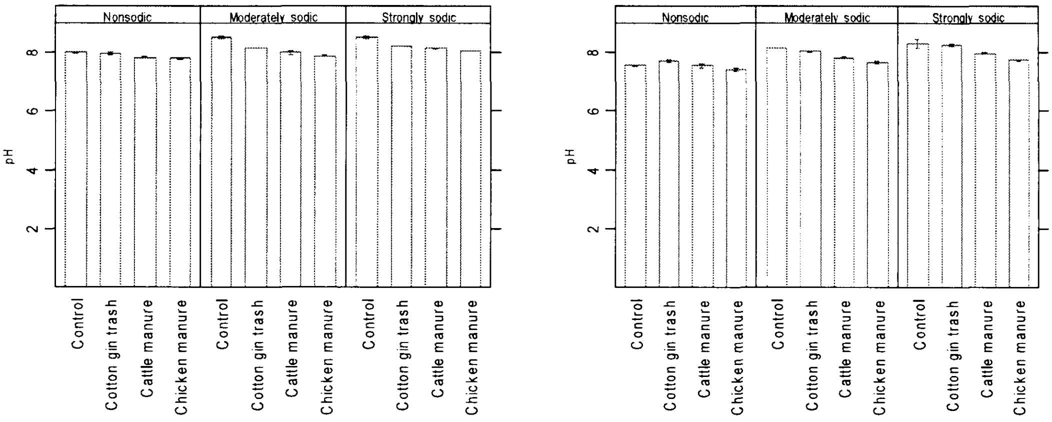
	Dispersion index		
ACRI soil			
Treatment		Sodicity level	
Control	32.1	Non-sodic	27.8
Cotton gin trash	28.9	Moderately sodic	27.7
Cattle manure	25.3	Strongly sodic	31.4
Chicken manure	29.5		
SE[a]	1.59		1.38
Dalby soil			
	Non-sodic	Moderately sodic	Strongly sodic
Control	26.9	33.9	63.6
Cotton gin trash	27.5	24.0	46.4
Cattle manure	24.1	26.3	44.1
Chicken manure	24.2	27.6	40.7
SE[a]		2.52	

[a]: Standard error of means

7.3.2 Effect on chemical properties

The two-way interaction (treatment × sodicity level) was highly significant ($P < 0.001$) for soil pH for both ACRI and Dalby soil. ACRI soil pH was significantly decreased by application of cattle manure and chicken manure in all three sodicity levels, whereas cotton gin trash significantly decreased the soil pH only at moderately and strong sodic ACRI soil (Figure 7.1). For Dalby soil, application of chicken manure resulted in a significant decrease in soil pH in all three sodicity levels (Figure 7.1).

The two-way interaction (treatment × sodicity level) was not significant ($P \geq 0.05$) for the electrical conductivity (EC) of the Vertosols. However, there a significant increase in EC over control was observed due to the application of organic amendments (Table 7.7). Strong sodic ACRI soil showed the highest EC followed by non-sodic and moderately sodic soils. For Dalby soil, the highest EC was observed at lowest sodicity level followed by strongly and moderately sodicity level.



ACRI soil Dalby soil

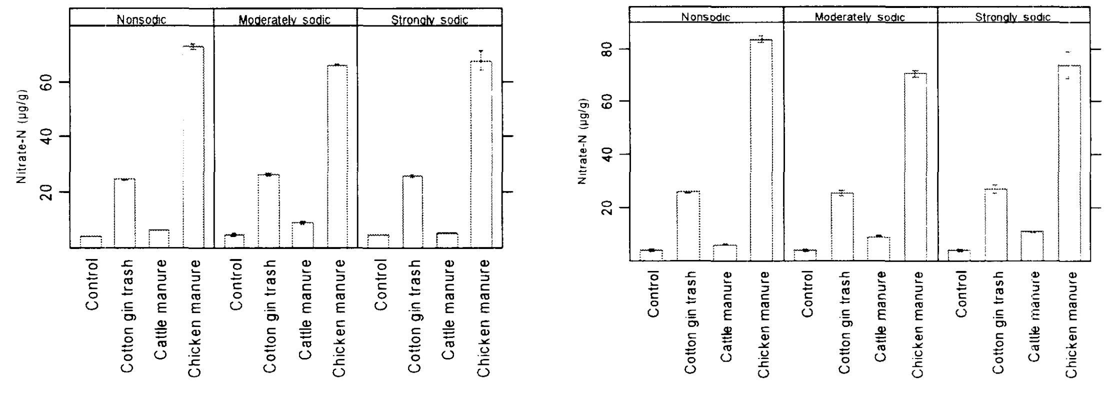
Figure 7.1 Effect of organic amendments on soil pH of the sodic Vertosols. Vertical bars show the standard error of means.

Table 7.7 Changes in EC of sodic Vertosols due to application of organic amendments

	Electrical conductivity ($EC_{1:5}$) (dS/m)				
	Control	Cotton gin trash	Cattle manure	Chicken manure	SE[a]
ACRI soil	0.70	1.02	1.38	1.18	0.024
Dalby soil	0.53	0.87	1.26	1.05	0.033
	Non-sodic	Moderately sodic	Strongly sodic		
ACRI soil	1.22	0.69	1.30		0.020
Dalby soil	1.30	0.71	0.77		0.029

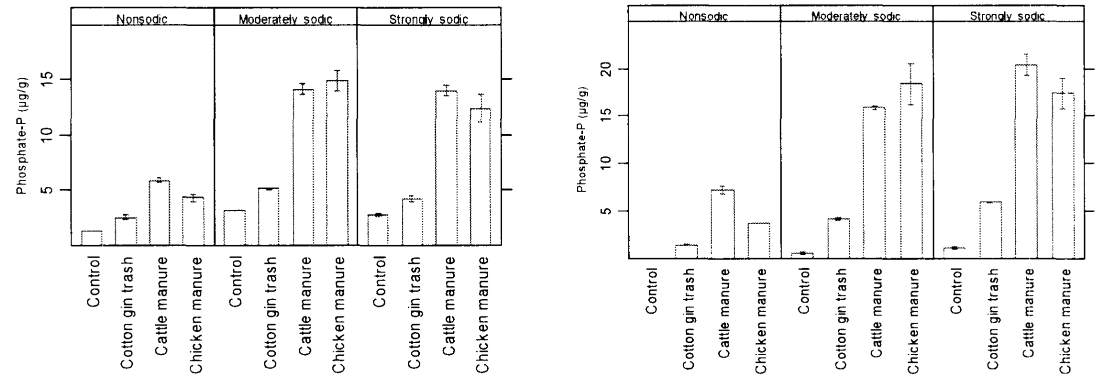
[a]: Standard error of means

The nitrate-N content was significantly affected by the application of organic amendments for both the Vertosols with three different sodicity levels as the two-way interaction (treatment × sodicity level) was highly significant ($P < 0.001$ for ACRI and $P < 0.01$ for Dalby) (Table 7.5). Both ACRI and Dalby soil showed significantly higher nitrate-N content in all three sodicity levels with the application of cotton gin trash and chicken manure as compared to control (Figure 7.2). A significantly increased nitrate-N was observed in moderately and strongly sodic Dalby soils due to the application of cattle manure; however, for ACRI soil, the amendment resulted in a significant increase only at moderate sodicity level. Figure 7.2 also showed that among the different organic inputs, chicken manure was most effective and caused the highest increase in nitrate-N over the control treatment of the Vertosols. There was a similar increase in nitrate-N from non-sodic to strongly sodic Vertosols due to the application of chicken manure.



ACRI soil Dalby soil

Figure 7.2 Effect of organic amendments on nitrate-N content of sodic Vertosols. Vertical bars represent the standard errors of the means.



ACRI soil Dalby soil

Figure 7.3 Effect of organic amendments on phosphate-P content of Vertosols with different sodicity levels. Vertical bars indicate the standard error of the means.

The two-way interaction between treatment and sodicity level was highly significant ($P < 0.001$) for the phosphate-P content of ACRI and Dalby soil (Table 7.5). A consistent increase in phosphate-P with increased sodicity levels was observed due to application of cattle manure (Figure 7.3). The cattle manure and chicken manure treatments significantly increased the phosphate-P content over the control in all three sodicity levels for both the soils. For ACRI soil, the cotton gin trash was effective in significantly increasing the phosphate-P content as compared to control only at a moderate sodicity level; whereas the same treatment significantly increased the amount of Dalby soil-P over the control in all the three sodicity levels.

The two-way interaction (treatment × sodicity level) was not significant ($P \geq 0.05$) for the exchangeable K content of the Vertosols (Table 7.5). However, a significant treatment difference ($P < 0.001$) was observed for both ACRI and Dalby soil (Table 7.5). An increasing trend of exchangeable K was observed in both the Vertosols with the addition of organic amendments (Table 7.8). There were 164, 76 and 41% increases as compared to control in exchangeable K due to cattle manure, cotton gin trash and chicken manure respectively in ACRI soil, where these amendments increased the K content of Dalby soil by 580, 275 and 212 % (Table 7.8) respectively.

The non-exchangeable K content of both the soils was not affected by the treatment × sodicity level interaction ($P \geq 0.05$) (Table 7.5). A significant treatment difference ($P < 0.001$) was observed for both the Vertosols. There was a significant 36% increase over the control in non-exchangeable K content of ACRI soil due to cattle manure application, whereas cotton gin trash and chicken manure resulted in an 18% increase over the control (Table 7.9). For the Dalby soil, cotton gin trash significantly increased the non-exchangeable K content up to 146% over the control and cattle manure and chicken manure increased up to 134 and 51% respectively (Table 7.9). The non-exchangeable K content also differed significantly with the sodicity levels in Dalby soil (Table 7.5). The amount of non-exchangeable K of Dalby soil was almost similar in non-sodic and strongly sodic levels, but a significantly lower amount was observed at the moderate sodicity level.

Table 7.8 Effect of organic amendments on exchangeable-K content of sodic Vertosols

	Exchangeable K ($cmol_c/kg$)				
	Control	Cotton gin trash	Cattle manure	Chicken manure	SE[a]
ACRI soil	1.7	3.0	4.5	2.4	0.11
Dalby soil	0.5	1.8	3.4	1.5	0.14

[a]: Standard error of treatment means

Table 7.9 Effect of organic amendments on exchangeable and non-exchangeable K pool of sodic Vertosols

	Non-exchangeable K (cmol$_c$/kg)				
	Control	Cotton gin trash	Cattle manure	Chicken manure	SE[a]
ACRI soil	2.8	3.3	3.8	3.3	0.16
Dalby soil	0.41	1.01	0.96	0.62	0.041
	Non-sodic	Moderately sodic	Strongly sodic		
Dalby soil	0.80	0.68	0.77		0.035

[a]: Standard error of means

In regard to exchangeable Na content of the soil, the two-way interaction (treatment × sodicity level) was highly significant ($P < 0.001$) for the ACRI soil; however, the interaction was not significant ($P \geq 0.05$) for the Dalby soil (Table 7.5). Application of cattle manure significantly increased the exchangeable Na content over the control in non-sodic and moderately sodic ACRI soil, but at higher sodicity level chicken manure significantly decreased its content (Figure 7.4) compared to control. For Dalby soil, a significantly higher Na content was observed due to application of cattle manure (Table 7.10). Table 7.10 also showed a significant increase in exchangeable Na with the increase in sodicity level of Dalby soil. In the non-sodic Dalby soil, the exchangeable Na content was 0.65 cmol$_c$/kg and the value was increased up to 5.2 cmol$_c$/kg at the highest sodicity level.

The ESP of ACRI soil was significantly affected by the application of organic amendments at three different sodicity levels as the two-way interaction (treatment × sodicity level) was highly significant ($P < 0.001$), but the interaction was not significant ($P \geq 0.05$) for the Dalby soil (Table 7.5). In non-sodic and moderately sodic ACRI soil, cattle manure significantly increased the ESP compared to control, whereas a significant decrease in ESP below the control treatment was observed for the cotton gin trash treatment at higher sodicity level (Figure 7.4). Application of cotton gin trash resulted in a significant decrease in ESP from the control levels in Dalby soil (Table 7.10). A significant increase in ESP with the increase in sodicity level was also observed in Dalby soil.

The electrochemical stability index (ESI) of the Vertosols was significantly affected by the addition of organic amendments as the two-way interaction (treatment ×

sodicity level) was highly significant (*P* < 0.001). In ACRI soil, there was a significant increase in ESI as compared with control due to addition of organic amendments, except for the cattle manure which significantly decreased the ESI at lower sodicity level (non-sodic) (Figure 7.5). For Dalby soil, organic amendments did not have any effect on ESI at strong sodicity level. However, they caused a significant decrease in ESI relative to the control for the non-sodic Dalby soil (Figure 7.5). Figure 7.5 also showed that except the cattle manure, the other two organic amendments decreased the ESI of moderately sodic Dalby soil.

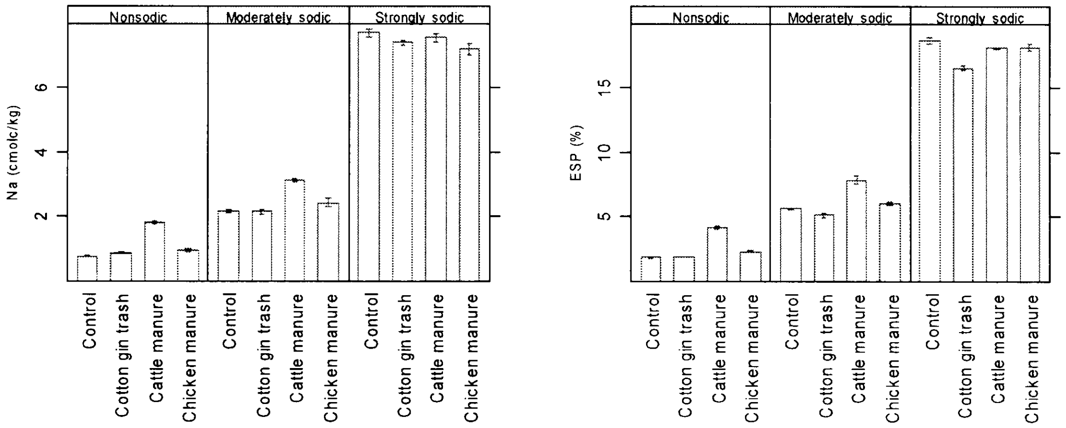
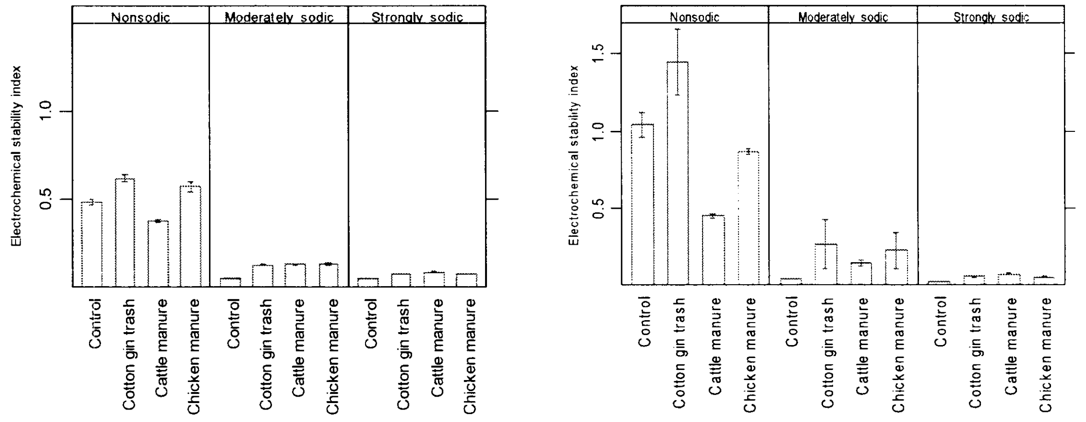


Figure 7.4 Effect of organic amendments on exchangeable-Na and ESP of ACRI soil. Vertical bars show the standard error of means.

Table 7.10 Effect of organic amendments and sodicity level on exchangeable Na and ESP of Dalby soil

Exchangeable Na (cmol$_c$/kg)				ESP			
Treatment		Sodicity level		Treatment		Sodicity level	
Control	2.5	Non-sodic	0.6	Control	7.8	Non-sodic	1.7
Cotton gin trash	2.2	Mod. sodic	2.2	Cotton gin trash	6.2	Mod. sodic	6.1
Cattle manure	3.4	Strongly sodic	5.2	Cattle manure	9.0	Strongly sodic	15.0
Chicken manure	2.6			Chicken manure	7.5		
SE[a]	0.23		0.20		0.61		0.53

[a]: Standard error of means



ACRI soil Dalby soil

Figure 7.5 Effect of organic amendments on ESI of the sodic Vertosols. Vertical bars show the standard error of means.

Both the Vertosols behaved in a similar way for the three different sodicity levels and application of organic amendments with respect to exchangeable Ca (Table 7.5) as the two way interaction was not significant ($P \geq 0.05$). Application of cotton gin trash significantly increased the exchangeable Ca content of the soils as compared to control up to 6 and 9% for ACRI and Dalby soil respectively (Table 7.11). However, a significant decrease in exchangeable Ca content relative to the control was observed for cattle manure and chicken manure treatments in ACRI soil (Table 7.11). Table 7.11 also showed that the Ca content decreased significantly with the increase in sodicity level for both the Vertosols.

Table 7.11 Changes in exchangeable Ca content of sodic Vertosols due to application of organic amendments

	Exchangeable Ca (cmol$_c$/kg)				
	Control	Cotton gin trash	Cattle manure	Chicken manure	SE[a]
ACRI soil	24.7	26.2	21.6	23.0	0.37
Dalby soil	23.1	25.3	22.2	23.6	0.79
	Non-sodic	Moderately sodic	Strongly sodic		
ACRI soil	28.0	22.8	21.0		0.32
Dalby soil	26.3	24.0	20.2		0.68

[a]: Standard error of means

The two way interaction (treatment × sodicity level) was significant ($P < 0.05$) with respect to exchangeable Mg content for ACRI soil; however for Dalby soil, the interaction was not significant ($P \geq 0.05$) (Table 7.5). In non-sodic ACRI soil, application of cattle manure and cotton gin trash significantly increased the exchangeable Mg content as compared to control, but in highly sodic ACRI soil, only cattle manure significantly increased its content over the control (Table 7.12). Application of organic amendments significantly increased the exchangeable Mg content of the Dalby soil (Table 7.12) as compared with control. Cattle manure caused the highest increase (31%) followed by chicken manure (22%) and cotton gin trash (12%). The exchangeable Mg content also differed significantly ($P < 0.001$) with the different sodicity levels for Dalby soil. The lowest Mg content was observed in the strongly sodic Dalby soil, and the highest at the moderate sodicity level.

The two-way interaction (treatment × sodicity level) was not significant ($P \geq 0.05$) for the ECEC of the Vertosols (Table 7.5). However, a highly significant ($P < 0.001$) treatment difference was observed in both ACRI and Dalby soil (Table 7.5). Both the soils showed an increase in ECEC due to application of organic amendments (Table 7.13). Only cotton gin trash significantly increased the ECEC up to 8% over the control in ACRI soil, whereas a significant increase in ECEC was observed due to all three organic inputs for Dalby soil and the highest increase (15%) was caused by the application of cattle manure. In non-sodic ACRI soil, the ECEC was 43.6 $\mathrm{cmol_c/kg}$, but it significantly decreased by 8 and 4% at moderate and strong sodicity levels respectively. The ECEC did not change significantly at non-sodic and moderately sodic levels in the Dalby soil, but a significant decrease was observed at the highest sodicity level (Table 7.13).

Table 7.12 Effect of organic amendments on exchangeable Mg concentrations of sodic Vertosols

	Exchangeable Mg (cmol$_c$/kg)		
ACRI soil			
Treatment	Non-sodic	Moderately sodic	Strongly sodic
Control	10.8	11.8	9.9
Cotton gin trash	12.0	12.2	10.6
Cattle manure	12.1	11.5	11.0
Chicken manure	11.4	13.0	10.2
SE^a		0.48	
Dalby soil			
		Sodicity level	
Control	6.8	Non-sodic	7.8
Cotton gin trash	7.6	Moderately sodic	8.6
Cattle manure	8.9	Strongly sodic	7.3
Chicken manure	8.3		
SE^a	0.17		0.15

^{a}: Standard error of means

Table 7.13 Effect of organic inputs and sodicity level on ECEC of Vertosols

	Effective cation exchange capacity (ECEC)				
	Control	Cotton gin trash	Cattle manure	Chicken manure	SE^a
ACRI soil	40.8	44.3	41.8	40.6	0.63
Dalby soil	32.9	36.9	37.9	36.0	0.70
	Non-sodic	Moderately sodic	Strongly sodic		
ACRI soil	43.6	40.2	41.8		0.55
Dalby soil	36.6	36.6	34.5		0.60

^{a}: Standard error of means

7.4 Discussion

Sodic soils are characterized by high soil solution concentrations of Na (Naidu *et al.* 1995). Dodd (2007) showed that high solution Na is unlikely to cause nutritional problems in sodic Vertosols, but it resulted in poor soil structure. The increase in dispersion with increasing ESP of the soils can be explained by the diffuse double layer (DDL) theory in relation to internal and external exchange surfaces. The increase in dispersion with higher ESP means the clay consists of individual platelets in suspension and was therefore dominated by external exchange surfaces. These external surfaces then showed an overall preference for Na$^+$ due to their small electric potentials. Cattle manure added the highest amount of Na (1.5 cmol$_c$/kg) into the soil (Table 7.4) resulting in increased Na concentration and increased ESP. Contributions from cotton gin trash (0.2 cmol_c/kg) and chicken manure (0.5 cmol_c/kg) were much lower. A significant decrease in exchangeable Na concentration in the strongly sodic ACRI soil due to addition of chicken manure might be attributed to its higher Ca concentrations causing displacement of Na^+ by Ca^{2+} from the cation exchange complex.

In sodic soils, high concentrations of Na ions in the soil solution severely restrict the presence of divalent cations (Guerrero-Alves *et al.* 2002), which may, in turn, have implications for the availability of Ca and Mg to plants. In our study, we also observed a lower exchangeable Ca concentration in soils with increased sodicity which might be due to the changes in the electric potential of the DDL. High amounts of Ca present in cotton gin trash resulted in an increase in exchangeable Ca of the sodic Vertosols. Whereas chicken manure, although adding the highest amount of Ca, did not result in high exchangeable Ca in soil. The addition of exchangeable Mg by the organic amendments (Table 7.4) increased the exchangeable Mg of the Vertosols. The increased Mg may help reduce the amount of Na-induced dispersion and keep soil flocculated because of the competition for the same space as Na for binding onto clay particles. The highest increase in exchangeable Mg content of the Vertosols due to the cattle manure treatment might be attributed to its high concentration of exchangeable Mg (6.8 cmol_c/kg) into the soil.

With the increase in EC, soil dispersion may decrease for a given sodicity value. Conversely, soil with very low EC may become dispersive where the ESP of the soil is low. Therefore, for understanding soil dispersion, along with ESP, the ESI needs to be calculated. ESI (EC ÷ ESP) is a very useful index of soil dispersibility (McKenzie 1998). A tentative critical ESI value for Australian cotton soil is 0.05 and the soil is unlikely to disperse in water when ESI > 0.05. When a soil has a high ESP and the electrolyte concentration of the soil is sufficiently low, the distance between clay particles upon hydration increases to such an extent that the particles begin to separate, resulting in accentuated swelling. If the distance between adjacent clay particles increases beyond 7 nm upon further hydration, the soil will undergo dispersion, with the clay particles becoming independent of each other (Rengasamy and Sumner 1998); this can occur either spontaneously or due to additional mechanical input, The dominant soil factor contributing to the dispersion of soil is exchangeable Na, although some non-soil factors, such as application of external stresses, also contribute (So and Cook 1993). The increase in exchangeable Na (Figure 7.4) might have contributed to the higher dispersion in the strongly sodic ACRI soil. At the lower sodicity level (non-sodic), the Vertosols were not dispersible as the ESI value was higher than 0.05. There was a decrease in dispersion in non-sodic Dalby soil due to addition of cattle manure, although ESI values showed that the amendment significantly decreased the ESI (Figure 7.5). The Vertosols were highly dispersible at higher sodicity levels, but addition of organic amendments significantly increased the ESI value above the critical level (0.05) (Figure 7.5), consequently lowering the DI of ACRI soil. For Dalby soil, organic amendments increased the ESI at the moderately sodicity level, and thereby decreased the DI. The high dispersion could result in formation of a massive structure, when dry, without any hierarchical arrangement of clay particles into micro- and macro-aggregates (Barzegar *et al.* 1994). Dispersion ratios were strongly inversely correlated with organic matter contents with relatively low ESP values (Loveland *et al.* 1987). However, additions of organic matter could increase the dispersion of soils at high SAR (Gupta *et al.* 1984). Similarly, we observed a higher dispersion at high ESP values even with organic amendment treatments for both the Vertosols. The cations accompanying Na on soil exchange sites also have a significant impact on the dispersion of sodic soils. The higher dispersion in Dalby soil than in ACRI soil might be attributed to the amount and type of clay present in those soils (Churchman *et al.* 1993). There was a difference in DI of the Vertosols at the strongly sodicity level (Table 7.6). The low ESI values of Dalby soil (0.02) compared with ACRI soil (0.05) might be the reason for higher DI of Dalby soil at that level. However, Dalby soil, dominated by montmirillonitic clay, with the increase in ESP showed increased preference for Na^+, thereby resulting in higher DI with increased ESPs. Cation exchange sites on organic matter tend to have a lower affinity for Na than exchange sites on clay minerals (Nelson and Oades 1998b). High Ca^{2+} input from the organic amendments might help reduce the thickness of the diffuse double layer, causing the dispersed clay particles to flocculate and thereby reducing the dispersion. The lower cation composition at higher sodicity levels of the soils might result in a higher dispersion of the control soil in each of the sodicity levels. Barzegar *et al.* (1997) found that organic matter had a positive effect on the stability of aggregates in Vertosols, irrespective of the ESP of the soil. Similarly, Yates (1972) found that soil organic matter was positively correlated with aggregate stability in Vertosols, but that the cation composition and

EC of the soil was more important. The conflicting result with DI and ESI in the non-sodic Dalby soil for the cattle manure indicated that it is not only salt or ESP which control the soil dispersion, but there might be some other mechanism that also affects the organic bonds, and thereby dispersion. Therefore, future work is needed to explore the other possible mechanisms controlling the dispersion of sodic Vertosols.

In Australian sodic Vertosols, denitrification is the major pathway of N-loss. Chicken manure, only, was found to be effective in stimulating the nitrate production in sodic soils to about 65-83 mg/kg, although other amendments had the higher N input (Table 7.4). The recovery of nitrate-N for cotton gin trash was about 2.2% and for cattle manure was 0.4%; the N loss at different sodicity levels probably resulted from a combination of microbial immobilization or denitrification.

We observed a higher available phosphate-P with increased sodicity levels of the Vertosols (Figure 7.3). Our result is supported by Naidu and Rengasamy (1993), who reported that, except for the weathered soils in Australia, most sodic soils contain adequate levels of P. Gupta and Abrol (1990) also reported that soil P tends to be more readily available in sodic soils than in comparable non-sodic soils. The high P input from cattle manure and chicken manure resulted in a significant increase in phosphate-P in sodic Vertosols. In sodic soils, Na concentration was more influential in controlling P availability (Willett and Cunningham 1983). The soil solution P concentrations increased with increasing soil sodicity due to the dissolution of Ca-P compounds and the release of sorbed P with increasing clay surface negative potential (Gupta *et al.* 1990; Curtin *et al.* 1992). However, we observed low levels of soil P in these soils even after the addition of organic matter, compared with levels found in previous field and pot trials. This may be due to changes in chemical composition of the soils with sodification (Section 7.2.1.2).

Soil K occurs in solution, exchangeable, non-exchangeable (fixed), and mineral (structural) forms (Sparks and Huang 1985). Although the Dalby soil was characterized by low K, but it was above the critical value of 150 mg/kg. Low K is a widespread feature of dryland Vertosols. K in ACRI soil was higher due to K inputs in irrigation water (~ 8-15 kg K/year), whereas Dalby was a dryland soil. In our study, the organic amendments significantly increased the exchangeable K content of the Vertosols irrespective of ESP of the soils and the increase was higher in ACRI soil as compared with Dalby soil. Similarly, Bernal *et al.* (1993) observed that with the addition of pig slurry at different rates, the soil with higher clay content and of the illite type retained K in the exchangeable form to a much greater extent than the soil with low clay content. Among the applied organic inputs, the highest amount of K added by cattle manure, followed by cotton gin trash and chicken manure (Table 7.4) was also reflected in the K-pool of the soils. Cattle manure added about 5 cmol_c/kg of K into the soils and its contribution was about 56-58% to the exchangeable pool, whereas the recovery for chicken manure on the exchangeable pool was about 54% for ACRI soil and 77% for Dalby soil. Cotton gin trash contributed about 43-44% to the exchangeable pool. K availability in soil is mostly dependent on the rate and direction of the equilibrium reactions between solution and exchangeable/non-exchangeable phases of soil K. However, K applied through fertilizers or organic amendments initially dissolves into the soil solution and is available to the plants, but after some time becomes unavailable when it is adsorbed onto clay particles. The portion of added K from the organic amendments was observed in the non-exchangeable pool with the proportion added being higher in Dalby soil than in ACRI soil. The Dalby soil was dominated by smectitic clay, whose layer charge ($\geq$ 0.55 mol/half formula unit) is very close to vermiculite, and thus had greater potential to fix K (Singh and Heffernan 2002). Furthermore, a substantial portion of the layer charge originates in the tetrahedral sheet and contributes to stronger adsorption and greater fixation of K^+ in the interlayers of smectite (Bedrossian and Singh 2004) and thereby increased the non-exchangeable pool. The non-exchangeable value for the ACRI soil was comparable with the values reported by Bedrossian and Singh (2004) for the same location. K is released from the non-exchangeable form, when levels of exchangeable and solution K are decreased by crop removal (Singh and Goulding 1997). Therefore, K deficiency caused by an increase in soil Na^+ levels can be ameliorated by application of organic amendments.

7.5 Conclusions

The two different Vertosols behaved in a different manner with varying ESPs, particularly for clay dispersion because of their different mineralogy. Organic amendments had a strong influence on physical and chemical properties of sodic Vertosols when applied at higher rates. Their application increased the ESI above the critical level, thereby reducing soil dispersion. There may be some other factors which affect dispersion of the sodic Vertosols apart from salt concentrations and ESP values. Future research is needed to explore those factors affecting dispersion. Increased nutrient availability at higher sodicity levels was also an important feature of using the organic amendments. These results indicate that organic amendments may be useful for the amelioration of sodic Vertosols and also to sustain soil quality. There is a need for further research comparing these organic amendments to currently used ameliorants such as gypsum and polyacrylamide (PAM). Field testing of the effects of the organic amendments on sodic soils is also needed. Future work needed to identify the economic feasibility of applying these amendments at higher rates in broadacre farming.

Chapter Eight

Economic affordability of using organic amendments in cotton

8.1 Introduction

The declining chemical and structural fertility of Australian Vertosols is an issue which needs to be addressed to ensure sustainable production. There is an increasing awareness of the potential for using organic amendments in order to maintain soil quality from an ecological perspective but questions arise as to the economic feasibility of using organic materials on a broad scale. OWRU (2000) reported that in order to gain a better appreciation of the economics of compost use, research should be conducted over a number of years and the full range of benefits, not just yield responsiveness, assessed. ROU (2003) also highlighted the need to assign a monetary value to the environmental benefits associated with applying composted waste organics. Moreover, few studies have quantified these benefits in terms of increased crop productivity, reduced variable costs, increased profitability or gross margin ($/ha).

In our study, we have identified a number of potential organic amendments and their optimal application rates in terms of improving the quality of Vertosols used for cotton production systems. Hence, it is also necessary to explore the economical feasibility of using those amendments in broadacre farming. To fulfill that objective, an economic analysis was performed with potential organic amendments and their varying application rates.

8.2 Methodology

The economic analysis provides the estimate of the affordability of using these amendments for irrigated cotton.

The first part of the analysis summarized the variable costs involved in the agronomic practices for cotton, which included application of fertilizer, irrigation, spraying of insecticides, herbicides, defoliation, and sowing. Our assumptions of variable costs are based on the cost involved for the agronomic practices undertaken at our research field at ACRI, Narrabri (Table 8.1).

Table 8.1 Calculations of the variable costs for the research field at ACRI, Narrabri for the 2004-05 seasons (Fiona Scott, pers. comm.)

Operations	Machinery	Inputs			Total cost ($/ha)
	cost ($/ha)	Rate/ha	Cost ($)	Total ($/ha)	
Fertiliser-single super	2.68	280.00	0.25	70.00	72.68
Fertiliser- urea	4.26	130.00	0.49	63.70	67.96
Planter	10.20	18.00	8.00	144.00	154.20
Herbicide spray (6)	17.04	3.00	20.00	360.00	377.04
Insecticide (8)	112.00	2.10	60.00	126.00	1120.00
Cultivation	10.68				10.68
Irrigation (6)		1.00	20.95		125.70
Defoliation (2)	14.00	0.15	150	22.50	59.00
Other costs					200.00
				Total variable costs ($/ha)	**2187.00**

**Figures in parentheses indicate the number of operation procedures

Table 8.1 shows that the total variable cost for the 2004-05 growing season was $2187.00, whereas the same cost in the following season was around $2400. Therefore, for our calculation, an averaged variable cost of $2300 was assumed. These costs will be lower, especially the fertilizer costs with the increase in application rate of the organic amendments. However, to simplify the analysis, we assumed same averaged variable cost ($2300) throughout our economic analysis.

The second step involved estimating the retail price for different organic amendments, and also, the likely cost of transporting and applying them into the field. These prices were based on the prices currently being used in different cotton farms, such as cotton gin trash ($25/ton), cattle manure ($15/ton), biosolids ($1.5/ton), chicken manure ($15/ton) and vermicompost ($60/20 L). The transport costs were similar for all the amendments, except the liquefied vermicompost. The transport cost up to 10 km, was approximately $10, and for distances further than 10 km, a further $1 was added for every 5 km. For the vermicompost, the transport varied with the area and it was higher when transported to the country than within the city area. However, the application cost of this amendment was much lower than that of other amendments.

The last step was to calculate the break-even economic yield (lint + seed) in order to evaluate the practical feasibility of applying organic amendments at different rates. The lint yield of the NSW cotton growing region varied from 9-12 bales/ha (N. Hulugalle, pers. comm.). On the basis of that, the break-even yield was calculated assuming an average production yield of 10 bales/ha, assuming the market price for lint was $400/bale and that for seed was $175/ton.

8.3 Results

The summary of the economic analyses are presented below in Table 8.2, 8.3 and 8.4.

8.3.1 Cotton gin trash

The total input cost involved for cotton gin trash varied from $2690-6980 when it was supplied from within a 10 km distance (Table 8.2). However, considering the distance (up to 100 km), the benefit could only be achieved when the amendment was applied at 30 t/ha. The increase in transport cost between 100-200 km increased the break-even yield, and in that situation, the appropriate application rate might be 10 t/ha.

8.3.2 Cattle manure

The cost of this amendment was lower than the gin trash, but considering the other input costs, the analysis showed that a farmer could maximize the whole farm profit by using cattle manure at 30 t/ha when transport distances did not exceed 100 km (Table 8.2). The break-even yield was significantly higher for the greater distances transported, therefore 10 t/ha would be the maximum possible rate for this amendment when supplied from 100-200 km distance.

8.3.3 Biosolids

The cost of biosolids ($1.5/ton) was much cheaper as compared with other amendments (Table 8.3). When it was supplied within 10 km distance, it could be applied at 60 t/ha, but for greater distances (100 and 200 km), the maximum rate would be 30 t/ha to achieve any economic benefit.

8.3.4 Chicken manure

The appropriate application rate for chicken manure was much lower than the other amendments (Table 8.3). The analysis showed that a normal yield was achievable even at higher application rates (up to 36 t/ha) when it was transported within 100 km distance. However, the further the distance transported (100-200 km), the further the total input cost increased ($4712/ha) and the appropriate rate might be a maximum 18 t/ha.

Table 8.2 Economic analysis for cotton gin trash and cattle manure

Organic amendment	Rate	Variable costs	Cost of amendment	Transport cost	Spreading cost	Total cost	Break-even yield	
							Lint	Seed
	(t/ha)	($/ha)	($/ton)	($/ton)	($/ton)	($/ha)	(bales/ha)	(t/ha)
Cotton gin trash				**Up to 10 km**				
		2300	**25**	**6**	**8**			
	10	2300	250	60	80	2690	6.06	1.52
	30	2300	750	180	240	3470	7.82	1.96
	60	2300	1500	360	480	4640	10.46	2.61
	120	2300	3000	720	960	6980	15.73	3.93
				10-100 km				
	10	2300	250	240	80	2870	6.47	1.62
	30	2300	750	720	240	4010	9.03	2.26
	60	2300	1500	1440	480	5720	12.88	3.22
	120	2300	3000	2880	960	9140	20.59	5.15
				100-200 km				
	10	2300	250	440	80	3070	6.92	1.73
	30	2300	750	1320	240	4610	10.38	2.60
	60	2300	1500	2640	480	6920	15.59	3.90
	120	2300	3000	5280	960	11540	25.99	6.50
Cattle manure				**Up to 10 km**				
		2300	**15**	**6**	**8**			
	10	2300	150	60	80	2590	5.84	1.46
	30	2300	450	180	240	3170	7.14	1.79
	60	2300	900	360	480	4040	9.10	2.28
	120	2300	1800	720	960	5780	13.02	3.26
				10-100 km				
	10	2300	150	240	80	2770	6.24	1.56
	30	2300	450	720	240	3710	8.36	2.09
	60	2300	900	1440	480	5120	11.53	2.88
	120	2300	1800	2880	960	7940	17.89	4.47
				100-200 km				
	10	2300	150	440	80	2970	6.69	1.67
	30	2300	450	1320	240	4310	9.71	2.43
	60	2300	900	2640	480	6320	14.24	3.56
	120	2300	1800	5280	960	10340	23.29	5.82

Table 8.3 Economic analysis for biosolids and chicken manure

Organic amendment	Rate	Variable costs	Cost of amendment	Transport cost	Spreading cost	Total cost	Break-even yield	
							Lint	Seed
	(t/ha)	($/ha)	($/ton)	($/ton)	($/ton)	($/ha)	(bales/ha)	(t/ha)
Biosolids				**Up to 10 km**				
		2300	**1.5**	**6**	**8**			
	10	2300	15	60	80	2455	5.53	1.38
	30	2300	45	180	240	2765	6.23	1.56
	60	2300	90	360	480	3230	7.28	1.82
	120	2300	180	720	960	4160	9.37	2.34
				10-100 km				
	10	2300	15	240	80	2635	5.94	1.48
	30	2300	45	720	240	3305	7.44	1.86
	60	2300	90	1440	480	4310	9.71	2.43
	120	2300	180	2880	960	6320	14.23	3.56
				100-200 km				
	10	2300	15	440	80	2835	6.39	1.60
	30	2300	45	1320	240	3905	8.79	2.20
	60	2300	90	2640	480	5510	12.41	3.10
	120	2300	180	5280	960	8720	19.64	4.91
Chicken manure				**Up to 10 km**				
		2300	**15**	**6**	**8**			
	3	2300	45	18	24	2387	5.38	1.34
	9	2300	135	54	72	2561	5.77	1.44
	18	2300	270	108	144	2822	6.36	1.59
	36	2300	540	216	288	3344	7.53	1.88
				10-100 km				
	3	2300	45	72	24	2441	5.50	1.37
	9	2300	135	216	72	2723	6.13	1.53
	18	2300	270	432	144	3146	7.09	1.77
	36	2300	540	864	288	3992	8.99	2.25
				100-200 km				
	3	2300	45	132	24	2501	5.63	1.41
	9	2300	135	396	72	2903	6.54	1.63
	18	2300	270	792	144	3506	7.90	1.97
	36	2300	540	1584	288	4712	10.61	2.65

Table 8.4 Economic analysis for vermicompost

Organic amendment	Rate	Variable costs	Cost of amendment	Transport cost	Spraying cost	Total cost	Break-even yield	
							Lint	Seed
	(L/ha)	($/ha)	($/20L)	($)	($/ha)	($/ha)	(bales/ha)	(t/ha)
	City area (up to 500 km)							
Vermicompost		**2300**	**58**	**30**	**5**			
	60	2300	174	30	5	2509	5.65	1.41
	200	2300	580	30	5	2915	6.57	1.64
	600	2300	1740	30	5	4075	9.18	2.30
	1000	2300	2900	30	5	5235	11.79	2.95
	Country area (up to 500 km)							
	60	2300	174	35	5	2514	5.66	1.42
	200	2300	580	35	5	2920	6.58	1.64
	600	2300	1740	35	5	4080	9.19	2.30
	1000	2300	2900	35	5	5240	11.80	2.95

8.3.5 Vermicompost

The transport cost did not vary much for the vermicompost (Table 8.4). To gain an economic benefit using vermicompost, the appropriate rate could be up to 200 L/ha. Increased rates substantially increased the break-even yield and at 600 L/ha application rate, the output cost might be similar to the input cost ($4075-4080).

8.4 Discussion

The break-even economic yield is the yield needed to compensate the input costs involved in a production system and if the farm achieves higher yields than the predicted break-even yields, the enterprise becomes profitable. Using organic amendments at higher rates (3 to 4 times than the rate currently used by local cotton farmers) could improve the Vertosol quality in short-term. Cotton gin trash and cattle manure, if applied at 30 t/ha and if they are available within 100 km distance, could easily benefit farmers who apply those amendments. Biosolids are generally produced as municipal solid wastes and may not be available locally; however, its low cost may allow applying higher rates (60 t/ha), if available within 100 km. The application rate for chicken manure was lower than that of the other amendments. Even though this amendment is often supplied from longer distances (200 km), the higher application rates might be profitable for the farmers (break-even yield is 9.2 bales/ha). Because of low transport cost, vermicompost could be used at higher rates and still be profitable for the farmers.

8.5 Conclusions

Although higher application rates of the organic amendments resulted in improved soil quality, those rates may not be economically feasible for the cotton farmers. If the amendments are available locally (within 100 km), then it could be recommended to apply them at the higher rates in order to have economic and sustainable production.