Influence of organic amendments on growth, yield and quality of wheat and on soil properties during transition to organic production

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Abstract

A transition period of at least two years is required for annual crops before the produce may be certified as organically grown. The purpose of this study was to evaluate the effects of the three organic amendments on yield and quality of wheat (*Triticum aestivum* L.) and on soil properties during transition to organic production. The organic amendments were composted farmyard manure (FYMC), vermicompost and lantana (*Lantana* spp. L.) compost applied to soil at four application rates (60, 90, 120 and 150 kg N ha^{-1}). The grain yield of wheat in all the treatments involving organic amendments was markedly lower (36-65 % and 23-54 % less in the first and second year of transition, respectively) compared with the mineral fertilizer treatment. For the organic treatments applied at equivalent N rates, grain yield was higher for FYMC treatment closely followed by vermicompost. In the first year of transition, protein content of wheat grain was higher (85.9 g kg^{-1}) for mineral fertilizer treatment whereas in the second year, there were no significant differences among the mineral fertilizer treatment and the highest application rate (150 kg N ha^{-1}) of three organic amendments. The grain P and K contents were, however, significantly higher for the treatments involving organic amendments than their mineral fertilizer counterpart in both years. Application of organic amendments, irrespective of source and rate, greatly lowered bulk density (1.14-1.25 Mg m^{-3}), and enhanced pH (6.0-6.5) and oxidizable organic carbon (13-18.8 g kg^{-1}) of soil compared with mineral fertilizer treatment after two-year transition period. Mineral fertilized plots, however, had higher levels of available N and P than plots with organic amendments. All the treatments involving organic amendments, particularly at higher application rates, enhanced soil microbial activities of dehydrogenase, β-glucosidase, urease and phosphatase compared with the mineral fertilizer and unamended check treatments. We conclude that the application rate of 120 and 150 kg N ha^{-1} of all the three sources of organic amendments improved soil properties. There was, however, a 23-65% reduction in wheat yield during the two years of transition to organic production.

Key words: Grain quality; Manure; Organic transition; Soil properties; Wheat

Introduction

The concept of organic agriculture is receiving increased attention, and organic food markets are also expanding rapidly in many countries including India (Willer and Yussefi 2005). This organic market expansion makes it possible for farmers to sell their products at high price premiums. India's National Program for Organic Production (NPOP) requires at least a two-year transition period for annual crops before the produce may be certified as organically grown. These two years pose many challenges because the changes in the chemical, physical, and biological properties of the soil take time to reach an ecological balance. Several experimental transitional studies have reported initial lower yields, followed by yields similar to conventional production (Liebhardt et al. 1989; MacRae et al. 1993). Lower yields in the transition from conventional to organic production are expected due to lower nutrient concentration and slower release rates of organic materials (Liebhardt et al. 1989; MacRae et al. 1993). Nutrient management is, therefore, one of the most critical management areas for organic growers. Because synthetic inputs (i.e. chemical fertilizers and pesticides) are disallowed in organic crop production, there is need for research on organically approved soil amendments and methods for improving soil fertility in organic farming systems, particularly during initial years. Organic fertility inputs like composted farmyard manure (FYM) and green manure improve soil physical properties by lowering bulk density, increasing water-holding capacity, and improving infiltration rates (Tester 1990; Werner 1997; Petersen et al. 1999). Several studies show that organic farming improves soil fertility over time (Drinkwater et al. 1995; Clark et al. 1998; Petersen et al. 1999). These organic systems also lead to higher soil quality and more biological activity in soil than conventionally managed systems (Reganold 1988; Drinkwater et al. 1995; Castillo and Joergensen 2001).

Farmers in Indian Himalayas routinely apply composted farmyard manure (FYMC) and vermicompost to their soil either alone or in combination with mineral fertilizers. But there is limited research on the effects of these organic amendments on yield and quality of crops and on soil properties particularly during the period of transition to organic production. We chose to evaluate the impact of different organically approved soil amendments on wheat (*Triticum aestivum* L.), an important winter season crop in north-western Himalayas of India. Emphasis was placed on on-farm inputs or locally produced manures such as FYMC, vermicompost and lantana (Lantana spp. L.).

The latter is a fast-growing weed in nearby wastelands with minimal alternate uses as fodder and fuel. It also contains about 1.5% nitrogen, 0.25% phosphorus and 1.3% potassium and is, therefore, a potential soil organic amendment (Sharma et al. 2003; Saha et al. 2007b). The objectives of the study were to assess the effect of different soil amendments on (i) growth, yield and quality of wheat, (ii) and on soil chemical and biological properties during transition to organic production.

Materials and methods

Experimental setup and crop management

A field experiment was conducted on a silty clay loam soil under irrigated conditions at the Research Farm of Vivekananda Institute of Hill Agriculture (29^0 36' N, 79^0 40' E and 1250 m above mean sea level), India during the winter seasons of 2004-05 and 2005-06. Before the present experiment, the land was farmed almost exclusively in a maize-wheat rotation, which included commercial mineral fertilizer and pesticide applications. Soil samples taken from the surface 15 cm before treatment applications had organic C content of 11.4 mg kg^{-1}, available N 153.7 mg kg^{-1}, available P 7.8 mg kg^{-1}, available K 115.3 mg kg^{-1}, and a pH of 6.1.

The experimental design was a randomized complete block with three replications. Plot size was 2.53 m (11 rows with a 23 cm row spacing) by 5.0 m. The 14 treatments applied included composted farmyard manure (FYMC), vermicompost and lantana compost each applied at four rates (60, 90, 120 and 150 kg N ha^{-1}), and mineral fertilizer and unamended checks. The mineral fertilizer plots received 120 kg N ha^{-1} as urea (46-0-0, N-P-K), 26.5 kg P ha^{-1} as single superphosphate (0-7-0, N-P-K), and 33.3 kg N ha^{-1} as muriate of potash (0-0-50, N-P-K). Half the N and full P and K were applied just before sowing of wheat. The remaining N was applied as a top dressing at the tillering stage (35-40 days after sowing). All of the manure and composts were produced on the Research Farm of Vivekananda Institute of Hill Agriculture, India. The composted farmyard manure was prepared after composting cattle dung and bedding material for 30 days. Crop residues (soybean) and partially decomposed cattle dung were used in 2:1 ratio (w/w) for vermicomposting. These materials were thoroughly mixed and filled in a pit of size 2 m (L) X 1.5 m (W) X 0.5 m (D). Water was sprinkled to make the material sufficiently wet and 4000 earthworms (*Eisenia foetida*) were introduced into the pit and were covered with a jute bag to prevent direct exposure to sunlight. The material in the pit was thoroughly mixed with hands twice at an interval of 30 days. The compost was removed from the pit after 90 days and earthworms were separated using a sieve. *Lantana* compost was prepared by composting the chopped plant shoots and leaves in a pit for 55 days. Composite samples of each amendment were collected 1 wk before application to plots and were analyzed for different properties (Table 1).

Manure and composts were applied at four rates each (60, 90, 120, and 150 kg N ha^{-1}), based on moisture and total N content of samples. Amendments were applied by hand 2 wk before sowing and were incorporated within 24 h of application using a spade.

Wheat (cv. VL 804) was sown at a seeding rate of 100 kg ha^{-1} and a row spacing of 23 cm. Based on a 2 year variety trial at the Research Farm of the Institute, VL 804 has been identified as a suitable variety for organic wheat production. Sowing was done on 15 November 2004 and 2005. Four irrigations were given to crop in each year. No chemical insecticides, fungicides or herbicides were used in keeping with organic standards. Weeds were managed by hand-weeding once followed by two hoeings by using a manually operated wheel-hoe. The crop was not infested by any major insect-pests and diseases in both the years. All plant and soil parameters were measured from the center seven rows of each plot. Wheat was harvested by hand on 13 May 2005, and 15 May 2006 and grain yield was measured. Grain yields were adjusted to moisture contents of 150 g kg^{-1}.

Sampling and analysis of soil and wheat grain

Soil samples were collected from the surface layer (0-15 cm) of all the plots before treatment applications and immediately after wheat harvest in May 2006. Three random cores were taken from each plot with 5-cm diameter tube auger and bulked. Soil samples were air-dried and ground to pass a 2-mm sieve. All soil samples meant for chemical analysis were stored at room temperature until analysis. The rest of the soil samples were immediately transferred to the laboratory for analysis of enzyme activities. Soil samples were kept at 4°C in plastic bags for a few days to stabilize the microbiological activity disturbed during soil sampling and handling, and were then analyzed within 2 weeks. The enzyme activities reported are the means of six replicates and are expressed on a moisture-free basis. Bulk density was determined by determining the soil dry weight (dried at 110^0c) and volume of the soil sample. The pH of amendments and soil was determined in 1:2.5 soil/amendment: water suspension (Jackson 1962). Available K was determined using 1 N NH_4OAc and a flame photometer (Jackson 1962). Oxidizable soil organic C was determined following the method of Walkley and Black (1934), Kjeldahl N by using a FOSS Tecator analyzer (Model 2200), and available P following the method of Olsen et al. (1954). All chemical results are means of triplicate analyses and are expressed on an oven-dry basis. Soil moisture was determined after drying at 105 °C for 24 h.

Soil dehydrogenase activity was estimated by reducing 2, 3, 5-triphenyltetrazolium chloride (Casida et al. 1964). Soil sample (5 g) was mixed with 50 mg $CaCO_3$ and 1 ml 3 % (w/v) 2, 3, 5-TTC and incubated for 24 h at 37±1 ^{0}C. Dehydrogenase enzyme converts TTC to 2, 3, 5-triphenylformazan (TPF). The TPF formed was extracted with acetone (3 × 15 ml), the extracts were filtered through Whatman No. 5 and absorption was measured at 485 nm in a spectrophotometer (Analytik Jena, Germany).

β-glucosidase activity was estimated by determining the p-nitrophenol released after one hour of incubation with p-nitrophenyl-β-D-glucopyranoside (Eivazi and Tabatabai 1977). Urease activity was measured following the method developed by Tabatabai and Bremner (1972). Five g of soil is incubated with 1 ml of 0.2 % of urea solution at 37 ± 1 ^{0}C for 5 h. Excess urea was extracted with KCl-PMA solution and estimated colorimetrically at 527 nm. The activity was expressed as μg urea hydrolysed g^{-1} h^{-1}. Acid phosphatase was assayed using 1 g soil (wet equivalent), 4 ml 0.1 M modified universal buffer (pH 6.5), and 1 ml 25 mM p-nitro phenyl phosphate (Tabatabai and Bremner 1969). After incubation for 1 h at 37 ± 1°C the enzyme reaction was stopped by adding 4 ml 0.5 M NaOH and 1 ml 0.5 M $CaCl_2$ to prevent dispersion of humic substances. The absorbance was measured in the supernatant at 400 nm; enzyme activity was expressed as μg p-nitro phenol released g $^{-1}$ soil h $^{-1}$.

Wheat grains were harvested at maturity and air-dried for further processing. The dried grains were stored at room temperature for three months prior to analysis. The samples were analysed in laboratory for chemical parameters after tri-acid digestion. Protein content was determined using the formula: N × 5.83 (AOAC, 1990). Phosphorus content was estimated photometrically via development of phospho-molybdate complex, as described by Taussky and Shorr (1953). Potassium content was determined using flame photometer.

Statistical analysis

All of the soil and plant data were analyzed using Duncan's multiple range tests (Duncan 1955) at the $P \leq 0.05$ level. Differences between mean values were evaluated by a one-way analysis of variance (ANOVA) (SPSS version 10.0).

Results and discussion

Crop growth and yield

Plant height was significantly greater for all the treatments, except lower rates (60 and 90 kg N ha^{-1}) of lantana compost application, than those for the check plots (Table 2). In 2004-05, mineral fertilizer application resulted in significantly higher plant height compared with other treatments. In 2005-06, however, mineral fertilizer and 150 kg N ha^{-1} applied as FYMC had similar effect on plant height. In general, at equivalent rates of application, FYMC resulted in comparatively higher plant height followed by vermicompost and the least was lantana compost. In both years, mineral fertilizer application resulted in significantly more ears m^{-2} than did the manure and compost treatments. Among the organic amendments, ears m^{-2} for all the treatments, except lower rates of lantana compost application, were significantly greater than the unamended control. At equivalent application rates (60 and 90 kg N ha^{-1}), there were no significant differences among the three sources of organic amendments in terms of ears m^{-2} in both years. At higher application rates (120 and 150 kg N ha^{-1}), however, FYMC and vermicompost yielded similar results and produced significantly more ears m^{-2} compared with lantana compost application. All the treatments resulted in significantly more grains ear^{-1} than the check plots (Table 2). In 2004-05, mineral fertilizer treatment produced significantly more grains ear^{-1} than the manure and compost amended treatments. In contrast, 2005-06, higher application rates (120 and 150 kg N ha^{-1}) of FYMC and 150 kg N ha^{-1} applied as vermicompost had similar effect on grains ear^{-1} as that of the mineral fertilizer treatment. At equivalent rates of application, all the three sources of organic amendments had similar effect on grains ear^{-1}.

There were significant differences among treatments with respect to grain yield in both years (Fig. 1). Grain yields for all the treatments were greater than the unamended control. In both years, mineral fertilizer treatment produced significantly higher grain yields than the manure and compost amended plots. Compared with mineral fertilizer treatment, the grain yield reduction for treatments involving organic amendments ranged from 36.1 to 65.4% in 2004-05 and 23.2 to 54.2% in 2005-06. These results suggest that the yield gap between the mineral fertilizer and organic amendment treatments narrowed in the second year of transition. Furthermore, the grain yields for all the treatments involving organic amendments were marginally higher in 2005-06 than 2004-05, whereas mineral fertilizer and unamended control treatments recorded a slight dip in grain yield in 2005-06 compared to 2004-05. Results obtained here compare with earlier reports (Mader et al. 2002; Ryan et al. 2004) where organic wheat yields were 17-84% lower than that of conventional yields. Lower grain yields in the plots amended with organic manures and composts may have been associated with the less readily available nutrients in the initial years of transition (Table 4) as nutrient cycling processes in first-year organic systems change from inorganic N fertilization to organic amendments (Harris et al. 1994; Reider et al. 2000) and slower release rates of organic materials (Liebhardt et al. 1989; MacRae et al. 1993).

Soil fertility in organic production systems is controlled by organic amendments, such as FYMC, vermicompost and lantana compost used in this study. Nitrogen fertility is maintained through the synchronization across space and time of net N mineralization from soil organic N pools and plant uptake of inorganic N. This process depends on the constant renewal of biologically available N to soil organic N pools (Delate and Canbardella 2004). The grain yields increased with increasing application rate of organic amendments (Fig. 2).

As plant height and grains ear^{-1} in highest rate of FYMC application yielded almost comparable results to mineral fertilized treatment, it can be concluded that application of FYMC during transition period can be helpful in initial build up of soil nutrients, which can be depicted from crop growth.

Quality of wheat grain

In the first year of experiment, the mineral fertilizer treatment and the treatments of 150 kg N ha^{-1} applied as FYMC and vermicompost registered significantly higher 1000-grain weight compared with other treatments (Table 3). However, in 2005-06, all treatments involving organic amendments, except lantana compost at lower rates (60 and 90 kg N ha^{-1}), had similar effect on 1000-grain weight as that of the mineral fertilizer treatment. In 2004-05, after one year of transition, protein content of wheat grain was significantly higher for the mineral fertilizer treatment compared with manure and compost amended plots. After the second year of transition, however, there were no significant differences among mineral fertilizer treatment, and the 150 kg N ha^{-1} as FYMC, vermicompost, and lantana compost treatments. This lower protein content in organically produced wheat may lead to undesirable consequences for baking properties (Woese et al. 1997). At equivalent application rates, all the organic amendments had similar effect on grain protein content in both years. In contrast, irrespective of application rate, all the three sources of organic amendments registered significantly higher P and K contents in wheat grain compared with mineral fertilizer treatment in both years. Saha et al. (2007a) also reported that rice grown on organic composts had better nutritional quality. Our results, however, contrast with those of Ryan et al. (2004) where conventional grain had higher P than organic grain whereas only minor variations occurred in grain N and K concentrations. At equivalent application rates, the P content of wheat grain did not differ significantly between FYMC and vermicompost, but was significantly superior to lantana compost except at 150 kg N ha^{-1} in 2004-05. After the second year of transition, the three sources of organic amendments did not significantly affect P content of grain except that lantana compost amended plots (60 kg N ha^{-1}) registered the lowest P content. Similarly, at equivalent rates of application, the K content of wheat grain was similar among the three sources of organic amendments.

Both FYMC and vermicompost application at highest rate of application resulted in comparable test weight and protein content in wheat grain to mineral fertilized treatment and better in terms of phosphorous and potassium content.

Soil properties

The soil bulk density reduced significantly in all the treatments except fertilized plots compared with the unamended control (Table 4). Higher application rates of organic amendments resulted in lower bulk density compared with mineral fertilizer check and lower rates of organic amendments. Similar results have also been reported by others (Tester 1990; Werner 1997; Petersen et al. 1999). At equivalent application rates, all the three organic amendments had similar effects on bulk density. The soil pH increased significantly in all the plots applied with organic amendments compared with mineral fertilizer treatment after two years of transition (Table 4). Among the organic amendments, FYMC application (150 kg N ha^{-1}) registered the highest soil pH (6.5), and was significantly superior to all other treatments except the 150 kg N ha^{-1} as vermicompost treatment. Our results are similar to earlier reports (Reganold et al. 1993; Drinkwater et al. 1995; Werner 1997; Clark et al. 1998) where organic systems had higher pH levels in mildly acidic soils than their conventional counterparts. This illustrates the important role organic manures and other organic matter inputs can have in buffering the soil (Stroo and Alexander 1986; Arden-Clarke and Hodges 1988). Similarly to pH, soil organic carbon (SOC) was also significantly higher in manure and compost amended plots compared with mineral fertilizer treatment. Among the organic amendments, FYMC application (150 kg N ha^{-1}) resulted in the highest SOC compared with other treatments. During the transition years from conventional to organic farming systems, soils show a very slow but important increase in soil organic matter (Kuo et al. 1997; Clark et al. 1998). Mineral fertilizer applied plots, however, had higher levels of available N and P compared with other treatments except 150 kg N ha^{-1} as FYMC which had similar content of available N as that of the mineral fertilizer treatment (Table 4). Lower availability of plant nutrients in plots applied with organic amendments is expected due to slower release rates of organic materials, particularly during initial years of transition to organic production (Liebhardt et al. 1989; MacRae et al. 1993).

At equivalent application rates, there were no significant differences among the three organic amendments except that 150 kg N ha^{-1} as FYMC registered higher available N. At higher application rates (120 and 150 kg N ha^{-1}), FYMC and vermicompost amended plots had higher content of available P compared with lantana compost but the latter had higher content of available P at lower application rates. Available P in FYMC and vermicompost amended plots increased with successive increase in application rates. It, however, showed a negative trend in lantana compost amended plots. FYMC application (150 kg N ha^{-1}) registered significantly higher available K compared with other treatments except 120 kg N ha^{-1} as FYMC. Clark et al. (1998) and Reganold et al. (1993) also observed an increase in available K in the organic and low-input systems. At all application rates except 60 kg N ha^{-1}, the K content was higher in FYMC than vermicompost and lantana compost amended plots.

All the treatments involving organic amendments except vermicompost and lantana compost at lower application rate (60 kg N ha^{-1}) registered significantly higher dehydrogenase activity compared with mineral fertilizer and unamended check (Fig. 3). The incorporation of organic amendments to soil influences soil enzymatic activities because the added material may contain intra- and extracellular enzymes and may also stimulate microbial activity in the soil (Pascual et al. 1998). The development of microbial populations, which is favored by the root exudates of plants, may also be responsible for the dehydrogenase activity stimulation. FYMC application (150 kg N ha^{-1}) resulted in greater dehydrogenase activity compared with other treatments. Parham et al. (2002) also observed significantly higher dehydrogenase activity in the soils treated with cattle manure compost. The dehydrogenase activity increased with increase in application rates of FYMC and vermicompost. The greater dehydrogenase activity noted at the high dosage suggests that the added amendments did not include compounds, which were toxic for this activity (Pascual et al. 1998). Higher application rate of lantana compost (150 kg N ha^{-1}), however, adversely affected the dehydrogenase activity.

Plots treated with lantana compost showed highest β-glucosidase activity (Fig. 3). The activity was in similar level in both FYMC and vermicompost treated plots. Overall, our results have shown that the addition of organic residues to an agricultural soil has a variety of effects on enzyme activities. Changes in soil phosphatase activities, which play an essential role in the mineralization of organic phosphorus, were also observed among organic amended treatments. Reduction in enzymatic activity was observed with the decrease in nutrient application in all the organic amended treatments. This is consistent with earlier reports (Nannipieri et al. 1978; Saha et al. 2007b). In lantana compost at higher rate of application, there was reduction in activity. This may be due to toxic/allelopathic effect of lantana extract on soil microbes/plant root.

FYMC amended plots had the greatest urease activity followed by vermicompost and lantana compost treatments. This may be due to more simplified organic compounds in FYMC, which leads to faster mineralization. Urease activity was more in FYMC amended plots as compared to other two amendments at all four rates of application. Very little variation was observed across the doses in all three amended plots.

Application of FYMC enhanced SOC, available P and K in soil along with reduction in bulk density. There was significant improvement in soil biological properties related to nutrient cycling including soil dehydrogenase activity, which is an indicator of soil biological health.

Conclusions

Research-based recommendations must be developed for suitable organic amendments that provide high yields, grain quality, and adequate soil fertility during the transition to organic production. The comparison of three sources of organic amendments such as FYMC, vermicompost and lantana compost revealed that there was 23-65 per cent reduction in grain yield of wheat compared with mineral fertilizer treatment. Among the organic amendments, at equivalent application rates, FYMC was found to be better followed by vermicompost in terms of growth, yield and quality of wheat during transition to organic production. Wheat grain yields increased in both years in response to increasing application rates of organic amendments. Mineral fertilizer treatment was superior in terms of grain protein content. However, grain P and K contents were higher for the treatments involving organic amendments. Application of organic amendments improved soil properties in terms of lower bulk density, and increase in pH, oxidizable organic C, available K and enzymatic activity in soil after a two-year transition period. We conclude that composted farmyard manure can be used for betterment of yield and grain quality of wheat, and adequate soil fertility during the transition to organic production.

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Figure captions:

*Figure 1***.** Effect of source and application rate of organic amendments on grain yield of wheat (: 2004-05; : 2005-06) (F150, F120, F90, F60: 150, 120, 90 and 60 kg N ha^{-1} as FYMC, respectively; V150, V120, V90, V60: 150, 120, 90 and 60 kg N ha^{-1} as vermicompost, respectively; L150, L120, L90, L60: 150, 120, 90 and 60 kg N ha^{-1} as lantana compost, respectively; Fert.: Mineral fertilizer; Con: Unamended control). *Means sharing different letters are significantly (P*<0.05) *different*.

*Figure 2***.** Wheat grain yield response to different application rates of organic amendments (FYMC: composted farmyard manure; VC: vermicompost; LC: lantana compost.

*Figure 3***.** Effect of organic amendments on the soil enzymatic activities (F150, F120, F90, F60: 150, 120, 90 and 60 kg N ha^{-1} as FYMC, respectively; V150, V120, V90, V60: 150, 120, 90 and 60 kg N ha^{-1} as vermicompost, respectively; L150, L120, L90, L60: 150, 120, 90 and 60 kg N ha^{-1} as lantana compost, respectively; Fert.: Mineral fertilizer; Con: Unamended control). *Means sharing different letters are significantly (P*<0.05) *different*.

Table 1. Important characteristics of soil amendments used in the experiment

Organic manure	Moisture (%)		N (%)		P (%)		K (%)	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
FYMC	54	50	1.00	0.83	0.58	0.45	0.89	0.80
Vermicompost	60	59	1.42	1.50	0.61	0.66	0.52	0.59
Lantana compost	33	32	1.75	1.30	0.23	0.27	1.33	1.26

FYMC: Composted farmyard manure, Y_1: 2004-05, Y_2: 2005-06

Table 2. Effect of source and application rate of organic amendments on growth and yield attributes of wheat

Treatment	Plant height (cm)		Ears m^{-2}		Grains ear^{-1}	
	2004-05	2005-06	2004-05	2005-06	2004-05	2005-06
150 kg N ha^{-1} as FYMC	93^{b}	96^{ab}	312^{b}	342^{b}	48^{b}	49^{ab}
120 kg N ha^{-1} as FYMC	89^{bcd}	94^{bc}	300^{bcd}	334^{bc}	46^{bc}	49^{ab}
90 kg N ha^{-1} as FYMC	85^{cdef}	91^{bcd}	284^{def}	312^{bcde}	45^{bcd}	46^{cde}
60 kg N ha^{-1} as FYMC	81^{efgh}	86^{edef}	264^{ef}	278^{fgh}	41^{def}	44^{cde}
150 kg N ha^{-1} as VC	90^{bc}	89^{bcde}	300^{bcd}	326^{bcd}	46^{bc}	49^{ab}
120 kg N ha^{-1} as VC	87^{bcd}	86^{cdef}	292^{bcd}	309^{cdef}	44^{bcd}	48^{bc}
90 kg N ha^{-1} as VC	84^{defg}	81^{efg}	272^{def}	290^{efg}	43^{cde}	45^{cde}
60 kg N ha^{-1} as VC	80^{fgh}	76^{gh}	256^{fg}	268^{gh}	39^{ef}	43^{de}
150 kg N ha^{-1} as lantana	86^{cde}	84^{defg}	284^{cde}	292^{efg}	44^{bcd}	47^{bcd}
120 kg N ha^{-1} as lantana	85^{cdef}	81^{efg}	272^{def}	280^{efgh}	43^{cde}	46^{bcde}
90 kg N ha^{-1} as lantana	78^{ghi}	77^{fgh}	260^{ef}	257^{hi}	41^{def}	43^{de}
60 kg N ha^{-1} as lantana	76^{hi}	73^{h}	252^{fg}	248^{hi}	40^{ef}	42^{e}
Mineral fertilizer	107^{a}	104^{a}	408^{a}	404^{a}	52^{a}	53^{a}
Unamended control	74^{i}	73^{h}	232^{g}	230^{i}	37^{f}	36^{f}

FYMC: Composted farmyard manure, VC: Vermicompost, Means in the same column with different letters are significantly ($P < 0.05$) different.

Table 3. Effect of source and application rate of organic amendments on grain quality of wheat

Treatment	Test weight (g)		Protein (g kg^{-1})		P (g kg^{-1})		K (g kg^{-1})	
	2004-05	2005-06	2004-05	2005-06	2004-05	2005-06	2004-05	2005-06
150 kg N ha^{-1} as FYMC	44.5^{ab}	44.0^{ab}	75.8^{b}	84.0^{bcdef}	3.65^{a}	3.82^{a}	3.09^{a}	3.11^{a}
120 kg N ha^{-1} as FYMC	43.3^{bc}	43.6^{abc}	74.9^{bc}	81.7^{defgh}	3.60^{ab}	3.80^{a}	2.94^{abc}	3.09^{ab}
90 kg N ha^{-1} as FYMC	42.9^{bc}	43.1^{abc}	73.9^{bcd}	79.8^{fgh}	3.51^{bc}	3.74^{ab}	2.82^{abc}	2.84^{bcd}
60 kg N ha^{-1} as FYMC	42.6^{bc}	42.4^{abc}	71.6^{cde}	79.8^{fgh}	3.44^{bc}	3.71^{ab}	2.80^{abc}	2.79^{cd}
150 kg N ha^{-1} as VC	43.5^{abc}	43.3^{abc}	74.7^{bc}	82.6^{cdefg}	3.60^{ab}	3.81^{a}	3.15^{a}	3.20^{a}
120 kg N ha^{-1} as VC	43.3^{bc}	43.1^{abc}	73.8^{bcd}	80.7^{efgh}	3.49^{bc}	3.76^{a}	3.04^{ab}	3.16^{a}
90 kg N ha^{-1} as VC	42.9^{bc}	42.8^{abc}	72.3^{bcde}	80.3^{efgh}	3.42^{c}	3.74^{ab}	2.80^{abc}	3.08^{ab}
60 kg N ha^{-1} as VC	42.3^{bc}	42.4^{abc}	69.8^{e}	78.0^{h}	3.41^{c}	3.70^{ab}	2.80^{abc}	3.04^{ab}
150 kg N ha^{-1} as lantana	43.2^{bc}	42.8^{abc}	73.9^{bcd}	89.1^{a}	3.53^{abc}	3.64^{ab}	3.06^{a}	3.10^{a}
120 kg N ha^{-1} as lantana	42.6^{bc}	42.6^{abc}	73.7^{bcd}	88.2^{ab}	3.27^{d}	3.62^{ab}	3.03^{ab}	3.08^{ab}
90 kg N ha^{-1} as lantana	42.4^{bc}	42.0^{bc}	70.6^{de}	85.4^{abcd}	3.24^{de}	3.52^{bc}	2.65^{c}	3.07^{ab}
60 kg N ha^{-1} as lantana	42.3^{bc}	41.6^{c}	69.7^{e}	84.4^{bcde}	3.13^{e}	3.38^{c}	2.63^{c}	3.01^{abc}
Mineral fertilizer	45.7^{a}	44.5^{a}	85.9^{a}	86.3^{abc}	2.65^{f}	3.04^{d}	2.00^{d}	2.54^{e}
Unamended control	42.2^{c}	41.5^{c}	70.7^{de}	78.9^{gh}	3.44^{c}	3.40^{c}	2.70^{bc}	2.76^{de}

FYMC: Composted farmyard manure, VC: Vermicompost, Means in the same column with different letters are significantly (P < 0.05) different.

Table 4. Effect of source and application rate of organic amendments on soil properties

Treatment	BD ($Mg\ m^{-3}$)	pH	SOC ($g\ kg^{-1}$)	Available N ($mg\ kg^{-1}$)	Available P ($mg\ kg^{-1}$)	Available K ($mg\ kg^{-1}$)
150 kg N ha^{-1} as FYMC	1.16^{de}	6.5^{a}	18.8^{a}	184.8^{ab}	6.7^{b}	170.0^{a}
120 kg N ha^{-1} as FYMC	1.16^{de}	6.3^{bc}	16.3^{bc}	164.0^{bcd}	4.7^{cd}	156.3^{ab}
90 kg N ha^{-1} as FYMC	1.19^{cde}	6.1^{de}	15.7^{c}	161.9^{cd}	3.4^{def}	142.8^{b}
60 kg N ha^{-1} as FYMC	1.22^{bcd}	6.1^{de}	13.8^{efg}	155.7^{d}	2.2^{fg}	117.5^{c}
150 kg N ha^{-1} as VC	1.14^{e}	6.4^{ab}	16.8^{b}	179.3^{bc}	5.2^{bc}	113.0^{cd}
120 kg N ha^{-1} as VC	1.22^{bcd}	6.3^{bc}	16.1^{bc}	166.5^{bcd}	5.0^{bcd}	108.5^{cde}
90 kg N ha^{-1} as VC	1.23^{bc}	6.3^{bc}	14.8^{d}	158.2^{cd}	4.6^{cde}	95.3^{ef}
60 kg N ha^{-1} as VC	1.24^{bc}	6.2^{cd}	14.4^{de}	160.8^{cd}	3.3^{def}	92.8^{f}
150 kg N ha^{-1} as lantana	1.16^{de}	6.2^{cd}	14.5^{de}	158.0^{cd}	1.2^{g}	113.5^{cd}
120 kg N ha^{-1} as lantana	1.21^{bcd}	6.2^{cd}	13.9^{ef}	153.5^{d}	2.2^{fg}	108.8^{cde}
90 kg N ha^{-1} as lantana	1.24^{bc}	6.1^{de}	13.4^{fg}	152.7^{d}	3.7^{cdef}	102.7^{def}
60 kg N ha^{-1} as lantana	1.25^{bc}	6.0^{e}	13.0^{g}	150.5^{de}	5.4^{bc}	102.5^{def}
Mineral fertilizer	1.27^{ab}	5.7^{f}	11.9^{h}	204.9^{a}	9.6^{a}	107.5^{cde}
Unamended control	1.33^{a}	6.0^{e}	10.6^{i}	129.0^{e}	2.9^{efg}	90.5^{f}

FYMC: Composted farmyard manure, VC: Vermicompost, BD: Bulk density, SOC: Soil organic carbon, Means in the same column with different letters are significantly ($P < 0.05$) different.