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ORIGINAL PAPER

Improving quality of sugarcane-growing soils by organic amendments under subtropical climatic conditions of India

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Abstract A field trial was conducted on an *inceptisol* to assess the effect of different bio-manures on sugarcane yield, cane quality, and changes in soil physico-chemical and microbial properties in plant–ratoon system. Seven treatments, viz. control, vermicompost, farmyard manure (FYM), biogas slurry, sulphitation pressmud cake (SPMC), green manuring with intercropped *Sesbania*, and recommended dose of NPK (150:60:60 kg ha^{-1}), were randomized within a block and replicated three times. Improvement in bulk density and infiltration rates was recorded after the addition of various bio-manures. The highest organic C was recorded in the vermicompost (0.54%) and pressmud (0.50%) treatments. The highest increase in soil microbial biomass C (185.5%) and soil microbial biomass N (220.2%) over its initial value was recorded with the addition of FYM. Dry matter production in plant, as well as ratoon crop, was significantly higher by bio-manure application over the control. Plant N uptake was highest in the pressmud treatment (227.7 kg ha^{-1}), whereas P and K uptake were highest (41.4 and 226.50 kg ha^{-1}) in vermicompost treatment. The highest number of millable canes (95.6 and 101.0 thousand ha^{-1}) in plant and ratoon crop were obtained with the addition of pressmud. The highest yield (76.7 t ha^{-1}) was recorded in planted cane with vermicompost application, whereas ratoon yield was highest (78.16 t ha^{-1}) with pressmud application. In both planted and ratoon crop, organic amendments produced yields statistically similar to those with recommended NPK (76.1 and 78.1 t ha^{-1} for plant and ratoon cane).

Keywords Bio-manure · Sugarcane · Soil Quality · Ratoon · Cane yield · Soil microbial biomass carbon (SMBC) and nitrogen (SMBN)

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Introduction

The northern subtropical region of India occupies more than 67% of the total cropped area under sugarcane. Modern farming practices such as intensive cropping, removal or burning of crop residues, imbalanced use of chemical fertilizers, and extra tillage have led to the depletion of soil organic matter reserves (Speir et al. 2004) and damaging the soil biodiversity (bacteria, fungi, actinomycetes, etc.). Consequently, alternative practices, viz. organic farming/bio-manuring, that would make agriculture more sustainable and productive are being considered. During the last decade, organic farming in India has drawn the attention of many farmers across the country.

Application of organic matter with nutrient resources, e.g., animal manures, crop residues, and green manuring, to replenish organic matter and improve soil structure and fertility is increasingly favored (Guisquiani et al. 1995; Parham et al. 2002; Saviozzi et al. 2002). A growing number of experiments show that organic farming leads to higher soil quality and more biological activity in soil than conventional farming (Alfoldi et al. 1993; Drinkwater et al. 1995; Droogers and Bouma 1996). Organic farming systems have also been shown to use nutrients and energy more efficiently than conventionally managed system (Mader et al. 2002).

Sugarcane is a long duration, nutrient exhaustive crop, and has been found to meet its nutrient requirement through microbial mediation, particularly during late stages of the crop growth (Neyra and Dobereiner 1977). Soils rich in organic carbon content favor the activity of microbes leading to mineralization and availability of nutrients to crops (Zaller and Kopke 2004). However, effects of different organic sources and their interaction with soil physical properties, nutrient dynamics, microbial activity, and overall crop productivity under the higher atmospheric temperature and humidity conditions of subtropics need detailed investigation. This study was initiated using commonly available organic sources of nutrients such as farmyard manure, sugar industry waste (pressmud), vermi-compost, biogas slurry, and green manure to compare their effect on soil physico-chemical properties, nutrient availability and uptake, soil microbial activity, and crop productivity.

Materials and methods

The experimental site and climate

The field experiment was initiated during the spring season of 2003 on an *inceptisol* soil at the research farm of the Indian Institute of Sugarcane Research, Lucknow (56′26°N, 52′80°E, and 111 m above m.s.l.). The climate of the experimental site is semi-arid subtropical, with dry hot summer and cold winter. The average annual rainfall is 976 mm, and nearly 80% of the total rainfall is received through the north–west monsoon during July–September. The average monthly minimum temperatures fluctuate from 6.9 to 8°C in January (the coldest month) and from 25.9 to 28°C in May (the hottest month). The respective maximum temperatures range from 21.2 to 23°C in January and 39.0 to 40.6°C in May. The soil of the experimental site was sandy loam and had the following properties: 13.3% clay, 24.5% silt, and 62.25% sand. It was of Indo-Gangetic alluvial origin, very deep (>2 m), well drained, flat, and classified as fine, loamy non-calcareous mixed hyperthermic udic Ustochrept with bulk density of 1.40 Mg m^{-3}. The soil was low in organic carbon (0.32%), with pH 7.68, EC 0.24 dS/m, low in available N (230 kg ha^{-1}), and medium in phosphorus (21.5 kg ha^{-1}) and potassium content (217.9 kg ha^{-1}).

Treatment and crop culture

Seven treatments, viz. control (no manures or fertilizer), vermi-compost (10 t ha^{-1}), FYM (10 t ha^{-1}), biogas slurry (10 t ha^{-1}), sulphitation pressmud cake (SPMC-10 t ha^{-1}), intercropped green manuring with *Sesbania aculeata* (2 tonnes of dry matter was added by turning at 45 days after sowing), and recommended dose of NPK (150:60:60 kg ha^{-1}), were randomized within a block, and three such blocks were maintained. The average composition of the organic amendments applied to the plots over the 2 years of the trial is given in Table 1. The plot size was 8×6m and sugarcane cv. CoSe 92423 was sown in rows that were 75 cm apart using 6 tonnes of seed ha^{-1} during the first week of March 2003. Six irrigations and three intercultural operations (hoeing) were provided in all the treatments uniformly. The incidence of disease and pests was below economic threshold, and no plant protection measures were applied. All the organic amendments were manually applied to field plots in each year (both plant and ratoon). The pressmud was collected from the Rojagaon sugar mill, Faijabad, while vermicompost was brought from Uttar Pradesh, Agro-Industry Lucknow. Biogas slurry was obtained from Ganjaria farm, Institute of State Planning, Government of UP, and other materials were obtained from the I ISR Research farm, Lucknow. The above materials were ground (<2mm) and analyzed for total N by Kjeldahl digestion (Blakemore et al. 1972). Samples were digested in nitric and perchloric acids, and P by the vanadomolybdate yellow-color method (Piper 1966) using UV–Vis spectrophotometer. Total potassium content of the plant samples was determined by flame photometer.

Observations like the number of millable canes and cane thickness were recorded at harvest. Ten sugarcane plants were taken randomly from each plot for cane length, cane diameter, and juice analysis. The juice was analyzed for brix (soluble solids) using a Bausch and Lomb refractometer (Bausch and Lomb, Rochester, NY). After clarifying the juice using lead-subacetate (Meade and Chen 1977), the pol (juice sucrose concentration) was determined using a polarimeter. The percentage sucrose in the juice was computed using a formula developed from sucrose tables and temperature brix correction table. The purity of cane juice was calculated as (sucrose %/brix %)×100, and the commercial cane sugar (CCS; t ha^{-1}) was computed as [sucrose %×cane yield (t ha^{-1})]/100.

Plant material was harvested from 1-m row length and oven dried at 65±5°C for 72 h or until a constant weight was attained. Before recording the weight, numbers of shoots were recorded every month from each plot. Both the sugarcane-planted crop and the subsequent ratoon crop

Table 1 Nutrient composition of organic amendments on dry weight basis

Organic amendments	Nutrient composition (%)			
	Organic C	N	P	K
Vermicompost	40	1.60	0.60	0.80
FYM	46	0.75	0.20	0.55
Biogas slurry	55	0.87	0.65	0.70
SPMC	40	1.60	1.00	1.20
Sesbania aculaeta	45	1.99	0.21	1.20

were harvested from ground level using a manual chopper (*Garasa*) on February 15, 2004 and January 31, 2005, respectively.

Soil and plant sampling and analysis

The soil samples were collected from 0- to 15-cm depth and from five places in the experimental field using a tube-type soil auger before commencement of the experiment in 2003. The subsamples obtained were mixed and bulked, and representative soil samples were taken for chemical analysis. The post-sugarcane harvest soil samples (0–15 cm) of all the treatments were also taken following the same procedure after completion of the plant crop cycle and subsequent ratoon. In all, four subsamples were collected from each plot of all three replications. The subsamples in a plot were mixed thoroughly to obtain a representative sample for chemical analysis; the initial and post harvest soil samples were pulverized using a wooden pestle–mortar and sieved through a 100-mesh sieve. The processed samples from each plot were analyzed separately for contents of organic C (Walkley and Black 1934), total soil N by the Kjeldahl method (Jackson 1973), and available N by the alkaline permanganate method (Subbiah and Asija 1956). Phosphate was extracted with 0.5 M sodium bicarbonate solution (pH 8.5) and determined in the extract colorimetrically with the blue-color method (Jackson 1973). Exchangeable potassium was extracted with ammonium acetate solution and determined by flame photometer (Jackson 1973). The soil pH was determined in 1:2.5 soil water suspensions by a glass electrode pH meter. The bulk density (BD) of the soil at the beginning of the experiment and after ratoon harvest were measured using a core sampler; mechanical analysis was done following the international pipette method (Piper 1966) and aggregate size distribution (wet sieving) by the Yodor (1936) method. Infltration was measured in situ using double ring infiltrometer (Bertrand 1965).

At final harvest, representative whole plants (aboveground portion) of the planted crop and ratoon were collected from four spots in each plot. The samples were chopped, homogenized, and dried at 70°C in a hot-air oven. The dried samples were ground in a stainless steel Willey mill and wet-digested in concentrated H_2SO_4 for determination of total N and in diacid mixture (HNO_3 and $HClO_4$ mixed in 4:1 ratio) for determination of total P and K (Jackson 1973).

From each experimental plot, five soil samples were taken randomly from 0- to 15-cm depth by a core sampler of 8-cm diameter. After removing visible plant residues and pebbles, soil, sieved through 2-mm mesh, was stored in plastic bags at 4°C. All microbiological measurements were done within 30 days of sampling, and before any measurement, soil moisture was adjusted to 60% of water-holding capacity, and samples were reincubated for 2 days at 28°C. Soil microbial biomass C and N (SMBC and SMBN) were determined using the chloroform fumigation extraction method (Anderson 1982; Vance et al. 1987). Basal respiration (mineralizable C) was estimated from the quantities of CO_2–C mineralized from unfumigated samples during the 30-day incubation.

Statistical analysis

For treatment comparison in the field experiment, *F* test was used following the procedures of randomized block design (Cochran and Cox 1957). The critical difference (CD), defined as the least significant differences beyond which all treatment differences are statistically significant, was computed to determine statistically significant treatment differences in the table and figure as

$$CD = \left(\sqrt{2\ V_E r^{-1}} x t_{5\%}\right)$$

where V_E is the error variance, *r* the number of replications of the factor for which CD is calculated, $t_{5\%}$ the table value of *t* at 5% level of significance at error degree of freedom.

Results and discussion

Soil physical properties, fertility and microbial activity

Improvement in soil physical properties such as bulk density and water infiltration rate was recorded due to addition of various organic amendments. As compared to no changes in bulk density under control and fertilizer applied plots, the plots receiving organic amendments showed decline in bulk density from 1.4 to 1.3 Mg m^{-3}. Similarly, water infiltration rate improved by 20 to 27.50% over the initial values under organic amendments treatments (Table 2). There was no improvement in infiltration rate with no nutrient addition (control) against an increase of 12.50% under fertilizer applied plots. Reduced bulk density and enhanced infiltration rate due to organic amendments may be attributed to the increased mean weight diameter of water stable aggregates under these treatments (from 0.483- to 0.531-mm mean weight diameter).

Availability of major nutrients (N, P, and K) after the harvest of plant and subsequent ratoon crops expressed as percentage change (Table 3) revealed a positive effect of various treatments on total N balance in the treatments, being least in control and highest in vermicompost plots. The balance of P and K in soil after the plant–ratoon cycle was

Table 2 Bulk density, infiltration rate, and soil aggregate after sugarcane plant–ratoon crop cycle and % change over initial values as influenced by various organic amendments

Treatment	Bulk density (mg m^{-3})		Infiltration rate (mm hr^{-1})		Soil aggregate mean weight diameter (mm)	
	Final	% change over initial (i.e., 1.40)	Final	% change over initial (i.e. 4.0)	Final	% change over initial (i.e., 0.370)
Control	1.40	–	4.0	–	0.373	0.8
NPK at 150–60–60 kg ha^{-1}	1.40	–	4.5	12.5	0.434	17.3
Vermicompost at 10 t ha^{-1}	1.30	7.14	5.1	27.5	0.483	18.4
FYM at 10 t ha^{-1}	1.30	7.14	4.9	22.0	0.506	36.8
Biogas slurry at 10 t ha^{-1}	1.30	7.14	4.9	22.5	0.549	40.2
SPMC at 10 t ha^{-1}	1.30	7.14	5.1	27.5	0.531	43.5
Intercropped *Sesbania* green manuring	1.30	7.14	5.1	27.5	0.485	31.1
CD (P=0.05)	0.05	–	0.30	–	0.071	–

CD Critical difference among two treatments

found to be negative, mainly owing to the heavy uptake by the crop (22.9 to 41.4 kg P and 114.6 to 226.4 kg ha^{-1} K in plant; 12.0 to 30.6 kg P and 104.3 to 228.8 kg ha^{-1} K in ratoon). On the other hand, enhanced microbial activity and increased SMBN indicate fixation of P applied through organic manures, leading to a final negative balance. Potassium in the labile pool could have become negative just after harvest of ratoon owing to rapid uptake by stubble roots to support the crop re-growth from underground buds. This is corroborated by the positive K balance under control conditions that recorded poor uptake of nutrient by the crop, leading to poor yield of both plant and ratoon.

Application of organic amendments resulted in substantial increases in the organic C content of soil (Table 4). The highest increase (68.7%) was recorded in the treatments receiving vermicompost of 10 t ha^{-1}. In control plots where no organic amendments or chemical fertilizer was added, a meager 6.25% increase in organic C content was recorded, and this may be attributed to the huge biomass addition (approximately 30% of the total biomass production by sugarcane crop) through underground stubble of the sugar cane crop. Soils treated with recommended doses of NPK through chemical fertilizers recorded an increase of 37.5% in organic C content, whereas it ranged from 43.7 to 68.7% in different organic amendment treatments, clearly indicating the superior effect of organic amendments over chemical fertilizers. Intercropping of *Sesbania aculeata* between two sugarcane rows could enhance soil organic C content by 50% over the initial.

SMBC increased to various extents under different treatments (Table 4). The addition of FYM at 10 t ha^{-1} caused 185.50% increase in SMBC over the initial value

Table 3 Total N, available P, and K contents of soil after sugarcane plant–ratoon crop cycle and change over initial content as influenced by organic amendments

Treatment	Total N (%)		Available P_2O_5 (kg ha^{-1})		Available K_2O (kg ha^{-1})	
	Final	% change over initial (i.e., 0.038%)	Final	% change over initial (i.e., 21.5 kg ha^{-1})	Final	% change over initial (i.e., 217.9 kg ha^{-1})
Control	0.041	7.9	14.0	−38.8	220.60	1.2
NPK at 150–60–60 kg ha^{-1}	0.053	39.5	15.8	−26.5	192.00	−11.9
Vermicompost at 10 t ha^{-1}	0.064	68.4	19.9	−7.4	181.08	−16.6
FYM at 10 t ha^{-1}	0.055	44.7	17.5	−18.6	194.92	−10.5
Biogas slurry at 10 t ha^{-1}	0.057	50.0	19.7	−8.3	195.27	−10.3
SPMC at 10 t ha^{-1}	0.060	57.9	17.7	−17.6	189.20	−13.1
Intercropped *Sesbania* green manuring	0.058	52.6	18.7	−13.0	175.38	−19.5
CD (P=0.05)	0.005	–	0.76	–	5.62	–

CD Critical difference among two treatments

Table 4 Soil organic C, soil microbial biomass C (SMBC), microbial biomass N (SMBN), and SMB C: SMBN ratio after sugarcane plant–ratoon crop cycle and changes over initial as influenced by various organic amendments

Treatment	Organic carbon (%)		SMBC (mg C–CO_2 kg soil^{-1} 10 day^{-1})		SMBN (mg N–NH_4 kg soil^{-1} 10 day^{-1})		SMBC/SMBN ratio at ratoon harvest (initial 21.1:1)
	Final	% change over initial (i.e. 0.32%)	Final	% change over initial (i.e. 76)	Final	% change over initial (i.e. 3.60)	
Control	0.34	6.25	178	134.2	5.33	48.1	33.3:1
NPK at 150–60–60 kg ha^{-1}	0.44	37.5	188	147.3	6.82	89.4	27.5:1
Vermicompost at 10 t ha^{-1}	0.54	68.7	217	185.5	9.31	158.6	23.3:1
FYM at 10 t ha^{-1}	0.46	43.7	217	185.5	7.93	120.2	27.3:1
Biogas slurry at 10 t ha^{-1}	0.48	50.0	209	175.0	9.11	153.0	22.9:1
SPMC at 10 t ha^{-1}	0.50	56.2	188	147.3	10.07	179.7	18.6:1
Intercropped *Sesbania* green manuring	0.48	50.0	198	160.5	6.96	93.3	28.4:1
CD (P=0.05)	0.04	–	–	–	–	–	–

CD Critical difference among two treatments

followed by a 175% increase due to the addition of biogas slurry (10 t ha^{-1}). Supply of nutrients through chemical fertilizers could enhance SMBC by 147.30% as against the 134.20% increase under control.

At ratoon harvest, SMBC accounted for 3.88 to 5.36% of the soil organic C content in different organic amendment treatments. These values were in agreement with reports that SMBC is generally comprised of 1–4% of organic C (Anderson and Domsch 1989; Sparling 1992). Microbial biomass, although small, plays a key role in controlling the nutrient cycling and energy flow due to its fast turnover (Jenkinson and Ladd 1981; Li and Chen 2004). The ratio of SMBC to organic C is a useful soil quality indicator for comparing soils containing different organic matter content. Generally, if a soil is being degraded, the microbial C-pool will decline at a faster rate than organic C and the SMBC: Organic C percentage will decrease. This indicates whether soils are accumulating or losing soil C. None of our organic amendment treatments observed any reduction in the percentage of organic C present as SMBC. After harvesting plant crop and one ratoon, soils under different treatments were accumulating more C. The SMBC content at ratoon initiation/plant crop harvest, grand growth stage, ratoon harvest was positively correlated with the content of organic C at harvest of first ratoon (r=0.695, 0.469, 0.242), respectively. Similarly, there was positive correlation between SMBC measured at different stages with the content of total N of the soil (r=0.609, 0.577, 0.280, respectively). These results support the fact that high soluble C and N concentrations stimulate microbial activity as organic substrates are sources of energy for microbes (Gaillard et al. 1999; Zaman et al. 1998).

The highest increase of 179.7% on SMBN over its initial value was recorded with the addition of SPMC (10 t ha^{-1}), while the lowest (48.1%) was under control plots. All the organic amendment treatments caused more increase in SMBN than the application of chemical fertilizers. Whereas all treatments observed significant increase in SMBN over the control treatment (28.3–110.7%) with maximum in treatments where SPMC were used, SMBN accounted for 1.2 to 1.98% of the total N present in the soil. Reduction in SMBN at the grand growth stage of ratoon crop indicates the mineralization of N and diversion to N uptake by plants. This resulted in wider SMBC: SMBN ratio in all treatments at grand growth Stage. SMBN at ratoon harvest was more positively correlated with soil organic C and total N (r=0.670, 0.570, respectively) than at ratoon initiation or grand growth stage (r=0.264, 0.111), respectively. The results support the fact that during crop growth, mineralization of N was directed toward plant N uptake. Anderson and Domsch (1989) found that the relationships of SMBC or SMBN with organic C or soil N were more significant when organic C content of soils present as SMBC was less than 2.5%. Because our soils in subtropical belt of India have organic C content up to 1% only, SMBC and SMBN are very sensitive indicators of soil quality.

The SMBC/SMBN ratio of the control soil was higher (33:1) than the initial ratio (21:1). The addition of SPMC decreased the SMBC/SMBN ratio to 18.6:1 (Table 4). The highest increase in organic C and total N over their initial content with vermicompost application must have been due

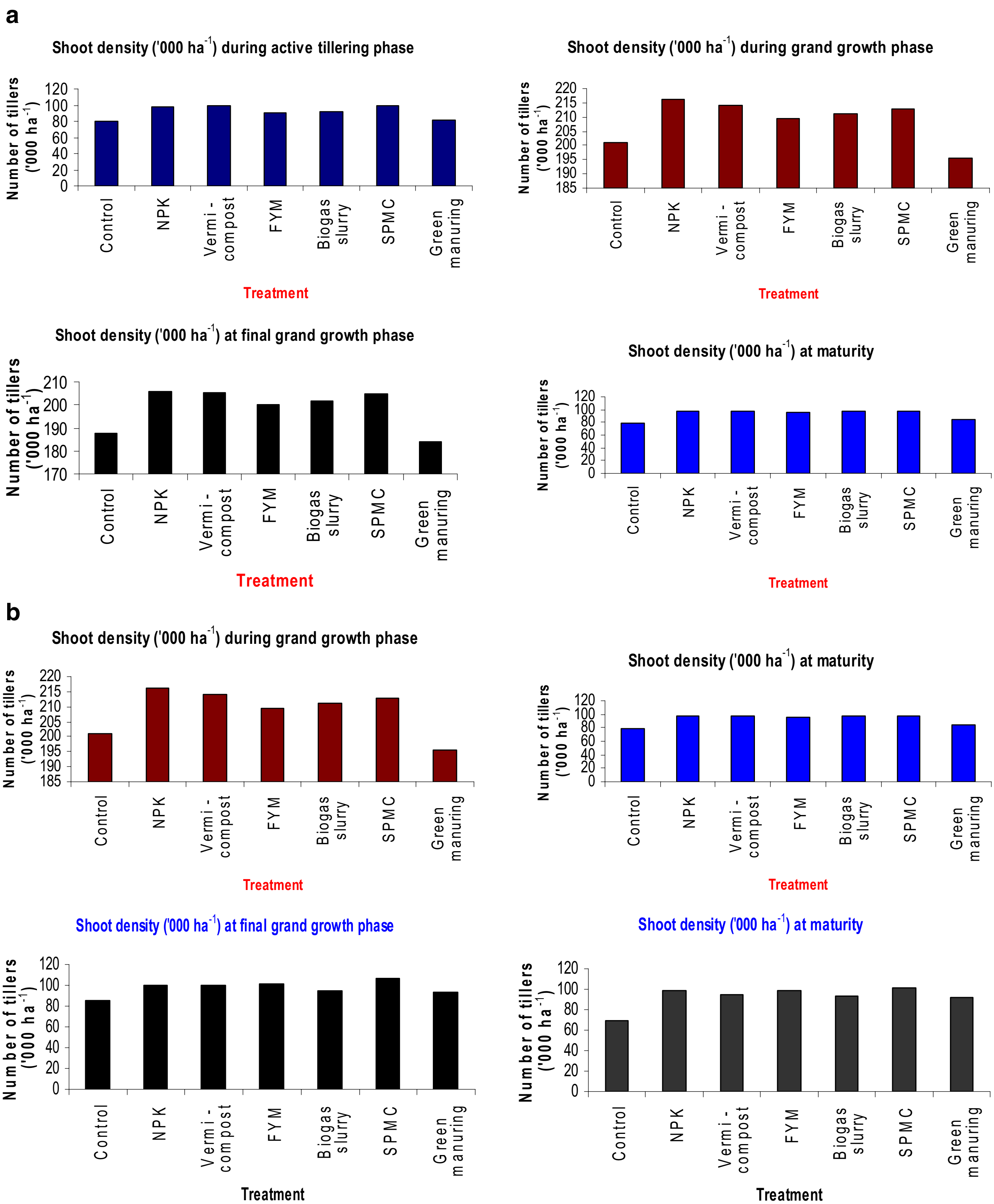

Fig. 1 **a** Tillering pattern in sugarcane plant crop at different growth stages as influenced by various treatments. **b** Tillering pattern in sugarcane ratoon at different growth stages as influenced by various treatments

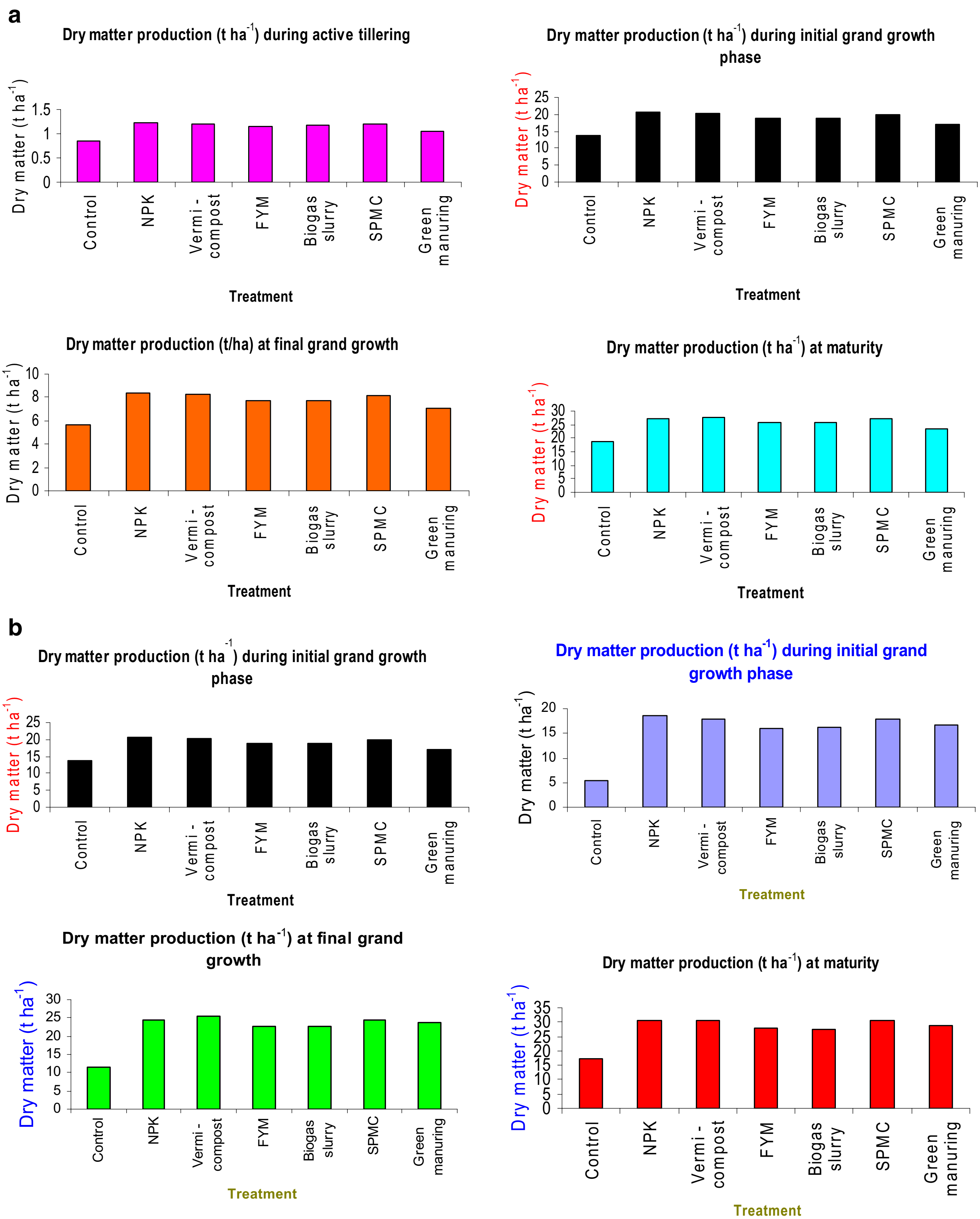

Fig. 2 **a** Dry matter production in sugarcane plant crop at different growth stages as influenced by various treatments. **b** Dry matter production in sugarcane ratoon at different growth stages as influenced by various treatments

Table 5 Yield parameters and yield of sugarcane plant and ratoon crop as influenced by different organic amendments

Treatment	Millable cane (thousand ha^{-1})		Cane length (cm)		Cane thickness (cm)		Cane yield (t ha^{-1})	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
Control	77.4	70.0	184.1	173.0	2.2	2.0	53.0	46.30
NPK at 150–60–60 kg ha^{-1}	95.2	98.5	221.0	216.5	2.4	2.3	76.1	78.10
Vermicompost at 10 t ha^{-1}	95.4	98.6	223.8	207.8	2.4	2.2	76.7	77.72
FYM at 10 t ha^{-1}	94.2	97.0	220.6	204.5	2.2	2.2	70.9	70.70
Biogas slurry at 10 t ha^{-1}	94.9	96.2	218.0	206.1	2.2	2.2	71.9	70.44
SPMC at 10 t ha^{-1}	95.6	101.0	224.7	210.6	2.4	2.3	75.3	78.16
Intercropped *Sesbania* green manuring	83.4	97.6	219.3	214.0	2.5	2.2	65.0	72.52
CD (P=0.05)	1.97	5.36	10.30	11.40	0.20	0.11	6.20	9.55

CD Critical difference among two treatments

to the content of recalcitrant compounds in vermicompost, with slow release of nutrients and reduced losses with build up of soil N pool.

Growth and yield of crop

Tiller population in plant crop recorded at monthly intervals indicated a significant effect of all the organic amendments at the early grand growth phase (July–August); only the treatments with vermicompost or SPMC significantly increased tiller population over control. However, by the cessation of grand growth (November), all the treatments significantly increased the number of tillers over control and at par with that of the recommended NPK application. This resulted in a similar trend of treatment effects on the number of millable canes (NMC) recorded just before harvest. The highest NMC (95.60 thousand ha^{-1}) was obtained with the addition of pressmud (Fig. 1a). Tillering in ratoon exhibited significantly positive effect of all the treatments over the control. By the cessation of the grand growth phase, all the treatments brought about significant increase in tiller population. The NMC by harvest (December) was found highest in pressmud (101.0) and recommended NPK (98.50 thousand ha^{-1}) treatments (Fig. 1b).

Dry matter production by the planted (Fig. 2a) as well as by the ratoon crop (Fig. 2b) was significantly influenced by organic amendments application. However, organic amendments of animal origin, FYM and biogas slurry, produced significantly less dry matter compared to the NPK application both in the plant and ratoon crops during tillering (June) and initial grand growth stages (July–August). Intercropping of *Sesbania* and its incorporation in the plant crop resulted in significantly less dry matter production compared to NPK application. Sugarcane yield is determined by the attributes number of millable canes (NMC), cane length, thickness, and weight at the time of harvest. The highest planted cane yield (76.70 t ha^{-1}) was obtained with vermicompost application, whereas ratoon yield was highest (78.16 t ha^{-1}) with pressmud application (Table 5). In both the crops, organic amendments produced statistically similar yields to that with recommended NPK (76.10 and 78.10 t ha^{-1} for planted and ratoon cane). *Sesbania* intercropping was, however, not as productive for the planted crop of sugarcane (65.00 t ha^{-1}). Significant

Table 6 Nutrient uptake by the plant and ratoon crops as influenced by various organic amendments

Treatments	Nitrogen (kg ha^{-1})		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
Control	147.0	119.7	22.9	12.0	114.6	104.3
NPK at 150–60–60 kg ha^{-1}	306.8	278.5	32.9	30.6	221.9	228.5
Vermicompost at 10 t ha^{-1}	212.6	271.5	41.4	31.5	226.5	228.8
FYM at 10 t ha^{-1}	184.0	213.3	33.2	30.5	201.9	205.0
Biogas slurry at 10 t ha^{-1}	199.5	229.1	31.1	30.4	202.1	188.6
SPMC at 10 t ha^{-1}	227.7	284.6	40.6	30.6	203.3	216.2
Intercropped *Sesbania* green manuring	196.7	225.9	25.7	28.6	189.7	184.0
CD (P=0.05)	10.10	12.14	2.40	2.50	12.00	13.10

CD Critical difference among two treatments increase in cane length and thickness was recorded due to various treatments in planted as well as ratoon crop. Pressmud application produced the longest canes in planted (224.7 cm), whereas the tallest canes in ratoon (216.5 cm) were obtained with the recommended application of N, P, and K. Cane thickness was highest (2.5 cm) with *Sesbania* green manuring in the planted crop, while application of recommended levels of NPK as well as SPMC application produced the thickest canes in ratoon (2.3 cm).

A mature and ripened sugarcane crop is composed of mother shoots and tillers turned into millable cane, and the final yield and sugar recovery (CCS) are directly and positively influenced by the proportion of mother shoots/ early formed tillers to the total number of millable canes (NMC; Yadav and Sharma 1978). Linear increase in shoot density of a sugarcane plant crop under organic amendment treatments, particularly vermicompost and pressmud was similar to that under recommended NPK application through fertilizers. Rapid increase in dry matter accumulation during the grand growth phase (July–September) in all these treatments confirms the efficacy of organic amendments for supporting the growth of sugarcane crops akin to that with fertilizer application. Similarly, in ratoon crops, behavior of shoot density and dry matter production in organic amendment treatments and fertilizer-applied plots over the entire growth duration corroborates the finding. Statistically, cane yield in plant and ratoon crops under fertilizer application (76.1 and 78.1 t/ha), as well as with most of the organic amendment treatments, is the same, and this may be attributed to their similar effect on growth and yield characters such as cane length, cane thickness, and NMC.

Nutrient uptake

Sugarcane is a high soil-nutrient-exploiting crop, as evident from the nutrient uptake data (Table 6). Planted crop under the conditions of recommended NPK supply removed 306.80 kg N, 32.80 kg P, and 221.90 kg K from the soil, whereas under control conditions, 147.0 kg N, 22.90 kg P, and 114.60 kg K were removed. Among organic amendment treatments, the highest amount of N was taken up by the crop under the treatment comprising pressmud application (227.70 kg ha^{-1}) followed by the N uptake under vermicompost application (212.60 kg ha^{-1}) treatment. P and K uptake were highest (41.40 and 226.50 kg ha^{-1}, respectively) under the vermicompost treatment. Sugarcane ratoon removed 119.10 kg N, 12.0 kg P, and 104.30 kg K ha^{-1} in the control, whereas under recommended NPK supply conditions, the nutrient removal was 278.50 kg N, 30.60 kg P, and 228.40 kg K ha^{-1}. Decomposition of organic amendments in the soil is accompanied by the release of appreciable quantity of CO_2, which on forming carbonic acid with soil water, is capable of dissolving certain primary minerals and making them available to the plants for uptake and higher biomass production.

Conclusions

Overall, we conclude that sugarcane crop responded well to organic amendments in the soil in terms of higher biomass production and crop yield of plant and its subsequent ratoon. Appreciable increase in organic C (44–69%) and soil microbial activity (147–185%) probably are responsible for nutrient release and overall energy flow in the system. In both planted and ratoon crop, the highest yield (76.7 t ha^{-1}) was recorded in planted cane with vermicompost application, whereas ratoon yield was highest (78.16 t ha^{-1}) with pressmud application. In both planted and ratoon crop, biomanures produced yields statistically similar to those with recommended NPK (76.1 and 78.1 t ha^{-1} for plant and ratoon cane, respectively).

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