Indian Journal of Agronomy **62** (1): 25–30 (March 2017)

Research Paper

Yield and soil organic carbon pool in relation to soil fertility of sugarcane (*Saccharum* species hybrid complex) plant-ratoon system under integrated nutrient management

S.K. SINHA[1], C.K. JHA[2], VIPIN KUMAR[3] AND S.S. PANDEY[4]

Sugarcane Research Institute, Dr Rajendra Prasad Central Agricultural University, Pusa, Samastipur, Bihar 848 125

Received : September 2016; Revised accepted : March 2017

ABSTRACT

A field experiment was conducted for consecutive 6 years (from 2008–09 to 2013–14) at Pusa, Bihar, to evaluate the integrated effect of organic and inorganic fertilizer on soil organic carbon pool, nutrient status and productivity of sugarcane ('BO 137') plant–ratoon system in Typic Ustochrept. The application of organics, viz. farmyard manure (FYM), bio-compost and bio-methanated distillery effluent (BMDE), along with inorganic fertilizer (100% NPK) in canes plant and its residual effect in ratoon significantly increased number of millable cane, cane yield and sugar yield over the control. The highest increment in yield in plant (24.95%) and ratoon (16.05%) was observed in plots treated with BMDE @ 150 m^3/ha. The mean uptake of nutrients (N, P, K and S) and sugar yield varied and followed the similar trends as cane yield. The soil organic carbon pool, viz. carbon storage (180.9–235.2 kg/m^2), water-soluble carbon (52.8–82.4 mg/g), CO_2 evolution (48.5–70.1 mg/100 g soil) and soil microbial biomass carbon (88.7–121 mg/g) varied significantly due to different treatments. The highest amount of soil organic pools were recorded in treatments receiving BMDE (150 m^3/ha) followed by bio-compost (20 t/ha) and the lowest being in the control. Integrated use of organics with inorganic fertilizers facilitated the accumulation of organic carbon which in turn had significant increment effect on the soil carbon pool and fertility status (N, P, K and S) of soil with reduction in bulk density beneficial for sustaining productivity of sugarcane plant - ratoon system. Thus, it is imperative that application of either 100% NPK recommended dose of fertilizer along with bio-compost 20 t/ha or 100% NP along with bio-methanated distillery effluent 150 m^3/ha (supplying 100% K) improved the fertility of soil which were reflected in increased productivity of sugarcane plant-ratoon system.

Key words: Cane yield, Carbon pool, Integrated nutrient management, Soil fertility, Sugarcane

Sugarcane (*Saccharum* species hybrid complex) is a long-duration nutrient exhaustive crop grown in India over an area of 5 million ha to meet country's total sugar requirement. North Indian sub-tropical contributes more than 60% to total sugar acreage in the country. The depleting soil health and crop productivity in sugarcane-cultivating area in Bihar is a major concern because of reduced yield. This can be clearly visualized from the static average productivity hovering close to 68 tonnes/ha in last five years compared to its potential yield of 150 tonnes/ha. Continuous reduction in returns obtained from applied inputs has been found to be associated with poor soil organic carbon content (< 0.40) of the sandy-loam soils prevalent in north India. On the other hand, continuous use of heavy doses of fertilizers and plant-protection chemicals potentially impaired the soil microbial activity, leading to poor soil health (Singh *et al.,* 2007a). As a result, gradual loss in factor productivity of various inputs is encountered everywhere. Situation therefore warrants for adoption of resources that supply nutrients to plants through microbial mediation and in the process enrich soil organic carbon and nutrient balance.

Sustaining or increasing soil organic carbon is of great importance in terms of cycling plant nutrient, minimizing the need of inorganic fertilizer and improving soil physical, chemical and biological properties. The soil organic carbon and its pool fractions lead to improvement in soil fertility, sustainability and environmental quality in long-run (Carter, 2002). Soil organic carbon influences a wide range of physical, chemical and biological properties of soil and is considered the most important indicator of soil

[1]**Corresponding author's Email:** sanjewsinhasri@gmail.com
[1]Junior Scientist (Senior Scale), Soil Science; [2]Junior Scientist, Soil Science, Sugarcane Research Institute, Pusa, [3]Junior Scientist, Soil Science, P.G. Department, [4]Director, Sugarcane Research Institute, Dr Rajendra Prasad Central Agricultural University, Pusa Samastipur, Bihar 848 125

quality. Soil microbial biomass carbon study reflects energy flow, acts as an agent of transformation of all substances and reflects on a labile pool of C, N, P, S and micronutrients (Mishra *et al.*, 2008).

With raising concern on soil health in the context of depleting traditional organic manures, efforts are needed to, harness the potentiality of sugar industry wastes effectively. Indian sugar mills and distilleries generate huge amount of pressmud and distillery effluent, which are considered as a source of organic matter and plant nutrients. The bio-methanated distillery effluent (BMDE) and bio-compost (BC) easily bio-degradable source of organic matter rich in plant nutrient and its application enhanced cane and sugar yield with significant improvement in soil health (Sinha *et al*., 2014). The integrated use of organic and inorganic plant nutrient sources not only recycles organic waste but also conserves rich pool of nutrients resources, which can reduce the sole dependence on chemical fertilizers. Keeping above considerations in view, present experiment was formulated to see the integrated effect of organic and inorganic fertilizers on various pools of soil organic carbon, nutrient status and productivity of sugarcane plant-ratoon system.

MATERIALS AND METHODS

The field experiment was conducted on sandy-loam calcareous soils (Typic Ustochrept), deficient in available K and soil organic carbon, for 6 years from 2008–09 to 2013–14 (3 years on cane plant and three years on ratoon crop) at Crop Research Farm, Dr Rajendra Prasad Central Agricultural University, Pusa, Bihar, under ad-hoc project of New Swadeshi Sugar Mills, Narkatiaganj, Bihar. The farm is situated at (25^o 98’ N, 85^o 67’ E, 52.1 m above mean sea-level). The climatic condition of area was sub-tropical and the mean annual rainfall is about 1,200 mm, most of which is received during May–October. The mean annual temperature is 24.5^{o}C with maximum 38.6$^<$ C during April and minimum 7.4^{o}C in January. The experimental soil (0–30 cm) had *p*H (8.2), electrical conductivity (EC) (0.18 dS/m) with rich in $CaCO_3$ (24.3 %) and low in organic carbon (0.43 %) as well as in available N (228 kg/ha), medium in P (18.1 kg/ha) and low in K (112.1 kg/ha) and available S (11.1 kg / ha). The initial soil had water-soluble carbon 52.7 mg/g, carbon storage 178.2 kg/m^2, microbial biomass carbon 85.2 mg/100 g and CO_2 evolution 46.4 mg/100 g soil. The treatments consisted of recommended dose of fertilizers (RDF) and its combination with different organic sources (FYM, BC and BMDE) with substitution of K (25, 50, 75 and 100%) through BMDE. The quantity of potassium was adjusted through BMDE as per technical plan. The experiment was laid down in randomized block design (RBD) with 4 replications. The treatments consisted of: T_1, 100% NPK (RDF); T_2, T_1 + FYM; T_3, T_1 + BC; T_4, 100% NP+ 75% K through inorganic fertilizer (IF) + 25% K through BMDE (37.5 m^3/ ha); T_5, 100% NP + 50% K through IF + 50% K through BMDE (75 m^3/ha); T_6, 100% NP + 25% K through IF + 75% K through BMDE (112.5 m^3/ha); T_7, 100% NP +100% K through BMDE (150 m^3/ha). The FYM (@ 20 t/ha), BC (@ 20 t/ha) and BMDE (37.5 to 150 m^3/ha) were applied as per technical plan. The residual effect of treatments was observed on ratoon crop. The BMDE and BC were characterized. The BMDE had neutral *p*H (7.46), EC (20.10 dS/ m) organic carbon (13.90%) with N (2.32%), P (0.81%) and K_2O (9.25%). The BC had *p*H (7.74), EC (3.32d S/m), organic carbon (22.18%) with N (2.36%), P (0.68%) and K_2O (0.57%) on oven dry basis. The RDF (150–33–50 kg N–P–K/ha) were applied through urea, diammonium phosphate (DAP) and muriate of potash (MOP). The organic manure was applied one month before sugarcane planting. Net plot size was 9.24 m × 5.40 m. Test crop was sugarcane (cv. ‘BO 137’). The half of fertilizer N and whole P and K were applied before planting of sugarcane and the rest half N was top-dressed at the time of earthingup. The crop was harvested and whole cane leaf and leaf sheath were analyzed for N, P, K and S by the standard procedures. The experimental soils (0–30 cm depth) were collected at the time of harvesting of ratoon crop (3rd cycle). Post-harvest soil samples were divided into 2 parts, one for chemical analysis and another stored at low temperature (0$^<$ C) for biological properties analysis. The soil samples were analyzed for various physico-chemical properties such as *p*H, EC, organic carbon, bulk density, Ca^{2+} + Mg^{2+} and available nutrient (N, P, K and S) of soil using standard procedures. Whole plant samples were also analyzed for nutrients uptake (N, P, K and S). The carbon dioxide evolution in soil was analyzed by the method given by Pramer and Schmidt (1964). The soil microbial biomass carbon (SMBC) was determined by chloroform fumigation method using Kc value of 0.45 (Vance *et al.,* 1987). Water-soluble carbon (WSC) was determined by the method outlined by Mc Gill *et al.* (1986). The cane juice quality was determined using procedure outlined by Spencer and Meade (1964). The data were pooled and analyzed statistically.

RESULTS AND DISCUSSION

Yield attributes and cane yield

Application of nutrients through organics in combination with inorganic nutrient sources resulted in significantly higher number of millable cane (NMC), cane and sugar yield over the control (Table 1). The combination of 100% NP + 100% BMDE (@ 150 m^3/ha) recorded highest NMC in plant and ratoon. The mean yield varied significantly between 58.87 and 73.56 t/ha in plant cane and 55.25 and 64.12 t/ha in ratoon crop. The highest cane yield was recorded in plots receiving 100% NP + 100% BMDE followed by RDF + BC and lowest in the control in cane plant. However, the differences among these organics treated plots were non-significant. The yield increased by 24.95% in plots treated with 100% NP + 100% BMDE followed by BC-treated plots by 22.47% in case of plant. The residual effect of organics on yield of ratoon crop was less than its direct effect on plant crop with increase in yield by 15.47% and 16.05% in BC and 100% BMDE-treated plots, respectively. The residual effect of organics was more pronounced in plots receiving BC @ 20 t/ha and BMDE @ 75 and 150 m^3/ha along with RDF. The results clearly indicated that application of 100% NPK along with BC, FYM and higher dose of BMDE registered significant enhancement in yield attributes and cane yield. It could be attributed to combination of organic and inorganic sources of nutrients, increased nutrient availability for healthy growth and development of plant. The yield of sugarcane plant and ratoon crops in each crop cycle is the function of NMC and individual cane length at harvesting of both plant cane and ratoon crops. The result indicated that application of organic manure in plant and its residual effect on ratoon were found beneficial for obtaining higher yield. The immediate and quick supply of plant nutrient through inorganic source for plant growth and steady supply of plant nutrients by organics throughout the growth period, resulting in higher yield. The result also indicated that higher yield of plant and ratoon can be maintained owing to different integrated nutrient- management practices over the cane productivity with inorganic fertilizers alone. It may be attributed to enhanced nutrient availability, improved soil quality and health.

Table 1. Effect of organic and inorganic fertilizer on yield attributes, yield and juice quality of sugarcane plant-ratoon system (pooled data of 3 years)

Treatment	Number of millable canes (× 10^3/ha)		Yield (t/ha)		Yield increase over the control (%)		Sugar yield (t/ha)	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
RDF (control)	74.2	69.5	58.87	55.25	0.00	0.00	6.90	6.20
RDF + FYM	84.4	78.8	66.91	58.28	9.36	5.48	7.91	6.35
RDF + BC	92.1	89.0	72.10	63.80	22.47	15.47	8.46	7.15
100% N, P + 75% K, IF + 25% K, BMDE	78.4	73.1	61.71	56.10	4.82	1.53	7.49	6.24
100% N, P + 50% K, IF + 50% K BMDE	85.2	71.5	64.38	57.46	9.35	4.71	7.55	6.61
100% N, P + 25% K IF + 75% K BMDE	92.7	83.6	71.56	59.50	21.55	7.69	8.49	6.96
100% N, P + 100% K BMDE	92.8	88.0	73.56	64.12	24.95	16.05	8.75	7.30
SEm±	3.9	3.5	2.34	2.46			0.26	0.31
CD (P=0.05)	11.2	10.9	6.68	7.68			0.74	0.99

RDF, Recommended dose of fertilizer (N: P: K, 150 : 33 : 50); FYM, farmyard manure @ 20 t/ha; BC, bio-compost @ 20 t/ha; BMDE, bio-methanated distillery effluent @ 37.5 (25%) ,75 (50%), 112.5 (75%) and 150 (100%) m^3/ha; IF, inorganic fertilizer

Table 2. Effect of organic and inorganic fertilizer on uptake of nutrients in sugarcane plant-ratoon system (pooled data of 3 years)

Treatment	Uptake of nutrient (kg/ha)							
	Plant				Ratoon			
	N	P	K	S	N	P	K	S
RDF (control)	139.8	14.6	168.8	9.2	123.0	11.6	132.2	8.3
RDF + FYM	156.9	17.3	197.6	10.8	125.7	11.9	135.4	8.8
RDF + BC	168.6	19.4	217.2	12.1	144.1	13.3	152.1	10.4
100% N, P + 75% K, IF + 25% K, BMDE	145.8	15.3	175.7	10.7	124.9	11.8	134.5	9.3
100% N, P+ 50% K, IF + 50% K BMDE	151.1	16.4	182.9	11.6	131.9	12.5	142.0	9.8
100% N, P + 25% K IF + 75% K BMDE	167.1	18.6	214.1	12.4	136.3	12.9	146.7	10.4
100% N, P + 100% K BMDE	173.1	20.0	218.6	12.4	141.3	13.6	155.1	11.6
SEm±	5.7	1.0	6.8	0.85	5.5	0.56	6.8	6.2
CD (P= 0.05)	16.4	3.0	19.6	2.6	16.9	1.7	20.9	19.1

RDF, Recommended dose of fertilizer (N: P: K, 150 : 33 : 50); FYM, farmyard manure @ 20 t/ha; BC, bio-compost @ 20 t/ha; BMDE, bio-methanated distillery effluent @ 37.5 (25%), 75 (50%), 112.5 (75%) and 150 (100%) m^3/ha, IF, inorganic fertilizer

Sugar yield

The sugar yield increased significantly with the application of various organics (FYM, BC and BMDE) in combination with inorganic fertilizer over control (Table 1). The highest sugar yield was recorded in treatment receiving 100% NP + 100% BMDE incombination, followed by BC-treated plots and the lowest in the control receiving only inorganics. The higher cane yield resulted in increased commercial cane sugar yield over the control. Sugar yield, a function of cane yield exhibited similar trend. Singh *et al*. (2007 b) reported similar findings.

Nutrient uptake

The uptake of N, P, K and S increased significantly over the control owing to application of various organics (FYM, BC and BMDE) in combination with inorganic fertilizer (Table 2). The highest uptake of nutrients in plant was recorded in the treatment receiving 100% NP + 100% BMDE and the lowest in the control. The uptake of potassium increased with graded dose of BMDE and the highest being in 100% BMDE-treated plots. The data indicated that application of organic manure along with inorganic fertilizer increased the uptake of nutrients and followed the similar trend as cane yield. The addition of BMDE improved the K nutrition in particular, N and P in general. It was evident from present findings that BMDE is as good as KCl to meet K requirement of crop. Improved nutrient concentration under organic-treated plots may be attributed to the improved nutrient availability and better crop growth as observed under this treatment. The higher yield resulted in higher uptake of nutrients owing to integrated nutrient management through organic and inorganic fertilizer. Sinha *et al.* (2014) reported similar findings.

Soil properties

Soil organic carbon pool: Significant improvement in soil biological properties, viz. water-soluble carbon (WSC), soil microbial biomass carbon (SMBC), carbon storage and CO_2 evolution, were recorded under integrated nutrient management receiving organics in combination with inorganic fertilizer (Table 3). In contrast, there was substantial reduction of all these in plots receiving only inorganics (100% NPK**.** Data revealed that at the end of plant-ratoon cycle, soil organic carbon varied significantly (0.47 to 0.54%) in organic-treated plots as compared to the control (0.43 %). The soil organic carbon increased by 25.58% in plots treated with BMDE over control. The mean carbon storage ranged from 180.9 to 235.2 kg /m^2 and WSC from 52.8 to 82.4 mg/g due to different treatments**.** The data further revealed that there was a significantly higher evolution of CO_2 (70.1 mg/100 g soil) and SMBC (121.0 mg/g) in 100% BMDE-treated plots, followed by BC-treated plots (CO_2 65.5 mg/100 g and SMBC 115.2 mg/g soil). Consequently, the soil carbon storage capacity significantly increased with magnitude of enhancement to the extent of 20.06 to 29.97% due to application of organics over control. Similar to SMBC, there was remarkable increase in carbon dioxide evolution to the extent up 35.05 to 44.53% under various treatments, indicating greater activity of soil microorganism. The integrated use of organics with inorganic also improved WSC with maximum increase by 56.0% in 100% BMDE, followed by 37.50% in BC-treated plots over the control. These findings evidenced that highly soluble carbon stimulates microbial activities, since organic substrates such as FYM, BC and BMDE are rich source of energy for microbes. Greater is the proportion of microbial biomass carbon higher is the total microbial activity and better is the soil health. The overall result indicated that at the end of plant-ratoon system, treatments receiving organics indicating more accumulation of carbon pool in soil. This plays a key role in controlling the nutrient recycling and

Table 3. Effect of organic and inorganic fertilizer on soil carbon fractions in post-harvest soil after 6 years

Treatment	Organic carbon (%)	Carbon storage (kg/m^2)	Water-soluble carbon (mg/g)	Soil microbial biomass carbon (mg/g)	CO_2 evolution (mg/100 gm soil)
RDF (control)	0.43	180.9	52.8	88.7	48.5
RDF + FYM	0.47	204.0	65.6	110.4	63.5
RDF + BC	0.52	217.3	72.6	115.2	65.5
100% N, P + 75% K IF + 25% K BMDE	0.46	186.3	57.8	90.2	54.6
100% N, P + 50% K, IF + 50% K BMDE	0.48	211.1	62.0	104.0	60.3
100% NP + 25% K IF + 75% K BMDE	0.51	219.4	72.3	113.3	66.5
100% N, P + 100% K BMDE	0.54	235.2	82.4	121.0	70.1
SEm±	0.01	2.3	1.7	2.1	3.0
CD (P=0.05)	0.03	7.2	5.2	3.4	9.3

RDF, Recommended dose of fertilizer (N : P : K, 150 : 33 : 50); FYM, Farmyard manure @ 20 t/ha; BC, bio-compost @ 20 t/ha; BMDE, bio-methanated distillery effluent @ 37.5 (25%) ,75 (50%),112.5 (75%) and 150 (100%) m^3/ha; IF, inorganic fertilizer energy flow due to its fast turnover Li and Chen (2004).

The increased active pool of soil organic carbon indicates improvement in soil quality. The CO_2 evolution is an index of microbial activity and rate of decomposition of organic matter in soil. The supply of additional mineralizable and readily hydrolysable C due to application of FYM, BMDE and BC resulted in higher microbial activity and higher SMBC. It reflects that manure input resulted in higher SMBC as compared to inorganic fertilization. Resultant increase in SMBC as recorded in 100% BMDE, BC and FYM treatment over the control may largely be attributed to addition of BMDE @ 150 m^3/ha, BC @ 20 t/ha and FYM @ 20 t/ha of organic manures and its decomposition under climate of sub-tropical with mean annual temperature of 24.5^{o}C and the supply of nutrients through 100% NPK over the control. The above findings indicated conspicuous improvement in soil organic carbon (25.58%) owing to application of organics in sugarcane-based production system. Sustaining or increasing soil organic matter is of great importance in terms of cycling plant nutrient, minimizing the need of inorganic fertilizer, and improving nutrient status of soil. The results are in conformity with the findings of Tyagi *et al*. (2011).

Physico-chemical properties

Addition of inorganic fertilizer in combination with organic manure improved the soil fertility in terms of available nutrients (N, P, K and S) with reduction in bulk density at post harvest stage (Table 4). The application of organics and its combination with inorganic fertilizer significantly decreased *p*H recorded lowest in 100% BMDE and the highest in the control. However, effects of various treatments on soil electrical conductivity were found non-significant. The reduction in *p*H might be due to production of weak organic acids due to decomposition of organic manure. There was significant effect of treatments on available nutrient status of soil receiving organic manure after 3-crop cycle. The available nutrients varied significantly N (227.8 to 239.7), P (18.6 to 22.0), K (110.5 to 123.8) and S (11.1 to13.8) kg/ha respectively. The results indicated that application of only inorganic fertilizer alone was not effective and leads to deterioration in nutrient status in sugarcane plant–ratoon system. Soil nutrients status and organic carbon sustained in all the treatments receiving organic and inorganic nutrient sources in combination. The data also indicated that cations especially (Ca^{2+}+Mg^{2+}) content of soils significantly increased in treatments of organics. This might have resulted owing to solubilization of nutrients through complexation process by humic and fulvic acid present in organic manure (Prasad and Sinha, 1984). In general, reduction in bulk density (BD) was recorded in organic treated plots after 3-crop cycles. It varied from 1.33 to 1.42 Mg/M^3 (Table 4) .The maximum reduction in BD (–0.09) unit was recorded in treatment receiving BC @ 20 t/ha. The mean pore space ranged from 46.4 to 49.8% and it increased with reduction of bulk density. The improvement in physical, chemical and biological properties of soil may be attributed to addition of organics, which resulted in buildup of fertility status of soil for sustainable sugarcane production. The organic manures released nutrients after decomposition and mineralization that would have increased the availability of plant nutrient on later stages and brought improvement in physical, chemical and biological properties of soil, resulting in improved soil fertility and absorption of nutrient by plants. The results are in agreement with findings of Virdia and Patel (2010) and Jha *et al*. (2015)

Integrated use of organics with inorganic fertilizers facilitated the accumulation of organic carbon which in turn had significant increment effect on the soil carbon pool and fertility status of soil beneficial for sustaining produc-

Table 4. Effect of organic and inorganic fertilizer on soil properties after harvest of sugarcane plant -ratoon system (pooled data of 3 years)

Treatments	pH	EC (dS/m)	Ca^{2+} + Mg^{2+} (me/L)	Available Nutrients (kg/ha)				Bulk density (Mg/M^3)
				N	P	K	S	
RDF (control)	8.24	0.19	11.01	227.8	18.6	110.5	11.1	1.42 (46.4)
RDF + FYM	8.19	0.21	11.17	233.8	20.3	114.5	12.2	1.34 (49.4)
RDF + BC	8.08	0.30	12.14	238.3	21.9	117.7	13.7	1.33 (49.8)
100% N, P + 75% K, IF + 25% K, BMDE	8.15	0.22	11.44	228.9	18.9	113.3	13.1	1.37 (48.3)
100% N, P + 50% K, IF + 50% K BMDE	8.14	0.25	11.59	230.5	19.2	114.4	13.0	1.36 (48.7)
100% N, P + 25% K IF+ 75% K BMDE	8.08	0.30	12.09	233.1	20.5	119.4	13.4	1.36 (48.7)
100% N, P + 100% K BMDE	8.05	0.32	12.57	239.7	22.0	123.8	13.8	1.35 (49.1)
SEm±	0.02	0.10	0.15	2.3	0.59	1.6	0.77	0.28
CD (P=0.05)	0.08	NS	0.43	6.5	1.7	4.6	2.4	0.08

RDF, Recommended dose of fertilizer (NPK, 150:33:50); FYM, Farm yard manure @ 20t/ha; BC, bio-compost @ 20 t/ ha; BMDE, bio-methanated distillery effluent @ 37.5 (25%) ,75 (50%),112.5 (75%) & 150 (100%) m^3/ha; IF, inorganic fertilizer parentheses denotes pore space % in soil tivity of sugarcane plant-ratoon system. Thus, it is imperative that application of either 100% NPK (RDF) along with bio-compost 20 t/ ha or 100% NP along with bio-methanated distillery effluent 150 m^3/ha (supplying 100% K) improved the fertility of soil which were reflected in increased productivity of sugarcane plant-ratoon system.

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