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ARTICLE

Subsoiling Affecting Soil Quality Parameters and Sugarcane Yield in Multiratooning System in Subtropical India

S. K. Shukla, V. P. Jaiswal, Lalan Sharma, A. D. Pathak, A. K Singh, Rajendra Gupta, S K Awasthi, Asha Gaur, Adil Zubair, and Raghvendra Tiwari

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ABSTRACT

Soil compaction in the plow layer of soils is becoming a serious concern because of conventional tillage practices adopted by sugarcane growers utilizing a rotavator, particularly in medium to heavy textured soils. Continuous use of machinery causes compaction in the plow layer; thus strategic tillage practices have become an essential component in intensive agriculture. Keeping these points in view, a field experiment was conducted in split plot design considering four pre-plant tillage treatments, i.e., (i) one subsoiling (SS) followed by two harrowings (H) (ii) subsoiling alone and direct planting through Sugarcane Cutter Planter (SS) (iii) one plowing through moldboard (MB) plow and two harrowings (MB+H) (iv) and conventional practice (CP) in main plots and three ratoon management treatments viz., (i) HW:Three hand weedings (HW) (ii) integrated weed management (IWM), trash mulching at the time of ratoon initiation and application of microbial consortia (TM +MC) in subplots. Results on bulk density in surface and subsurface layers indicated a significant reduction due to subsoiling. Higher availability of N (252 to 310.2 kg ha^{-1}) was analyzed with adoption of subsoiling as compared to conventional practice (218.4 to 224 kg N ha^{-1}). Subsoiling improved soil microbial biomass carbon (SMBC) by 39% to 73% and 32.20% to 46% as compared to conventional practice in 0–15 cm and 15–30 cm depth, respectively. Among all the primary tillage treatments, sub soiling enhanced SMBC at the highest level (1574 mg C/kg soil/day in 0–15 cm soil depth). Sugarcane (97.26 t ha^{-1}) and sugar (11.87 t ha^{-1}) yields also improved significantly under subsoiling as compared to other pre-plant tillage treatments. Subsoiling before planting also increased mean ratoon cane (117.6 t ha^{-1}) and sugar yields (14.48 t/ha). In addition to trash mulching and application of microbial consortia in ratoon crop proved effective for sustaining higher ratoon yields in sugarcane.

Short title: Minimum tillage affecting soil quality parameters and sugarcane yield

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KEYWORDS
Available n; bulk density; ratoon cane; soil microbial biomass carbon

Introduction

Nowadays soil compaction in the plow layer is becoming a serious concern because of conventional tillage practices adopted by sugarcane growers through rotavator/cultivator particularly in medium to heavy textured soils. Increasing bulk density due to reduced pore space and formation of hard pan in plow layer (Ishaq et al. 2001; Akhtar et al. 2005) restricts root growth. It also reduces water-holding capacity of soil and adversely affects water and air movement (Osunbitan, Oyedele, and Adekalu 2005; Sabir, Ahmad, and Aslam 1990). Subsoiling/chiseling before planting of sugarcane crop reduces the soil compaction and allows free movement of water and air (Shukla et al. 2018) in surface and subsurface layers (>30 cm

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depth). Subsoiler makes a slit in soil up to 45–50 cm depth without soil inversion. However, primary tillage through moldboard plow allows cutting and turning of top soil (20 cm depth). Excessive tillage provides larger exposure of soil to external environment, leading to higher release of CO_2 through soil, destructs soil structure, microbial community resulting in lower soil organic carbon, microbial biomass carbon, and nutrients availability (Garside et al. 1997; Karlen et al. 2013; Pankhurst et al. 2003).

In sugarcane cultivation, ratooning is an old-aged practice done for profitable crop production. Although in tropical and subtropical parts of India, minimum one or two ratoons are taken by sugarcane growers, However, multiratooning up to ten ratoons through single planting have also been successfully grown in the region (Srivastava et al. 2018). Most of the studies on tillage reported adverse effect of deep tillage on soil structure and soil biology. However, in sugarcane-based systems, tillage improved the crop yields particularly in medium to heavy textured soils (Shukla et al. 2018). Many studies concentrated on tillage and soil moisture availability in the root zone favored trash mulching in sugarcane ratoon (Yadav et al. 2009). Trash mulching in ratoon conserves soil moisture, controls weed growth and contributes soil organic carbon after decomposition. Mulching optimizes rhizospheric environment and accelerates soil microbial activities in sugarcane (Yadav et al. 2009). The importance of bioagents viz., *Trichoderma* (Cellulose decomposer and growth promoter), *Pseudomonas* fluorescens (phosphate solubiliser bacteria) and *Gluconacetobacter diazotrophicus* (N fixer) in sugarcane agriculture is well known (Shukla et al. 2008).

Nowadays preplant tillage (field preparation) in sugarcane growing regions is mostly done through rotavator and tractor mounted cultivators. Thus, continuous use of machinery provides compaction in top 15 cm depth (plow layer). Frequent use of heavy machines also encouraged soil compaction (Ahmed, Hassan, and Belford 2009; Ishaq, Ibrahim, and Lal 2001). In sugarcane cultivation, post plant tillage through manual hand weeding is very common. Although integrated weed management through combined use of pre-emergence and post emergence herbicides and one hoeing at 90 days after planting has been advocated and found at par with three manual weedings (Chauhan, Singh, and Srivastava 1994). However, its effect on soil chemical and biological parameters has not been thoroughly investigated. However, hoeing during tillering stage also adversely affects soil organic carbon accumulation and microbial population in root zone (Shukla et al. 2018).

Most of the research work reported the positive effect of minimum tillage/no tillage on soil quality parameters. However, conservation tillage has also been advocated in many places (Barber and Navarro 1994). About 70–80% sugarcane roots concentrate up to 15–20 cm depth (Shukla et al. 2018). Hard pan formation also restricts root growth in subsurface layer. It has been observed that subsoiling increased rooting depth and root biomass in crop required for higher yields (Abu-Hamdeh 2003). Several studies conducted in various countries recorded adverse effects of high-intensity tillage on soil quality parameters and soil microbial activities (Dick 1992).

Our hypothesis was that a reduction in soil inversion as done by moldboard plow, soil carbon loss could be arrested. Thus, soil organic carbon and microbial biomass carbon in sugarcane multiratooning system could be enhanced. Besides, soil compaction could also be reduced through subsoiling and trash mulching in subsequent ratooning. Therefore soil fertility could be sustained for a longer period without declining crop productivity. Keeping these points in view, the present investigation was undertaken i) to assess the effect of subsoiling and direct planting vs conventional tillage on soil physical, chemical and biological properties in multiratooning system, ii) to assess the effect of trash mulching and microbial consortia vs hand weeding on soil quality parameters and ratoon yields and iii) to assess the relationship between soil quality parameters and their contribution in sustaining soil fertility and crop yields.

Materials and methods

The experimental site and soil

A field experiment was conducted for four years crop cycle during 2014–2018 consisting sugarcane (plant crop)-ratoon1-ratoon 2-ratoon 3 system at ICAR-Indian Institute of sugarcane research, Lucknow (Uttar Pradesh), India located at 26.50° North and 80.50° East at an elevation of 123 m above sea level. Lucknow falls in subtropical zone having dry hot summer and cold winter experimental soil was loam (as per USDA classification having 45% sand, 33% silt and 22% clay) of Indo-Gangetic alluvial origin. Soil had well-developed profile (>2 M depth), well-drained flat classified as non-calcareous mixed *hyperthermic udic ustochrept*. Soil samples from 0 to 15 cm and 15 to 30 cm were collected by Core Sampler of 8 cm diameter from five spots in the experimental field before planting of the crop. Samples were used for determination of bulk density as per given formula.

Bulk density ($Mg\ m^{-3}$) = Dry soil weight (g)/soil volume (cubic cm)

Representative homogeneous samples from both depths were analyzed for determination of organic carbon (Walkley and Black 1934), available N (Alkaline permanganate method), 0.5 M sodium bicarbonate ($NaHCO_3$, pH 8.5)- extractable P and NH_4OAC extractable K, following Jackson (1973). Initial soil pH and Electrical conductivity in 0–15 cm and 15–30 cm depths (pH 7.20 and 7.30; 0.20 and 0.22 dsm^{-1}, respectively) were also recorded.

Climatic parameters

Climatic parameters (T_{max}, T_{min}, relative humidity (RH) and rainfall) during crop growth period (2014–2018) indicated that annual mean rainfall varied from 592.1 mm (2015–16) to 874.3 mm (2016–17). Mean T_{max} and T_{min} during 2014–15 were recorded as 40.3°C and 7.8°C during June 2014 and December 2014, respectively. However, corresponding values for 2015–16, 2016–17 and 2017–18 were recorded as 40.1°C (May 2015) and 7.7°C (Jan 2016); 39°C (May 2016) and 7.8°C (Jan 2017); 39.5°C (May 2015) and 5.4°C (Jan 2018), respectively. About 80% annual rainfall was concentrated from June to September (grand growth phase of sugarcane crop).

Tillage and crop culture

About 10 tonnes ha^{-1} well-decomposed FYM containing 0.5%N, 0.30%P and 0.5% K was applied on experimental field uniformly before applying pre-plant tillage treatments. Pre-plant tillage was done before planting of sugarcane crop. Sugarcane crop (Cv. CoPk05191) was planted on 10th February 2014 at 75 cm row spacing. Three bud sets (approx. 53000 ha^{-1}) were placed in furrows distanced at 75 cm row spacing. Full dose of P (25 kg P ha^{-1}) and K (50 kg ha^{-1}) and 1/3rd N (50 kg ha^{-1}) was applied basal at the time of planting beneath seed cane setts. Remaining 2/3rd N in sugarcane plant crop (main crop) was supplied through urea during tillering phase (April to June) in two equal splits. Sugarcane crop was fertilized with 150 kg N ha^{-1}. However, each ratoon crop was fertilized with 200 kg N ha^{-1} (100 kg N ha^{-1} during ratoon initiation and remaining 100 kg N ha^{-1} after 45–60 days of ratoon initiation) as per recommendations (Shukla et al. 2017a). The sugarcane ratoon crop was fertilized with N fertilizer only in two equal splits. Chemical fertilizers used for supply of NPK in plant and ratoon crops were urea, diammonium phosphate (DAP) and muriate of potash (KCl).

Management of termite was done through drenching of Chlorpyriphos 20 EC @ 1 kg ai ha^{-1} on seed cane furrows before covering through soil. For control of top borer in sugarcane crop, Furadon 3 G @ 1 kg ai ha^{-1} was applied before onset of monsoon. The sugarcane plant crop was harvested on 15th February 2015 and first ratoon was initiated immediately. Subsequent 1st, 2nd and 3rd ratoons were harvested on 14th Jan 2016, 10th Jan 2017 and 7th Jan 2018, respectively, as per maturity.

Treatment

Preplant tillage (primary) treatments i.e., T_1: One subsoiling (SS) and two harrowings (H), T_2: subsoiling alone and direct planting through Sugarcane Cutter Planter (SS), T_3: One plowing through MB plow and two harrowings (MB+H) and T_4: Conventional practice (CP- two ploughings through cultivator and one through rotavator) was applied in main plots before planting of sugarcane crop. These four treatments were applied before planting of sugarcane crop. Subsoiling (deep cutting of soil up to 45 cm depth without turning) before planting was done through tractor mounted subsoiler. However, MB plow turned soil up to 20 cm depth.

After harvesting of sugarcane plant crop (main crop), each main plot treatment was divided into three subplots. In these subplots, three ratoon management treatments viz., I_1: Three hand weeding (HW), I_2: Integrated weed management (IWM) through application of herbicide atrazin @ 2 kg ai ha^{-1} (pre-emergence) followed by 2, 4-D @ 1 kg ai ha^{-1} (post emergence) at 60 days after planting and one hoeing at 90 days after planting (IWM):, I_3: Trash mulching and application of microbial consortia (TM+MC) comprising *Trichoderma viride, Gluconacetobacter diazotrophicus* and *Pseudomonas fluorescens*-PSB (TM+MC)-CFU-10^{9-10} per ml culture) were applied. The microbial consortium was applied at the time of ratoon initiation, at 25 days after initiation and 50 days after initiation. About 1 liter culture was diluted in 800 liters of water/ha for each foliar spray. Size of main plots and subplots was kept as 25.5 m x 6 m and 8 m x 6 m, respectively. These treatments were repeated four times in field experiment. Twelve treatment combinations (4 x 3) were assessed in each ratoon crop. The experiment was continued up to three ratoon crops and all the treatments of ratoon crops were repeated every time in fixed layout. All other recommended package of practices for growing of sugarcane crop such as irrigation, cane tying, wrapping, ground level harvesting were followed during experimentation.

Soil and plant studies

Initial (as discussed in earlier section) as well as treatment wise periodic soil sampling was done for determining various components. Soil organic carbon and available N contents were also analyzed during peak tillering (June), grand growth (September) and at harvest stages (Jan/Feb) of sugarcane plant/ratoon crops. Soil organic carbon content (Mg ha^{-1}) was calculated using the formula given below.

SOC (Mg ha^{-1}) = Soil organic carbon (g kg^{-1} soil) x 2.22* x bulk density (Mg M^{-3})

*Plow layer at 0–15 cm depth contains 2.22 million kg soil, thus multiplied with 2.22 to convert it into Mg ha^{-1}.

Periodic recording of observations related to other soil microbial biomass carbon (SMBC) and available N was also done during tillering, grand growth and harvesting stages in surface (0–15 cm depth) and subsurface (15–30 cm depth) layers. Soil microbial biomass carbon (SMBC) was determined using Chloroform fumigation- incubation method (Jenkinson and Powlson 1976). Microbial biomass C is equal to Fc/Kc. Fc is the difference in CO_2-C evolved by the fumigated and unfumigated soil, respectively. The value of Kc constant was considered as 0.45.

At the time of harvesting of each crop, ten canes were randomly selected for determination of juice quality parameters. Dry and green leaves were removed and individual cane length, diameter and weight were recorded. These canes were crushed in motor operated Cane Crusher and juice was extracted. Quality parameters of cane juice (°brix, pol percent and purity) were determined through Auto Pol. Commercial cane sugar (%) was determined through following formula (Meade and Chen 1977).

CCS (%) = {S-(B-S) x 0.4} x 0.73

Where S is the Sucrose percent juice and B is the °Brix

Commercial cane sugar (CCS) per ha was estimated by multiplying CCS (%) with sugarcane/ratoon cane yield.

CCS (t/ha) = CCS (%) x Sugarcane yield (t ha^{-1})/100

Statistical analysis

The data on various soil and plant characters recorded for sugarcane plant crop was statistically analyzed. The data recorded for all three ratoon crops were statistically analyzed under split plot design applying four preplant tillage treatments in main plots and three ratoon management practices in sub plots. Pooled analysis of all three ratoon crops was done according to Cocharan and Cox (1957) and three years mean data of ratoon for growth and yields have been presented in the paper. The statistical analysis was done through software SAS (IASRI 2020) and standard error (SE) and LSD (Least Significant Difference) values were determined to assess the significant differences. First year data recorded for sugarcane plant crop (main plots only) was analyzed in RBD.

Results

Bulk density (BD) of soil

Bulk density of soil represents compaction faced by roots for crop growth. Initial bulk density of experimental soil in surface (0–15 cm) and subsurface (15–30 cm) layers was recorded as 1.45 and 1.55 Mg m^{-3}, respectively. Pooled data on bulk density presented through figure (1a-1d) described significant positive effect of subsoiling on reduction of soil compaction. Mean values of bulk density (1.50 Mg m^{-3}) in surface layer (0–15 cm depth) were significantly lower than subsurface layer (1.57 Mg m^{-3}). Plowing through moldboard plow and harrowing reduced BD in surface layer. However, subsoiling reduced BD up to 30 cm depth significantly. Conventional tillage treatment increased BD at the harvest of each crop in both the depths. Higher soil compaction was recorded due to practice of hand weeding and integrated weed management in ratoon crop. Trash mulching along with microbial consortia reduced bulk density of soil. Continuous application of trash pulverized soil, improved biosphere and decreased compaction measured through bulk density.

Soil organic carbon (SOC)

Tillage affected soil organic carbon content (SOC) during the growth of sugarcane plant and ratoon crops. SOC content of 0–15 cm depth was significantly higher than 15–30 cm depth (Figure 2a-d). In 0–15 cm depth, primary tillage through moldboard plow followed by harrowing recorded the lowest SOC (11.55 Mg ha^{-1}) at the harvest of plant crop. Moldboard plow turned top soil and recorded the lowest SOC in 0–15 cm depth. However, in subsurface layer, it could be increased up to 12.28 Mg ha^{-1} at the harvest of plant crop.

The higher SOC was recorded during tillering stage, further reduced during grand growth and increased thereafter during harvest. Higher mean SOC was recorded in sugarcane ratoon crop than plant crop. It showed that continuous sugarcane ratooning did not decrease mean soil organic carbon content. However, the significant differences among the tillage treatments were recorded. Significant reduction in SOC at all the growth stages was recorded after practicing moldboard plowing and harrowing. Subsoiling in sugarcane cultivation improved soil organic carbon contents. The greater increase (31.09%) was determined in 15–30 cm depth compared to 0–15 cm depth (16.52%). At all the growth stages, subsoiling improved SOC content as compared to other preplant tillage treatments (Figure 2a and b).

Soil organic carbon in plant crop at 0–15 cm depth has been reflected in Figure 2a. Positive correlation (R^2 0.413/r = 0.64) showed response of primary tillage practices on buildup of soil organic carbon. The management practices following minimum soil tilling showed the positive response in improving soil carbon. Three ratoons were taken from single plant crop and effect of primary tillage showed higher degree of positive correlation (R^2 = 0.757/r = 0.87) in soil organic carbon accumulation (Figure 2b). Post plant tillage practices applied in ratoon crops also had higher degree of correlation (R^2 = 0.983/0.838) in both the soil depths. Post plant tillage in ratoon also influenced SOC during the crop growth (Figure 2c and d). At the harvest of ratoon crop, the higher rate of increase (13.94%) was determined in subsurface layer as compared to surface layer (10.99%) by adoption of IWM. Trash mulching along with microbial consortia improved SOC by 10.99% to 19.91% percent at different growth stages. However, in 15–30 cm depth, it ranged from 11.76% to 13.94% as compared to hand

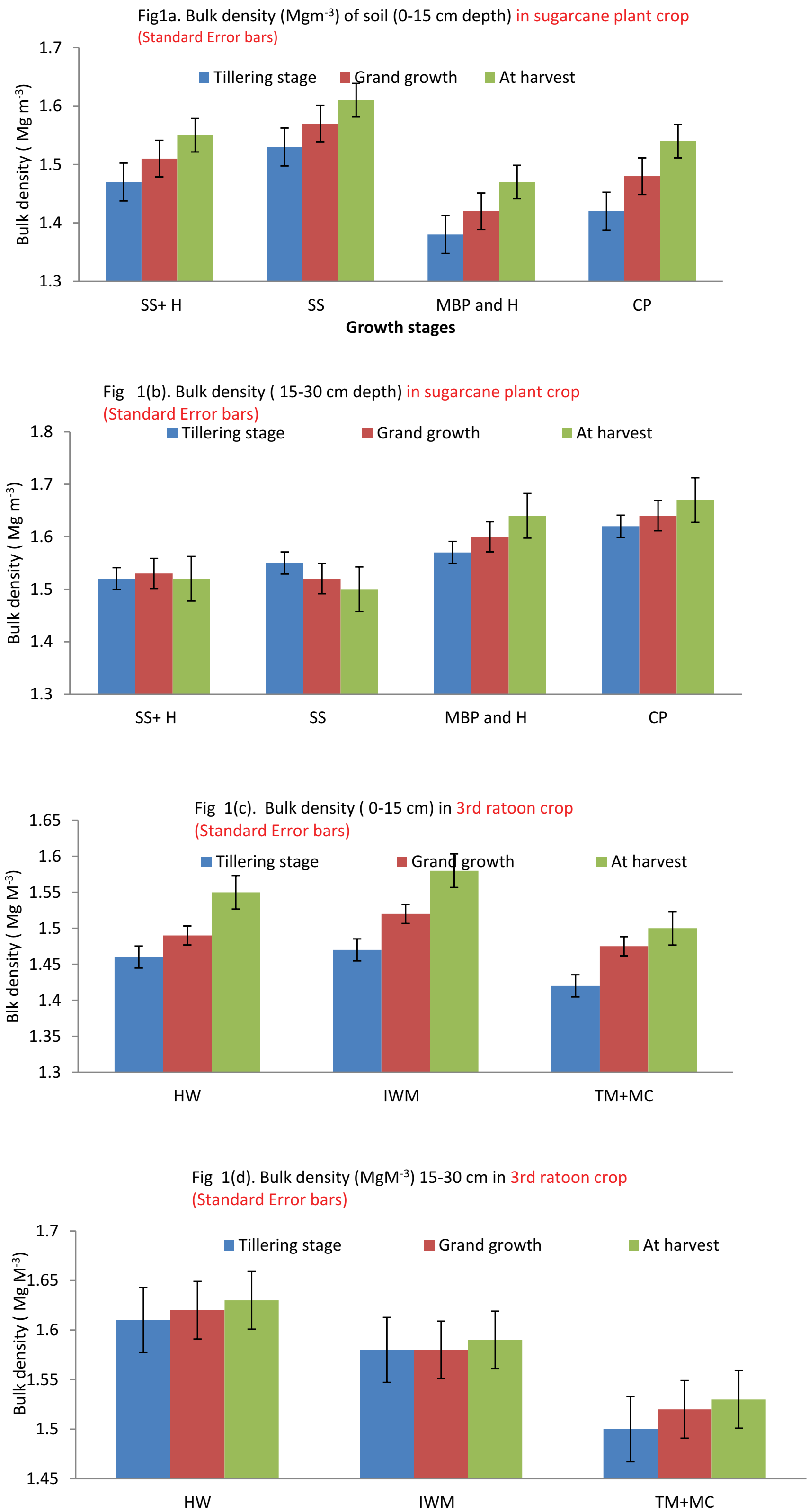

Figure 1. (a) Bulk density of soil (0–15 cm depth) as influenced by different pre plant tillage treatments.(b) Bulk density of soil (15–30 cm depth) as influenced by different pre plant tillage treatments. (c). Bulk density of soil (0–15 cm depth) as influenced by different ratoon management practices. (d). Bulk density of soil (15–30 cm depth) as influenced by different ratoon management practices.

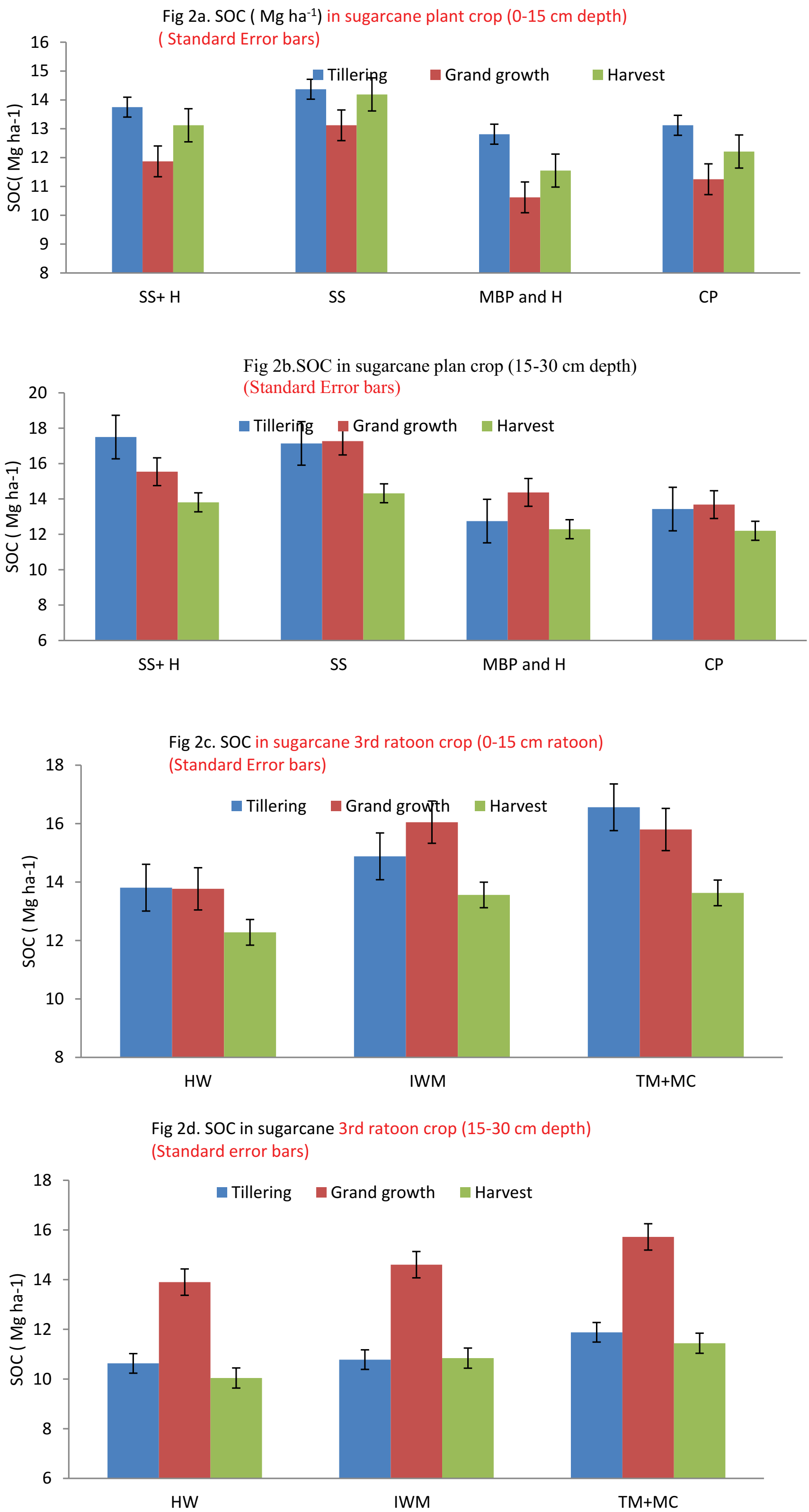

Figure 2. (a) Soil organic carbon (Mg ha^{-1}) in sugarcane plant crop (0–15 cm depth) as influenced by preplant tillage treatments. (b) Soil organic carbon (Mg ha^{-1}) in sugarcane plant crop (15–30 cm depth) as influenced by preplant tillage treatments. (c) Soil organic carbon (Mg ha^{-1}) in sugarcane ratoon (0–15 cm depth) as influenced ratoon management practices. (d) Soil organic carbon (Mg ha^{-1}) in sugarcane ratoon (15–30 cm depth) as influenced by ratoon management practices.

weeding. This showed that conventional practice of hand weeding is detrimental for sustaining soil organic carbon in sugarcane-based system. IWM ranked second in trash mulching and application of microbial consortia for sustaining soil organic carbon.

Soil organic carbon (SOC) and available N (Fig 3a) indicated positive correlation (R^2 = 0.084/ r = 0.28) in plant crop. However, the higher degree of positive correlation was worked out with ratoon crop (R^2 = 0.313/r = 0.56 -fig 3b). Multiratooning and buildup of soil organic carbon favored N release at higher rates in ratoon crop. In surface layer, SOC favored higher release of available N and correlation value of R^2 = 0.336/r = 0.579 was obtained (Fig 3 c). Ratoon crop showed higher degree of positive correlation (R^2 = 0.444/r = 0.666) in 0–15 cm depth between SOC and available N. This showed that SOC and available N both could be sustained and fertility and productivity of soil could be maintained simultaneously.

Available N

Available N in soil is the product of mineralization of organic compounds and ammonification/ nitrification of inorganic fertilizers used for growing of crop. Improvement in SOC also favored N mineralization due to enhanced bacterial population. Subsoiling favored available N (0–15 cm depth) at all the growth stages in sugarcane plant crop. Significant reduction of SOC in surface layer was recorded due to moldboard plowing and harrowing. Soil turning due to which subsurface soil became the surface soil might be one reason for reduced SOC in these plots. However, the moldboard plowing induced SOC in subsurface layer.

In sugarcane plant crop, the highest available N at all the growth stages was recorded with sub soiling (Table 1) and direct planting of sugarcane. However, sub soiling and harrowing also ranked second to sub soiling alone. Mean N level throughout crop period in 0–15 cm depth ranged from 203.3 to 267.4 kg ha^{-1}. However, significant lower values were recorded in subsurface layer (177.5 kg ha^{-1} to 224.5 kg ha^{-1}) as compared to surface layer. During tillering and grand growth stages, higher availability of N (252 to 310.2 kg ha^{-1}) was analyzed with adoption of subsoiling as compared to conventional practice (218.4 to 224 kg N ha^{-1}). Due to adoption of subsoiling, subsurface layer also showed an improvement in available N content (232 kg ha^{-1} during grand growth stage) over conventional tillage (184 kg N ha^{-1} during grand growth stage).

Mean data of three sugarcane ratoon crops at all the growth stages reflected superiority of subsoiling over other primary tillage treatments (Table 2). Subsoiling improved N availability by 23.89% and 13.65% in surface layer during tillering and grand growth phases as compared to conventional tillage. The practice also improved available N level in subsurface layer in the range of 9–10% during tillering and grand growth phases. Moldboard plowing and harrowing showed the lowest available N content in surface layer during tillering and grand growth stages. However, at the harvest it was marginally better than conventional tillage.

Trash mulching and application of microbial consortia (TM+MC) improved mean N availability at all the growth stages (Table 2). Surface layer showed mean enhancement of available N by 7.87% to

Table 1. Effect of pre plant tillage treatments on available N (kg ha^{-1}) in soil during sugarcane plant crop.

	0–15 cm depth			15–30 cm depth		
Treatments (Preplant tillage)	Tillering stage	Grand growth stage	At harvest	Tillering stage	Grand growth stage	At harvest
T_1 Subsoiling and harrowing	300.4	249	210	221	210	172
T_2 Subsoiling and direct planting	310.2	252	183	228	232	182
T_3 Disc plowing and harrowing	240.4	214	235	238	240	171
T_4 Conventional practice	218.4	224	185	210	184	185
S.E.	5.91	3.96	3.96	4.41	5.37	4.09
LSD.($P \le 0.05$)	12.40	8.90	8.42	9.50	10.34	8.43

Table 2. Effect of various treatments on available N (kg ha^{-1}) in soil during 3rd sugarcane ratoon crop.

Treatment	0–15 cm depth			15–30 cm depth		
	Tillering stage	Grand growth stage	At harvest	Tillering stage	Grand growth stage	At harvest
A Pre plant tillage (residual effect)						
T_1 Subsoiling and harrowing	266	278	219	228	229	221
T_2 Subsoiling and direct planting	280	308	226	229	242	231
T_3 Disc plowing and harrowing	201	267	239	216	231	218
T_4 Conventional practice	226	271	232	210	219	226
S.E.	6.36	6.79	5.30	5.80	6.08	5.09
LSD.($P \leq 0.05$)	13.20	14.46	11.24	12.45	12.78	10.65
B. Ratoon management practice						
I_1Hand weeding (HW)	201	267	218	218	211	211
I_2 Integrated weed management (IWM)	244	288	225	210	226	219
I_3 Trash mulching + Microbial consortia (TM+MC)	285	288	244	234	254	242
SE	5.37	5.83	5.09	5.37	5.37	4.52
LSD.($P \leq 0.05$)	11.20	12.34	10.89	11.35	11.45	9.90

*Treatments were applied in sugarcane (plant) – ratoon system

41.79% *vis-à-vis* 7.34% to 20.38% in subsurface layer. The highest available N content (288 kg ha^{-1} and 254 kg ha^{-1} in 0–15 and 15–30 cm depths, respectively) was analyzed at grand growth stages with application of trash and microbial consortia. Mean available N in surface layer was improved to the level of 244 kg N ha^{-1} due to adoption of trash mulching along with microbial consortia compared to 218 kg N ha^{-1} with hand weeding. A similar treatment gave consistent improvement in subsurface layer also in the tune of 211 kg N ha^{-1} to 242 kg N ha^{-1} at the harvest stage. Continuous mulching in all ratoon crops enhanced microbial population due to which mineralization activity could also be enhanced. Thus application of organics improved SOC level as well as available N level for further growth of crop.

Soil microbial biomass carbon (SMBC)

Soil Microbial biomass carbon (Table 3) is influenced by soil organic carbon and bacterial population in rhizospheric environment. Soil microbial biomass carbon (717.5 mg C/kg soil/day to 1120.3 mg C/kg soil/day) was reduced in 15–30 cm soil depth in comparison with 0–15 cm. Subsoiling improved SMBC by 39% to 73% and 32.20% to 46% in 0–15 cm and 15–30 cm depth, respectively. Moldboard plowing and harrowing before planting of sugarcane also improved SMBC in subsurface layer (Table 2). It was due to inversion of top soil which increased SOC in subsurface layer also. Integrated weed management in sugarcane plant crop also favored SMBC as compared to hand weeding. An improvement of 54.89% was registered in 0–15 cm depth at the harvest stage. Due to adoption of IWM, the higher increase (81%) in SMBC was recorded in subsurface layer compared to hand weeding. This showed adverse effect of hand weeding on soil microbial activity. In addition, benefit of minimum tilling on improving biological activity was recorded.

Higher mean SMBC in ratoon cane (Table 4) was recorded as compared to sugarcane plant crop. SMBC was reduced (981.25 mg C/kg soil/day to 1228.75 mg C/kg soil/day) in subsurface layer. High temperature along with high humidity during grand growth phase (July to September) accelerated SMBC. Higher microbial activity also mineralized SOC and released available N during grand growth phase. Among all the primary tillage treatments, sub soiling enhanced SMBC at the highest level (1574 mg C/kg soil/day at grand growth stage in 0–15 cm soil depth). In subsurface layer, sub soiling also enhanced SMBC significantly (>27%) over conventional tillage. Sub soiling improved SMBC by 11.47% to 20.81% in 0–15 cm depth *vis-à-vis* 27.62% to 37.42% in 15–30 cm depth. Conventional tillage and tillage through moldboard plow and harrowing could not reach to the level of subsoiling. Post plant tillage adopted in ratoon crop significantly influenced mean SMBC in ratoon. Improvement of 39.9% to 46.88% was recorded in surface layer due to adoption of trash mulching along with microbial consortia. However, higher increase (32.95% to 92.94%) was observed in subsurface layer. Integrated weed management in sugarcane ratoon also improved SMBC in surface and subsurface layers. Improvement in the range of 15.26% to 26.13% was discernable in top soil layer *vis-a-vis*16.17% to 36.23% in subsurface layer.

Table 3. Effect of pre plant tillage treatments on soil microbial biomass carbon (mg CO_2-C kg^{-1} soil day^{-1}) during sugarcane plant crop.

	0–15 cm depth			15–30 cm depth		
Treatments (Preplant tillage)	Tillering stage	Grand growth stage	At harvest	Tillering stage	Grand growth stage	At harvest
T_1 Subsoiling and harrowing	1070	1345	1112	660	1116	980
T_2 Subsoiling and direct planting	1379	1600	1540	780	1190	1105
T_3 Disc plowing and harrowing	880	1236	995	840	1360	1320
T_4 Conventional practice	985	1150	890	590	815	810
S.E.	31.28	25.78	27.04	15.88	21.82	18.55
LSD.(P ≤ 0.05)	65.34	56.56	56.24	32.45	45.34	39.45

Table 4. Effect of various treatments on soil microbial biomass carbon (mg CO_2-C kg^{-1} soil day^{-1}) during 3rd sugarcane ratoon crop.

Treatment	0–15 cm depth			15–30 cm depth		
	Tillering stage	Grand growth stage	At harvest	Tillering stage	Grand growth stage	At harvest
A. Pre plant tillage (Residual effect)						
T_1 Subsoiling and harrowing	1120	1412	1356	1050	1259	1210
T_2 Subsoiling and direct planting	1215	1574	1498	1120	1356	1340
T_3 Disc plowing and harrowing	912	1249	1120	940	1210	1190
T_4 Conventional practice	1090	1320	1240	815	1090	1050
s	27.19	31.59	30.49	22.00	29.41	32.06
LSD.($P \leq 0.05$)	56.23	65.34	62.67	46.34	61.90	67.23
B. Ratoon management practice						
I_1Hand weeding (HW)	888	1173	1075	690	1050	878
I_2 Integrated weed management (IWM)	1120	1352	1256	940	1240	1020
I_3 Trash mulching + Microbial consortia (TM+MC)	1245	1641	1579	1314	1396	1694
SE	24.67	26.55	27.43	20.43	27.19	30.49
LSD.($P \leq 0.05$)	52.34	58.34	58.34	42.23	56.23	62.23

*Treatments were applied in sugarcane (plant) – ratoon system

Sugarcane yield attributes, cane yield and sugar yield

Sub soiling at 45 cm depth and direct planting of sugarcane improved sugarcane growth and yield attributes (Table 5). The highest number of millable canes (135.4 thousand ha^{-1}) and individual cane length (236.8 cm), cane diameter (2.43 cm) were recorded with sub soiling and direct planting of sugarcane. Improved cane length and diameter also improved individual cane weight (1254 g). Thus sugarcane (97.26 t ha^{-1}) and sugar (11.87 t ha^{-1}) yields also improved significantly under subsoiled treatment compared to other pre plant tillage treatments. Subsoiling and harrowing were found almost at par with subsoiling alone. The tillage through moldboard plow and conventional tillage could not prove their superiority. This showed that subsoiling had greater benefit in sugarcane-based system. Increase in sugarcane and sugar yields due to improvement in soil quality parameters and yield attributes of sugarcane resulted in improvement of sugarcane and sugar yields.

The highest mean number of millable canes and all the yield attributes (cane length, diameter and weight) were recorded by subsoiling (Table 6). This increased ratoon cane (117.6 t ha^{-1}) and sugar yields (14.48 t/ha). Subsoiling and harrowing also produced results on par with subsoiling alone. Hand weeding and IWM produced results at par. Trash mulching along with application of microbial consortia brought forth significant improvement in growth, yield and sugar yields as compared to hand weeding/IWM. The highest sugarcane ratoon (110.5 t ha^{-1}) and sugar yields (13.62 t ha^{-1}) were obtained by trash mulching along with microbial consortium. Mean improvement (14–15%) was obtained in increasing sugarcane and sugar yields due to adoption of TM +MC as compared to hand weeding (Table 3). Interaction effect between year and treatments was not found significant which

Table 5. Effect of pre plant tillage growth, yield attributes and sugar yield in sugarcane plant crop.

Treatment (Preplant tillage)	Millable canes (000/ha)	Cane length (cm)	Cane diameter (cm)	Cane weight (g)	Sugarcane yield (t/ha)	CCS** (t/ha)
T_1 Subsoiling and harrowing	129.7	226.7	2.53	1181.5	92.75	11.23
T_2 Subsoiling and direct planting	138.39	240.83	2.42	1254.17	97.26	11.97
T_3 Disc plowing and harrowing	111.55	231.67	2.45	1206.5	82.73	10.29
T_4 Conventional practice	113.09	213.5	2.46	1092.5	87.4	10.85
S.E.	4.69	5.03	0.04	58.27	3.48	0.31
LSD.($P \leq 0.05$)	8.31	8.92	0.09	103.2	6.15	0.62

* Commercial cane sugar (CCS)

Table 6. Effect of pre plant tillage growth, yield attributes and commercial cane sugar (CCS) in sugarcane ratoon (mean data of three ratoon crops).

Treatment	Millable canes (000/ha)	Cane length (cm)	Cane diameter (cm)	Cane weight (g)	Ratoon cane yield (t/ha)	CCS**(t ha^{-1})
A. Preplant tillage (residual effect)						
T_1 Subsoiling and harrowing	119.8	210.4	2.19	923.3	103.3	12.72
T_2 Subsoiling and direct planting	132.1	231.2	2.23	973.3	117.6	14.48
T_3 Disc plowing and harrowing	116.9	220.2	2.21	925.6	94.7	11.66
T_4 Conventional practice	125.1	199.0	2.21	904.4	91.8	11.31
S.E.	3.68	5.03	0.06	21.80	2.29	0.40
LSD.($P \leq 0.05$)	7.86	11.42	0.12	46.85	4.86	0.86
B. Ratoon management practice						
I_1Hand weeding (HW)	123.5	221.5	2.20	951.7	96.4	11.86
I_2 Integrated weed management (IWM)	119.2	203.6	2.21	880.8	98.7	12.15
I_3 Trash mulching + Microbial consortia (TM +MC)	127.7	220.5	2.22	962.4	110.4	13.6
SE	2.69	3.96	0.04	16.26	2.47	0.28
LSD.($P \leq 0.05$)	5.84	8.62	NS	32.5	4.10	NS

* Commercial cane sugar (CCS)

Table 7. Mean sum of squares due to various components and pooled analysis of growth and yield data of three ratoon crops.

Source of Variation (DF in brackets)	Millable canes (000/ha)	Cane length (cm)	Cane diameter (cm)	Cane weight (g)	Ratoon cane yield (t/ha)	CCS(t ha^{-1})
Year (2)	26.427	9.231	0.005	225.185	88.875	0.006
Rep within Year (6)	57.763	1,911.615	0.010	1,401.809	66.889	0.138
Treatment (11)	446.522	2,052.592	0.003	19,212.416	1,356.340	20.620
Year x Treat (22)	4.846	320.369	0.001	150.784	6.863	0.041
Pooled Error (66)	17.099	601.555	0.003	214.768	9.204	0.042
Total (107)						
LSD for Year	4.750	27.326	0.062	23.400	5.112	0.232
LSD for Treatments	2.752	22.374	0.041	15.349	3.275	0.252
LSD for Years x Treatments	NS	NS	NS	NS	NS	NS

indicated that treatments behaved independently over the season/years. However as per year and treatment effects in growth and yield parameters were worked out (Table 7).

Discussion

Effect of preplant tillage

Preplant tillage through subsoiling reduced bulk density of soil and decreased compaction, improved water and air movement in subsurface layer (Kooistra and Tovey 1994), reduced soil temperature (Brussard and Van Fassan 1994) and influenced biological processes, increased denitrification (Linn and Doran 1984) and so on. Subsoiling could improve infiltration rate compared to other tillage practices performed up to 15–20 cm depth (Johnson and Mouldenhauer 1979). Experimental soil belongs to the category of silty loam. In silt and silt loam soil, a bulk density of 1.55 Mg M^{-3} is often a minimum value at which root restriction may be observed (USDA-NRCS 1996). Due to higher silt and clay contents, hard pan of plow layer formed which restricted root penetration and decreased water available to the crop. The subsoiler shattered soil at that depth and decreased bulk density (BD) and increased water and air movement in deeper layers (Hamza and Anderson 2002).

The higher bulk density of subsurface layer was recorded due to reduced porosity, low soil organic matter and deposition of silt and clay particles and due to larger soil aggregates after continuous shallow plowing (Osunbitan, Oyedele, and Adekalu 2005). Hard pan of plow layer also increases runoff and reduces the rate of nutrient cycling (Logsdon and Karlen 2004). Subsoiling cuts soil at 45 cm depth and facilitated movement of water and air. It also allowed for crop residues to be moved in deeper layer. This also reduces the bulk density in subsurface layer. Subsoiling increased macro porosity and increased saturated hydraulic conductivity and air permeability (Drewry and Paton 2000). However, moldboard plow could affect BD significantly up to top soil layer. Tillage increases the drying rewetting and freezing thawing cycles which increases the susceptibility of aggregates to physical disintegration (Lee et al. 2009). This was the main cause of reduction of bulk density. Intensive tillage through conventional cultivator, harrowing and rotavator resulted in degradation of soil chemical, physical and biological properties. Reduced BD in top soil layer and lower rates of microbial biomass were produced in this condition (Garside et al. 1997).

Agricultural activities affect the physical and chemical characteristics of the soil and also influence microbial population and their activities (Dick 1992). Soil organic matter affects soil physical, chemical and biological properties and processes and is considered a key indicator of soil sustainability and crop productivity (Gregorich et al. 1994). Retention of residue C in SOC pools involves complex environmental and biological control including initial SOC contents, mass of C inputs, tillage practices, climatic factors, soil N content and chemical composition of residue (Wilhelm et al. 2004).

Higher SOC was recorded in surface layer as compared to subsurface layer. Reduced SOC through conventional tillage was recorded in subsurface layer compared to subsoiling. Subsoiling increased the penetration of crop residues in deeper layer influencing higher organic carbon (Sun et al. 2015) and facilitated water and air movement suitable for root growth (Shahidi, Dyck, and Malhi 2014). Soil organic matter is derived more from root inputs than from above ground biomass, but C allocation from above ground biomass plays an important role in C dynamics (Doran, Wilhelm, and Power 1984). Plowing through moldboard plow opened the soil for carbon oxidation and reduced the SOC contents as compared to subsoiling (Fontaine et al. 2007).

In general labile SOC is considered to be more easily decomposed by soil microbes and lost due to tillage than humic C (Grandy and Robertson 2006). Subsoiling did not turn the soil and facilitated higher microbial activity which increased SOC. Several researchers reported increase in SOC due to reduced tillage (Kahle et al. 2013) compared to conventional tillage. Subsoiling provides extension of sugarcane roots in deeper layers and these roots supply substantial amounts of C through root exudates (Nair, Kumar, and Nair 2009). Adoption of continuous no tillage has contributed to buildup of herbicide-resistant weed population, increased incidence of soil and stubble borne diseases and stratification of nutrients and organic carbon near the soil surface (Thomas et al. 2007). Minimum tillage intervention (Dang et al. 2014) through subsoiling and direct sugarcane planting managed these problems. Globally growers are shifting toward the flexible approach (Kirkegaard et al. 2014).

The higher SOC during tillering phase was due to smaller accumulation (<20%) of dry matter up to maximum tillering phase (Shukla et al. 2009). During grand growth phase, more than 80% dry matter accumulation is done by sugarcane crop. Maximum microbial activity is concentrated during grand growth phase (rainy season) because of congenial temperatures and humidity (Dick 1992). Thus higher rate of decomposition of various organic compounds could be possible during grand growth stage to supply the nutrients required for crop growth. The higher microbial activity during grand growth phase released N from SOC which decreased its level temporarily. Effect of tillage on total N affects the SOC as the N cycle is linked to C cycle. Tillage increases aggregate disruption, making soil more accessible to microorganisms (Six et al. 2004) and increases mineral N release from soil N pools

(Kristensen, McCarty, and Meisinger 2000) with SOC and available N showed the positive correlation (Babujia et al. 2010). Surface layer showed higher degree of N release as compared to subsurface layer.

Higher mean SOC content in ratoon was reported due to continuous rhizodeposition, root biomass, release of organic acids compounds in rhizosphere (Bowman and Turnbull 1997; Garten 2002) as compared to plant crops. Sugarcane plant crop data of one year has been reported, however, ratoon data of three seasons continuously facilitated buildup of soil organic carbon. Moldboard plowing and harrowing decreased SOC due to maximum exposure of top soil to environment.

Subsoiling before planting increased mean SOC contents during raising of ratoon crop. It showed that in silty loam soil, zonal tillage provided through subsoiling improved the biological activity in deeper layers and further SOC level could also be improved (Garcia et al. 2007).

Moldboard plowing and harrowing affected SOC content adversely. Plowing through MB plow decreased SOC contents through fragmentation of macroaggregates, thereby improving microbial access to aggregate protected soil (Six et al. 2004) and are stimulating decomposition of soil C (Fontaine et al. 2007; Kettler et al. 2000).

Adoption of subsoiling improved higher availability of N particularly during tillering and grand growth stages. Higher availability of N during tillering was possible due to lower dry matter accumulation and N uptake (Shukla et al. 2009) during that time. However, during grand growth phase, the higher availability was due to improved microbial activities and greater release of N through mineralization (Jiang et al. 2011). Subsoiling created more congenial rhizospheric environment for nutrients availability as compared to other pre pant tillage measures. Tillage has greatest impact on soil biological properties. Physical disturbances affect soil water content, temperature, aeration and the degree of mixing of crop residues within the soil matrix (Dick 1992; Kladivko 2001).

Mold board plow turned top 20 cm soil surface. However, soil turning reduced water stable aggregates, organic carbon, SMBC (Karlen et al. 2013) and availability of N in surface layer. Moldboard plowing showed greatest negative effect on soil quality parameters. Moldboard plowing and harrowing reduced SOC which resulted in lowering available N content also during tillering and grand growth phases, etc.

Soil microbial communities are responsible for various soil functions viz., organic matter turn over and nutrient cycling (Dick 1992; Kladivko 2001). Minimum tillage integrated with mulch affects microbial biomass and activity (Kaschuk, Alberton, and Hungria 2010; Young and Ritz 2000). SMBC is influenced by SOC and bacterial population. Minimum tillage through subsoiling increased SMBC in surface and subsurface layers during crop growth period. Rincon-Florez et al. (2016) reported that in the three-month cycle, SMBC, total microbial activity and microbial community structure through one time chiseling was at par with no tillage. Higher microbial biomass has been recorded by several researchers after adopting no tillage/minimum tillage (Alvear et al. 2005; Bausenwein et al. 2008).

Moldboard plow decreased SMBC in ratoon crop especially in surface layer. Moldboard plowing reduced soil macroaggregates content which provides an important microhabitat for microbial density, diversity and activity (Six et al. 2002). Tilling tools disturb fungal hyphal growth at soil surface leading to a reduction of their relative population in the soil (Balesdent, Chenu, and Balabane 2000; Frey, Eliott, and Paustian 1999). Large animals (earth worms and termites) are more sensitive to tillage than smaller organisms due to longer life cycles, combined with physical disruption of soil and habitat destruction (Wardle 1995). Higher SMBC in ratoon was recorded due to higher accumulation of soil organic carbon and buildup of higher microbial population (Van Gestel, Merckx, and Vlassek 1996). The highest SMBC during grand growth phase was recorded due to improved microbial activities. Subsoiling before sugarcane planting significantly increased SMBC during grand growth phase because of higher microbial activities in favorable climatic conditions.

Lienhard et al. (2013) reported positive effect of reduced tillage in improving soil physical characteristics, organic carbon and microbial biomass. Microbial distribution pattern is influenced by pore size associated with particular aggregates or differences in the clay and organic carbon content (Van Gestel, Merckx, and Vlassek 1996). In sugarcane-based system, it could be inferred that subsoiling had great benefit in the build-up of SOC and SMBC particularly in poorly drained soils.

Positive effect could be recorded up to 30 cm depth. However, aggressive tillage through moldboard plowing and harrowing reduced soil aggregation, C and N storage and microbial biomass and activity (Vargas-Gil et al. 2011)

Composition and mass of C pools control soil respiration are soil organic matter, crop residues and organic substances released by living roots (Kuzyakov 2006). Soil temperature, moisture (Raich and Schlesinger 1992; Wang, Amundson, and Niu 2000) and enhanced microbial activities (Borken et al. 2003; Kim et al. 2012) during grand growth phase improved microbial biomass carbon. Subsoiling shattered the hard pan and released CO_2 accumulated in soil clods and aggregates. After this first degassing, the increase of O_2 availability in the subsoiler tilled soil promoted microbial activity resulting in enhanced soil respiration and microbial biomass carbon (Calderson and Jackson 2002).

Subsoiling affected sugarcane yield attributes positively in plant and ratoon crops. The higher mean growth attributes (cane length, diameter and weight) were recorded in subsoiling plots as compared to other tillage treatments. The higher soil organic carbon and N availability optimized rhizospheric environment for crop growth. Reducing bulk density through subsoiling facilitated root development which was reflected in higher biomass, growth attributes and cane yield (Shukla et al. 2018). Higher availability of nutrients, moisture and air in deeper layers also supported crop growth and yield attributes positively. One time strategic tillage could increase the total pH, buffer capacity and enhance the potential for increasing nutrient availability in deeper layers (Garcia et al. 2007). Positive effect of strategic tillage on increasing crop yields has been obtained by several researchers (Kettler et al. 2000; West, Griffith, and Steinhardt 1996). Removal of compaction through zonal tillage for improving cane productivity and yields has been profitable. Ripping and hilling the compacted soil to cane rows improved cane yield, sugar yields and water infiltration in subsurface layers also (Bangita and Rao 2012).

Effect of preplant tillage treatments affected plant cane as well as ratoon yields significantly. Conventional practice showed reduction in number of millable canes, cane length, cane diameter and weight as compared to subsoiling and subsoiling + harrowing (SS+H). Fine tilth could be obtained by harrowing resulted in higher cane yield as compared to conventional tillage. However, harrowing decreased soil quality parameters such as SOC, available N and SMBC. Subsoiling followed by direct planting of sugarcane influenced soil quality parameters, sugarcane yield attributes and sugar yields significantly (Abu-Hamdeh 2003). This practice has been found to be sustainable and could be adopted for sugarcane growers.

Effect of ratoon management practices

Practice of hand weeding in ratoon cane provided shallow tillage which pulverized the soil in upper layer. However, application of trash mulching along with microbial consortia reduced bulk density of top soil layer. Minimum tillage integrated with mulch demonstrated positive impact on soil physical and chemical properties. Conservation tillage is a widely adopted practice to improve sustainability (Blano-Canqui and Lal 2008).

Trash mulching along with microbial consortia enhanced SOC (Perez-Brandan et al. 2012). This also favored infiltration of water and reduced soil erosion and soil carbon loss, temperature conservation, increased efficiency in nutrient cycling and improvement in soil structure (Babujia et al. 2010). Any net changes in SOC are determined by the organic matter input of the land use and the degree of organic carbon protection from soil clay minerals (Dang et al. 2015). Sugarcane cultivation resulted in sequestration of sugarcane derived C which adequately compensates their losses (Shukla et al. 2017b).

Effect of tillage on N mineralization was found to be short lived for a few weeks (Silgram and Shepherd 1999). Besides, tillage reduces the potential for P loss in run off by redistributing nutrients into the soil. The higher microbial population and activity in 0–15 cm depth released higher amount of N. Tillage causes major shifts in the number and composition of a large range of soil micro-fauna and micro-flura (Bockus and Shroyer 1998).

Trash mulching along with microbial consortia improved N due to higher microbial activity, SMBC, SMBN, and available N in these plots (Jiang et al. 2011). Trash mulching showed higher availability of N in multiratooning system (Babujia et al. 2010). Conservation tillage through application of crop residues is gaining importance in India particularly in those areas of IGP which are facing deterioration in soil fertility due to extensive tillage operations (Ladha et al. 2003). Apart from low economic input benefits of nutrient conservation and minimizing soil erosion could also be achieved (Lal 2004) through conservation practices. Trash mulching along with microbial consortia enhanced SMBC (Pandey, Agarwal, and Bohra 2014) in plant and ratoon crops. Several researchers reported the efficiency of microbes viz., *Trichoderma viride, Gluconacetobacter and Pseudomonas spp* along with trash for further release of nutrients in soil (Shukla et al. 2012, 2008).

Trash mulching in ratoon favored microbial population and activity. Thus soil respiration (Kuzyakov 2006) and other quality parameters index could be improved (Ladha et al. 2003). The higher quality supported crop growth through nutrients conservation and minimizing soil erosion (Lal 2004). However, optimum sucrose content with higher cane yield resulted in higher sugar yields because of higher tonnage. Sugarcane and sugar yields with adoption of subsoiling and trash mulching along with microbial consortia could be improved. Crop residue retention improved soil structure, organic matter and increased crop yields (Alvear et al. 2005; More 1994).

Reduced yield in conventional tillage may be obtained due to soil compaction (Botta et al. 2010). This caused poor growth of roots and lowered rate of mineralization required for higher yields. Mold board plowing and harrowing led excessive tillage depleted soil organic matter and contributed to yield decline (Pankhurst et al. 2003).

Conclusions

Nowadays soil compaction in medium to heavy textured soils is becoming a serious concern because of conventional shallow tillage. Excessive tillage provides larger exposure of soil to external environment, leading to higher release of CO_2 through soil, destructs soil structure, microbial community resulting in lower soil organic carbon, microbial biomass carbon, and nutrients availability. It has been observed that subsoiling increased rooting depth and root biomass and crop yields without significant decline in soil fertility. Keeping above points in view, the present investigation was undertaken to assess the effect of subsoiling and direct planting vs conventional tillage on soil quality parameters in sugarcane multiratooning system. Results indicated that continuous application of trash in ratoon along with microbial consortia pulverized soil, improved biosphere and decreased compaction. The management practices following minimum soil tilling showed the positive response in improving soil organic carbon. Buildup of soil organic carbon in multiratooning system favored N release at higher rates. Subsoiling provides zonal tillage in soil profile and could shattered impervious hard pan of plow layer. Significant positive effect of subsoiling and direct planting of sugarcane through IISR Cutter Planter and post plant tillage through trash mulching along with microbial consortia was recorded on soil quality parameters. Enhanced quality parameters influenced growth and yield of plant and ratoon crops. The following conclusions could be drawn from the results of four year experimentation on sugarcane (plant)-ratoon 1-ratoon2-ratoon3 system.

Pre plant tillage through subsoiling decreased bulk density and improved soil organic carbon and soil microbial biomass carbon in sugarcane (plant)-ratoon system. Trash mulching along with microbial consortia containing *Gluconacetobacter diazotrophicus, Trichoderma viride* and *Pseudomonas fluorescens* effectively improved soil quality parameters and sugarcane and sugar yields in multiratooning system. Parameters viz., SOC and SMBC, SMBC and available N had positive relationship among them. Those preplant or post plant tillage practices improved buildup of SOC, also improved SMBC and available N.

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