



Impact of subsoiling and preparatory tillage on productivity of sugarcane (*Saccharum officinarum*) and soil physico-chemical properties in sugarcane plant-ratoon cropping system

SATENDRA KUMAR¹, S K SAINI², AMIT BHATNAGAR³ and T C THAKUR⁴

Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145

Received: 14 September 2011; Revised accepted: 29 April 2013

ABSTRACT

A field experiment was conducted during 2008-10 at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand to study the effect of subsoiling and preparatory tillage on productivity of sugarcane (*Saccharum officinarum* L.) and soil physico-chemical properties. The experiment consisting of five subsoiling practices (no subsoiling, subsoiling at 1.0 m distance, subsoiling at 1.5 m distance, cross subsoiling at 1.0 m distance and cross subsoiling at 1.5 m distance) and three preparatory tillage practices (two harrowing, four harrowing and one rotavator) was laid out in strip plot design with three replications. Subsoiling operations resulted in significant increase in yield attributes and yield in plant and ratoon crop. Cross subsoiling at 1.0 m distance produced significantly more cane yield of 75.8 in plant and 74.9 tonnes/ ha in ratoon crop with 28.0 and 37.9 % increase over no subsoiling treatment, respectively. A significant improvement in soil physico-chemical properties was observed due to subsoiling operations. Bulk density and soil strength decreased and cumulative infiltration increased significantly under subsoiling treatments but soil pH and EC remained unaffected. Significantly more content of organic carbon, available soil N, P and K were noticed under subsoiling practices. Preparatory tillage practices did not exhibit significant effect on productivity of sugarcane and soil physico-chemical properties.

Key words: Harrowing, Productivity, Ratoon, Rotavator, Soil physico-chemical properties, Subsoiling, Sugarcane, Tillage

Sugarcane (*Saccharum officinarum* L.) assumes an important position in the Indian economy, contributing nearly 2.0% of national gross domestic product. India shares 13.2% of the world and 41.1% of Asian sugar production. The productivity of sugarcane in India is quite low owing to several factors, viz. poor crop management, poor soil condition, extreme weather situation, abiotic and biotic stress, etc. Hence, there is great need to enhance sugarcane productivity. Sugarcane is a deep rooted crop. Hence, effective exploitation of soil from deeper layers is important for harnessing potential crop productivity and/or quality. Preparatory tillage operations are usually carried by harrow and rotavator. However, the depth of tillage is confined to 10-15 cm. Repeated operations by harrowing confining to

constant depth over long period results in formation of hard pan in plough sole (Thakur and Kumar 1999). The presence of hard/compact layer in subsoil leads to restricted water infiltration thereby bringing many chemical and biological changes. During rainy season and/or on watering field temporary anaerobic conditions persist in root zone which adversely affects the plant growth. Further, compact layer in subsoil limits vertical root growth, which subsequently reduces nutrients and water uptake by the crop. Subsoil compaction also restricts the movement of nutrients as the application of fertilizers is usually accomplished by broadcasting and mixing and/or placing in upper 2-5 cm soil layer. Hence, there is need to break this subsurface compact layer and ameliorate aeration in subsoil for better root zone environment.

Subsoiling enhances or re-establishes the soil profile structure allowing rapid infiltration. Hard pan could be alleviated with the help of deep soil loosening equipment like chisel plough and subsoiler. This equipment improves soil structure by establishing a system of deep cracks and or fissures in the subsoil, facilitating the downward movement of water, air and roots enabling plants to withstand better

¹Former Ph D Scholar (e mail: satendrayadav.agro@gmail.com), ²ICAR Emeritus Scientist (e mail: drsaini.sk@gmail.com), ³Junior Research Officer (e mail: bhatnagaramit75@gmail.com), Department of Agronomy, College of Agriculture and ⁴ICAR National Professor (e mail: drtcthakur@yahoo.com), Department of Farm Machinery and Power Engineering, College of Technology

against short term anaerobic. Management of top soil helps in better moisture conservation, which is essential for proper establishment of the crop. Soil tillage is one of the fundamental agro-technical operations in agriculture because of its influence on soil properties, environment and crop growth. Since continuous soil tillage strongly influence the soil properties, it is important to apply appropriate tillage practices that avoid the degradation of soil structure, maintain crop yield as well as ecosystem stability. Hence, the present study was undertaken to assess the impact of subsoiling and preparatory tillage on productivity of sugarcane and soil properties in plant-ratoon cropping system.

MATERIALS AND METHODS

The field experiment was conducted during 2008-2009 and 2009-2010 at the NE Borlaug Crop Research Centre (29° N and 79.5° E, 243.8 m above msl), Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. The soil of the experimental plot was silty clay loam in texture having high content of organic carbon (1.1 and 0.686 %), low available nitrogen (196.2 and 166.7 kg/ha), medium phosphorus (21.4 and 12.6 kg/ha) and potassium (202.2 and 139.1 kg/ha) and neutral to slightly alkaline reaction (pH 7.4 and 8.1) at 0-15 and 15-30 cm depths, respectively. The initial soil bulk density was 1.44 and 1.61 Mg/m³ at 0-30 and 30-60 cm depth, respectively. The treatments consisting of five subsoiling [no subsoiling (S₁), subsoiling at 1.0 m (S₂), subsoiling at 1.5 m (S₃), cross subsoiling at 1.0 m (S₄) and cross subsoiling at 1.5 m (S₅)] and three preparatory tillage practices [two harrowing (2H), four harrowing (4H) and one rotavator (1R)] were laid out in strip plot design with three replications. The fertilizer dose of N:P₂O₅:K₂O was applied @ 120:60:40 kg/ha in plant crop

and 150:60:40 kg/ha in ratoon crop. Subsoiling was done by Pant ICAR Subsoiler-cum-Differential Rate Fertilizer Applicator at the depth of 40 cm. Planking was done to break the clods and field was leveled after final tilling. The dimensions of individual plots were 8 m × 4.5 m. The plant crop was planted on 29/03/2008 and harvested on 16/02/2009 and ratoon crop was harvested on 02/01/2010. Ring infiltrometre for cumulative infiltration, cone penetrometre for soil strength and core sampler for bulk density were used for determination of soil physical properties. Soil pH was determined by glass electrode pH meter and EC by conductivity meter. Soil organic carbon, available N, available P and available K were determined by modified Walkley and Black, alkaline potassium permanganate, spectro-photometry and flame photometric method (Jackson 1973), respectively.

RESULTS AND DISCUSSION

Yield attributes

Subsoiling treatments exhibited significant effect on yield attributes, viz. cane length, number of internodes, cane weight and number of millable canes (NMC) except cane girth in ratoon crop (Table 1). Cross subsoiling at 1.0 m recorded significantly more value of yield attributes both in plant and ratoon crop, however in plant crop it remained at par with cross subsoiling at 1.5 m and subsoiling at 1.0 m for cane length (225.8 cm), girth (7.8 cm) and NMC (100.2 thousand/ha), and with cross subsoiling at 1.5 m for number of internodes per cane (24.0). Plant crop raised without subsoiling operation produced significantly the lowest cane weight (755.8 g). In ratoon crop, cross subsoiling at 1.0 m attained significantly the highest cane length (221.6 cm) and cane weight (752.2 g), whereas it was at par cross subsoiling

Table 1 Yield attributes of sugarcane plant and ratoon crop as influenced by subsoiling and preparatory tillage

Treatment	Cane length (cm)		Cane girth (cm)		No. of internodes per cane		Cane weight (g)		NMC ('000/ha)	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
<i>Subsoiling</i>										
S ₁	204.3	185.9	7.1	6.6	21.0	18.2	755.8	652.9	82.8	91.3
S ₂	218.1	208.1	7.5	6.9	22.4	19.5	852.6	691.8	93.5	107.1
S ₃	210.4	199.6	7.2	6.7	21.7	18.9	827.2	669.6	89.1	105.5
S ₄	225.8	221.6	7.8	7.1	24.0	20.2	883.8	752.2	100.2	118.2
S ₅	222.2	212.3	7.5	7.0	22.9	19.8	872.2	700.1	95.2	114.3
SEm±	3.6	2.1	0.1	0.4	0.4	0.3	20.1	11.6	2.7	2.7
CD (P=0.05)	11.9	7.0	0.4	NS	1.4	1.0	65.5	37.7	8.9	8.7
<i>Preparatory tillage</i>										
2H	214.3	199.4	7.1	6.7	22.1	19.1	770.3	644.1	89.6	100.2
4H	218.2	212.1	7.7	7.0	22.7	19.5	924.1	741.7	94.0	114.8
1R	216.0	205.0	7.4	6.8	22.4	19.3	820.7	694.3	92.7	106.9
SEm±	3.4	2.4	0.2	0.3	0.8	0.7	36.8	36.7	3.3	2.7
CD (P=0.05)	NS	9.4	NS	NS	NS	NS	NS	NS	NS	10.8

at 1.5 m for number of internodes (20.2) and NMC (118.2 thousand/ha). Response of subsoiling operations on NMC in ratoon was more pronounced as compared to plant crop, hence ratoon was superior to plant crop in terms of NMC. Increase in NMC in ratoon over plant crop under subsoiling practice at 1.0 and 1.5 m and cross subsoiling at 1.0 and 1.5 m was 14.5, 18.4, 18.0 and 20.0 %, respectively as compared to 10.3 % in no subsoiling treatment. The higher NMC, cane length, cane girth and number of internodes per cane under subsoiling treatments might be due to better crop growth owing to favourable soil condition which facilitated moisture and nutrient availability from deeper layer of soil. The differences in individual cane weight could be attributed to the variations in cane length and cane girth. Mandal and Thakur (2010) also observed more number of millable canes, individual cane weight and over all cane growth under subsoiling operation. The preparatory tillage operation did not significantly improve the yield attributes in the plant and ratoon crop except cane girth and NMC in ratoon crop where four harrowing being at par with one rotavator exhibited significantly more value than two harrowing.

Yield

Significant increase in yields of plant and ratoon crop was observed with increasing intensity of subsoiling (Table 2). Cross subsoiling at 1.0 m distance produced the significantly more cane (75.8 and 74.9 tonnes/ha) and biological yield (97.4 and 95.4 tonnes/ha) than rest of the treatments but remained at par with cross subsoiling at 1.5 m in both the crops. The increase in cane yield under cross subsoiling at 1.0 m was to the tune of 28.0 and 37.9 % over no subsoiling in plant and ratoon crops, respectively. Cross subsoiling at 1.0 m also resulted in significantly more green top (12.4 and

11.8 tonnes/ha) and trash yield (9.2 and 8.7 tonnes/ha) than no subsoiling but did not vary with other subsoiling treatments. Improvement in cane yield under subsoiling practice was due to higher value of yield attributes. Crop grown under cross subsoiling at 1.0 m had 21.0 and 29.5 % more millable canes and 16.9 and 15.2 % cane weight than that of without subsoiling in plant and ratoon crops, respectively. Mandal (2007) and Singh (2008) also observed higher cane yield under subsoiling treatment owing to increased individual cane weight coupled with number of millable canes. The higher green top, trash and biological yield under subsoiling practices might be attributed to better crop growth and higher shoot population. The variations in yields due to preparatory tillage were not significant except for green top in both the crops and trash yield in ratoon crop. Four harrowing treatment produced the highest green top yield (14.0 and 12.7 tonnes/ha), being at par with that of one rotavator treatment, was significantly superior to two harrowing practice in plant and ratoon crops, respectively. Moreover, in plant crop four harrowing recorded significantly the highest trash yield (9.4 tonnes/ha).

Soil physical properties

The bulk density, cone index and cumulative infiltration improved significantly due to subsoiling operations (Table 3 and 4). In all the cases cross subsoiling at 1.0 m resulted in improvement in soil physical properties. None of the treatments had higher soil bulk density than initial in either of the layers in plant crop. The soil bulk density increased in each treatment as the study progressed, i.e. the lowest being on April of plant crop and the highest at harvest (January) of ratoon crop. At all the stages of plant and ratoon crop at both the depths the bulk density decreased significantly under all

Table 2 Influence of subsoiling and preparatory tillage on yields of sugarcane and ratoon

Treatment	Cane yield (tonnes/ha)		Green top yield (tonnes/ha)		Trash yield (tonnes/ha)		Biological yield (tonnes/ha)	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
<i>Subsoiling</i>								
S ₁	59.2	54.3	10.1	8.6	6.5	6.4	75.9	69.5
S ₂	68.2	66.8	12.1	10.0	8.9	8.0	89.2	85.2
S ₃	67.6	63.6	11.0	9.6	8.5	7.9	87.2	80.7
S ₄	75.8	74.9	12.4	11.8	9.2	8.7	97.4	95.4
S ₅	70.6	69.7	12.2	10.5	8.7	8.6	91.5	90.2
SEm±	2.1	1.7	0.3	0.8	0.3	0.4	2.0	1.8
CD (P=0.05)	6.7	5.5	1.1	2.4	1.0	1.3	6.5	5.8
<i>Preparatory tillage</i>								
2H	66.8	63.1	9.1	8.0	7.7	7.4	83.6	78.5
4H	69.2	68.3	14.0	12.7	9.4	8.7	92.6	89.7
1R	68.8	66.2	11.6	10.2	8.0	7.9	88.4	84.6
SEm±	2.5	1.8	0.9	0.7	0.3	0.6	3.3	3.0
CD (P=0.05)	NS	NS	3.7	2.7	1.0	NS	NS	NS

Table 3 Effect of subsoiling and preparatory tillage on bulk density of soil in sugarcane plant-ratoon cropping system

Treatment	Bulk density (Mg/m ³)									
	0-30 cm					30-60 cm				
	Plant		Ratoon			Plant			Ratoon	
	April	June	Feb	June	Jan	April	June	Feb	June	Jan
Subsoiling										
S ₁	1.424	1.426	1.432	1.427	1.435	1.552	1.555	1.550	1.553	1.562
S ₂	1.398	1.400	1.406	1.401	1.407	1.528	1.533	1.534	1.537	1.545
S ₃	1.398	1.400	1.405	1.402	1.407	1.532	1.535	1.535	1.536	1.546
S ₄	1.375	1.376	1.383	1.381	1.386	1.524	1.526	1.526	1.526	1.536
S ₅	1.390	1.393	1.400	1.399	1.399	1.528	1.533	1.530	1.536	1.545
SEm±	0.008	0.009	0.009	0.004	0.004	0.005	0.005	0.004	0.005	0.004
CD (P=0.05)	0.027	0.029	0.028	0.014	0.013	0.015	0.016	0.014	NS	0.012
Preparatory tillage										
2H	1.404	1.406	1.412	1.410	1.414	1.536	1.540	1.540	1.540	1.550
4H	1.391	1.393	1.398	1.396	1.400	1.530	1.532	1.529	1.534	1.543
1R	1.398	1.398	1.404	1.402	1.406	1.533	1.537	1.536	1.538	1.549
SEm±	0.012	0.019	0.020	0.027	0.023	0.008	0.007	0.005	0.004	0.006
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4 Effect of subsoiling and preparatory tillage on cone index and cumulative infiltration in sugarcane plant-ratoon crop sequence

Treatment	Cone index (kg/cm ²)					Cumulative infiltration (cm)				
	Plant		Ratoon			Plant			Ratoon	
	April	June	Feb	June	Jan	April	June	Feb	June	Jan
Subsoiling										
S ₁	2.19	2.02	2.45	2.38	2.86	11.49	10.10	8.24	9.07	8.04
S ₂	1.44	1.50	2.29	2.12	2.76	15.91	12.80	10.48	13.20	9.44
S ₃	1.44	1.51	2.44	2.12	2.79	14.30	11.47	9.47	12.88	8.34
S ₄	1.33	1.23	1.75	1.67	2.55	19.99	17.05	13.16	16.27	12.00
S ₅	1.40	1.43	2.20	2.09	2.70	18.01	15.45	11.86	15.56	10.24
SEm±	0.07	0.10	0.14	0.11	0.17	0.44	0.37	0.28	0.36	0.29
CD (P=0.05)	0.25	0.33	0.45	0.36	NS	1.42	1.22	0.92	1.16	0.96
Preparatory tillage										
2H	1.69	1.71	2.27	2.15	2.94	15.40	12.94	10.26	12.99	9.14
4H	1.47	1.46	2.10	1.94	2.61	16.46	13.79	10.98	14.02	10.18
1R	1.51	1.44	2.31	2.14	2.65	15.96	13.39	10.68	13.17	9.44
SEm±	0.07	0.12	0.13	0.10	0.09	0.76	0.54	0.52	0.47	0.49
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

the subsoiling practices compared to no subsoiling, except in plant crop in 0-30 cm layer where subsoiling at 1.0 and 1.5 m remained at par with no subsoiling. The bulk density at all the stages in both the soil depths in general followed the order as, being the maximum in no subsoiling followed by subsoiling at 1.5 m distance, subsoiling at 1 m distance, cross subsoiling at 1.5 m distance and cross subsoiling at 1.0 m distance. Cone index value due to subsoiling operations was significant at all the stages in both the crops, except at harvest stage in ratoon crop (Table 4). In plant crop, during

April and June no subsoiling recorded significantly the highest cone index but in February and in ratoon in June was significantly more than only cross subsoiling at 1.0 m distance. The cumulative infiltration increased with increase in intensity of subsoiling operation. Cumulative infiltration was significantly the highest and the lowest under cross subsoiling at 1.0 m distance and no subsoiling, respectively at all the stages in plant crop. Similar trend was also observed in ratoon crop cross except that subsoiling at 1.0 m in June and no subsoiling at harvest remained at par with cross

subsoiling at 1.5 m and subsoiling at 1.5 m distance, respectively. Effect of preparatory tillage operations on bulk density, soil strength and cumulative infiltration was not significant. However, the highest bulk density and soil strength was estimated with two harrowing practices followed by once rotavator and the lowest with four harrowing. The higher bulk density and cone index under no subsoiling treatment might be due to no deep loosening of soil. The development of cracks and fissures during subsoiling operation resulted in reduced bulk density and soil strength. Muthamilselvan *et al.* (2006) and Naseri *et al.* (2007) also reported improvement in soil physical properties with

subsoiling. Significantly more cumulative infiltration under subsoiling practices may be contained to lower bulk density, more and better tilth and less compactness of soil. Matsuo *et al.* (2003) also noted decreased soil bulk density and improved permeability and infiltration rate under subsoiling practices.

Soil chemical properties

Subsoiling practices did not vary significantly with respect to soil pH and electrical conductivity in both crops but differences in soil organic carbon, soil available N, P and K were significant (Table 5, 6 and 7). Organic carbon after harvest of the crop was more in all the treatments tested as

Table 5 Effect of subsoiling and preparatory tillage on pH and EC at harvest in sugarcane plant-ratoon crop sequence

Treatment	Soil pH				EC (dS/m)			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
<i>Subsoiling</i>								
S ₁	8.19	8.20	8.19	8.20	0.320	0.321	0.320	0.321
S ₂	8.17	8.16	8.17	8.16	0.311	0.312	0.311	0.312
S ₃	8.17	8.14	8.17	8.14	0.324	0.324	0.324	0.324
S ₄	8.15	8.17	8.15	8.17	0.321	0.324	0.321	0.324
S ₅	8.15	8.15	8.15	8.15	0.315	0.315	0.315	0.315
SEm±	0.02	0.05	0.02	0.05	0.003	0.003	0.003	0.003
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS
<i>Preparatory tillage</i>								
2H	8.15	8.12	8.15	8.12	0.320	0.322	0.320	0.322
4H	8.15	8.16	8.15	8.16	0.315	0.317	0.315	0.317
1R	8.19	8.22	8.19	8.22	0.317	0.318	0.317	0.318
SEm±	0.01	0.12	0.01	0.12	0.002	0.003	0.002	0.003
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table 6 Effect of subsoiling and preparatory tillage on organic carbon and available nitrogen in soil after harvest of plant and ratoon crop

Treatment	Organic carbon (%)				Available nitrogen (kg/ha)			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
<i>Subsoiling</i>								
S ₁	1.17	1.19	0.646	0.654	185.7	183.6	160.4	158.3
S ₂	1.12	1.14	0.657	0.658	193.4	180.1	166.3	160.6
S ₃	1.15	1.17	0.649	0.656	192.7	184.7	163.9	155.9
S ₄	1.06	1.11	0.691	0.691	199.2	189.6	168.9	166.5
S ₅	1.09	1.12	0.676	0.676	194.9	187.3	168.5	162.8
SEm±	0.01	0.01	0.004	0.006	2.4	1.1	1.6	1.4
CD (P=0.05)	0.03	0.03	0.014	0.021	7.7	3.6	5.2	4.7
<i>Preparatory tillage</i>								
2H	1.13	1.13	0.629	0.664	187.2	186.5	166.6	160.4
4H	1.12	1.15	0.620	0.659	203.2	183.8	165.4	161.0
1R	1.13	1.14	0.631	0.670	189.2	184.8	164.8	160.9
SEm±	0.01	0.01	0.004	0.003	4.3	1.8	1.9	1.4
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

Table 7 Effect of subsoiling and preparatory tillage on available phosphorus and available potassium in soil after harvest of plant and ratoon crop

Treatment	Available phosphorus (kg/ha)				Available potassium (kg/ha)			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon	Plant	Ratoon
<i>Subsoiling</i>								
S ₁	17.1	17.0	12.7	12.6	196.6	191.5	132.9	128.0
S ₂	18.0	18.4	13.2	13.3	197.4	194.1	137.0	130.2
S ₃	17.2	17.5	12.7	12.9	196.9	192.6	135.8	130.0
S ₄	19.6	20.1	15.4	15.5	202.0	199.7	139.1	136.5
S ₅	18.9	19.4	14.7	14.8	199.9	196.6	138.6	133.2
SEm±	0.2	0.3	0.04	0.2	1.0	2.0	2.6	2.2
CD (P=0.05)	0.5	1.1	0.1	0.5	3.2	NS	NS	NS
<i>Preparatory tillage</i>								
2H	18.2	18.6	13.6	13.7	197.6	193.9	136.8	132.7
4H	18.0	18.3	13.7	13.7	198.6	194.9	136.2	130.1
1R	17.7	18.0	13.3	13.4	199.4	195.8	137.0	131.9
SEm±	0.5	0.8	0.4	0.7	2.7	2.8	1.0	3.4
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS

compared to initial value. Organic carbon at 0-15 cm depth was significantly higher with no subsoiling (1.17 and 1.19%) than other practice but remained at par with the subsoiling at 1.5 m distance while at 15-30 cm depth cross subsoiling at 1.0 m (0.691 and 0.691%) being at par with cross subsoiling at 1.5 m exhibited significantly higher soil organic carbon in both the crops. Significantly lower N, P and K content in soil was observed under no subsoiling treatment. At 0-15 and 15-30 cm depth, cross subsoiling at 1.0 m distance exhibited significantly higher available nitrogen than without subsoiling treatment in both the crops but remained at par with rest of the treatments in plant crop and with cross subsoiling at 1.5 m in ratoon crop. Cross subsoiling at 1.0 m resulted in significantly higher phosphorus content in soil at both the depth than other treatments in the plant and ratoon crops, except cross subsoiling at 1.5 m in ratoon crop. Available potassium content was significant only at 0-15 cm in plant crop where cross subsoiling at 1.0 m being at par with cross subsoiling at 1.5 m was superior to rest of the treatments. The differences in soil chemical properties due to preparatory tillage practices were not significant in both the plant and ratoon crops. Significantly lower organic carbon at shallower depth under cross subsoiling at 1.0 m distance might be due to accelerated decomposition of plant material because of intensively highly disturbed soil. Similar opinion was also expressed by Singh (2008). However, at deeper soil depth significantly lower organic carbon under no subsoiling might be attributed to fewer amounts of root residue/biomass. The higher soil nutrient status under subsoiling operation might

be due to mobilization of nutrients with in soil profile owing to better soil physical condition facilitating the downward movement of water, air and roots.

REFERENCES

- Jackson M L. 1973. *Soil Chemical Analysis*, pp 183-204. Prentice Hall of India Pvt Ltd, New Delhi.
- Mandal S. 2007. 'Design and development of subsoiler-cum-differential rate fertilizer applicator and its evaluation on sugarcane crop.' Thesis submitted to G B Pant University of Agriculture and Technology, Pantnagar, 178 p.
- Mandal S and Thakur T C. 2010. Effect of subsoiling, deep and differential rate placement of fertilizer on sugarcane crop response. *Journal of Agricultural Engineering* 47 (1): 9-13.
- Muthamilselvan M, Manian R and Kathirvel K. 2006. *In situ* moisture conservation techniques in dryfarming - A review. *Agricultural Reviews* 27(1): 67-72.
- Matsuo K, Wonwiwatchai C and Yashiro M. 2003. Alternative tillage system for soil conservation, enhancement of crop growth and increasing working efficiency. *Japan International Research Centre for Agricultural Sciences* 35: 111-9.
- Naseri A A, Jafari S and Alimohammadi M. 2007. Soil compaction due to sugarcane (*Saccharum officinarum*) mechanical harvesting and the effects of subsoiling on the improvement of soil physical properties. *Journal of Applied Sciences* 7: 3 639-48.
- Singh P. 2008. 'Studies of pre-planting tillage operations and fertilizer placement in sugarcane.' M Sc Thesis, G.B.Pant University of Agriculture and Technology, Pantnagar, 110 p.
- Thakur T C and Kumar A. 1999. Subsoil compaction and methods of alleviation-A review. *Agricultural Engineering Today* 23 (3&4): 58-74.