Subsoiling and fertilizer placement effect on yield performance, soil physico-chemical properties, nutrient uptake and nutrient recovery by sugarcane (*Saccharum officinarum* L.)

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ABSTRACT : A field experiment was conducted during 2007-2008 at G. B. Pant University of Agriculture and Technology, Pantnagar, India to study the effect of subsoiling and deep placement of fertilizers on soil fertility and nutrient uptake in sugarcane (Var : Co-Pant 90223). The experiment consisting of eight treatments, viz. Ploughing + 4 Harrowing + Furrow application of fertilizers (FAF), Ploughing + 2 Rotavator + FAF, Subsoiling + 4 Harrowing + FAF, Subsoiling + 2 Rotavator + FAF, Subsoiling + 4 Harrowing + Differential rate placement of fertilizers (DRPF), Subsoiling + 2 Rotavator + DRPF, Cross-subsoiling + 4 Harrowing + DRPF and Cross-subsoiling + 2 Rotavator + DRPF was laid out in randomized block design with four replications. The data indicated that subsoiling and cross-subsoiling prior to harrowing or rotavator resulted in significantly higher NPK uptake, NPK recovery efficiency and yields in sugarcane plant crop.

Sugarcane (*Saccharum officinarum* L.) is the second most important agro-industrial crop after cotton but the average productivity is low in the order of about 70 t/ha which needs to be increased to keep pace with the population growth. There are a number of factors such as untimely planting, imbalanced use of fertilizers, non-judicious use of irrigation water, poor weed management etc. responsible for low cane productivity and sugar recovery, but the pre-planting tillage and fertilizer placement methods are more important. Over four decades, there had been regular use of plough along with harrow for pulverizing the top 15-20 cm soil, which has led to formation of compact /hard layers beyond the tilling depth at a number of locations in the country. The presence of hard/compact subsoil while irrigating fields or during rainy season results in temporary anaerobic conditions in root zone due to restricted infiltration which adversely affects plant growth and yield. Moreover, the compact layer in subsoil limits vertical root growth affecting thereby the 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 or by placement in upper 5 cm soil layers. Hence, there is a need to break this compact layer and improve aeration in subsoil for better root environment (Torres *et al.,* 1994)

Hard pan could be alleviated with the help of deep soil loosening equipment like chisel plough and subsoiler. These equipments improve soil structure by establishing a system of deep cracks and fissures in the subsoil, thus facilitating the downward movement of water, air and roots to a greater depth of soil profile which enables plants to withstand better against short term anaerobic conditions (Raper *et al.,* 1998).

Apart from fertilizer dose, the time of its application and methods of placement are important for effective utilization and improvement in crop yield. The common method of applying fertilizer is broadcasting just before last tillage operation or after seeding. Thus fertilizers are localized in the upper layers of soil. As a result, large volume of plant roots particularly in deeper horizon does not make sufficient access to fertilizer especially during dry periods. Therefore, it is essential to place fertilizer below the surface in moist zone so that plant roots have better access to nutrients. The vertical distribution of fertilizer in different soil layers is more important than horizontal distribution. Augmenting crop yield by increasing the fertilizer dose is not a wise solution as it would add to the cost, apart from increasing pollution. Hence, efforts are needed on efficient fertilizer use by proper distribution in the root zone. With these points in view, the present field experiment was conducted to study the effect of subsoiling and conventional methods of preparatory tillage on nutrient uptake by sugarcane plant crop and soil fertility status.

MATERIALS AND METHODS

The field experiment was conducted during 2007-08 at the N.E. Borlaug Crop Research Centre (29^0 N and 79.5^0 E, 243.8 m above msl), G. B. P. U. A & T., Pantnagar, Uttarakhand, India. The soil of the experimental site was classified under Mollisol; sub-order–Udoll, great group–Hapludoll and series-Khamia, silty clay loam (Deshpande *et al*., 1971). The soil was rich in organic carbon (0.857 %), low in available nitrogen (137.98 kg/ha), medium in available phosphorus (22.4 kg/ha) and potassium (166.65 kg/ha) and slightly alkaline in reaction (pH 7.82). The bulk density of soil at 0-15, 15-30, 30-45 and 45-60 cm depth was 1.40, 1.45, 1.48 and 1.44 Mg/m^3, respectively. The experiment consisting of eight treatments, *viz*. T_1 : Ploughing + 4 Harrowing + Furrow application of fertilizers (FAF), T_2 : Ploughing + 2 Rotavator + FAF, T_3 : Subsoiling + 4 Harrowing + FAF, T_4 : Subsoiling + 2 Rotavator + FAF, T_5 : Subsoiling + 4 Harrowing + Differential rate placement of fertilizers (DRPF), T_6 : Subsoiling + 2 Rotavator + DRPF, T_7 : Cross-subsoiling + 4 Harrowing + DRPF and T_8 : Cross-subsoiling + 2 Rotavator + DRPF was laid out in randomized block design with four replications.

The placement of fertilizers at differential rate was carried out while subsoiling with 'Pant-ICAR Subsoiler-cum-Differential Rate Fertilizer Applicator' which has been designed, developed and is being patented. This machine has now been commercialized (Thakur, 2012). It consisted of a rectangular frame, a main winged subsoiling tine, two shallow leading winged tines, a pair of depth control device, a fertilizer box of 100 kg capacity, grooved roller type positive feed fertilizer metering devices and a ground drive wheel with sprockets and chains for transmitting power to the metering mechanism. It can perform two operations simultaneously, viz. subsoiling upto 50 cm depth and fertilizer application in the subsoil which ultimately saves fuel and time. The equipment had the option to place fertilizers up to the tilling depth (50 cm) by the main winged tine as well as fertilizer placement up to 25 cm depth with two shallow leading tines, thereby helping to place fertilizers at two different depths in vertical soil profile in a single pass. All the three tines had independent metering systems. Options were provided to meter and deliver either 33.30 or 20.0% of the total recommended dose of fertilizers with the main tine and the remaining amount of 66.70 or 80% through two shallow leading tines. In the present study, half of the nitrogen and full amount of phosphorus and potassium was applied as basal dose through subsoiler-cum-differential rate fertilizer applicator with 80 % dose at the depth of 25 cm and remaining 20% at 35 cm depth while subsoiling at 1.5 m spacing. In cross- subsoiling operation, fertilizer was adjusted to half in each pass for equal distribution. The recommended dose of fertilizer was 150:60:40 kg $N:P_2O_5:K_2O$/ha. Half of the nitrogen and full dose of phosphorus and potassium were applied as basal in furrows at about 15 cm depth in treatments T_1, T_2, T_3 and T_4, whereas in treatments T_5, T_6, T_7 and T_8 at differential depths as mentioned above. The remaining half of nitrogen was top dressed in two equal splits in the month of July at 20 days interval. After subsoiling operation, planking was done to break the clods and field was levelled. Three budded setts of sugarcane (variety: Co-Pant 90223) were taken from the healthy crop and dipped in 0.25 % Emisan solution for 15 minutes to protect the cane setts from fungal infection. The field was prepared as per treatments and 15 cm deep furrows were opened at a distance of 75 cm with the help of tractor drawn ridge and furrow maker. Treated three budded setts were planted in furrows at the rate of 4 setts per meter of furrow length. Furrows were covered immediately with loose soil with the help of spade and finally the field was planked with a tractor drawn roller to maintain good soil contact with setts. Urea (46% N), single super phosphate (16% P_2O_5) and muriate of potash (60% K_2O) were used as the source of nitrogen, phosphorus and potassium, respectively. The net plot size was 8 m ×3 m. The crop was planted on April 4, 2007 and harvested on March 12, 2008. The uptake of nitrogen, phosphorus and potassium by canes, green top and trash was determined at harvesting stage. N, P and K contents in the plant were determined by following micro-Kjeldahl's method (Jackson, 1973), Vanadomolybdo-phosphorus yellow colour method (Jackson, 1973) and neutral ammonium acetate method (Jackson, 1973), respectively. The nutrient recovery efficiency at harvest was calculated by using the following formula:

Nutrient recovery efficiency (kg cane obtained per ha/ kg nutrient applied per ha) = (A-T)/Nutrient applied (kg/ha)

Where,

A = Cane yield (kg/ha) in respective treatment

T = Cane yield kg/ha in control treatment

The bulk density was measured using a bulk density kit. The infiltration rate was measured one month after planting and at harvest using a ring infiltrometer. Soil pH was determined by using glass electrode pH meter (Jackson, 1973). Soil organic carbon was determined by using modified Walkley and Blacks method (Jackson, 1973). Available nitrogen, phosphorus and potassium were determined at harvest of sugarcane crop by following alkaline potassium permanganate method (Subbiah and Asija, 1956), Spectrophotometry method (Jackson, 1973) and Flame photometric method (Jackson, 1973), respectively. The techniques of analysis of variance prescribed for randomized block design was used to test significance of the differences among treatments mean by the 'F' test (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Cane, Green top, Trash and Biological Yields

The data indicated that variations in cane, trash and biological yields were significant due to different pre-planting tillage and fertilizer placement methods but differences in green top remained unaffected (Table 1). Cross-subsoiling + 4 Harrowing + Differential rate placement of fertilizers (T_7) produced significantly higher cane yield (98.8 t/ha) and biological yield (120.9 t/ha) than rest of the treatments but remained statistically at par with Cross-subsoiling + 2 Rotavator + Differential rate placement of fertilizers (T_8) and those subsoiling operations which were followed by harrowing. Moreover in treatments, where rotavator was used along with either ploughing or subsoiling (i.e. T_1, T_2, T_3 and T_4) was found inferior to harrowing for cane yield. But when rotavator was used after either subsoiling or cross subsoiling (i.e. T_5, T_6, T_7 and T_8) it remained on par with harrowing. It indicated that primary deep tillage either by subsoiling or cross subsoiling overcome the poor effect of secondary shallow tillage by rotavator. Cross subsoiling proved significantly better than sub soiling only when these tillage operations were used in conjunction with rotavator. The results for cane yields showed that under subsoiling treatments differential rate placement did not improve cane yield substantially over the conventional furrow placement method. Maximum trash yield (8.8 t/ha) was also obtained in treatment T_7 which was significantly higher than that of all the tillage treatments except T_8. Although differences in green top yield due to different pre-planting tillage and fertilizer placement methods were non-significant, the crop grown under treatment T_7 produced highest green top yield of 13.1 t/ha. Among different pre-planting tillage and fertilizer placement methods, the treatment T_2 i.e. Ploughing +2 Rotavator + Furrow application of fertilizer exhibited significantly lowest cane, trash and biological yields.

The higher yield under cross-subsoiling and subsoiling treatments may be due to over all better growth of crop owing to improved soil health and higher availability of nutrients throughout the crop growth period as evident from nutrient uptake studies. Low yield in ploughing treatments may be imputed to poor growth as the growth factors such as soil moisture, aeration, nutrients etc. might not have been properly available to the crop in this treatment. Mandal and Thakur (2010) also reported higher cane yield under subsoiling with differential rate of fertilizer application method.

Nutrients Uptake by Plants

Nitrogen uptake in cane, green top and trash

The differences in nitrogen uptake in cane and trash were found significant due to various pre-planting tillage operations and fertilizer placement methods but were non-significant in green top (Table 1). The crop grown under Cross-subsoiling + 4 Harrowing + Differential rate

Table 1: Effect of tillage and fertilizer placement methods on cane, green top, trash and biological yields and on nitrogen (N) uptake

Treatments		Yields (t/ha)				N uptake (kg/ha)			
		Cane	Green top	Trash	Biological	Cane	Green top	Trash	Total
T_1	P+ 4 H + FAF	81.6	11.8	7.0	100.6	67.3	28.2	28.0	123.7
T_2	P + 2 R+ FAF	65.9	11.8	6.1	83.8	57.0	27.2	23.6	107.9
T_3	Sub+ 4 H + FAF	93.7	12.1	7.2	113.1	82.1	28.4	28.7	139.5
T_4	Sub+ 2 R+ FAF	79.5	12.0	7.2	98.8	79.1	30.7	28.6	138.6
T_5	Sub+ 4 H + DRPF	94.0	12.3	7.4	113.8	84.0	30.5	29.5	144.1
T_6	Sub + 2 R+ DRPF	87.4	12.1	7.4	106.9	75.5	29.3	29.5	134.4
T_7	C-sub + 4 H + DRPF	98.8	13.1	8.8	120.9	92.4	33.5	36.8	162.9
T_8	C-sub + 2 R + DRPF	97.2	12.9	7.8	117.9	86.7	31.6	31.7	150.2
S.Em.±		2.8	0.4	0.4	3	4.3	1.8	1.8	5.7
CD (P = 0.05)		8.2	NS	1.3	8.6	13	NS	5.4	16.9

P: Ploughing, H:Harrowing, R:Rotavator , FAF : Furrow application of fertilizer, DRPF : Differential rate placement of fertilizer, Sub:Subsoiling, C-Sub:Cross-subsoiling placement of fertilizer (T_7) removed significant amount of nitrogen in cane (92.4 kg/ha) which was statistically at par with that of Cross-subsoiling + 2 Rotavator + Differential rate placement of fertilizers (T_8) and subsoiling prior to harrowing (T_3). The maximum amount of nitrogen removed by green top (33.5kg/ha) was found in Cross-subsoiling + 4 Harrowing + Differential rate placement of fertilizer (T_7). The maximum nitrogen uptake in trash (36.8 kg/ha) and total N uptake of 162.9 kg/ha computed under T_7 was at par with treatment T_8 but statistically superior to other tillage and fertilizer application methods. The lowest N uptake of 107.9 kg/ha by the crop was computed under Ploughing + 2 Rotavator + Furrow application of fertilizer (T_2).

Phosphorus uptake in cane, green top and trash

The differences in phosphorus uptake by different plant parts except green top were significant due to various pre-planting tillage and fertilizer placement methods (Table 2). The treatment T_7 exhibited significantly higher phosphorus uptake of 10.9 kg/ha though at par with that of treatment T_8 and subsoiling treatment followed by harrowing. The differences in phosphorus uptake in green top due to different pre-planting tillage operations and fertilizer placement methods were found to be non-significant but mathematically higher value of 3.75 kg/ha were found in treatment $T_{7.}$

The maximum phosphorus uptake in trash (5.18 kg/ha) and total P uptake of 19.88 kg/ha computed under treatment T_7 was at par with treatment T_8 but significantly superior to other pre-planting tillage and fertilizer placement methods. Significantly lowest P uptake of 13.21 kg/ha by the crop was found under Ploughing + 2 Rotavator + Furrow application of fertilizer (T_2).

Potassium uptake in cane, green top and trash

Various pre-planting tillage and fertilizer placement methods resulted in significant difference in potassium uptake in cane, trash and total uptake, but remained non-significant in green top (Table 2). The potassium uptake in cane was significantly higher (134.9 kg/ha) under treatment T_7 which was statistically at par with that of treatments T_8 and $T_{3.}$ The differences in potassium uptake in green top due to different pre-planting tillage and fertilizer placement methods were non-significant, but treatment T_7 resulted in maximum potassium uptake of 43.8 kg/ha in green top.

Potassium uptake in trash and total K uptake were computed maximum under treatment T_7 in the order of 41.7 and 220.6 kg/ha, respectively, being at par with that of treatment T_8 but significantly superior to other pre-planting tillage and fertilizer placement methods. Treatment T_2 resulted in significantly lower total K uptake of 150.6 kg/ha by the crop.

NPK Recovery Efficiency

The variation in nitrogen recovery efficiency due to different pre-planting tillage and fertilizer placement methods (Table 3) revealed that treatment T_7 recorded the highest nitrogen recovery efficiency of 114.6 kg cane/ha per kg N applied followed by 103.6 kg cane/ha per kg N applied under treatment T_8 over treatment T_1 (control). However, N recovery efficiency under treatment T_2 (-104.6 kg cane/ha per kg N applied) and treatment T_4 (-14.3 kg cane/ha per kg N applied) did not improve rather it declined over rest of the treatments.

In case of phosphorus, it ranged from -35.8 kg cane/ha per kg P_2O_5 applied under treatment T_4 to 286.5

Table 2: Effect of tillage and fertilizer placement methods on phosphorus (P) and potassium (K) uptake

Treatments		P uptake (kg/ha)				K uptake (kg/ha)			
		Cane	Green top	Trash	Biological	Cane	Green top	Trash	Total
T_1	P+ 4 H + FAF	8.11	3.16	3.97	15.26	104.5	38.0	32.8	172.4
T_2	P + 2 R+ FAF	6.85	3.04	3.31	13.21	86.2	36.4	27.8	150.6
T_3	Sub+ 4 H + FAF	9.84	3.25	4.08	17.17	123.9	38.8	33.7	196.6
T_4	Sub+ 2 R+ FAF	9.39	3.46	4.08	16.94	119.3	41.5	33.6	194.6
T_5	Sub+ 4 H + DRPF	10.04	3.42	4.21	17.67	125.7	40.6	34.3	200.7
T_6	Sub + 2 R+ DRPF	8.98	3.33	4.19	16.51	113.6	39.7	41.3	187.7
T_7	C-sub + 4 H + DRPF	10.94	3.75	5.18	19.88	134.9	43.8	41.7	220.6
T8	C-sub + 2 R + DRPF	10.29	3.57	4.53	18.40	128.9	41.4	36.6	207.4
S.Em.±		0.50	0.19	0.25	0.73	6.4	2.4	2.1	8.1
CD (P = 0.05)		1.49	NS	0.74	1.97	19	NS	6.2	23.8

P: Ploughing, H:Harrowing, R:Rotavator, FAF : Furrow application of fertilizer, DRPF : Differential rate placement of fertilizer, Sub:Subsoiling, C-Sub:Cross-subsoiling

Table 3: N, P and K recovery efficiency under different subsoiling treatments over ploughing and soil bulk density at different depths after harvest of crop

Treatments		Recovery efficiency (kg cane/ha per kg nutrient applied)			Bulk density (Mg/m^3)			
		N	P	K	0-15 cm	15-30 cm	30-45 cm	45-60 cm
T_1	P+ 4 H + FAF	-	-	-	1.40	1.42	1.44	1.45
T_2	P + 2 R+ FAF	-104.6	-262	-392	1.42	1.42	1.44	1.46
T_3	Sub+ 4 H + FAF	80.5	201.3	301.8	1.39	1.40	1.42	1.45
T_4	Sub+ 2 R+ FAF	-14.3	-35.8	-53.7	1.38	1.40	1.42	1.44
T_5	Sub+ 4 H + DRPF	82.4	206	309	1.38	1.39	1.40	1.44
T_6	Sub + 2 R+ DRPF	38.4	96	144	1.38	1.39	1.39	1.44
T_7	C-sub + 4 H + DRPF	114.6	286.5	429.7	1.37	1.38	1.39	1.44
T_8	C-sub + 2 R + DRPF	103.6	259.1	388.7	1.38	1.39	1.39	1.45

P: Ploughing, H:Harrowing, R:Rotavator, FAF : Furrow application of fertilizer, DRPF : Differential rate placement of fertilizer, Sub:Subsoiling, C-Sub:Cross-subsoiling

kg cane/ha per kg P_2O_5 applied under treatment T_7 while the response to applied potassium ranged from -53.7 kg cane/ha per kg K_2O applied under treatment T_4 to 429.7 kg cane/ha per kg K_2O applied under treatment T_7.

Nutrient recovery efficiency study indicated that crop grown under Cross-subsoiling + 4 Harrowing + Differential rate placement of fertilizer (T_7) produced additional 114.6, 286.5 and 429.7 kg cane yield per kg N, P_2O_5 and K_2O applied per hectare, respectively over control i.e. Ploughing + 4 Harrowing + Furrow application of fertilizer (T_1). It might be due to proper root development, placement of fertilizer in root zone, better aeration and improved surface and subsurface soil conditions which enabled the crop to extract more nutrients from the soil and assimilated them in the yield.

The practice of Ploughing + 2 Rotavator + Furrow application of fertilizer (T_2) and Subsoiling + 2 Rotavator + Furrow application of fertilizer (T_4) resulted in a loss of additional cane yield over Ploughing + 4 Harrowing + Furrow application of fertilizer (T_1) probability due to inefficient use of nutrients owing to improper tillage operation and fertilizer application in furrow. Lian (1988) also reported that subsoiling and deep fertilizer placement increased fertilizer use efficiency.

Soil Physico-Chemical Properties

Soil bulk density

The effects of pre-planting tillage operations and fertilizer placement methods on soil bulk density at harvest were pronounced up to the depth of 45 cm (Table 3). The field treatment with Cross-subsoiling + 4 Harrowing + Differential rate placement of fertilizer (T_7) had the lowest bulk density of 1.37 to 1.39 Mg/m^3 as against the highest value under treatment T_2 i.e. Ploughing + 2 Rotavator + Furrow application of fertilizer (1.42 to 1.44 Mg/m^3). Cross-subsoiling at 35 cm depth loosened the soil vertically as well as horizontally with multiple cracks and fissures which resulted in lower bulk density. The higher bulk density under treatment T_2 may be ascribed to comparatively shallow depth (18 cm) of tillage and undisturbed soil beyond A_p horizon. Jagpat *et al.* (1991) and Bodhinayake *et al.* (1998) also reported lower soil bulk density due to subsoiling operation.

Infiltration rate

The higher cumulative infiltration after one month of planting (24.2 cm) and at harvest (14.9 cm) in the field was observed in treatment T_7 (Table 4) due to lower bulk density, more voids and better tilth of soil. The field treatment T_2 i.e. Ploughing + 2 Rotavator + Furrow application of fertilizer showed the lowest cumulative infiltration at one month after planting and at harvest in the order of 13.8 and 9.9 cm, respectively owing to higher bulk density and compactness of surface and sub-surface soil. Jagpat *et al.* (1995) and Matsuo *et al.* (2003) also observed lower soil bulk density, and improved permeability and infiltration rate under subsoiling treatments.

Organic carbon and available NPK

Organic carbon, available nitrogen, phosphorus and potassium contents at harvest did not vary appreciably in various treatments (Table 4). The organic carbon and available nitrogen, phosphorus and potassium were comparatively more in the treatments comprising of cross- subsoiling/subsoiling and were maximum in differential rate placement of fertilizers (T_7) in the order

Table 4: Cumulative infiltration and soil fertility status at harvest as affected by pre-planting tillage and fertilizer placement methods

Treatments		Cumulative infiltration (cm)		Soil fertility status			
		One month after planting	At harvest	OC (%)	N (kg/ha)	P (kg/ha)	K (kg/ha)
T_1	P+ 4 H + FAF	14.3	11.9	0.86	122.6	24.6	160.2
T_2	P + 2 R+ FAF	13.8	9.9	0.85	117.2	24.3	161.0
T_3	Sub+ 4 H + FAF	20.5	13.1	0.86	124.3	25.2	163.4
T_4	Sub+ 2 R+ FAF	17.3	11.7	0.85	121.1	25.1	162.6
T_5	Sub+ 4 H + DRPF	18.5	14.3	0.86	125.7	25.9	163.8
T_6	Sub + 2 R+ DRPF	15.3	12.9	0.85	124.9	24.9	163.8
T_7	C-sub + 4 H + DRPF	24.2	14.9	0.86	128.5	26.8	163.4
T_8	C-sub + 2 R + DRPF	20.8	12.3	0.857	126.6	26.6	164.5

P: Ploughing, H:Harrowing, R:Rotavator, FAF : Furrow application of fertilizer, DRPF : Differential rate placement of fertilizer, Sub:Subsoiling, C-Sub:Cross-subsoiling

of 0.859 % and 128.5, 26.8 and 164.5 kg/ha, respectively. This may be attributed to better mobilization of nutrients in the soil profile owing to better aeration and more root biomass which facilitated mineralization of nutrients.

It can be finally concluded from the present study that the nutrient uptake and sugarcane productivity can be enhanced substantially by subsoiling or cross-subsoiling.

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