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Effects of Sub–Soiling on Soil Physical Properties and Root Distribution in Sugarcane

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ABSTRACT. A study was conducted on well–drained Alfisols to determine the effect of gravel layer on root distribution of three commercial sugarcane cultivars under rain–fed conditions and to observe the improvements with sub–soiling. Before tillage operations, bulk density and soil strength of all horizons were above 1.68 Mg m^{-3} and 588 kPa, respectively. Normal ploughing reduced bulk density and soil strength of surface horizon to 1.59 Mg m^{-3} and 343 kPa, respectively. In the gravelly horizon, sub–soiling decreased bulk density to 1.61 Mg m^{-3} and soil strength to 441 kPa. Total porosity and macro–porosity were significantly increased while micro–porosity and available water were not significantly affected. The mean steady infiltration rates increased from 0.71 cm h^{-1} before tillage to 1.76 and 19.78 cm h^{-1} with normal ploughing and sub–soiled treatments, respectively.

Under normal ploughing, about 74% of the roots were confined to the surface horizon in sugarcane variety SLI 121 while it was about 60% for CO 775 and SL 8306. In the gravelly horizon, the percentage root distribution among varieties and between sub–soiled and normal ploughing treatments was significantly different. Sub–soiling significantly increased the percentage of roots below the gravelly horizon in varieties CO 775 and SLI 121, but not in SL 8306. Having a relatively high proportion of roots in the surface horizon, variety SLI 121 may be susceptible to moisture stress conditions. The other two varieties could be less affected by moisture stress because of their deep rooting habit. Improving soil physical properties through sub–soiling may have caused an increase in root penetration in the gravelly horizon and below.

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INTRODUCTION

In Sri Lanka, sugarcane (*Saccharum officinarum* L.) is cultivated under irrigated and rain–fed (dry land) conditions. The rain–fed sugarcane cultivation solely depends on rainfall for the soil water replenishment.

The Sevanagala sugar project in Moneragala district is situated in the low country dry zone (DL_1). It covers about 4,219 ha of total cultivable land with approximately 2,387 ha under rain–fed conditions (Keerthipala, 1997). For a better plant growth and sugar assimilation, sugarcane requires about 1500–2500 mm rainfall (Mettananda, 1990) which should be evenly distributed over the growing season. However, due to uneven distribution of rainfall and high evapotranspiration rate in the area, moisture stress occurs during the growth period (Shanmuganathan, 1992). The average cane yield in the irrigated sector at Sevanagala is about 102 t ha^{-1} while under rain–fed conditions it is about 52 t ha^{-1} which is nearly half that of the irrigated sector (Sugarcane Harvesting Report, 1994). This low cane yield in rain–fed sector is mainly attributable to moisture stress during the growth period of sugarcane.

In Sevanagala/Uda Walawe area, the Reddish Brown Earth soils (RBE), which are classified as Alfisols according to Soil Taxonomy (USDA, 1975), represents the largest extent under sugarcane. According to Joshua (1988), a gravel horizon is a compact layer which is present in the sub–soil of RBE soils. Due to its high soil strength, high bulk density and low aeration, the gravel layer acts as a barrier for root development and penetration into the sub–soil. This reduces the effective root zone by limiting most of the roots to the horizons overlying it. As a result, moisture stress occurs even at a relatively low soil water potentials which seriously affects sugarcane growth and yield under rain–fed conditions. Presence of a gravelly horizon at a shallow depth in the soil profile is common especially on the crests and upper slopes of the catena. Field observations in this area indicate the inhibitory effects of the gravelly horizon on root distribution in sugarcane.

The adverse effects of the gravelly horizon have to be removed in order to improve the root growth and distribution. Thereby the utilisation of available water and nutrients in the gravelly horizon as well as the underlying horizons would enhance helping the plants to withstand moisture stress better (Tisdale *et al.*, 1985). The physical causes which limit root distribution in the gravelly horizon and other compacted layers could be overcome by ripping or sub–soiling. However, there is very little information available on root distribution of commercially grown sugarcane cultivars in RBE soils. Such information is useful in deciding management practices to overcome the problem of poor root penetration when gravel layer is present.

The objective of this study was to examine the effect of gravel layer in RBE soils on root distribution of three commercial sugarcane cultivars under rain–fed situation and to observe the improvements with sub–soiling.

MATERIALS AND METHODS

This study was carried out at the Research Farm of the Sugarcane Research Institute, Uda Walawe, Sri Lanka ($6^0 21'$ N latitude, $80^0 48'$ E longitude, 76 m amsl). The soil has been classified as Ranna series of well–drained RBE soils (de Alwis and Panabokke, 1972). According to Soil Taxonomy (Soil Survey Staff, 1992) these are classified as Rhodustalfs. The experimental site was selected to represent RBE soils with the gravel layer at about 30 cm depth. The examination of soil profile at the experimental site showed four distinct soil horizons as given in Table 1.

Table 1. Horizon designation and depths of the RBE soil used for the experiment.

Horizon designation		Depth (cm)	Abbreviation
Surface	Ap	0-22/27	D1
	B2	22/27-34	D2
Gravelly	iiB2	34-46	D3
	iiB3	46-63/67	D4
Below gravelly	iiB3	63/67-88	D5
DPM*	C	>88	D6

* DPM - Decomposing Parent Material

Two tillage practices and three sugarcane varieties were used as treatments in a split plot design where tillage was the main factor and variety the sub factor. The tillage treatment consisted of normal ploughing (disc ploughing to about 25 cm depth) and sub–soiling (loosening soil to a depth of about 50 cm). Sub–soiling was done using a sub–soiler mounted to a bulldozer. It was carried out in two directions, perpendicular to each other. Harrowing and preparation of ridges and furrows were carried out in both sub–soiled and normal ploughed plots. Three commercially grown sugarcane varieties namely, CO 775, SL 8306 and SLI 121 were used in this study as these varieties differ in their rooting depth and distribution (Gunasena, 1995). The treatments were replicated four times.

The gravel content (particles>2 mm dia.) of each horizon was determined by wet sieving and soil texture by pipette method (Gee and Bauder, 1986). Bulk density, soil strength, moisture retention relationship and infiltration rate were measured before as well as after tillage operations. Soil bulk density was determined using three undisturbed soil core samples (5 cm height × 5 cm dia.) from the middle of each horizon.

The functional relationship between cumulative infiltration I (cm) and elapsed time t (min) can be given as;

$$I = at^{n} \qquad (1)$$

where *a* and *n* are constants. The results on cumulative infiltration *vs* time fitted well into this function and the *a* and *n* parameters were estimated using regression techniques. Using these, *a* and *n* values of the relationship between infiltration rate and time were obtained and the steady state (basic) infiltration rates were calculated.

Total porosities were calculated using soil bulk and particle densities. Three undisturbed soil core samples (5 cm dia. × 3 cm height) from middle of each horizon and were equilibrated at water potentials of -10 kPa and -1500 kPa (Joshua, 1988) to estimate field capacity (FC) and permanent wilting point (PWP), respectively. The difference between volumetric water content at FC and PWP was taken as available water capacity. The difference between total porosity and volumetric moisture held at -10 kPa suction was taken as macro–porosity. The micro–porosity was estimated as volume of water retained at -10 kPa suction. The double ring infiltrometer method with inner and outer rings of 30 and 60 cm diameter, respectively, was used to determine the cumulative and steady infiltration rates (Bower, 1986). In each treatment, eight infiltration runs were carried out in randomly selected places before and after the tillage operations. A soil sample was removed prior to the measurements to obtain the antecedent moisture content. In each soil layer, soil strength was measured before and after tillage treatments using a cone penetrometer (using a cone of 20.3 mm basal diameter and 30^0 cone angle) as described by Bradfold (1986). Soil moisture content was also determined at the time penetrometer readings were taken. After land preparation, single budded sugarcane setts were planted in furrows of sub plots with 5 m length × 4 rows at 1.37 m furrow spacing. After germination, plants were spaced approximately 0.5 m apart within a row. Fertiliser application and other cultural practices were done according to the recommendations made for rain-fed sugarcane farming (Mettananda, 1990). At four months of crop age, roots were counted using Trench Profile Method (Bohm, 1979). When using this method, a trench was dug transversely to the plant rows up to the rooting depth and the profile wall near the plant was smoothed. Then, about 5 mm thick layer of soil was removed by spraying water and the exposed roots were counted using a 5 cm × 5 cm grid net, placed against the profile wall.

RESULTS AND DISCUSSION

Particle size distribution and gravel content

The mean sand, silt, and clay percentag. —— textural class and gravel content for different depths of the RBE soil profile are given in Table 2. All horizons showed a sandy clay loamy texture.

The D3 (34–46 cm) layer, which is the upper part of the gravelly horizon consists of more than 65% gravel and 34% clay. Mapa and Yapa (1992) observed that over 40% clay and 65% gravel in the gravelly horizon in RBE soil sampled at Maha Illuppallama in the North Central Province of Sri Lanka. As suggested by Joshua (1988), the clay particles deposited in the gravelly horizon occupy the macro-pores to a great extent making it a compacted horizon which limits root penetration of sugarcane.

Bulk density and soil strength

Before tillage operations, bulk density of all the horizons were very high. Soil strength also increased with the maximum depth the iiB2 horizon and then decreased (Figures 1 and 2). The highest bulk density was observed in the B2 horizon indicating a compacted layer just below the plough depth.

Table 2. Mean sand, silt, clay percentages, textural class and gravel content of the RBE soil used for the experiment.

Depth	Sand (%)	Silt (%)	Clay (%)	Textural class	Gravel (% g/g)
D1	65.11	11.86	23.03	SCL*	4.6
D2	57.31	11.24	31.45	SCL	8.0
D3	54.71	11.28	34.00	SCL	65.5
D4	54.71	10.42	34.86	SCL	32.3
D5	56.01	13.40	30.58	SCL	8.0

* SCL - Sandy clay loam

The iiB2 (gravelly) horizon showed a bulk density of 1.75 Mg m^{-3}. Mapa and Yapa (1992) also reported a high bulk density of about 1.72 Mg m^{-3} in this horizon. Its soil strength showed the maximum value of 1079 kPa. These soil strength values are comparatively higher than those observed by Somapala (1983) in cultivated RBE soils but less than 1700 kPa which impedes root penetration of maize seedlings in coarse textured soils (Fiskell *et al.*, 1968). High bulk density and soil strength of Ap and B2 horizons may be due to the compaction of soil by four wheel tractors during inter cultivation and transportation of sugarcane after harvest.

Ploughing has loosened the soils of Ap horizon decreasing the bulk density to 1.59 Mg m^{-3} and soil strength to 343 kPa. Sub-soiling has considerably decreased bulk density and soil strength of B2 and iiB2 horizons. Ploughing and sub-soiling were not able to decrease soil bulk density to the optimum value of 1.40 Mg m^{-3} or 50% total pore space (Trouse and Humbert, 1960). However, bulk density of Ap horizon, and Ap, B2 and iiB2 horizons decreased by ploughing and sub-soiling, respectively, to the critical value of 1.63 Mg m^{-3} (Taylor and Gardner, 1963) which would improve the root distribution of sugarcane.

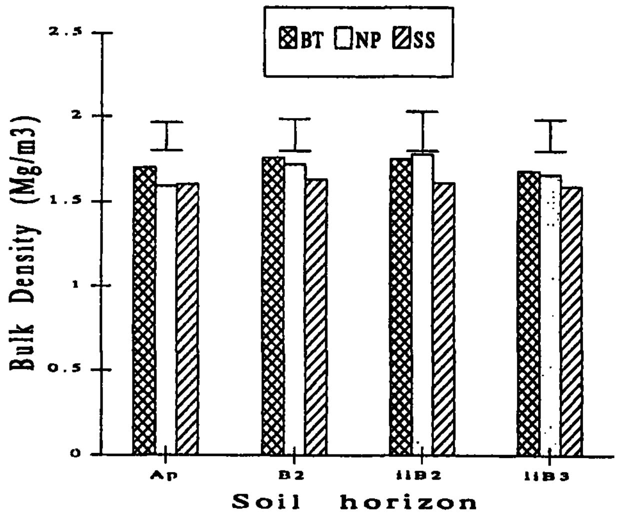

Figure 1. **Bulk density of experimental site before and after tillage operations.**
[Note: Treatments: BT=Before tillage; NP=Normal ploughing; SS=Sub-soiled; The vertical bars indicate the LSD at P=0.05]

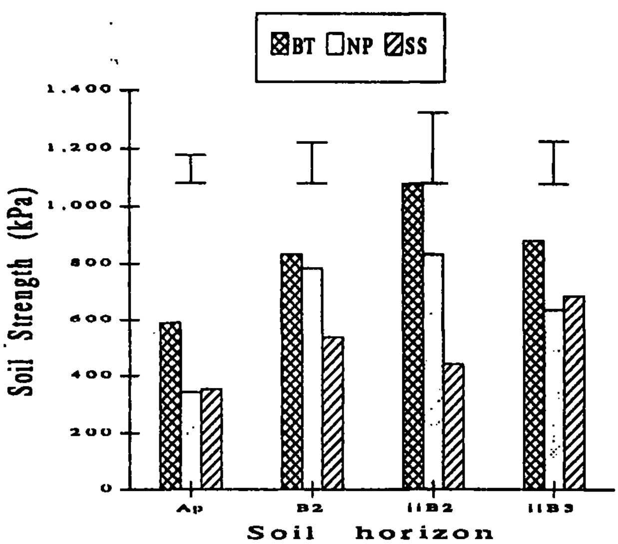

Figure 2. **Soil strength of the experimental site before and after tillage operations.**
[Note: Treatments: BT=Before tillage; NP=Normal ploughing; SS=Sub-soiled; The vertical bars indicate the LSD at P=0.05]

Infiltration

The initial infiltration rates were affected by tillage and values were higher in sub–soiled treatments followed by normal ploughed treatments indicating that soil surface conditions have become more favourable for infiltration by tillage (Table 3). The increase in basic infiltration rate under normal ploughing when compared to that of before tillage would be due to the decrease in bulk density in the "plough layer". Sub–soiling resulted in a greater increase in infiltration rate than normal ploughing. Vittal *et al.* (1983) also observed increased infiltration rates, both initial and final, with deep ploughing, possibly because of de–cementation of the profile by deep cultivation. Joshua (1988) reported a steady state infiltration rate of 1.3 cm h^{-1} for Alfisols in Sri Lanka. However, the infiltration rate of the experimental site before tillage was much less than this reported value. Since the soil texture showed less variability, the difference in the infiltration rate may be due to the high bulk density of the "plough layer". Sub–soiling has disturbed the "plough layer" as well as the gravel layer thus, increasing the infiltration rate to a very high value. This is mainly due to the decrease in bulk density and increase in macro–porosity of gravel layer.

Table 3. Infiltration parameters obtained using Equation (1) and steady infiltration rates.

Tillage treatment		Parameter		Steady infiltration rate (cm h^{-1})	Time to achieve steady state (h)
		a	n		
Initial	Mean	1.31	0.37	0.71	5.8
	CI*	1.25-1.36	0.30-0.43	0.13-1.29	
NP*	Mean	2.00	0.41	1.76	4.7
	CI*	1.95-2.06	0.37-0.45	0.45-3.07	
SS*	Mean	3.53	0.64	19.78	3.5
	CI*	3.32-3.74	0.61-0.67	17.9-21.66	

CI* = Confidence interval at 95% probability level
NP = Normal ploughing.
SS = Sub-soiled

The infiltration characteristics of the soil is very important specially in irrigated agriculture for determining the most suitable irrigation system and also for planning of furrow lengths and application rates. According to the ratings of Landon (1990), the plots under normal ploughing showed an optimum infiltration rate for surface irrigation system. The furrow irrigation which is practised at present in sugarcane farming is best for these soils. The sub-soiled fields may not be suitable for surface irrigation as the infiltration rates are too high.

Porosity, moisture storage and availability

Compared to Ap and iiB3 horizons, the saturated water content is less in iiB2 horizon (Table 4). Loosening of the iiB2 horizon significantly increased the saturated water content by 19%. Barbola and Lal (1977) also reported a decrease in total porosity with increase of sub-soil gravel concentration and increase in macro-porosity by loosening of gravelly horizon but the micro-pores were unaffected.

The available water holding capacity of iiB2 horizon was less when compared to Ap and iiB3 horizons. Increase in sub-soil gravel concentration decreased the available water holding capacity (Barbola and Lal, 1977). Soil horizons of both treatments did not show a significant difference in available water content.

The amount of air-filled porosity at FC is known as field-air capacity (Hillel, 1982). This is estimated by macro-porosity which is the volume of pores drained from saturation to field capacity. When the macro porosity is less than 10% roots may suffer from oxygen deficiency (Greenwood, 1975). In the plots under normal ploughing, only the Ap horizon had a high field-air capacity, but iiB2 and iiB3 horizons showed air capacities much less than 10%. This low aeration porosity coupled with high bulk density of these horizons may hinder the root proliferation of sugarcane. Sub-soiling significantly increased the macro-porosity (Table 4). This will help to increase water intake during high rainfall that minimises soil erosion and occurrence of anaerobic conditions. This may also improve root proliferation.

Root distribution

In variety SLI 121, about 74% of the roots were in the surface horizon while it was about 60% for CO 775 and SL 8306, under normal

Table 4. Total porosity, moisture storage and availability of sub–soiled and normal ploughed treatments.

Parameter	Horizon	Treatment NP	Treatment SS
Total porosity (% v/v)	Ap	40.00^{a}	39.53^{a}
	iiB2	32.93^{b}	39.24^{a}
	iiB3	37.55^{a}	40.13^{a}
Macro–Porosity (% v/v)	Ap	12.54^{a}	11.70^{a}
	iiB2	08.90^{b}	20.40^{a}
	iiB3	06.68^{a}	08.31^{a}
Field Capacity (10 kPa) (% v/v)	Ap	27.46^{a}	27.83^{a}
	iiB2	24.03^{a}	18.84^{a}
	iiB3	30.87^{a}	31.82^{a}
PWP* (1500 kPa) (%, v/v)	Ap	17.56^{a}	18.65^{a}
	iiB2	18.56^{a}	14.50^{a}
	iiB3	23.79^{a}	23.35^{a}
Available water (% v/v)	Ap	09.90^{a}	09.18^{a}
	iiB2	05.67^{a}	04.34^{a}
	iiB3	07.08^{a}	08.47^{a}

*PWP - Permanent Wilting Point ,NP - Normal ploughing, SS - Sub–soiled, LSD - Least Significant Difference (Within each row, means followed by the same letter are not significantly different at $p=0.05$)

ploughing (Table 5). This is in consistent with the previous observations made by Gunasena (1995). Having a relatively high proportion of roots in the surface horizon on RBE soils, variety SLI 121 could easily be affected by relatively short–term droughts. However, the other two varieties tested on the same soils may be less affected because of their deep feeding roots. The

Table 5. Percentage root distribution of 3 sugarcane varieties for normal ploughing and sub–soiled treatments at 4 months age.

Variety	No. of root tips (%)					
	Surface horizon		Gravelly horizon		Below gravelly horizon	
	NP	SS	NP	SS	NP	SS
CO 775	59.34[a]	56.03[a]	38.05[a]	29.56[a]	1.73[b]	14.36[b]
SL 8306	60.19[a]	60.74[a]	26.46[b]	30.77[a]	6.50[a]	8.49[c]
SLI 121	73.54[a]	59.46[a]	26.46[b]	19.03[b]	0.00[c]	21.46[a]
LSD	15.29	13.40	5.70	4.99	0.57	4.20

NP = Normal ploughing SS = Sub–soiled
LSD = Least Significant Difference
(Within each column, means followed by the same letter are not significantly different at p=0.05)

percentage of root tips in iiB2 horizon was significantly different among varieties and between sub–soiled and normal ploughing treatments. In plots with normal ploughing, the percentage of root tips found in iiB3 horizon (below gravelly horizon) was less in both CO 775 and SL 8306 varieties while there were no roots in this horizon in SLI 121. However, sub–soiling has significantly increased the percentage roots in iiB3 horizon, in varieties CO 775 and SLI 121 but, not in SL 8306. Improving soil physical properties by sub–soiling may have increased distribution of roots in iiB2 and iiB3 horizons. Effect of sub–soiling on root distribution was the highest in SLI 121 and lowest in SL 8306 varieties.

CONCLUSIONS

The results of this experiment show the restrictive nature of the gravel layer in well–drained RBE soils where sugarcane is grown at Sevanagala/Uda Walawe area, and the value of tillage in improving soil physical properties and root distribution. Ploughing reduced the bulk density and soil strength in the Ap horizon whereas sub–soiling reduced these parameters in both surface and gravelly horizons. In iiB2 horizon, sub–soiling increased the volume of macro–pores significantly but, micro–porosity and available water capacity were not significantly affected. The steady infiltration rates increased with depth of ploughing. Sub–soiling significantly increased the percentage of roots in the iiB3 horizon in varieties CO 775 and SLI 121, but not in SL 8306. By having a relatively high proportion of roots in the surface horizon on RBE soils, variety SLI 121 could easily be affected by moisture stress. The improvement of soil physical properties as a result of sub–soiling may have caused an increase in root penetration in variety SLI 121 in the gravelly horizon and below. Therefore, if farmers intend to grow SLI 121 under rain–fed conditions, the sub–soiling is beneficial. The sub–soiled fields are not suitable for furrow irrigation, which is practised at present, as the infiltration rates become too rapid.

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