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Investigation on Effective Soil Layer for Sugarcane Production in Limestone Area of Miyako Island, Japan

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ABSTRACT

The study was conducted to find out effective soil layer for sugarcane cultivation in limestone areas of Miyako Island, Okinawa, Japan. Sugarcane production in Okinawa prefecture was restricted due to underlying limestone rock. Three experimental areas were prepared in the same farmer's field, whose effective soil layers were (a) Shallow (40 cm), (b) Medium (60 cm) and (c) Deep (80 cm) and sugarcane was planted in each area for three cultivation cycles. The first two cycles of experiment was in rainfed and third cycle was in irrigated conditions. After harvesting of crops, cane yield, quality and sugar productions of each area were compared. Soil water conservation in sub-soil of 60 cm soil layer was found to be the highest than 40 and 80 cm soil layers. Water consumption and extraction of sugarcane were significantly ($P<0.05$) higher in area of 40 cm shallow soil layer due to higher root concentration followed by 60 cm soil layer and was at 80 cm deep soil layer. It is recognized from experimental results that influences of effective soil layer on water use and sugarcane production differed between the rainfed and irrigated conditions. The effective soil layer of 80 cm produced the highest cane yield and sugar productions compared to 40 and 60 cm soil layer under rainfed condition while those were higher at 60 cm soil layer under irrigated condition compared to 40 and 80 cm soil layers. Therefore, it is concluded that effective soil layer of 60 cm was proper in land consolidation and irrigation improvement in limestone area.

Key words: Cane yield, effective soil layer, limestone soil, root distribution, sugar production, water consumption.

INTRODUCTION

Sugarcane is the main cash crop in Okinawa prefecture and covers 55% of total farmland. Seventy per cent of farmers are engaged in sugarcane production and contributing 15.6-20% of national income (Anon., 2000). Sugarcane grown in Shimajiri Maji soils (Cromic Luvisols / Cambisols; according to the FAO classification) widely spread in Miyako Island of Okinawa prefecture of Japan. Although average annual rainfall (2235 mm) in Miyako Island is sufficient for sugarcane production but uneven distribution of rainfall during the growing season causes severe drought (Yamashiro, *et al.*, 1994). Thus sugarcane suffers from water stress and affecting the growth of young plants, which ultimately reduces yield and quality of sugarcane (Hossain *et al.*, 2002). Specially,

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shallow rooting depth of soils in Miyako Island is not capable of conserving rain water due to existing of porous limestone below the shallow soil depth. Due to this constraint, rooting depth of sugarcane is limited for absorption of nutrients and water from sub-soils, thereby decreased sugarcane yield. Therefore, sugarcane production is unable to maintain at its potential level. Appropriate soil water management techniques are required to improve the soil water storage to reduce deep drainage or percolation by providing water spatially and temporally according to the crop need, which will substantially increase the water use efficiency of crops. Many studies were conducted else where to improve soil water conservation and sub-soil water use techniques of crops in relation to water balance, agronomic practices and soil characters (Hossain *et al.*, 2002; Abou-Salama, 2000; Izuno and Lentini, 2000; Singh *et al.*, 1997; Singh and Mohan, 1994; Shih, 1985). Root distribution and effective rooting depth of sugarcane in Shimajiri Maji soils of Miyako Island, Okinawa were studied by Yamashiro et al. (1994) on the basis of adequate water supply. Available information on the effect of underlying limestone barrier, effective soil layers for root distribution and soil water extraction pattern of sugarcane in Miyako Island with respect to consumptive water use are scanty. In this study, the tensiometer data reflects water consumption at various depths in the root zone of sugarcane that provide reliable information on basic arrangement of optimum effective soil layer for sugarcane cultivation under existing irrigation conditions in the lime stone soils of Miyako Island. Therefore, the studies were carried out to investigate the effective soil layer for optimum use from sub-soil storage water in relation to cane yield, quality, sugar production, root distribution and water extraction pattern in the limestone soils of Miyako Island.

MATERIALS AND METHODS

Experimental site :

The field experiment was conducted at Simokita area of Miyako Island (24^{0}47'N, 125017' E, 40 m altitude) of Okinawa prefecture, which is the southwestern landmass of Japan. Soils at this site was classified as Shimajiri Maji (Cromic Luvisols / Cambisols; according to the FAO classification) derived from Ryukyu limestone. The mean annual rainfall was 2235 500 mm and fluctuation of mean average monthly temperature during cold and summer season were 17.3$\pm$ 1.4 and 30.02 $\pm$ 2.2 ^{0}C respectively. Rainfall distribution in each experimental site through out the rainfed (1993-94 and 1996-97 crop seasons) and irrigated (1998-99 crop season) conditions is indicated in the Figure 1. Limestone rock barrier is occupied beyond shallow rooting depth of 0 to 20 cm and different sizes of limestone rock particles spread in effective soil depth (within 0-40 cm depth). Limestone rock occupied beyond 20 cm depth was excavated and removed to make different soil layers namely, (a) Shallow (40 cm), (b) Medium (60 cm), and (c) Deep (80 cm) using back hoe machine (Fig.2). The area of each improved (consolidated) plots with respect to soil layers was 20m 15m. Thereafter, hole of each experimental plot was filled by topsoil of Shimajiri Maji and two budded sugarcane setts (variety NiF 8) were then planted following standard spacing (row to row distance is 120 cm and centre to centre distance of two budded sugarcane setts is 30 cm). Bulk density of lime stone soil beyond 40 cm depth before excavation was 1.54$\pm$ 0.50 g/cc. Before planting of sugarcane in the excavated plots, bulk density was monitored in every experimental plot and values of bulk density were found to be almost similar (1.17 $\pm$ 0.21 g/cc). The percentage of sand, silt and clay in Shimajiri Maji soil surface were 17.70 $\pm$ 0.51, 32.90 $\pm$ 0.39 and 49.40 0.37% respectively.

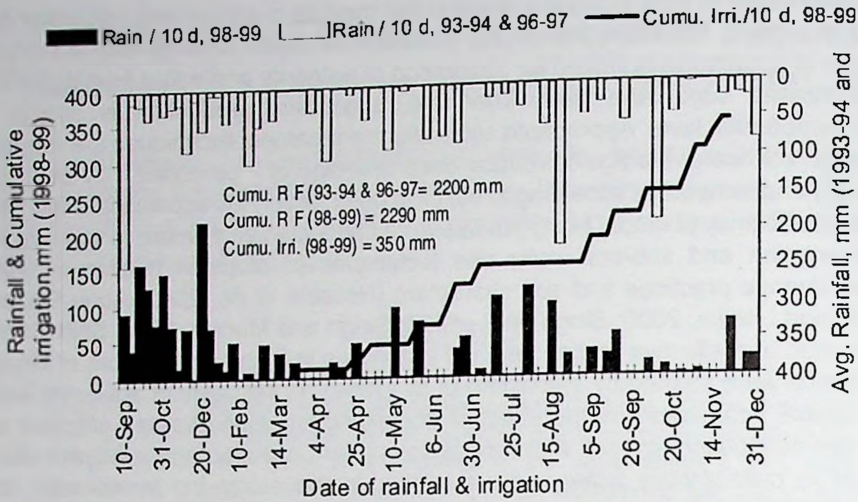

Figure 1. Rainfall distribution during 1993-94, 96-97 and 1998-99 crop season and irrigaion amount for 1998-99 crop season per 10 days interval.

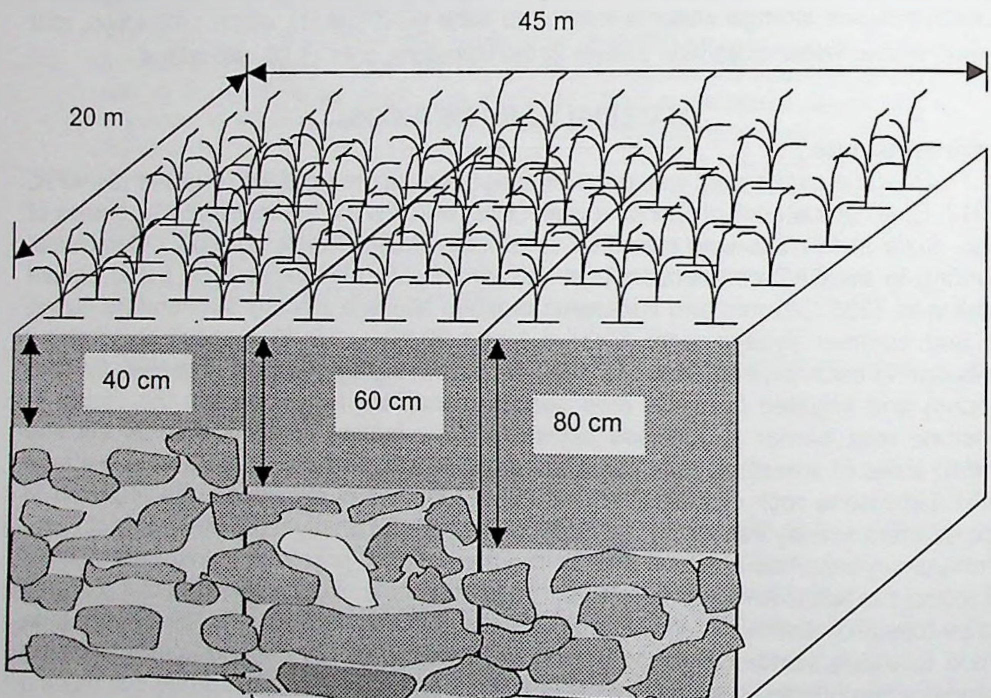

Figure 2. Schematic diagram of sugarcane field made by land consolidation, Planting technique of sugarcane in the field of 20 m × 15 m for each of 40 cm, 60 cm and 80 cm soil layer.

Soil physical properties and root study :

Bulk density, porosity, total and readily available water for each plot in 10 cm interval up to 80 cm depth of profile were estimated (Daniel, 1997; Table 1). For root sampling, undisturbed soil core samples (1.8 m x 1.1 m) were extracted at 10 cm interval and 10 cm beyond depth of each experimental plot (Bohm, 1979).

Table 1. **Physical properties of experimental site.**

Properties	Plots	Depth of soil profile (cm)							
		10	20	30	40	50	60	70	80
Bulk density, (gm/cc)	40 cm	1.173 ±0.053	1.190 ±0.047	1.278 ±0.033	1.335 ±0.031	1.210 ±0.020	1.236 ±0.013	1.276 ±0.050	1.299 ±0.055
	60 cm	1.151 ±0.076	1.068 ±0.068	1.047 ±0.112	1.222 ±0.108	1.332 ±0.062	1.233 ±0.120	1.334 ±0.012	1.314 ±0.084
	80 cm	0.980 ±0.510	1.006 ±0.045	1.077 ±0.048	1.111 ±0.005	1.104 ±0.034	1.129 ±0.009	1.047 ±0.002	1.073 ±0.007
Porosity,(%)	40 cm	57.99 ±5.78	55.88 ±5.12	53.71 ±3.54	50.68 ±5.23	49.71 ±4.12	49.71 ±3.99	47.65 ±7.89	51.75 ±11.0
	60 cm	59.80 ±5.82	58.00 ±2.25	56.77 ±5.01	55.06 ±5.12	53.70 ±4.22	52.65 ±10.12	45.66 ±8.09	48.60 ±8.81
	80 cm	58.69 ±3.67	57.93 ±4.58	55.53 ±1.95	56.57 ±5.99	56.99 ±3.48	55.02 ±6.47	50.60 ±2.46	52.94 ±5.97
Field Capacity, (% in Vol)	40 cm	35.20	39.60	46.15	42.80	42.55	44.95	47.30	42.70
	60 cm	34.20	34.95	36.60	44.50	42.55	41.90	46.45	47.70
	80 cm	36.30	38.75	42.60	44.95	44.88	44.85	42.15	42.20
Primary wilting, (% in Vol)	40 cm	18.01	23.50	32.12	32.40	31.40	36.30	39.10	36.50
	60 cm	20.91	22.02	25.30	37.20	34.90	33.50	41.00	40.00
	80 cm	22.20	24.95	31.60	37.80	33.40	36.50	35.50	35.30

Soil water measurement and irrigation :

Irrigation interval was predicted for each experimental plots based on soil moisture depletion, which was monitored by using digital tensiometer, and soil water content of each experimental plot was then maintained at field capacity level (Fig. 3). The total amount of irrigation applied to each plot during experimental period was equal to daily water consumption multiplied by irrigation interval as proposed by the Board of Land Reclamation, Irrigation and Drainage Project of Miyako Island, Okinawa. Drop irrigation technique was used to irrigate sugarcane (JSIDRE, 1995). Soil water consumption rate and extraction patterns for three soil layers were estimated using the pF-moisture calibration curve (Fig. 4) which was determined by high-speed centrifugal machine in the laboratory (JSSMFE, 1983).

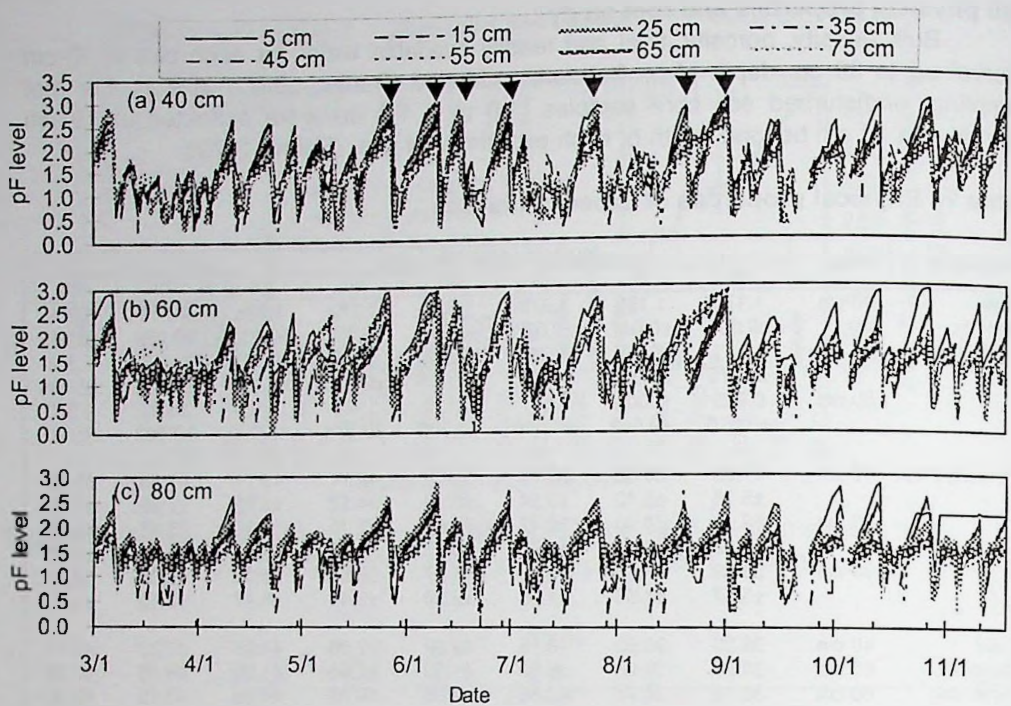

Figure 3. Soil moisture fluctuation under three different soil layers (40, 60 and 80 cm) during 1998-99 crop season (arrow indicates the period of soil moisture extraction and ET).

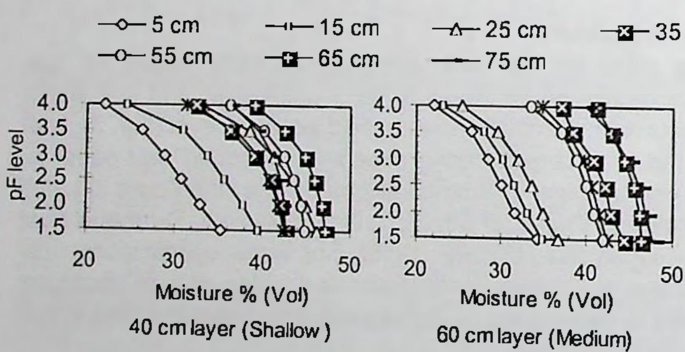

Figure 4. pF-soil moisture calibration curves for three different soil layers (40, 60 and 80 cm), pF= 1.9 and 4.0 represents the field capacity and wilting point.

Yield and growth parameters :

Sugarcane yield, sucrose percentage and total sugar production were recorded under both rainfed and irrigated conditions with respect to different soil layers. Sugarcane yield under irrigated condition of 1998-99 crop season was also compared with the average yield in rainfed condition of 1993-94 and 1996-97 crop seasons. Analysis of variance (ANOVA) followed by pair wise comparison of mean was performed using Least Significant Difference (LSD) method.

RESULTS AND DISCUSSION

Water conservation after irrigation :

The consolidated 40, 60 and 80 cm soil layers significantly influenced water conservation (storage) in sub-soils. It is clearly evident that 60 cm medium soil layer significantly stored the highest amount of water. To compare effects of consolidated soil layers, soil water storage was measured in two steps. First step was measured up to the profile depth of 40, 60 and 80 cm vertically in the consolidated field of 40, 60 and 80 cm soil layers respectively, which is shown in the bar charts of light color (Fig. 5). In the second step, efficiency of consolidated soil layers of 40, 60 and 80 cm were compared between them with the measured water storage up to the maximum possible soil depth of 60, 80 and 80 cm respectively shown in the bar charts of dark black color (Fig. 5). Results showed that 60 and 80 cm soil layers significantly (LSD = 35, $P<0.05$) conserved higher amount of water than 40 cm soil layer when measured up to 40, 60 and 80 cm soil depths (shown in Fig. 5 by light color).

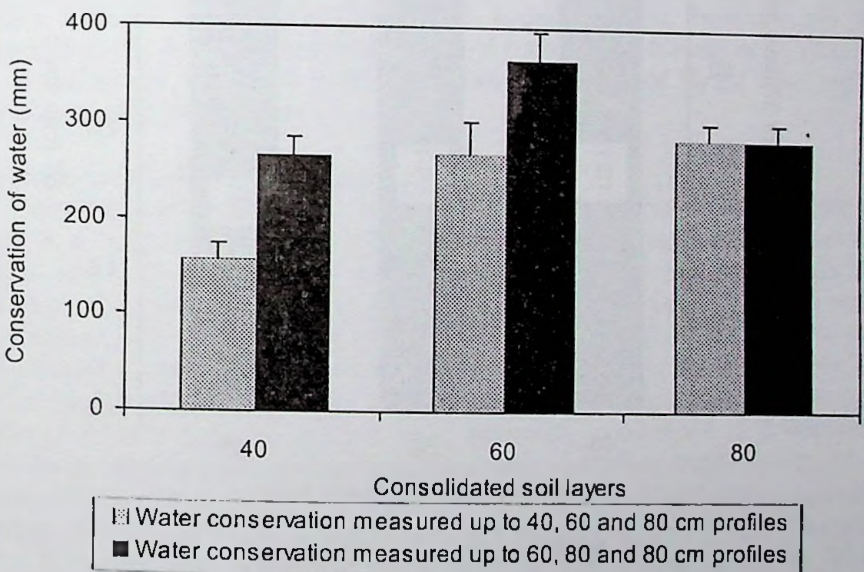

Figure 5. Soil water conservation after irrigation in three consolidated soil layers of 40 , 60 and 80 cm. Bars of light color are water conservation up to 40, 60 and 80 cm soil depths and the bars of deep color are water conservation up to 60, 80 and 80 cm soil depths in the area of 40, 60 and 80 cm consolidated layers.

On the other hand, 60 cm soil layer conserved the highest (LSD = 37, $P<0.05$) amount of water in the sub-soils than 40 and 80 cm soil layers. Low water storage in the sub-soil of 40 cm consolidated soil layer was due to effects of shallow soil depth and loss of irrigation and rain water by deep percolation and seepage through the embedded porous limestone below 40 cm soil depth. While on the other hand, existing weekly interval of irrigation system in Miyako Island stored adequate amount of water in deeper soil layers and thus being the 80 cm soil depth, storage of water in 80 cm consolidated soil layer was low. The interaction of the existing 7 d interval of irrigation and farm land consolidation up to 60 cm proved to be able in producing better cane yield and total sugar production.

Water consumption through evapotranspiration

Total and daily consumption of water through evapotranspiration from the area of 40 cm soil layer was significantly ($P<0.05$) higher than 60 and 80 cm soil layers due to its higher root concentration and excess water loss through leaching and deep percolation (Fig. 6; Fig. 7).

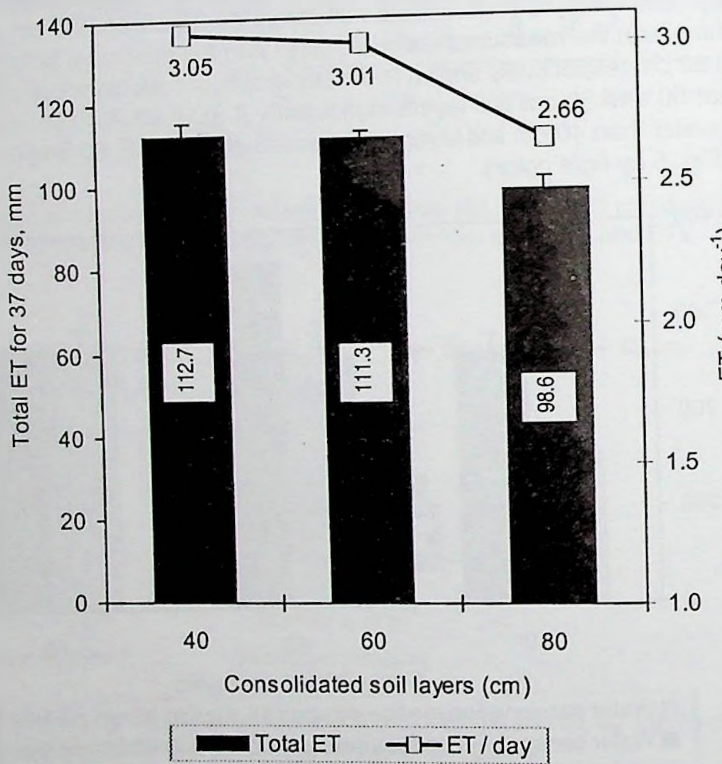

Figure 6. Evapotranspiration (ET) of sugarcane for six dry period of 37 d as affected by different rooting depth.

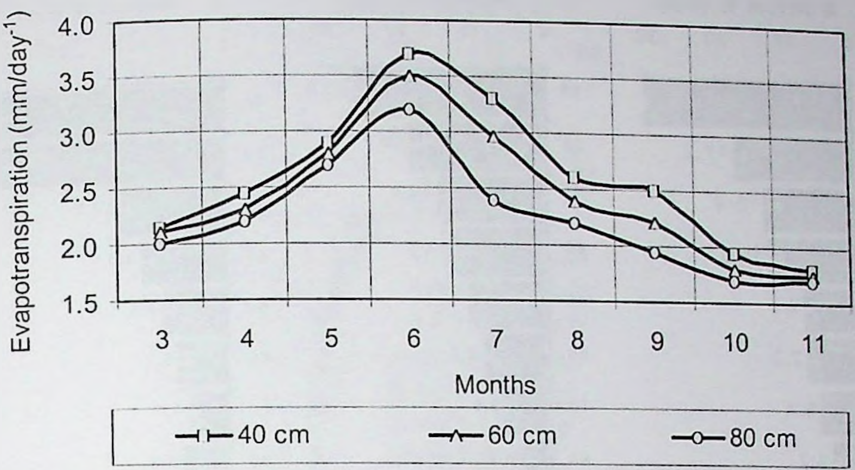

Figure 7. Mean monthly water consumption of sugarcane (1998-99)

Low water storage capability of shallow soil layer was due to presence of limestone beyond 40 cm soil depth, which promoted loss of water through leaching and deep percolation. Vidhana Arachchi (1998) reported that activity of coconut root for water absorption was limited in upper layer of soil profile due to high compaction of sub soil layers. Author reported earlier that water losses was lower than 2.20 mm/day, which adversely affected physiological function of sugarcane and therefore this value is represented as the critical evapotranspiration of sugarcane (Hossain *et al.*, 2002). In this study, evapotranspiration from area of medium and deep soil layers were higher than critical evapotranspiration level.

Water extraction pattern of sugarcane :

Water extraction pattern of sugarcane within 40 cm rooting depth under shallow, medium and deep soil layers were 72.4, 76.6 and 76.5% respectively. However, water extraction at 10 cm soil depth of shallow soil layer (40 cm) was significantly ($P<0.05$) higher than other two layers due to high concentration of roots within 40 cm depth (Fig. 8). High rate of soil water extraction was limited to 10 cm depth of this treatment (shallow soil layer) due to existing limestone barrier. Therefore, activity of sugarcane roots for water extraction was limited at topsoil of 40 cm soil layer. Although, soil water content was maintained at field capacity level in each treatment, occurrence of limestone barrier beyond 40 cm layer could accumulate excess water in shallow depth treatment would be adversely affected on sugarcane production (Fig. 3). Water extraction by sugarcane roots beyond 40 cm profiles of medium soil layer was significantly ($P<0.05$) higher than other treatments. It was also observed that for avoiding water stress at top 10 cm profiles, sugarcane crops produced more roots (Fig. 9) and enhanced the ability of a root system to extract soil water (Fig. 8) which coincided with the report of Richard and Rowe (1977).

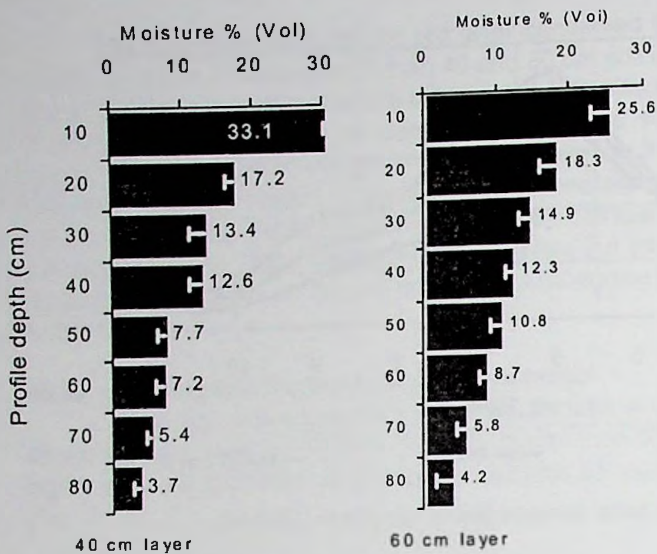

Figure 8. Soil water extraction pattern of sugarcane under three different soil layers.

Root development

Root growth and distribution in each treatment (40 cm shallow, 60 cm medium and 80 cm deep rooting depth) are illustrated in the Fig. 9. Total root growth of sugarcane in the area of 1.80 m ˙ 1.10 m up to 40 cm depth of above treatments were 133.72, 104.50 and 62.81 g and total root mass beyond 40cm depth for the above treatments were 3.23, 12.1 and 7.71 g respectively. Limestone rock barrier adversely affected root penetration of sugarcane in treatment of shallow soil layer (40 cm) and produced a high density of root masses in the top 0-20 cm profiles. It was observed that due to low water holding capacity and to avoid water stress at the top 0-20 cm profiles increased the root density, which enhances the ability of a root system to extract soil water. Although the root distribution in the top soil of medium soil layer of 60 cm was lower than shallow soil layer of 40 cm, sugarcane planted in the medium soil layer was able to produce higher root mass beyond 40 cm rooting depth compared to other soil layers. These roots could beneficially affect on the absorption of nutrient and water from deeper rooting depth compared to other soil layers (40 cm and 80 cm). Towards the deeper soil depth of 80 cm soil layer, soil water storage was higher than 40 and 60 cm soil layers. The existing irrigation schedule (10 d interval) in Miyako Island showed excess storage of water in soil beyond 60 cm soil depth and capillaries and pore spaces were full then the roots had continuous exposure to oxygen for its normal growth. As a result root system tended to get poor and damaged by excess water.

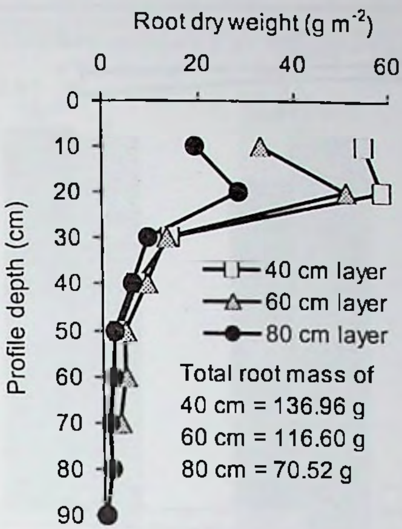

Figure 9. Root distribution of sugarcane grown in different soil layers.

Sugarcane yield and quality :

Sugarcane yield mainly depends on the prevailing optimum water and nutrient status of soil (Singh and Mohan, 1994; Prasad *et al.*, 1994). Yield of sugarcane in the medium and deep soil layers was significantly (LSD0.05=7.18) higher than that of shallow soil layer (40 cm) under irrigated condition (Fig. 10). It was observed that extensively high rate of root growth (Fig. 9) at 40 cm soil layer reduced sugarcane productivity (Fig. 10), because water stress diverted carbon as a growth factor to the root system instead of additional shoot growth of sugarcane. Similar morphological adaptation was also reported for soybean crops (Schulze *et al.*, 1983). Water deficit in the area of shallow soil layer promotes pith formation resulted in reduced cane yield (Parihar *et al.*, 1975). The rain or irrigation water of the shallow soil layer (40 cm depth area) enhances fertilizer leaching beyond the effective rooting zone of sugarcane due to low thickness of soil layer. This could be one of the reasons getting low vegetative growth (length and diameter) of sugarcane in area of shallow soil layer compared to 60 and 80 cm soil layers. Figure 10 shows that cane yield under irrigation and rainfed condition was significantly ($P<0.05$) higher in the area of 60 cm and 80 cm soil layer compared to 40 cm soil layer. Optimum water status and absorption of nutrients from sub-soils by sugarcane roots in 60 cm soil layer could be reason of giving higher sugarcane yield compared to 40 cm soil layer. Under rainfed condition (Fig. 10), sugarcane yield was significantly ($P<0.05$) higher in the area of 80 cm soil layer. Although, sugarcane grown in 80 cm soil layer and giving higher yield than other soil layers, it is not economical due to higher capital investment for land consolidation. Sucrose content (%) was significantly ($P<0.05$) higher in the area of 40 cm soil layer due to water stress prevailing in the maturity stage of sugarcane growth (Fig. 10). Many researchers stated that sugar concentration increases when the soil water stress occurred during maturity stage of sugarcane and excessive water in the root zone dilute the sugar concentration, which ultimately reduces the total sugar production and quality of sugar (Prasad *et al.*, 1990).

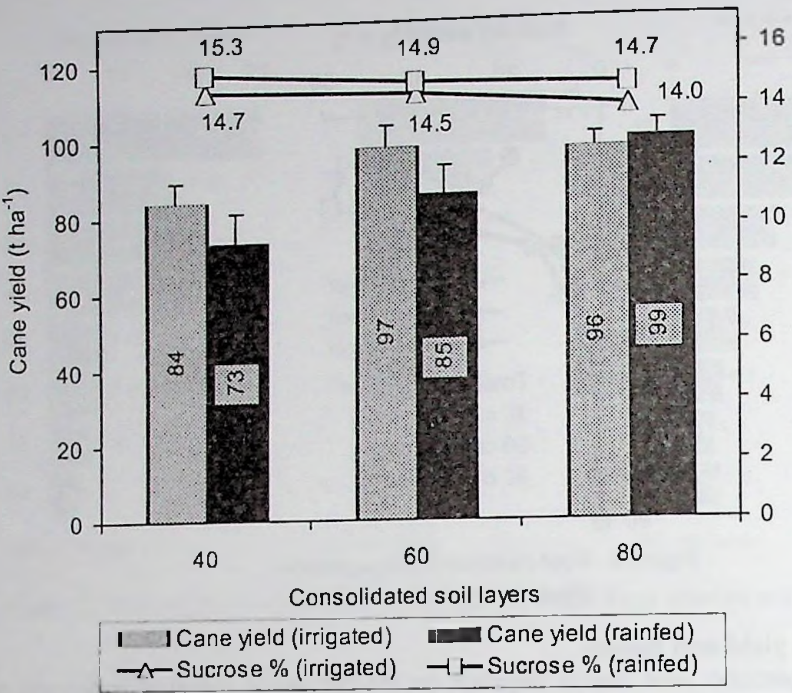

Figure 10. Effect of soil layers on cane yield and sucrose content (%) of sugarcane under irrigation (1998-99) and rainfed (1993-94 & 1996-97) conditions.

Total sugar production :

Total sugar production was influenced significantly by the effects of soil water status and absorption of fertilizer under 40, 60 and 80 cm soil layers for both irrigated ($LSD_{0.05}$ = 1.37) and rainfed (LSD0.05 = 1.45) conditions (Fig. 11). The effective soil layer of 60 cm depth produced the highest sugar yield (14.0 t ha^{-1}) under irrigated condition and soil layer of 80 cm produced the highest sugar yield (14.5 t ha^{-1}) under rainfed condition. Further, it revealed that having high concentration of sugar (Fig. 10) in the shallow soil layer (40 cm) did not enhance total sugar production due to low cane yield at this soil layer.

It is evident from the results that sugarcane grown in medium soil layer (60 cm depth) under irrigated condition promotes water storage, cane yield and total sugar production. However, application of optimum water to shallow soil layer (40 cm) with combine fertilizer conservation practices is possible of getting higher yield of cane and sugar. Getting of higher yield by planting of sugarcane in deep soil layer (80 cm) under rainfed condition would not be economical due to initial higher cost of land consolidation and irrigation improvement in limestone area.

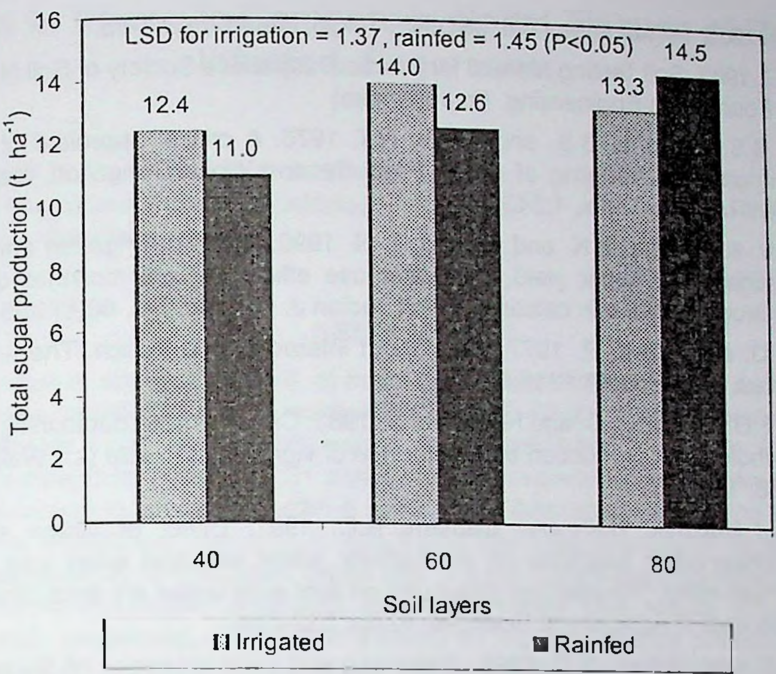

Figure 11. Efecs of soil layers on total sugar production in limestone soil area of Miyako Island, Okinawa, Japan under irrigation and rainfed conditions.

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