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ROOT DENSITY, DISTRIBUTION AND YIELD RELATIONSHIPS OF HIGH YIELDING SUGARCANE VARIETIES UNDER SANDY SOIL CONDITION

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ABSTRACT

Roots are the less explored part of the sugarcane plant but are essential for sufficient nutrient and water supply to ensure better growth, development and sugar yield. Understanding the nature of the root system will help the plant breeder in selecting superior varieties that are adapted to different soil conditions. An experiment using ten high yielding sugarcane varieties was conducted to determine the root characteristics and yield performance in sandy soil of Pampanga, Philippines. The experiment was laid-out in RCBD with four replications. ANOVA revealed significant differences in 16 out of 18 parameters. Phil 8013, Phil 7544, Phil 97-3933, Phil 99-1793, Phil 04-0081, Phil 00-2569 and Phil 03-1727 produced significantly highest sugar yield (LKg/ha) which ranged from 223.05-257.93. Root density (RD) (g) and distribution at different soil depths from 0-100cm with interval of 10cm were 318.35 (46.47%), 132.36 (21.59%), 81.02 (14.05%), 26.24 (4.57%), 14.77 (2.61%), 14.58 (2.53%), 13.23 (2.32%), 11.53 (2.05%), 10.80 (1.93%) and 10.63 (1.87%). Stalk characteristics such as diameter, length and number of millable stalks and RD at 0-10cm, 11-20cm, 21-30cm, 51-60cm, 61-70cm, 71-80cm and 90-100cm were positively correlated with cane yield while percent brix and purity were positively correlated with sucrose content.

Contribution/Originality: This study is one of very few studies in the country which investigated sugarcane roots. Information derived from this study may guide farmers in the selection of varieties suited in sandy soil including the adoption of appropriate cultural management practices for a more efficient utilization of resources.

1. INTRODUCTION

Cultivated sugarcane varieties (*Saccharum spp.*, hybrid.), are perennial grass of the family *Poaceae*, primarily cultivated for its juice from which sugar is processed [1]. Most of the world's sugarcane is grown in subtropical and tropical areas, often under rain-fed conditions with supplementary irrigation in some areas. It is preferably planted in clay loam if there is less rainfall and sandy loam under heavy rainfall.

Sugarcane is globally an important crop used in the production of 80% of global sugar production [2]. Aside from sugar, it provides renewable source of materials to produce biofuel, fiber, fertilizer, and other co-products with ecological sustainability.

The Philippines has been growing sugarcane since 1856 and is the second largest producer among ASEAN countries [3] next to Thailand. It is estimated that the industry provides direct employment to about 700,000 sugarcane workers spread across 27 sugarcane producing provinces [4]. The industry has contributed about 70 billion pesos to the nation's economy annually [5].

Presently, the sugarcane industry is facing a major problem concerning low farm productivity due to various factors such as variety, soil condition, cultural management, pest and diseases and climatic conditions.

In commercial production, varieties play a vital role in obtaining high cane tonnage and juice quality. The inherent potential of a variety to give better yields is of paramount importance for sustaining high productivity [6]. This means that the use of superior cane cultivars is a primary requirement for high productivity and profitability and in many countries substantial yield increases due to variety improvement had been achieved.

At present, there are nine mill districts situated in the Luzon and Mindanao areas with an average productivity of 56.33 tons cane per hectare (TC/ha) and sucrose content of 1.77 LKg/TC. The highest TC/ha of 66.62 and LKg/TC of 1.83 were produced in the Bukidnon Mill District while the lowest was produced in CARSUMCO and Pampanga mill districts with 35.15 and 39.79 TC/ha and 1.57 and 1.59 LKg/TC, respectively [7]. The difference in productivity is mainly due to the adaptability of varieties and agro-climatic conditions in the districts.

In Pampanga, approximately 6,310 hectares are planted to sugarcane of which 97.58% is grown under sandy soil condition. The productivity ranged from 34.49-42.00 TC/ha from CY 2011-2017 which is far below the national average of 66.62 TC/ha [7] inspite of the interventions provided by agriculturists by way of information dissemination of research results and technology demonstrations. There seems to be a need to look closely into the problem of some of the major factors that affect productivity such as variety and agro-climatic conditions.

Variety performance depends upon its adaptability to agro-climatic conditions in the area. Selection of the appropriate variety to be planted is a primary requisite when exploring yield and sugar recovery potential [8].

One important aspect to consider is the effect of soil and climate on the root characteristics of HYVs as this is fundamental in understanding relations with water and nutrients uptake. It is also important in employing agronomic practices on spacing, fertilizer application, land preparation and cultivation for better anchorage, cultural operation, soil drainage and irrigation. For many years until the middle of the last century, roots were considered the "hidden half" of plants [9] with a significant scarcity of research results on this issue throughout the world due to methodological difficulties, inaccessibility of the root system, its three-dimensional complexity and its notable spatial and temporal variability [10]. In this aspect, there is a need to evaluate the root characteristics, cane yield and quality of HYVs to determine their suitability to production under a specific soil type and climatic condition.

1.1. Objectives

In commercial sugarcane production, identification of suitable high yielding varieties is very critical since the use of superior cultivars is an essential factor in the realization of the industry to optimize productivity and ensure profitability. This study was conducted under sandy soil condition to determine the following: (1) yield performance of high yielding sugarcane varieties; (2) quantify the root density and distribution of sugarcane varieties at different soil depths; (3) degree of association between yield and yield components and root density with cane yield and sucrose content, and (4) recommend varieties adapted to sandy soil condition.

2. METHODOLOGY

The study was conducted in the experimental area of the Sugar Regulatory Administration-Luzon Agricultural Research and Extension Center (SRA-LAREC), Paguiruan, Floridablanca, Pampanga, Philippines from January 2017-January 2018 with an elevation of 27 meters above sea level. Average proportions of sand, silt and clay textural particles in the soil are 76.95%, 7.75% and 16.81%, respectively. Based on the proportion of soil particles it was classified as loamy sand with soil pH of 6.05 which is slightly acidic in range. Average organic matter of soil was 0.5% and with an available amount of 35 ppm of Phosphorus, 68 ppm of K and 791 ppm of Calcium. Based on soil analysis the recommended dose of fertilizer used was 195-0-340 NPK kg/ha. Average temperatures were 24.26^{0}C during germination stage (January-February 2017), 26.32^{0}C at tillering stage (February-May 2017), 25.56^{0}C at stalk elongation stage (May-August 2017), 25.44^{0}C (September-January 2018). Rains occurred in July-November 2017 with minimum and maximum rainfall of 100.40 and 697.60 mm, respectively. It received an annual rainfall of 1,565 mm with maximum and minimum temperatures of 27.54^{0}C and 24.24^{0}C, respectively.

Ten high yielding varieties (HYVs) of sugarcane namely; Phil 93-1601, Phil 97-3933, Phil 99-1793, Phil 00-1419, Phil 00-2155, Phil 00-2569, Phil 8013, Phil 03-1727, Phil 04-0081 and Phil 75-44 were used and planted in a randomized complete block design (RCBD) with four replications. Each plot measured 7.8 meters wide and 9.0 meters long with six rows spaced at 1.3 meters. Wider border spaces of 2.6 meters between blocks were provided to facilitate data gathering, weeding and harvesting. A two-meter alley was also established between plots. Three node cuttings were used for planting at five canepoints per linear meter. Recommended cultural practices in the growing of sugarcane in the locality were employed.

Ten stalks were randomly selected from four inner rows in each plot from which data on stalk length (cm), stalk diameter (cm) were recorded at harvest. The same stalks were also used for juice analysis. Cane yield (TC/ha.) was computed from harvested four inner rows per plots. Brix reading (%), apparent purity (%) and sucrose content (LKg/TC) were determined and computed from the results of the juice analysis performed in the laboratory. Sugar yield (LKg/ha) was computed as product of cane yield and sucrose content.

Root density (g) and percent distribution (%) measurements were taken in three replications at soil depths (cm) of 0-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, 91-100. An area of 1.0m^2 was excavated per plot. The collected soil at corresponding soil depth was sieved using 2mm mesh wire until the roots were extracted. The collected roots were weighed and recorded.

The variation among sugarcane varieties was assessed using analysis of variance (ANOVA) in Randomized Complete Block Design (RCBD). Means were compared using Tukey's Honestly Significant Difference (HSD) at 5% probability. Pearson's Product Moment Correlation (PPMC) was used to determine the associations between yield components and root characteristics with yield. STAR version 2.0.1 [11] developed by IRRI was used to analyze the data.

3. RESULTS AND DISCUSSION

The result of the analysis of variance showed highly significant differences among the varieties for all the traits except apparent purity (%) and root density at 81-90cm depth, indicating considerable amount of genetic variability among varieties tested in the study. This means that different varieties have distinctive adaptation mechanism to sandy type of soil due to their diverse morphological characteristics.

3.1. Yield Components and Yield Parameters

A. Stalk Characteristics

Yield components of cane yield (TC/ha) namely, millable stalk length (cm), stalk diameter (cm) and number of millable stalk of test varieties under sandy soil condition were presented in Table 1.

Stalk length varied significantly among varieties which ranged from 216.00 to 275.25 cm. Phil 8013 produced significantly the longest stalk with a mean value of 275.25 cm but comparable to Phil 75-44, Phil 97-3933, Phil 00-2569 and Phil 03-1727 with mean values of 262.75 cm, 261.50 cm, 260.75cm, and 259.00 cm, respectively.

In stalk diameter, differences between varieties were observed. Stalk diameter among varieties varied from 2.53 to 3.67cm. The thickest stalks were observed in Phil 00-2569 comparable to Phil 75-44 which has a mean value of 3.39 cm. On the other hand, Phil 00-1419, Phil 04-0081 and Phil 93-1601 were observed to have the thinnest stalks with mean values that ranged from 2.53 to 2.66 cm.

Number of millable stalks produced per plot was significantly different among varieties. Number of millable stalks ranged from 225.75 to 330.00. It can be observed from the result that the varieties can be grouped into three, with Phil 75-44 producing significantly highest number of millable stalks (330.00), followed by Phil 8013, Phil 97-3933, Phil 00-2569, Phil 04-0081, and Phil 93-1601 producing intermediate number of millable stalks (285 to 268.25) while, the lowest number of millable stalk were observed from Phil 99-1793, Phil 03-1727, Phil 00-1419 and Phil 00-2155 (244.25 to 225.75). The number of millable stalks is directly influenced by percent germination and number of tillers [12]. The differences in millable stalk length, stalk diameter and number of millable stalks can be mainly attributed to varied inherent potential of the varieties since environmental conditions are held constant.

Table-1. Stalk length, stalk diameter and number of millable stalk of HYVs grown under sandy soil.

	Varieties	Stalk Length (cm)	Stalk Diameter (cm)	Number of Millable Stalks
1	Phil 00-1419	220.25^{c}	2.53^{f}	238.50^{c}
2	Phil 00-2155	227.25^{bc}	2.89^{de}	225.75^{c}
3	Phil 00-2569	260.75^{ab}	**3.67^{a}**	281.50^{b}
4	Phil 03-1727	259.00^{ab}	3.04^{cd}	241.25^{c}
5	Phil 04-0081	205.00^{c}	2.67^{ef}	277.50^{b}
6	Phil 7544	262.75^{ab}	3.39^{ab}	**330.00^{a}**
7	Phil 8013	**275.25^{a}**	3.11^{bcd}	285.00^{b}
8	Phil 93-1601	216.00^{c}	2.66^{ef}	268.25^{b}
9	Phil 97-3933	261.50^{ab}	3.31^{bc}	282.25^{b}
10	Phil 99-1793	218.00^{c}	2.90^{de}	244.25^{c}
	F-test	11.69**	31.11**	51.82**
	C.V. (%)	6.20	4.28	3.20
	$HSD_{0.05}$	36.26	0.32	20.82

Note: Means in a column with the same letter are not significantly different based on HSD at 0.05 probability.
** Significant at 1% level of probability.

Significant differences in millable stalk length, stalk diameter, average weight per stalk and number of millable stalk had also been reported by Tena, et al. [13]; Khalid, et al. [14] and Sharar, et al. [15]. Longer millable stalks, bigger stalk diameter and more number of millable stalks are the foundations of high yield [16]. Taller and thicker stalks with minimum pith possess heavier weight per stalk. Storage capacity for sugars also increase as stalk height and diameter increases, hence, not only cane yield but also sugar yield per unit area is also increased [17].

Production of millable stalks can also be due to the inherent capacity of a variety for tiller formation while the attainment of favorable stalk length, stalk diameter and stalk weight lie in the ability to utilize the available resources present in the environment.

These components can be used as criteria in recommending varieties that have potential for commercial production in sandy soil condition. Since stalk characteristics reflect the potential tonnage a variety may achieve, it is necessary to give attention to this as criteria in the varietal selection program.

B. Juice Quality

Two juice characteristics that can influence sucrose content (LKg/TC) are percent brix reading (%), apparent purity (%). Brix content provides information on the quality of juice in terms of percent soluble solids in juice. Most of the soluble solids in sugarcane juice are sugars [18]. On the other hand, apparent purity is the percentage sucrose in total solids in the juice. Apparent purity (%) and polarity are the main factors used in maturity determination and quality judgment [14]. Higher purity indicates higher sucrose content out of the total solids present in juice. A cane crop is considered fit for harvesting if it has attained a minimum of 85% purity [19].

Brix reading (%) and apparent purity (%) of high yielding sugarcane varieties grown in sandy soil are presented in Table 2.

Percent brix reading ranged from 19.16 to 23.34%. Significantly highest brix reading was recorded in Phil 8013 compared with Phil 03-1727, Phil 00-2569 and Phil 00-1419 with mean values of 20.02%, 19.50% and 19.16%, respectively. However, Phil 8013 gave comparable brix reading to the other varieties. Ganapathy and Purushothaman [20] also observed variation in percent brix reading among varieties. This could be due to the variation in inherent capacity of the varieties to accumulate soluble solids during maturation which is a physiological process involving the synthesis, translocation, and accumulation of sugars in the storage tissues of the stalks. Apparent purity of the varieties ranged from 91.17 to 95.02%. No significant differences were observed in the apparent purity of the tested varieties. However, numerically, high apparent purity reading was observed in Phil 97-3933 with a mean value of 95.02%. As mentioned by Kanchannaiwal [19] the ideal apparent purity for mature canes starts at 85%.

This result may be due to the uniform expression of the varieties tested for this attribute. The results observed in brix and purity coincide with the findings of Khalid, et al. [14] but contradictory to Ganapathy and Purushothaman [20] who observed variation among varieties in both brix and purity.

The search for varieties exhibiting desirable characteristics such as high cane yield (TC/ha), high sucrose content (Lkg/TC) and high sugar yield (Lkg/ha) is an important endeavor in sugarcane production. Among the three characteristics sucrose content (Lkg/TC) is considered the most important determining factor in obtaining high sugar yield from the outlook of millers and producers.

Table-2. Brix and apparent purity of HYVs grown under sandy soil.

	Variety	Juice Quality Characteristics	
		Brix (%)	Apparent Purity (%)
1	Phil 00-1419	19.16^{b}	91.17
2	Phil 00-2155	20.76^{ab}	93.73
3	Phil 00-2569	19.50^{b}	93.12
4	Phil 03-1727	20.02^{b}	93.62
5	Phil 04-0081	22.13^{ab}	91.98
6	Phil 7544	20.98^{ab}	92.58
7	Phil 8013	**23.34**^{a}	94.72
8	Phil 93-1601	22.11^{ab}	93.23
9	Phil 97-3933	21.55^{ab}	95.02
10	Phil 99-1793	22.32^{ab}	93.39
	F-test	4.07**	ns
	C.V. (%)	6.30	1.95
	$HSD_{0.05}$	3.25	

Note: Means in a column with the same letter are not significantly different based on HSD at 0.05 probability.
** Significant at 1% level of probability ns- not significant.

C. Yield Parameters

Cane yield (TC/ha), sucrose content (LKg/TC) and sugar yield (LKg/ha) of high yielding sugarcane varieties grown in sandy soil are presented in Table 3. Cane yield is one of the two factors that determine number of bags of sugar per hectare or sugar yield. It is a function of the stalk weight and the number of millable stalks. Data showed highly significant differences among the varieties. Cane yield varied from 98.49 to 132.86 TC/ha. Phil 75-44 significantly produced the highest cane yields of 132.86 TC/ha and comparable to Phil 00-2569 with a mean value of 126.55 TC/ha. This is attributed to the superiority of both varieties in the stalk length, stalk diameter, weight per stalk and number of millable stalks produced Table 1. Phil 93-1601 and Phil 00-1419 significantly gave the lowest cane yields of 98.49 TC/ha and 102.06 TC/ha, respectively, as a result of their poor stalk characteristics performance. Many earlier workers have also reported significant yield differences among the varieties [14, 20, 21].

Table-3. Cane yield, sucrose content and sugar yield of HYVs under sandy soil grown under sandy soil.

	Varieties	Cane Yield (TC/ha)	Sucrose Content (LKg/TC)	Sugar Yield (LKg/ha)
1	Phil 00-1419	102.06^{ef}	1.75^{b}	169.03^{d}
2	Phil 00-2155	109.34^{de}	1.99^{ab}	206.36^{bcd}
3	Phil 00-2569	126.55^{ab}	1.84^{b}	223.05^{abc}
4	Phil 03-1727	122.08^{bc}	1.91^{ab}	222.59^{abc}
5	Phil 04-0081	117.38^{bcd}	2.06^{ab}	229.81^{abc}
6	Phil 7544	132.86^{a}	1.96^{ab}	249.63^{ab}
7	Phil 8013	118.85^{bc}	2.27^{a}	257.53^{a}
8	Phil 93-1601	98.49^{f}	2.10^{ab}	195.10^{cd}
9	Phil 97-3933	122.98^{bc}	2.11^{ab}	248.45^{ab}
10	Phil 99-1793	116.28^{cd}	2.12^{ab}	235.24^{abc}
	F-test	30.81**	3.31**	8.19**
	C.V. (%)	3.31	8.33	8.53
	HSD 0.05	9.39	0.41	46.42

Note: Means in a column with the same letter are not significantly different based on HSD at 0.05 probability.
** Significant at 1% level of probability.

Sucrose content in cane juice is an important quality character of sugarcane. Its determination is useful in deciding the quality of sugarcane and it influences the sugar recovery and sugar production in the factory (Thangavelu, (2007) as cited by Ganapathy and Purushothaman [20]. The sucrose content varied significantly among the varieties. Sucrose content ranged from 1.75 Lkg/TC to 2.27 LKg/TC. Highest sucrose content of 2.27 Lkg/TC was recorded in variety Phil 8013 compared to Phil 00-2569 and Phil 00-1419 with mean values of 1.84 LKg/TC and 1.75 LKg/TC, respectively. However, Phil 8013 gave comparable result to the other test varieties. The variation among varieties in sucrose content is mainly because of genetic makeup of the different varieties. Many earlier workers have also reported significant sucrose content (Lkg/TC) differences among varieties [20, 22].

Sugar yield is the product of cane yield and sucrose content. Result of the analysis showed significant differences among varieties. Sugar yield ranged from 169.03 to 257.53Lkg/ha. Among the ten high yielding varieties, Phil 8013 produced the highest sugar yield with a mean value of 257.52 Lkg/ha compared with Phil 00-2155, Phil 93-1601 and Phil 00-1419 with mean values of 206.36 Lkg/ha, 195.10 Lkg/ha and 169.03 Lkg/ha, respectively. These differences were mainly due to the variation in cane yield and sucrose content between varieties. Shanmuganathan, et al. [21] and Ganapathy and Purushothaman [20] also reported differences in sugar yield among varieties.

These results could serve as information on the genetic variability among varieties which partly explains the variation in cane and sugar yields since each variety may have its own specific adaptive characteristics for specific environment in order to exhibit its potential.

3.2. Root Characteristics of Sugarcane Varieties in Sandy Soil

Roots comprise the lesser known part of the sugarcane and yet are essential for the supply of sufficient water and nutrients to ensure outstanding growth, development and sucrose storage. By understanding root characteristics, yields can be optimized through improved strategies in cultural management. Roots serve as the primary factor in the survival, development and performance of the plants since the above ground parts depend on it for anchorage and absorption of soil nutrient and water.

A. Root Density (g)

Root density or the amount of roots in the total surface area indicates the absorptive capacity for nutrients and moisture [23]. Root density among varieties differed significantly at varying soil depths except at 81-90 cm Table 4.

Table-4. Root density at different soil depths of high yielding sugarcane varieties grown in sandy soil.

Varieties	Root Density (Grams)												
	TOP LEVEL (cm)				Middle Level (cm)				Bottom Level (cm)				Grand Total
	0-10	11-20	21-30	Total	31-40	41-50	51-60	TOTAL	61-70	71-80	81-90	91-100	TOTAL	
Phil 00-1419	126.43^{de}	195.65^{b}	45.24^{cd}	367.32	29.73^{abc}	6.29^{abcd}	10.82^{cd}	56.84	9.37^{c}	9.70^{abc}	9.73	8.89^{bc}	28.32	461.85
Phil 00-2155	431.84^{b}	76.11^{d}	44.67^{cd}	552.62	33.32^{ab}	18.94^{ab}	18.54^{a}	70.80	9.44^{c}	9.21^{c}	10.85	11.10^{abc}	31.16	664.02
Phil 00-2569	184.27^{cde}	115.78^{cd}	104.02^{b}	404.07	25.68^{bcde}	10.56^{d}	12.86^{bcd}	49.10	15.98^{a}	13.68^{a}	9.65	11.31^{abc}	34.64	503.79
Phil 03-1727	106.60^{e}	102.69^{cd}	101.82^{b}	311.11	21.84^{cde}	15.94^{bcd}	12.87^{bcd}	50.65	15.59^{a}	12.15^{abc}	12.70	11.49^{abc}	36.34	413.69
Phil 04-0081	267.28^{c}	92.08^{cd}	87.66^{b}	447.02	20.63^{de}	22.69^{a}	17.86^{a}	61.18	14.55^{ab}	11.73^{abc}	12.06	12.02^{ab}	35.81	558.56
Phil 7544	946.33^{a}	275.96^{a}	106.07^{b}	1328.36	34.70^{a}	13.96^{bcd}	17.98^{a}	66.64	16.98^{a}	13.61^{ab}	11.45	12.86^{a}	37.92	1449.9
Phil 8013	184.94^{cde}	129.21^{c}	134.62^{a}	448.77	25.47^{bcde}	11.16^{cd}	16.91^{ab}	53.54	15.41^{a}	11.97^{abc}	10.41	9.63^{abc}	32.01	549.73
Phil 93-1601	274.89^{c}	78.21^{cd}	25.49^{d}	378.59	27.00^{abcd}	10.69^{d}	10.06^{d}	47.75	8.82^{c}	9.54^{bc}	9.19	8.22^{c}	26.95	462.11
Phil 97-3933	444.90^{b}	191.32^{b}	103.98^{b}	740.27	25.97^{bcde}	17.44^{abc}	15.18^{abc}	58.59	15.87^{a}	13.04^{abc}	12.41	11.74^{ab}	37.15	851.92
Phil 99-1793	215.99^{cd}	66.62^{d}	56.60^{c}	339.21	18.07^{e}	10.01^{d}	12.67^{bcd}	40.75	10.32^{bc}	10.70^{abc}	9.51	9.07^{bc}	39.28	419.56
Mean	318.35	132.36	81.02	531.73	26.24	14.77	14.58	55.58	13.23	11.53	10.80	10.63	32.96	633.51
F-Test	162.65**	44.10**	56.53**		11.28	10.91**	112.31**		12.30**	4.28**	1.97^{ns}	5.18**		
C.V. (%)	10.60	13.34	10.08		10.42	15.04	10.59		12.31	12.15	14.79	11.14		
$HSD_{0.05}$	98.79	51.70	23.91		8.01	6.5	4.52		4.77	4.10		3.47		

Note: Means in a column with the same letter are not significantly different based on HSD at 0.05 probability.
**Highly significant; ns-not significant.

a. Root Density at Top Soil Level

Root density at soil depth of 1-10 cm ranged from 106.60 to 946.33g with Phil 75-44 having the densest roots. This was followed by Phil 97-3933 and Phil 00-2155 having mean values of 444.97 and 431.84g, respectively.

At 11-20 cm soil depth root density among varieties ranged from 66.62 to 275.96g. Highest root density was also observed from Phil 75-44.

Root density at 21-30 cm soil depth among varieties ranged from 25.49 to 134.62g. Maximum root density was recorded in Phil 8013 followed by Phil 75-44, Phil 00-2569, Phil 97-3933, Phil 04-0081 with a mean value which ranged from 106.07 to 87.66g.

b. Root Density at Middle Soil Level

Root density at 31-40 cm soil depth among varieties ranged from 18.07 to 34.70g. Phil 75-44 was observed to produce the highest root density while three other varieties namely, Phil 00-2155, Phil 00-1419 and Phil 93-1601 gave comparable results with values ranging from 27.00 to 33.32g.

At soil depth of 41-50 cm, root density ranged from 10.01 to 22.69g. Phil 04-0081 recorded the highest root density with a mean value of 22.69g. Moreover, Phil 00-2155, Phil 97-3933 and Phil 00-1419 also gave comparable results with Phil 04-0081 with mean values ranging from 17.44 to 18.94g.

Root density at 51-60 cm soil depth ranged from 10.06 to 18.54g. Phil 00-2155 recorded the highest root density with a mean value of 18.54g. Four other varieties namely, Phil 75-44, Phil 04-0081, Phil 8013, and Phil 97-3933 gave comparable result with Phil 00-2155 having mean values ranging from 15.18 to 17.98g.

c. Root Density at Bottom Soil Level

Root density at 61-70 cm soil depth ranged from 8.82 to 16.98g. Phil 75-44 obtained highest root density compared with Phil 99-1793, Phil 00-2155, Phil 00-1419 and Phil 93-1601 with mean values of 10.32g, 9.44g, 9.37g, and 8.82g, respectively. The remaining varieties gave comparable value of Phil 75-44.

At 71-80 cm soil depth root density ranged from 9.21 to 13.68g. Phil 00-2569 was recorded to have the highest root density with mean value of 13.68g compared with Phil 93-1601 and Phil 00-2155 with mean values of 9.54 and 9.21g, respectively. All other remaining varieties gave comparable result with Phil 00-2569.

At 81-90 cm soil depth root density ranged from 9.19g to 12.70g. Although Phil 03-1727 obtained the highest root density numerically based on ANOVA, it did not differ significantly with other varieties.

At 91-100 cm soil depth, RD among varieties varied significantly and ranged from 8.22 to 12.86g. Phil 75-44 was recorded to have the highest root density of 12.86g compared with Phil 00-1419, Phil 93-1601 and Phil 99-1793. All other remaining varieties gave comparable results with Phil 75-44.

Generally, root density of the tested varieties ranged from 10.63 to 318.35g at soil depths of 1-100 cm. From the top level (1-30 cm) mean of root density ranged from 318.35 to 81.02g, 26.24 to 14.58g at the middle level and 10.63 to 13.23g at the bottom soil level. Greater root density was observed in the top level with a mean value of 531.73g than in the middle level which has a mean value of 55.58g which in turn has a greater root density than bottom level with a mean value of 32.96 g. These results indicate that root density decrease with increasing distance from soil surface.

The capacity of root system to take up water and nutrients from the soil is of primary importance when considering the functional behavior of the root system of a plant. Within the context of root system, Manschadi, et al. [24] stated that effectiveness of roots is associated with root density, thus making it one of the most important root parameters. Therefore, a variety with higher total root density may allow for greater absorption of water and nutrients which could result to higher cane yield. Also, a variety with a higher root density in the bottom soil level reduces the vulnerability of crops to soil water deficits by providing increased capacity for uptake of deep reserved of soil water, which has also been observed by Wood and Wood [25]. In this regard, it could be said that Phil 75-44 and Phil 97-3933 have higher probability of obtaining high cane yield under sandy soil condition. Variations in root density is therefore, indicate the magnitude of the absorptive capacity of the varieties for water, nutrition and production of assimilates. The variation in the rooting characteristics among varieties is primarily due to its inherent genetic make-up.

B. Root Distribution (%)

The knowledge concerning root distribution and location of roots in the soil is very important as this may serve as a guide in the selection of the most efficient methods of cultivation and drainage and also in the application of fertilizers and irrigation water so that one could place such inputs where the largest proportion of roots exist.

a. Root Distribution at Top Soil Level

Percent root distribution of HYVs at different soil depths was presented in Table 5. At the top soil level percent root distribution at 1-10 cm soil depth ranged from 25.77% to 65.27%. Among varieties, the highest percent was recorded to Phil 75-44 while the lowest has been observed from Phil 03-1727. At soil depth of 11-20 cm, values ranged from 11.46% to 42.36%. Phil 00-1419 had the highest distribution while the lowest has been observed from Phil 00- 2155. At soil depth of 21-30 cm, values ranged from 6 to 25%. Phil 00-1727 had the highest distribution while Phil 93-1601 had the lowest.

Table-5. Percent root distribution at corresponding soil depth of high yielding sugarcane varieties at top, middle and bottom level in sandy soil.

Root Distribution (cm)		Phil 00-1419	Phil 002155	Phil 00-2569	Phil 03-1727	Phil 04-0081	Phil 75-44	Phil 8013	Phil 93-1601	Phil 97-3933	Phil 99-1793	Mean
Top level	1-10	27.37%	65.03%	36.58%	25.77%	47.85%	65.27%	33.64%	59.49%	52.23%	51.48%	46.47%
	11-20	42.36%	11.46%	22.98%	24.82%	16.49%	19.03%	23.50%	16.92%	22.46%	15.88%	21.59%
	21-30	09.80%	06.73%	20.65%	24.61%	15.69%	07.32%	24.49%	05.52%	12.21%	13.49%	14.05%
	Total	**79.53%**	**83.22%**	**80.21%**	**75.20%**	**80.03%**	**91.62%**	**81.63%**	**81.93%**	**86.89%**	**80.85%**	**82.11%**
Middle level	31-40	06.44%	05.02%	05.10%	5.28%	03.63%	02.39%	04.63%	05.84%	03.05%	04.31%	04.57%
	41-50	03.53%	02.85%	02.10%	03.85%	04.06%	00.96%	02.03%	02.31%	02.05%	02.39%	02.61%
	51-60	02.34%	02.79%	02.55%	03.11%	03.20%	01.24%	03.08%	02.18%	01.78%	03.02%	02.53%
	Total	**12.31%**	**10.66%**	**09.75%**	**12.24%**	**10.95%**	**04.60%**	**09.74%**	**10.33%**	**06.88%**	**09.71%**	**09.72%**
Bottom level	61-70	02.03%	01.42%	03.17%	03.77%	02.60%	01.17%	02.80%	01.91%	01.86%	02.46%	02.23%
	71-80	02.10%	01.39%	02.72%	02.94%	02.10%	00.94%	02.18%	02.06%	01.53%	02.55%	02.05%
	81-90	02.11%	01.63%	01.92%	03.07%	02.16%	00.79%	01.89%	01.99%	01.46%	02.27%	01.93%
	91-100	01.92%	01.67%	02.24%	02.78%	02.15%	00.89%	01.75%	01.78%	01.38%	02.16%	01.87%
	Total	**08.16%**	**06.11%**	**10.05%**	**12.55%**	**09.02%**	**03.79%**	**08.63%**	**07.74%**	**06.23%**	**09.44%**	**08.17%**

b. Root Distribution at Middle Soil Level

At the middle soil level percent root distribution at 31-40 cm soil depth the value ranged from 2.39 to 6.44%. Among varieties, Phil 00-1419 gave the highest distribution while the lowest has been observed from Phil 7544. At the soil depth of 41-50cm, Phil 03-1727 recorded the highest root distribution of 3.58%. Percent root distribution at 51-60 cm soil depth ranged from 1.24 to 3.20%. The highest distribution was recorded from Phil 04-0081 while the lowest was recorded from Phil 75-44.

c. Root Distribution at Bottom Soil Level

Root distribution at the bottom level at soil depth of 61-70 cm soil depth ranged from 1.17 to 3.77%. Phil 03-1727 gave the highest distribution while the lowest was observed from Phil 75-44. Percent root distribution at 71-80 cm soil depth ranged from 0.94 to 2.94%. Phil 03-1727 gave the highest while the lowest was recorded from Phil 75-44. Percent root distribution at 81-90 cm soil depth ranged from 0.76-3.07%. Phil 03-1727 gave the highest while the lowest distribution was recorded from Phil 75-44. At 91-100 cm soil depth, values ranged from 0.89-2.78%. Phil 03-1727 gave the highest distribution while the lowest was recorded from Phil 75-44.

Generally, highest percent mean distribution of the roots is found close to the surface and then declines with depth Figure 1. Mean root distributions among varieties at 0-100cm with an interval of 10cm were presented in Figure 2. The result indicated that approximately 68.06% of the roots are found in top 20 cm depth and 82.11% in the top 30 cm depth. That most of the root concentration was found in the upper soil layer within a depth of 0-30cm is in agreement with the findings of Głąb [26] and Raizada, et al. [27]. According to Zhang, et al. [28] the root distribution is more pronounced at the top than at the deeper soil layers due to the presence of high organic matter and other nutrients. Thus, root distribution is expected to be higher in nutrient rich zones which could influence the yield performance of a variety.

Among the HYVs tested Phil 75-44 and Phil 97-3933 had higher percent distribution at the top level than the other eight varieties were also observed to have significantly higher cane yield Table 3 compared with other varieties which had lower percent distribution. Acquisition of the available phosphorus (P) is advantageous for shallow rooting varieties [29] as most available phosphorus is concentrated at the surface of soil [30]. The mean RD of these two varieties were also high at the middle and bottom which can be advantageous when accessing water at deeper soil depths [31] and leached nutrients such as nitrates [32]. This result, however, needs to be further investigated since other varieties with slightly lower distribution than Phil 75-44 produced significantly lower yield. It seems that root characteristics other than density and distribution might have affected the outcome of the cane yield.

3.3. Correlated Traits

The knowledge of association between characters provides strength of linear relationship between two traits and helps identify the most important character(s) to be considered in effective selection. In this study it is imperative to obtain information on the relationship between plant characters to cane yield (TC/ha) and sucrose content (Lkg/TC) to facilitate quicker assessment of high yielding varieties grown in sandy soil. Since cane yield and sucrose content is a complex character, therefore selection for yield per se may not be much rewarding unless yield components are taken into consideration. Thus, it is important to examine the contribution of each of the traits in order to give more attention to those traits having the greatest influence on yield.

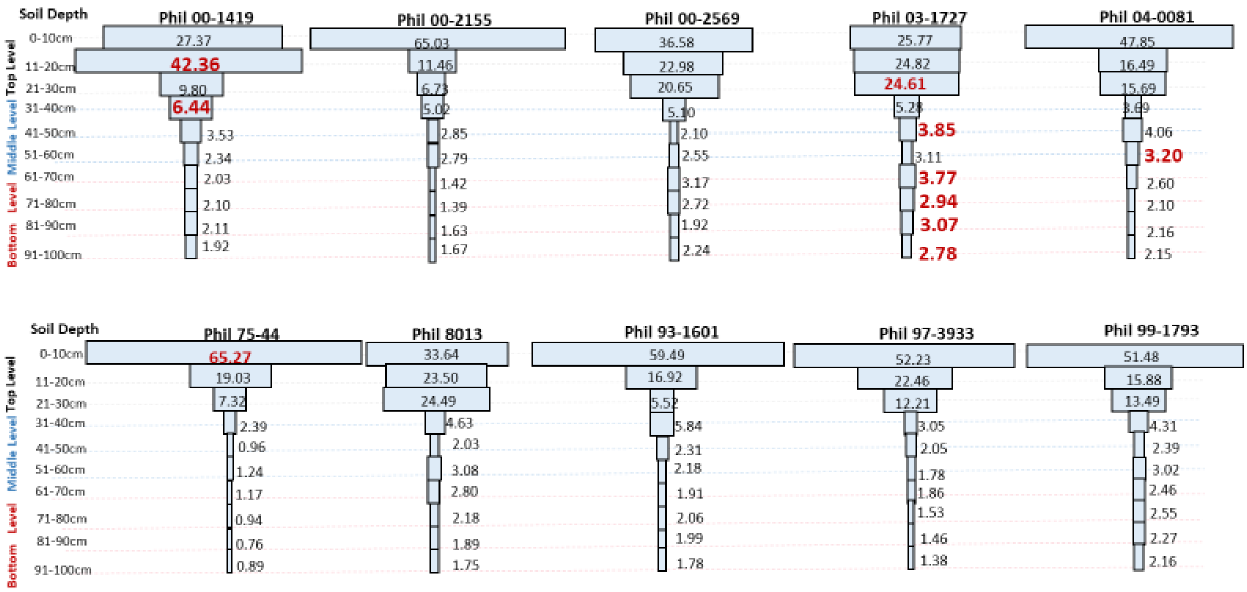

Figure-1. Graphical illustration of percent root distribution of HYVs at different soil depths under sandy soil.

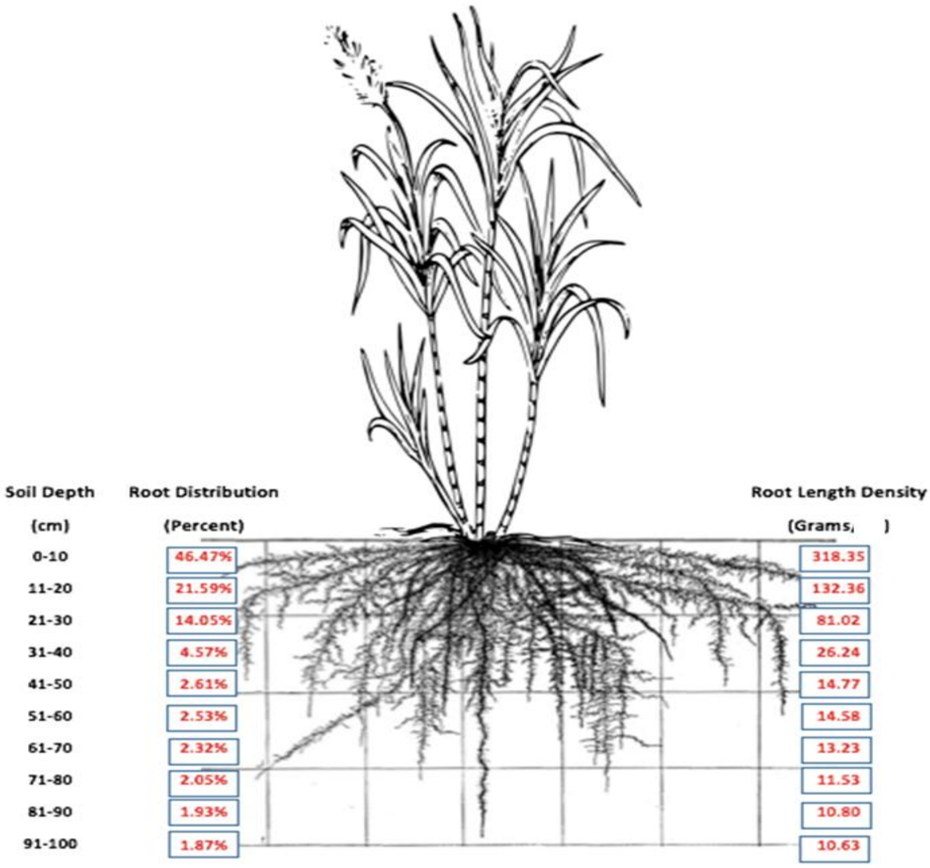

Figure-2. Mean root density and distribution of HYVs at different soil depths under sandy soil.

Among the characters tested for correlation with cane yield 10 were found to be positively correlated Table 6. Among stalk characteristics, correlation (r) with cane yield ranged from 0.74 to 0.60 with stalk diameter having the highest correlation while number of millable stalk has the lowest. Among RD at different soil depths correlation with cane yield ranged from 0.26 to 0.76 with RD at 61-70cm having the highest correlation while the lowest was observed from RD at 21-30cm.

These results indicate that bigger diameter, longer stalks and more number of millable stalks is positively associated with high cane yield varieties and should be considered for selecting varieties adapted under sandy soil condition. Similar results were also obtained by Thippeswamy, et al. [33]; Delvadia and Baraiya [34] and Ravishankaran, et al. [35]. Moreover, it is also important to consider selection for varieties with RD at the top soil level (1-30cm), middle (51-70cm) and bottom level (71-80 and 91-100cm) because RD may affect nutrient uptake at the top level and acquisition of water and leached nutrients at middle and bottom soil level which can favorably influence cane yield. This may also serve as water conservation mechanisms to maintain plant functions during periods of significant soil water deficits in the top soil layer.

Other yield components and root characteristics did not show significant linear correlation with cane yield indicating no significant influence on this trait.

Among the characters tested for correlation with sucrose content (LKg/TC) two were found to be significantly and positively correlated Table 7. Percent brix reading has a high r value of 0.96 while percent apparent purity has an r value of 0.71. This is evidence since percent brix reading and apparent purity were used in deriving the LKg/TC. As such these two characters are usually used as basis for determining sucrose content and selection criteria for high sugar recovery. Kang, et al. [36] also found the similar result. Thangavelu [37] and Ravishankaran, et al. [35] also obtained strong association of brix and purity with sucrose content, which were in conformity with these results.

Table-6. Characteristics of HYVs significantly correlated with cane yield under sandy soil.

Yield Correlated Characters	Correlation Coefficient (R)	Probability Value (P)
Number of millable stalk	0.60 **	<.0001
Stalk diameter	0.74 **	<.0001
Stalk length	0.64 **	<.0001
Root density at 1-10cm (top layer)	0.38 *	0.0396
Root density at 11-20cm (top layer)	0.37 *	0.0461
Root density at 21-30cm (top Layer)	0.26 *	<.0000
Root density at 51-60cm (middle layer)	0.42*	0.0226
Root density at 61-70cm (bottom layer)	0.76 **	<.0001
Root density at 71-80cm (bottom layer)	0.74 **	<.0001
Root density at 91-100cm (bottom layer)	0.57**	0.0011

Note: ** Significant at 1% level of probability .
* Significant at 5% level of probability.

Table-7. Characteristics that are significantly correlated to sucrose content of HYVs under sandy soil.

Sucrose Content	Correlation Coefficient (R)	Probability Value (P)
Brix reading	0.96 **	<.0001
Purity	0.71 **	<.0001

Note: ** Significant at 1% level of probability.
* Significant at 5% level of probability.

4. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

This study was conducted at Luzon Agricultural Research and Extension Center (LAREC) Paguiruan, Floridablanca, Pampanga, Philippines from January 2017 to January 2018 under sandy soil condition to determine the following: (1) yield performance of high yielding sugarcane varieties; (2) quantify the root density and distribution of sugarcane varieties at different soil depths; (3) degree of association between yield and yield components and root density with cane yield and sucrose content, and (4) recommend varieties adapted to sandy soil condition.

The experiment was laid out in a Randomized Completely Block Design (RCBD) with 10 high yielding varieties as treatments replicated four times. Analysis of variance among HYVs revealed significant variation in all parameters except for apparent purity and root density at soil depth of 81-90 cm.

Highest cane yield was obtained from Phil 75-44 (132.86 TC/ha) and Phil 00-2569 (126.55 TC/ha). Phil 8013 gave the highest sucrose content (2.27 Lkg/TC) but comparable to all varieties except for Phil 00-1419 and Phil 00-2569. Phil 8013 gave the highest sugar yield (257.53 Lkg/ha) but with comparable result to the other varieties except Phil 00-1419 and Phil 00-2155.

Mean root density (g) and distribution (%) of HYVs at different soil depths are 318.35g (46.47%) at 1-10 cm, 132.36g (21.59%) at 11-20 cm, 81.02g (14.05%) at 21-30 cm, 26.24g (4.57%) at 31-40 cm, 14.77g (2.61%) at 41-50 cm, 14.58g (2.53%) at 51-60, 13.23g (2.32%) at 61-70 cm, 11.53g (2.05%) at 71-80 cm, 10.80g (1.93%) at 81-90 cm and 10.68g (1.87%) at 91-100 cm. Among the HYVs tested, Phil 75-44 and Phil 97-3933 had highest root density and distribution at the top, middle and bottom level.

Correlation analysis revealed that cane yield is positively and significantly correlated with three stalk traits namely, number of millable stalk (r=0.60), stalk diameter (r=0.74), stalk length and root density at soil depths of 1-10 cm (r=0.38), 11-20 cm (r=0.37), 21-30 cm (r=26), 51-60 cm (r=0.42), 61-70 cm (r=0.76), 71-80 cm (r=74) and 91-100 cm (r=0.57). On the other hand, sucrose content (LKg/TC) was positively and significantly correlated with brix reading (r=0.96) and apparent purity (r=0.71).

Based on sugar yield, Phil 8013, Phil 75-44, Phil 97-3933, Phil 99-1793, Phil 04-0081, Phil 00-2569 and Phil 03-1727 are the most suitable varieties under sandy soil condition. These seven HYVs generally produced higher mean yields in terms of cane yield and sucrose content had better stalks and juice characteristics compared with other HYVs. In terms of adaptability to sandy soil condition, Phil 75-44, Phil 97-3933 possessed higher root distribution in the top level and root densities in three soil levels that were found to be positively correlated with cane yield.

In selecting varieties for high cane yield under sandy soil condition some good criteria in selecting high cane yield are the number of millable stalk, stalk diameter, stalk length, root density at top level (0-30 cm), middle level (51-60cm) and bottom level (61-80cm & 91-100 cm). While brix (%) and apparent purity (%) could be useful criteria in attaining high sucrose content.

Few foreign published studies on root characteristics were encountered during the search for related studies on sugarcane, none locally. Hence, information on the root density and distribution derived from this study could be useful in selecting superior sugarcane varieties for sandy soil. It may also help sugarcane farmers in the decision-making process with regards to various cultural management practices particularly in land preparation, fertilization, cultivation and irrigation for more efficient utilization of resources. Further studies in different soil types and across years to verify the adaptability and stability of the selected sugarcane varieties is recommended.

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