Effect of Soil Type and Crop Cycle on Root Development and Distribution Pattern of a Commercial Sugarcane Cultivar under Normal Irrigation and Field Conditions at Bacita Estate, Nigeria[1]

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ABSTRACT

The effects of soil type and crop cycle on the root development and distribution of a commercial sugarcane cultivar in the irrigated fields were studied at the sugarcane estate of the Nigerian Sugar Company, Bacita, Nigeria (latitude 9°N) during the 1984/85 cropping seasons. Roots were observed to grow down to a depth of 120 cm; however, 99.79, 97.08 and 90.73 percent of these roots were found within the 0-60 cm depth of the plant, first and second ratoon fields, respectively. Root development and vertical growth were influenced by soil physical conditions. Light soil encouraged denser and deeper rooting while the heavy soils promoted less dense and more superficial rooting. The crop cycle significantly affected the root density and the percentage root distributions in all the soil types. The plant canes had better total root development than the ratoon canes. However, the ratoon canes had more of their roots distributed in the lower soil layers.

COMPENDIO

Se estudiaron los efectos del tipo de suelo del ciclo de cultivo, sobre el desarrollo y distribución de las raíces en un cultivar comercial de caña de azúcar, establecido en plantaciones irrigadas de este cultivo. El estudio se hizo en la plantación de caña de azúcar de la Nigerian Sugar Company, en Bacita, Nigeria (latitud 9° N), en las cosechas 1984-85. Se observaron las raíces en su crecimiento hasta una profundidad de 120 cm; se constató que el 99.79/97.08 y 90.73 por ciento de esas raíces crecía a una profundidad de 0-60 cm, en el primero y segundo cultivo de soca, respectivamente. El crecimiento de la raíz y el crecimiento vertical de las plantas fueron influenciados por las condiciones físicas del suelo. Los suelos livianos indujeron un enraizamiento menos denso y más superficial. El ciclo de cultivo afectó la densidad de la raíz y el porcentaje de las raíces, en todos los tipos de suelos. Las plantas procedentes de la semilla de caña dieron un mejor desarrollo total de la raíz que las plantas de soca (rebrotes). Sin embargo, las plantas del soca presentaron proporciones mayores de sus raíces distribuidas en las capas más bajas del suelo.

INTRODUCTION

Root growth in the soil is influenced by cultural practices, irrigation and fertilizer application as well as plant species or culivar. Root studies usually involve soil excavation around the plant or the removal of the soil in measured layers before separating roots from the soil by means of a wire screen (4, 18). Both of these methods are very labour intensive, hence not much attention has been paid to this type of study. However, studies on root development and distribution of various crops has been receiving increasing attention in the last few decades (4, 6, 7, 13, 18, 19). Root development and distribution has been found to be influenced by a series of internal and external factors, which Russell (18) classified into three broad groups which are often interrelated; these are physical, chemical and biological factors. Studies on the effects of these factors on root growth have revealed many interesting features, which have practical bearing on irrigation and fertilizer application. Soil water content is one of the most important factors affecting the rate of root growth and rooting distribution (16). Low moisture encourages deep rooting while adequate moisture promotes surface rooting of sugarcane (4). Root growth and penetration has been reported to decrease with an increase in soil density (19, 20); however, Howard and Herbert (8) reported that soil strength is the critical independent factor controlling root penetration of cotton.

Studies by various workers on the root distribution pattern of sugar cane have revealed similar patterns of distribution within the soil profile. Dillewijn (4) reported that, in irrigated cane, more than 50% of the roots occurred in the topmost 8 inches (20 cm) and 85% in the upper 24 inches (60 cm) of the soil. Paz-Vergara *et al.* (14) indicated that sugarcane roots grow to a 180 cm depth in the soil with approximately 60% and 85% of them within the first 30 cm and 60 cm respectively. In deep, loose soils, the bulk of the (90-95%) were found in the upper 60 cm of the soil (10). Quantitative data have been reported to show that the percentage of roots present in the upper 8 inches (20 cm) gradually decreases while there is an increase in the percentage present in the lower layers as the plant ages (4).

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Differences in water use efficiency of the fields of Bacita estate had been reported, with most of them being considerably low (13). This is particularly so in the heavy soils with furrow irrigation. The efficiency of water utilization is determined by the moisture characteristics of the soil, the depth to which the plant roots extend and the density of the roots in different soil layers (9). The Bacita estate has different soil types and hence different properties which will influence the root development and distribution pattern and consequently the efficiency of water utilization.

It was therefore the objective of the present study to investigate quantitatively the root development and distribution patterns of a commercial sugarcane cultivar (Co 1001) grown on three soil types and with three crop cycles.

MATERIALS AND METHODS

The study was carried out in nine selected fields representing three soil types of Belle, Egbungi, and Singo (Table 1) and three crop cycles, first and second ratoon crops during the 1984/85 cropping season. All the selected fields were planted with cultivar Co 1001, which constituted about 35% of the total area under commercial sugarcane cultivation.

The normal estate agronomic and irrigation management practices were observed in all the fields studied. In each plot, planting was done in rows 1.67 m apart. Each plot received basal fertilizer applications of 150 kg N, 100 kg K_2O and 50 kg P_2O_5 per hectare in form of sulphate of ammonia (21% N), muriate of potash (60% K_2O) and single superphosphate (18% P_2O_5) respectively. Weeds were chemically controlled in each plot using Velpar 90 and Diuron as tank mixtures at rates of 2.0 and 0.7 kg per hectare respectively. Six fields with heavy soils were irrigated by the gravity system, while the three with light porous soils were served by an overhead irrigation system using the sprinkler. This is the normal estate practice, as the light porous soils are erodable with a high percolation rate and thus could not support furrow irrigation. The gravity-irrigated fields received 3 inches of water per 14-day cycle through the furrow, while the sprinkler-irrigated fields received 2 inches of water per 9-day cycle.

Soil cores were obtained by driving a hollow tube (15 cm diameter) into the soil to a depth of 120 cm. Sampling was done about 10 cm from the cane rows. The soil cores were divided into sections of 30 cm in depth, for root extraction. Roots in the core sections were washed free of soil, air-dried and weighed. Another set of soil samples (0-60 cm depth) were taken from the studied fields at the same time the fields were being sampled for root development and distribution. These samples, taken from the middle of the furrows, were air-dried, ground and run through a 2 mm sieve. The p^H of the soil samples was determined in 0.01 M $CaCl_2$ (11, 15) while the moisture saturation percentage was determined using the saturated paste method (3). The bulk density of the soil from the different fields was determined using the core sample method. Both the textural classification and the infiltration rates of the soil series had been determined earlier (13). All determinations were replicated four times. Variance and correlation analyses were carried out on all data collected.

RESULTS

A summary of the characteristics of the soil types used is presented in Table 1, while the summary of the fields sampled for the study showing their soil type, crop cycle and age of the plant at sampling is presented in Table 2. Fields of the Shigo soil types were freely drained, while those of Belle and Egbungi were fairly and poorly drained respectively. All three soil types are acidic.

Table 1. Summary of the soil characteristics of fields used for the study.

Soil Types	Structural Classification*	Basic Infiltration Rate (cm/hr)*	p^H	Bulk Density	K%
Belle	Brown clay loam overlain by brown silt loam	7.36	5.5	1.39	28.38
Egbungi	Heavy black clay	0.83	4.8	1.24	25.54
Shigo	Coarse-grained structureless sand overlain by about 15 cm grey silt loam	10.00	4.6	1.47	7.61

* After Makanjuola 1980.

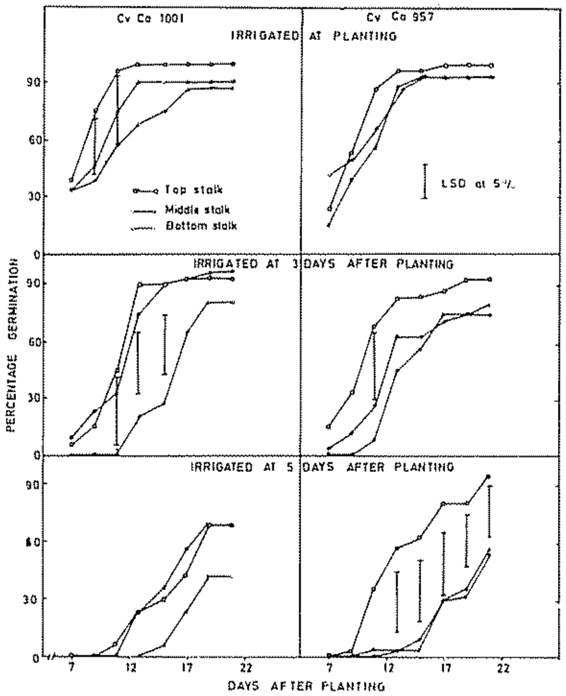

Fig 1. Effect of part of stalk on germination percentage at different irrigation dates of all coverage depth

The effects of soil type and crop cycle on root development (root density g/m^2) are shown in Table 3. The highest root densities were obtained in the fields of the freely drained Shigo soil type at all soil depths. These were significantly better than the corresponding root densities in fields of Belle and Egbungi soil types except at the 0-30 cm soil depth where there was no significant difference in the root densities of Belle and Shigo soil types.

Except at the 0-30 cm depth, the root densities obtained in the fields of Belle and Egbungi soil types were not significantly different. Generally, the Egbungi soil type supported the least dense root systems.

Plant crops have significantly higher root density than both the first and second ratoon crops, which showed no significant difference in the root developments at the uppermost soil depth (0-30 cm). However, at the lower depths (30-120 cm), the second ratoon crop recorded the highest root densities, which were significantly better than those of the first ratoon crops. Overall, the plant cane recorded the best total root density over all layers, and was significantly better than those of the ratoon crops.

The bulk density and the basic infiltration rate of the soils were positively correlated with total root density while moisture saturation percentage and soil pH were negatively correlated with total root density. However, only the basic infiltration rate ($r = 0.95$) and moisture saturation percentage ($r = 0.68$) were significant.

Table 4 shows the percentage root distributions per each soil layer as affected by soil type and crop cycle. The Shigo soil type has a significantly lower percentage of root distributed in the topmost layer (0-30 cm), while the Belle and Egbungi soil types did not show any significant difference in their percentage root distribution at the same layer. However, the Shigo soil type has a greater percentage of its roots distributed within the lower soil layers (30-120 cm) and these were significantly different from those of the Belle and Egbungi soil types at 30-60 cm depth.

The Egbungi soil type has more roots distributed at the 60-90 cm layer than the Belle soil type, while there was no significant differences among the soil types in their percentage root distributions at the lowest depth (90-120 cm). Overall, fields of the Belle and Egbungi soil types had most of their roots distributed within the first 60 cm soil depth, while the fields of Shigo soil type had more of their roots distributed in the lower soil layers.

Table 2. Summary of the fields showing crop cycle, age and irrigation and soil types.

Field	Soil type	Crop Cycle	Irrigation type	Age at Sampling (DAYS)
W7B	Belle	Plant	Gravity (furrow)	298
EE27B	Belle	1°	Gravity (furrow)	289
B36S	Belle	2°	Gravity (furrow)	258
E144	Egbungi	Plant	Gravity (furrow)	290
E26B	Egbungi	1°	Gravity (furrow)	294
W15E	Egbungi	2°	Gravity (furrow)	264
S41	Shigo	Plant	Sprinkler (overhead)	279
S10B	Shigo	1°	Sprinkler (overhead)	254
S34	Shigo	2°	Sprinkler (overhead)	251

While the plant crop has a significantly higher percentage of roots distributed in the uppermost soil layer (0-30 cm), it has lower percentages distributed in the lower layers (30-120 cm). There was no significant differences in the percentage root distributions of the first and second ratoon crops at 30-60 cm. However, the second ratoon has significantly more roots distributed at the lower layers (60-120 cm). Generally, while the percentage of roots distributed in the topmost layer (0-30 cm) of soils decreased with increasing crop cycles, the reverse was the case in the lower (30-120 cm), where the percentage root distributions increased with crop cycles. Moreover, in all soil types and crop cycles, the root distribution below the 60 cm soil depth was more variable than in the top 60 cm. There were no significant interaction effects between the soil sypes and crop cycles for root development and distributions except at the 60-90 cm soil layer where the root density showed significant interactions.

DISCUSSION

The result of this study has confirmed the findings elsewhere that sugarcane root development and distribution is affected primarily by the soil physical and drainage conditions. Overall, more than 90 percent of total roots were found within the first 60 cm soil layer, and the root distribution below this depth was more variable than in the top 60 cm. This pattern of distributions is similar to those described by Lee *et al.* (12) and Paz-Vergara *et al.* (14).

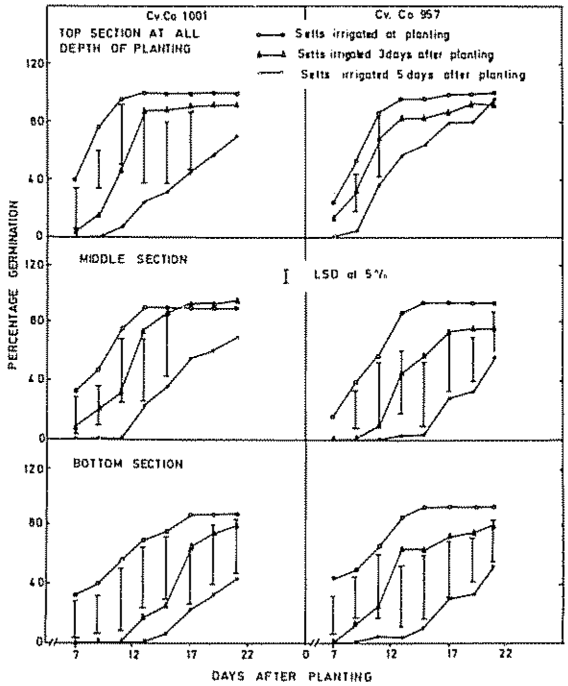

Fig. 2. Effect of date of first irrigation after planting on the germination of sugarcane setts from three sections of matured stalk.

The lighter and freely draining soils of Shigo encouraged denser root development, with a relatively high proportion in the lower soil layers. However, the heavier soils, either heavy clay or silt loam, supported lower root densities, with a greater proportion of these located in the 0-60 cm soil layer. This agrees with the observations of Alexander (1), who reported that about 75% of root occurred in the upper few inches of well drained soil as against 97% in the same zone in a poorly drained soil. Similarly, the effect of drainage on root distribution of winter wheat had shown that in clay soil with poor drainage most roots remained above 20 cm while in well-drained soil they freely explored the top 40 cm of soil (6).

The heavy soils of Belle and Egbungi are usually irrigated by the furrow system, while the lighter soil of Shigo is served by overhead system. It has, however, been observed that the water use efficiency of the overhead irrigated fields was better than those of the surface irrigated fields (13). But studies in Mauritius comparing the overhead and furrow irrigations showed that there was no difference in cane growth as growth measurements indicated normal elongation with both types of irrigation (2). The poor and superficial rooting associated with the heavy soils of Egbungi (Tables 3 and 4) could then be due to its poor structure, and this could possibly explain the observed poor water use efficiency. The efficiency of water utilization is determined by the depth to which roots extend, and the density of root in different soil layers (9); hence the Egbungi soil with few roots and shallow distribution could not effectively utilize the applied water and nutrients.

The poor root development (density) in the Egbungi soil type may be due to the fact the root would have to exert some metabolic energy in order to penetrate the predominantly tiny pores characteristic of the soil. The rate of root growth had been found to be much reduced whenever the roots had to exert substantial pressure in enlarging pores smaller than themselves (18). The surface rooting also characteristic of plants on this soil (Egbungi) could also be due to the water-logging of the fields. Sugarcane root penetration had been observed to reduce to a few straggler roots, some with flattened and distorted sections under water-logged conditions (9); this superficial rooting system serves to supply oxygen for the normal aerobic respiration of submerged tissue.

The crop cycle significantly affected the overall root density and distribution in this study (Tables 3 and 4). However, an earlier study elsewhere (14) showed that the percentage of root per layer was not affected by crop cycle. The percentage of root in the top 0-30 cm layer was observed to decrease with increasing crop cycle, while the lower soil layers (30-120 cm) recorded increments (Table 4). This is in consonance with the report that the vertical distribution of root changes with the age of the plant, with the percentage of root present in the upper layer gradually decreasing while the percentage in the lower layer increases (12). The distribution of more root at the lower layer at the first and second ratoon crop is probably due to the activities of the previous crop's roots, which might have loosened the soil structure, thereby affording the new roots easy penetration. Plant canes, however, had better root density than the ratoon canes (Table 3). This is in agreement with the reported findings that the root systems of ratoon crops were less well-developed than those of plant crops (5, 7, 9). Hence, the better cane yield was often produced by plant canes, as growth is a function of the amount of nutrients and moisture made available by the root system.

Table 3. Effects of soil type and crop cycle on root development (root density g/m²) of sugarcane cultivar Co 1001.

	Soil Type				
Crop Cycle	Belle	Egbungi	Shigo	Crop Cycle Mean	S.E.
	0–30 cm Soil Depth				
Plant (P)	2 207.87	473.84	3 059.50	1 913.74	
1st ratoon (1°)	738.91	663.82	1 225.76	876.16	260.987
2nd ratoon (2°)	1 306.32	1 030.50	1 473.89	1 270.24	
Soil type mean	1 417.70	722.72	1 919.72	–	
S.E.		230.311			
	30–60 cm Soil Depth				
P	77.21	74.23	389.35	180.26	
1°	81.33	46.17	191.25	106.25	32.907
2°	133.20	139.20	303.65	192.02	
Mean	97.25	86.53	294.75	–	
S.E		38.890			
	60–90 cm Soil Depth				
P	13.04	38.91	32.69	28.21	
1°	37.70	19.54	19.54	25.59	12.510
2°	29.62	27.50	153.45	70.24	
Mean	26.79	28.65	68.56	–	
S.E		12.024			
	90–120 cm Soil Depth				
P	6.72	16.01	22.46	15.06	
1°	12.52	4.64	4.64	7.27	11.310
2°	12.03	10.00	87.33	36.45	
Mean	10.42	10.22	38.14	–	
S.E		10.299			

	Soil Depth (cm)			
Standard errors for interactions	0–30	30–60	60–90	90–120
Crop cycle means for the same soil type	452.043	56.997	21.668	19.590
Soil type mean for the same or different crop cycle	435.054	60.648	21.391	19.024

Table 4. Effects of soil type and crop cycle on percent root distribution of sugarcane cultivar Co 1001.

	Soil Type				
Crop Cycle	Belle	Egbungi	Shigo	Crop Cycle Mean	S.E.
	0–30 cm Soil Depth				
Plant (P)	94.82	90.77	87.20	85.81	
1st ratoon (1°)	86.42	86.48	83.47	85.46	2.337
2nd ratoon (2°)	85.07	78.55	71.42	78.35	
Soil type mean	85.77	85.27	80.70	–	
S.E.		1.691			
	30–60 cm Soil Depth				
P	4.07	6.15	10.37	6.86	
1°	9.90	9.90	15.10	11.63	1.652
2°	9.30	12.17	15.65	12.37	
Mean	7.76	9.41	13.71	–	
S.E.		1.435			
	60–90 cm Soil Depth				
P	0.70	2.52	1.62	1.61	
1°	2.58	2.52	1.06	2.05	9.614
2°	4.32	6.47	8.32	6.37	
Mean	2.53	3.84	3.67	–	
S.E.		0.498			
	90–120 cm Soil Depth				
P	0.41	0.56	0.81	0.59	
1°	1.10	1.10	0.37	0.86	0.483
2°	1.31	2.81	4.58	2.90	
Mean	0.94	1.49	1.92	–	
S.E.		0.370			

	Soil Depth (cm)			
Standard errors for interactions	0–30	30–60	60–90	90–120
Crop cycle mean for the same soil type	4.047	2.849	1.064	0.837
Soil type mean for the same or different crop cycle	3.712	2.733	1.002	0.777

The results of the above study have shown that in the fields of the Nigerian Sugar Company, Bacita, sugarcane roots did not extend beyond 120 cm soil depth. This is, however, in contrast with the report of Paz-Vergara *et al.* (14), who reported that sugarcane roots extended to a depth of 180 cm in the fields of the Chicama Valley. The height of the water table is an important factor in root vertical growth. In the present study, it was observed that while the Shigo soil with a low water table had deeper root penetration, the Egbungi soil with a very high water table had shallow rooting. It is then suspected that the water tables in the cane fields of the Chicama Valley could be very low, hence a deeper root penetration than observed in this study.

The study further showed that even though the physical characteristics of the soils affected root distribution, most roots in all soils are distributed within the first 60 cm soil layer. It is therefore imperative that the irrigation and fertilizer input should be made available within this zone for optimum utilization by cane plants. The water use efficiency of Belle and Egbungi soils could be improved by deep ploughing of the fields to loosen the soil structure, thus allowing root proliferation and deeper penetration.

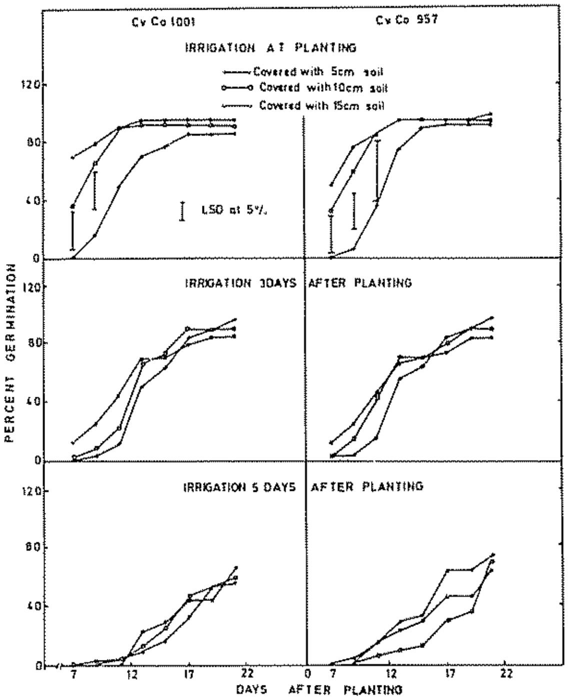

Fig 3. Effect of coverage depth on germination of sugar cane setts at different period of first irrigation after planting.

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