SUGARCANE ROOT SYSTEM DEPTH IN THREE DIFFERENT COUNTRIES

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Abstract

THE SUGARCANE root system depth is crucial as it determines the potential depth of soil available for water and nutrient uptake by the crop. It was reported in an early publication that these roots could grow quite deep (6 m), but otherwise very little data are available on the root system depth. The present study was carried out in three countries: Côte d'Ivoire (var. NCo376), Brazil (var. RB72454) and Réunion, France (var. R570) at various sugarcane growth stages. There were no shoot or root growth constraints (deep soil with enough water). For plant cane, the root front growth (RF in cm) was linear. In Côte d'Ivoire, from 45 to 160 days after planting (DAP), RF = 0.81 DAP; R^2 = 0.91. On the island of Réunion, from 100 to 280 DAP, sugarcane root front growth was: RF = 0.56 DAP; R^2 = 0.70. When DAP was replaced by thermal time (TT: sum of degree-days), the root front growth patterns were quite similar in Réunion and Côte d'Ivoire (RF = 0.045 and 0.049 TT, respectively). In ratoon conditions, RF was stable when roots from the previous cycle were still in the soil at the onset of the cropping season. Thus, the observed root depth was approximately 4 m in Brazil and Réunion, even though the environment and cultivars were different. These findings showed that, when there is no marked crop growth constraint, roots of modern commercial sugarcane varieties can grow to depths of about 4 m in ratoon crops. While these values were lower than those reported in previous studies, they were higher than those generally accepted at present.

Introduction

The depth of the sugarcane root system determines the volume of soil available for water and mineral uptake. A review of recent results indicates that this depth is still not clearly established (Smith *et al.*, 2005). Evans (1936) found that roots of old sugarcane varieties could grow to a depth of 6 m under very favourable conditions. These estimates have been partially challenged for modern varieties (Blackburn, 1984). Since the 1930s, no publication has reported sugarcane roots growing below a depth of 2 m. However, the rooting depth is a particularly useful factor for crop modelling and for fertilisation and irrigation decision-making. For example, modelling studies carried out by scientists in Réunion were based on a root system depth of about 1.5 m, as roughly estimated in some unpublished studies. The root system depth in live sugarcane plants is particularly hard to assess. Sugarcane plants grow again after the first plant sugarcane cropping season and the first shoot harvest, and the extent of time that the previous root system remains alive is not well-known. Moreover, to our knowledge, very few studies have been published on relationships between the environment (especially deep soil characteristics) and the root front depth.

The authors have pooled root depth findings from three different environments in Brazil, Côte d'Ivoire and Réunion. The aim of this study was to combine these results in order to estimate the root system depth in these three ecosystems so as to come up with more precise root front depth values to be used in decision support tools and crop models. Sugarcane root front data are also essential for determining nutrient and water balances and subsequently identifying the soil limit zone where nutrients switch from being fertilisers to becoming potential groundwater pollutants.

Material and methods

Experimental design, environments and treatments

Studies were carried out at three sites located very far apart: Côte d'Ivoire (Africa), Brazil and Réunion (Indian Ocean), within the framework of agronomic research programs under way to investigate several parameters including the sugarcane root front. There were thus some methodological variations between experiments. The experimental site in Côte d'Ivoire was located at Bouaké (7°40N, 5°5W, 350 m elevation) in a deep (> 2 m) sandy clay oxisol with a high gravel content ranging from 25% in the surface horizon to 50% at depths below 1 m. The soil bulk densities differed very little at the Réunion and Brazil sites, at least in unaltered soils (Table 1). The markedly higher bulk densities in Côte d'Ivoire were due to the presence of coarse elements with bulk density of about 2.7 Mg/m^3, but the fine soil structure was favourable for root growth. In Brazil, the experiments were conducted at Londrina University (23°2S, 51°1W, 560 m elevation) in a very deep clayey red eutroferric latosol without gravel. In Réunion, the experimental site was located at Saint Pierre in the southern part of the island (21°S, 55°E, 250 m elevation) in a deep (over 5 m) clayey cambisol, free of coarse elements as in Brazil, but with a lower soil structure quality. The Côte d'Ivoire study was carried out in 1994, but the findings were never published. The Brazilian study was conducted in 2005 and 2006, while in Réunion it was carried out in 2007, 2008 and 2009.

Table 1—Bulk density at the three sites. At the Réunion site: unaltered soil (control) and soil removed from the surface to 2 m depth and put back 4 years earlier.

Bulk density (Mg m^{-3})				
	Côte d'Ivoire	Brazil	Réunion	
Depth(cm)	Unaltered soil	Unaltered soil	Unaltered soil	Altered soil
0–40	1.52	1.02	1.15	1.14
40–80	1.68	1.00	1.12	1.10
80–120	1.63	0.98	1.17	1.03
120–200	1.60	0.97	1.17	1.03
200–400		0.97	1.23	1.23

The three sites have a tropical (Côte d'Ivoire, Réunion) or subtropical (Brazil) climate. Rainfall (with supplementary irrigation in Reunion and Côte d'Ivoire) was sufficient for normal crop growth, particularly for the development of deep roots. During the study periods, mean air temperatures were: 28.4°C, 21.9°C and 23.2°C in Côte d'Ivoire, Brazil and Réunion, respectively, with mean temperatures always above 16°C/d. The sugarcane varieties (NCo376 in Côte d'Ivoire, RB72454 in Brazil and R570 in Réunion) were representative of varieties grown by farmers. The cropping systems were conventional and tailored to local conditions. Spacing between rows was 1.5 m (Côte d'Ivoire and Réunion) or 1.4 m (Brazil). Plant sugarcane only was studied in Côte d'Ivoire, whereas only a ratoon crop was studied in Brazil. In Réunion, the study concerned both plant sugarcane (in 2006 and 2009) and ratoon crops (2007 and 2008). In 2009, plant sugarcane root systems were studied in an area of the site where the soil had been altered (removed and put back) up to 2 m in depth for soil studies 4 years earlier. The soil put back in each soil horizon was similar to the surrounding soil, except that it remained looser (Table 1). There were thus three treatments in Réunion: plant sugarcane in unaltered and altered soil and a ratoon crop.

Root depth study: dates, methods, replications

In Côte d'Ivoire, the study was carried out at three different dates: 45, 113 and 160 days after planting (DAP) using the monolith method (Lee, 1927). Each monolith had the following dimensions: length 0.25 m, width 0.2 m, thickness 0.2 m, with five replications. In Brazil, the ratoon crop root fronts were estimated with the trench profile technique (Chopart *et al.*, 2008a, 2009) adapted from Böhm (1976). The trench profiles were 2 m wide and as deep as the root front. The maximum root depths were measured directly in the field. The study was carried out at 240 and 300 days after ratoon (DAR) with six replications at each measurement date. In Réunion, the plant sugarcane study was performed with the rhizotron (Van de Gien *et al.*, 1994) and the trench profile techniques. Vertical rhizotrons were 1.5 m wide and 1.4 m deep. Measurements were thus limited to the period when the root depth was less than 1.4 m. For plant and ratoon sugarcane, the trench profiles were 1.5 m wide, with depths varying according to the root front. The intersections between the trench profile and the roots were counted and mapped. This made it possible to assess the root length density (RLD) distributions in the profile (Chopart *et al.*, 2008b, 2009). In addition, about 10 cm of soil was removed in the profile at the root front level to monitor the presence or absence of roots in these samples in the field. The soil profiles were about 4.5 m deep. In plant sugarcane, root fronts were studied in two rhizotrons at nine dates and with the trench profile technique at eight dates with one to three replications. The ratoon sugarcane study was carried out on a single date between 235 and 245 DAR, with six replications. Correlations were determined between the crop age and the root front depth. For a better comparison of the results at the various sites, the time from planting or ratoon date was also expressed as a sum of each day's mean temperature (sum of degree-days[SDD]) above the sugarcane baseline temperature (estimated to be 12°C).

After planting, roots grow from cuttings (sett roots) buried 10 to 20 cm deep. After a few days, shoot roots grow from the first nodes on the new stalks, close to the surface (van Dillewijn (1952). Analysis of these complex rooting dynamics that take place during the first days of the plant cropping season was beyond the scope of the present study. Measurements were first recorded 45 DAP in Côte d'Ivoire or even later in Réunion (70 DAP), once the root system grown from the year's shoots predominated over the initial system grown from cuttings. To simplify the analysis and future use of the results, regressions between the crop age (or thermal time) and the root front depth were thus assigned a 0 cm y-coordinate on the planting day (DAP = 0). The established relationships were valid only within the range of the measured results, from around 50 DAP.

Results

Plant sugarcane (Côte d'Ivoire and Réunion)

In Côte d'Ivoire, the root front depth progressed linearly from 45 DAP to 160 DAP, i.e. a growth rate of about 0.8 cm/day (Figure 1A). In Réunion, with the rhizotron technique, plant sugarcane root front growth was also linear between 70 and 170 DAP (Figure 1B), at a rate of approximately 0.7 cm/day. After 170 DAP, the rhizotron, whose depth was limited to 140 cm, could no longer be used. Outside of the rhizotrons, the root front growth rate measured with the trench profile method was approximately 0.56 cm/day, i.e. slightly lower than that noted in the rhizotron (Figure 1C). The difference seemed to be due to the fact that roots were in a relatively less constrained environment against the rhizotron glass panel and could thus grow at a slightly more vertical angle. The results obtained in the rhizotron and through the trench profile technique were complementary. With the rhizotrons, the measurements were obtained more frequently but in somewhat artificial conditions. Data obtained by the trench profile technique were representative of the root front in natural conditions but, as the measurements were more time consuming and costly, they were less numerous. The rhizotron findings confirmed that the root front growth was linear.

The trench profile technique made it possible to assess the growth rate in unaltered soil which was representative of the local soil, i.e. between 0.55 and 0.6 cm/day.

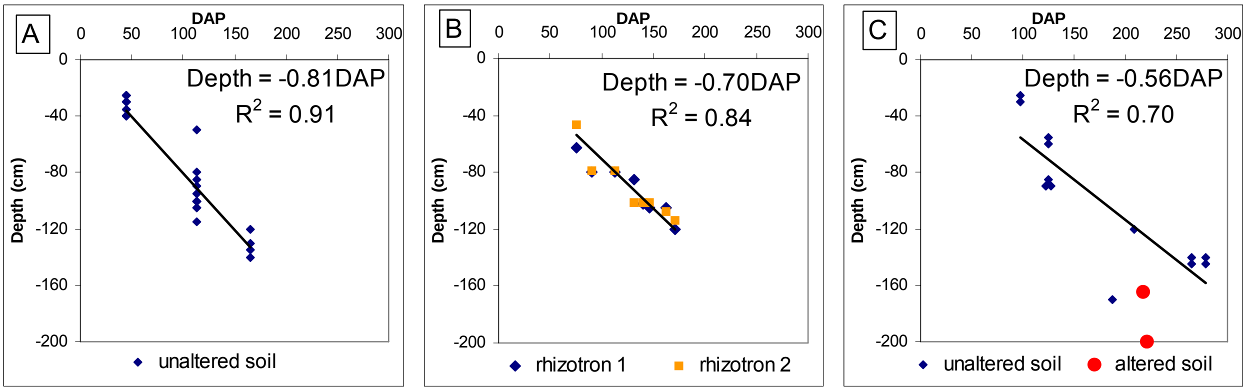

Fig. 1—Relationships between plant sugarcane crop age and root front depth. A: Côte d'Ivoire; B: Réunion in two rhizotrons; C: Réunion in unaltered soil (small dots) and altered (2 m decompacted soil), (large dots, not used in the regression).

In Réunion, after 170 DAP, root front growth (measured by the trench profile technique only) continued at a constant rate until the end of the study (265 DAP). In the same year, at the same site, but in a soil that was decompacted 4 years earlier and whose bulk density and mechanical resistance to penetration remained lower, the root front was deeper: 200 cm 220 DAP, i.e. 0.9 cm/day (Figure 1C). In unaltered soil, the root front reached 170 cm in only one profile (at 187 DAP). In Réunion, in natural conditions, the mean root front growth rate was 0.55 to 0.6 cm/day.

The growth rate reached as high as 0.9 cm/day when the soil physical conditions were particularly favourable, or when the soil was tilled very deeply some years before measurement. Root front between 280 DAP and harvest (360 DAP) is still being studied. Decreased growth has been observed at the end of the cycle in other tropical crops such as pearl millet and sorghum (Chopart, 1985).

It is therefore quite probable that sugarcane root front growth will not increase during its final stage. We can tentatively assume that in Réunion the plant sugarcane root front depth would be approximately 2 m at harvest. When thermal time was used instead of DAP, the root front growth rates observed in Côte d'Ivoire and Réunion, where the weather is slightly less hot, were closer than rates expressed in number of DAP (Figure 1).

Côte d'Ivoire
Root depth (cm) = –0.049 TT $R^2 = 0.91$ n = 31
Réunion
Root depth (cm) = –0.045 TT $R^2 = 0.67$ n = 14
TT: Thermal time (degree-days above 12°C)

This showed the influence of temperature on root front growth in relation to shoot growth, which was also higher. There was still a slight difference, which could be explained by several factors (varieties, soil characteristics, study methods); however, none of these parameters had a major impact.

Ratoon sugarcane (Réunion and Brazil)

In Brazil, in 3rd year and 4th year ratoon sugarcane, the maximum root system depth levelled off between 240 and 300 DAR (Table 2). The soil tillage method used when the sugarcane crop was planted 4 years earlier (between 0 and 30 cm deep) had no effect on the root front depth (data not shown), which was approximately 4 m, with 6 replications on average. In Réunion, at the same cycle stage the mean depth in the 6 replications was 3.70 m (Table 2).

Table 2—Maximum ratoon sugarcane root depth in Brazil and Réunion (mean, standard deviation, highest and lowest root front of 6 replications at both Brazil and Réunion) observed on measurement dates with some related characteristics.

	Brazil	Réunion
∑ Temp in °C >12	2700	3000
DAR	270	260
Millable yield (kg/m²)	10	9.4
Mean maximum depth (m)	4.0	3.7
Standard deviation	0.20	0.43
Highest value (m)	4.3	4.1
Lowest value (m)	3.7	3.1

2-D mapping of the root distribution was carried out with the method used in Réunion (trench profile technique, root intersection mapping and root length density from root intersection; Chopart *et al.*, 2008a, b, 2009). In the deepest profile (Figure 2A), the root distribution was very irregular at deep horizons where roots took advantage of soil areas with lower resistance in order to progress vertically. This was not as clear in the less deep profile (Figure 2B). Roots that grew vertically had large diameters, but they had the same appearance and internal structure as roots of the same diameter that were less vertical, or horizontal.

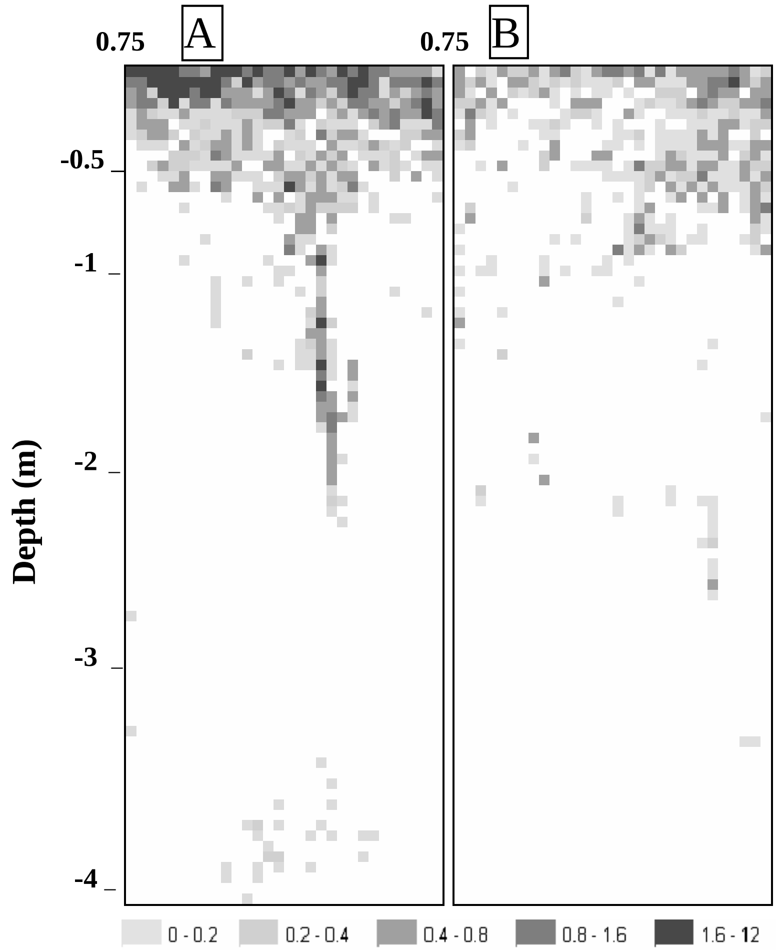

Fig. 2—Ratoon sugarcane in Réunion: 2-D root length density (cm/cm^3) distribution in a 1.5 m large profile. A: deepest profile among the four studied profiles, and B: least deep profile.

Very similar results were obtained in Réunion and Londrina (Brazil), although they were obtained with two different varieties and at sites that were far apart, despite the slightly lower temperatures in Brazil. However, the sites shared some similar characteristics, including deep soil with low density and resistance to penetration, and variable soil moisture but which was always sufficient to ensure root growth. The 4-m root depth was inferior to the 6-m depth obtained by Evans (1936), but deeper than is generally accepted for sugarcane root systems.

Discussion and conclusion

No definitive conclusion could be drawn on the basis of the results obtained in three countries concerning plant sugarcane and ratoon sugarcane root system depths. However, they provided greater insight into sugarcane root system depths in the studied environments. In particular, in deep moderately compact soils, the root front growth rate was constant after the shooting and root system development stage, i.e. approximately 0.55 cm/day with a maximum of 0.9 cm/day under very favourable conditions (soil tilled to a depth of 2 m four years earlier). These results obtained in very well structured soil up to 2 m deep could explain the particularly spectacular findings of Evans, i.e 6 m deep roots in ratoon sugarcane.

The marked variation noted in Réunion between the root system depth in the second part of the plant sugarcane cycle (under 2 m) and that observed roughly at the same cycle stage in a 5th year ratoon sugarcane (4 m) suggests that the root front grows deeper from year to year between plant sugarcane and ratoon crops in Réunion. If this is the case, the roots (at least the deepest ones) could remain alive long after the sugarcane crop has been harvested and deeper parts of the root system could sprout new roots during the following growing season. This still has to be confirmed, in particular by studying the root system depth throughout several sugarcane growing seasons in the field with various soil penetration resistance levels. This would be laborious work but the findings could be highly interesting for modelling sugarcane water uptake and growth under water stress conditions in plant or ratoon sugarcane with various numbers of ratoon cycles.

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PROFONDEUR DU SYSTEME RACINAIRE DE LA CANNE A SUCRE DANS TROIS PAYS DIFFERENTS

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MOTS CLES: Brésil, Côte d'Ivoire, Réunion, Système Racinaire, Front Racinaire de la Canne à Sucre.

Résumé

LA PROFONDEUR du système racinaire de la canne à sucre est un paramètre important car elle détermine la profondeur potentielle du sol utile pour l'alimentation hydrique et minérale de la culture. Il a été reporté, dans une publication ancienne, que le système racinaire de la canne à sucre peut atteindre une profondeur de 6 m, mais peu de données récentes sont disponibles sur la profondeur du système racinaire de cette culture. L'étude a été menée dans trois pays: Côte d'Ivoire (var. NCo376), Brésil (var. RB72454) et Réunion, France (var. R570), à différents stades de végétation de la canne à sucre. Il n'y a pas eu de contraintes majeures à la croissance racinaire (sols profonds, avec une humidité suffisante). Pour une canne vierge, la croissance du front racinaire (RF, en cm) a été linéaire, de 45 à 160 jours après plantation (DAP) : RF = 0.81 DAP; R^2 = 0.91. A la Réunion, le front racinaire de la canne à sucre a été : RF = 0.56 DAP; R^2 = 0.70, de 100 à 280 DAP. Si l'on remplace DAP par le temps thermique (TT : somme des degrés-jours), les niveaux de croissances des fronts racinaires deviennent alors proches à la Réunion et en Côte d'Ivoire (RF= 0.045 et 0.049 TT, respectivement). En repousses, RF a été stable, les racines du cycle précédent restant encore dans le sol en début de cycle. La profondeur racinaire observée a été de 4 m au Brésil et à la Réunion, dans des environnements pourtant très différents. Ces résultats montrent que, en absence de contraintes marquées à la croissance racinaire, les racines des variétés modernes peuvent atteindre 4 m en repousse. Bien que ces valeurs soient plus faibles que celles avancées dans des travaux anciens, elles sont supérieures à celles généralement admises actuell

PROFUNDIDAD DEL SISTEMA RADICULAR DE LA CAÑA DE AZUCAR EN TRES DIFERENTES PAISES

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PALABRAS CLAVE: Brasil, Costa de Marfil, Reunión, Sistema de raíz, Frente de raíz de la Caña de Azucar.

Resumen

LA PROFUNDIDAD del sistema radicular de la caña de azúcar es crucial pues determina la profundidad del suelo disponible para la absorción potencial de agua y nutrimentos por parte del cultivo. En una publicación anterior a esta se reportó que las raíces podrían crecer muy profundas (6 m), pero por otra parte, hay disponible muy poca información sobre la profundidad del sistema radicular. El presente estudio fue realizado en tres países: Costa de Marfil (variedad NCo376), Brasil (variedad RB72454) y Réunion, Francia (variedad R570) en diferentes etapas de crecimiento de la caña de azúcar. No hubo impedimentos para el crecimiento de la parte aérea o de la raíz (suelo profundo con suficiente humedad). En la plantilla, el frente de crecimiento de la raíz (RF en cm) fue

lineal. En Costa de Marfil de 45 a 160 días después de la siembra (DAP), RF = 0.81 DAP; R^2 = 0.91. En la isla de Réunion, de 100 a 280 DAP, el frente de crecimiento las raíces de la caña de azúcar fue: RF = 0.56 DAP; R^2 = 0.70. Cuando DAP fue substituido por tiempo térmico (TT: suma de grados-día), los patrones del frente de crecimiento del sistema radicular fueron similares en Réunion y Costa de Marfil (RF = 0.045 y 0.049 TT, respectivamente). En condiciones de soca, al inicio del nuevo ciclo del cultivo y cuando las raíces del ciclo anterior todavía estaban en el suelo, el RF fue estable. De esta forma, la profundidad observada de la raíz fue de aproximadamente 4 m en el Brasil y Réunion, aunque el ambiente y los cultivares fueron diferentes. Estos resultados demostraron que, cuando no hay impedimento para el crecimiento del cultivo, las raíces de las variedades comerciales modernas de caña de azúcar pueden alcanzar profundidades de casi 4 m en socas. A pesar de que estos valores fueron menores que los reportados en estudios anteriores, fueron mayore que los actualmente aceptados.