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Root system of 'BRS Platina' banana under irrigation levels and planting densities

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Abstract

Banana production stands out in Brazilian semiarid agriculture; however, due to little availability of water resources, associating water-saving technologies with the knowledge of parameters involved in the interplay between plants and soil is critical to improving banana production systems. The objectives of this study were to evaluate the effect of planting densities and irrigation levels on root length density of 'BRS Platina' banana and to correlate root parameters to crop yield and leaf area. A randomized block design was used, with factors arranged in split-split plots and treatments replicated three times: four irrigation levels (55%, 70%, 85% and 100% ETc) were assigned to plots, four planting densities (1,600; 2,000; 2,666; and 3,333 plants ha^{-1}) to subplots and distance from pseudostem or sampling depth to sub-subplots. Root length density (RLD) was measured at five distances from the pseudostem, longitudinally to a row of plants: 0.10, 0.25, 0.50, 0.75 and 1.10 m; and at three depths for each distance: 0 to 0.20 m, 0.20 to 0.40 m and 0.40 to 0.60 m from surface level. Root length densities were highest at 100% ETc irrigation level and at 2,666 plants ha^{-1} and 3,333 plants ha^{-1}, within 0.31 m deep and within 0.78 m of the pseudostem. Irrigation interacts with root system, and coupled with higher planting densities, contributes to increasing crop yields of 'BRS Platina' banana plants.

Keywords: irrigation management, *Musa* spp., plant population, water deficit

Introduction

The banana (*Musa* spp.) is one of the most produced fruit crops in Brazil and the world. In 2019, Brazil was the world's fourth largest banana producer, with a production of 6,812,708 tons of bananas (Faostat, 2021). 'BRS Platina', a progeny of 'Prata-Anã' banana, is a tetraploid hybrid developed by Embrapa Mandioca e Fruticultura in partnership with Epamig Norte and the Instituto Federal Baiano campus Guanambi.

The main fruit-producing hubs in northeastern Brazil are located in semiarid regions characterized by an average annual rainfall lower than 800 mm, a drought risk greater than 60% or an aridity index of up to 0.5 (Brazil, 2017). Under such conditions, growing water-demanding fruit trees, such as bananas, is only feasible with the use of irrigation; therefore, using water-saving irrigation technologies plays a major role in increasing water-use efficiency (WUE).

Increasing WUE may be accomplished by adopting irrigation strategies aimed at rational water use (Santos et al., 2014). These strategies include maintaining or increasing productivity while reducing irrigation depth (Santos et al., 2016a), increasing planting density while reducing irrigation depth (Santos et al., 2019), using fertigation (Pramanik et al., 2016), using organic mulching (Amorim et al., 2019), and knowing soil-climate-plant interrelationships (Silva et al., 2017).

One of the most important interactions between plants and the environment occurs at the root system (Paltineanu et al., 2018). Root length density (RLD) is an important parameter when studying root development. It is the total length of roots contained in a volume of soil and reflects the potential of crops to take up water and nutrients (Azevedo et al., 2011).

Root length density are correlated with several factors. Root development is particularly influenced

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by changes in soil water content caused by irrigation scheduling (Santos et al., 2014), irrigation system (Sant'ana et al., 2012), soil properties (Segura et al., 2015) and plant population density, in addition to the interplay between those factors.

Knowing how roots are distributed in the soil profile aids in determining efficient water and fertilizer application strategies, especially when employing drip irrigation systems and fertigation (Donato et al., 2010). Moreover, such knowledge allows a better arrangement of irrigation systems, accurate placement of moisture sensors in the soil, and efficient fertilizer application (Santos et al., 2017).

Despite the importance of managing crops, studies on root distribution are lacking, especially when associated with the effect of two or more factors. The objectives of this study were to evaluate root length density of 'BRS Platina' banana under different planting densities and irrigation levels and to correlate root parameters to yield and leaf area.

Material and Methods

The experiment was carried out on an experimental area at the Instituto Federal Baiano, campus Guanambi, southwestern Bahia, Brazil (14° 13'S, 42°46'W, and altitude of 545 m). The climate of the region is Aw — hot and dry semiarid — according to Köppen climate classification; mean annual temperature and precipitation are 25.6 °C and 680 mm, respectively, with rains occurring mostly between November and March. Maximum and minimum temperature, wind speed, relative humidity, reference evapotranspiration and precipitation measured during the experiment are shown in Figure 1.

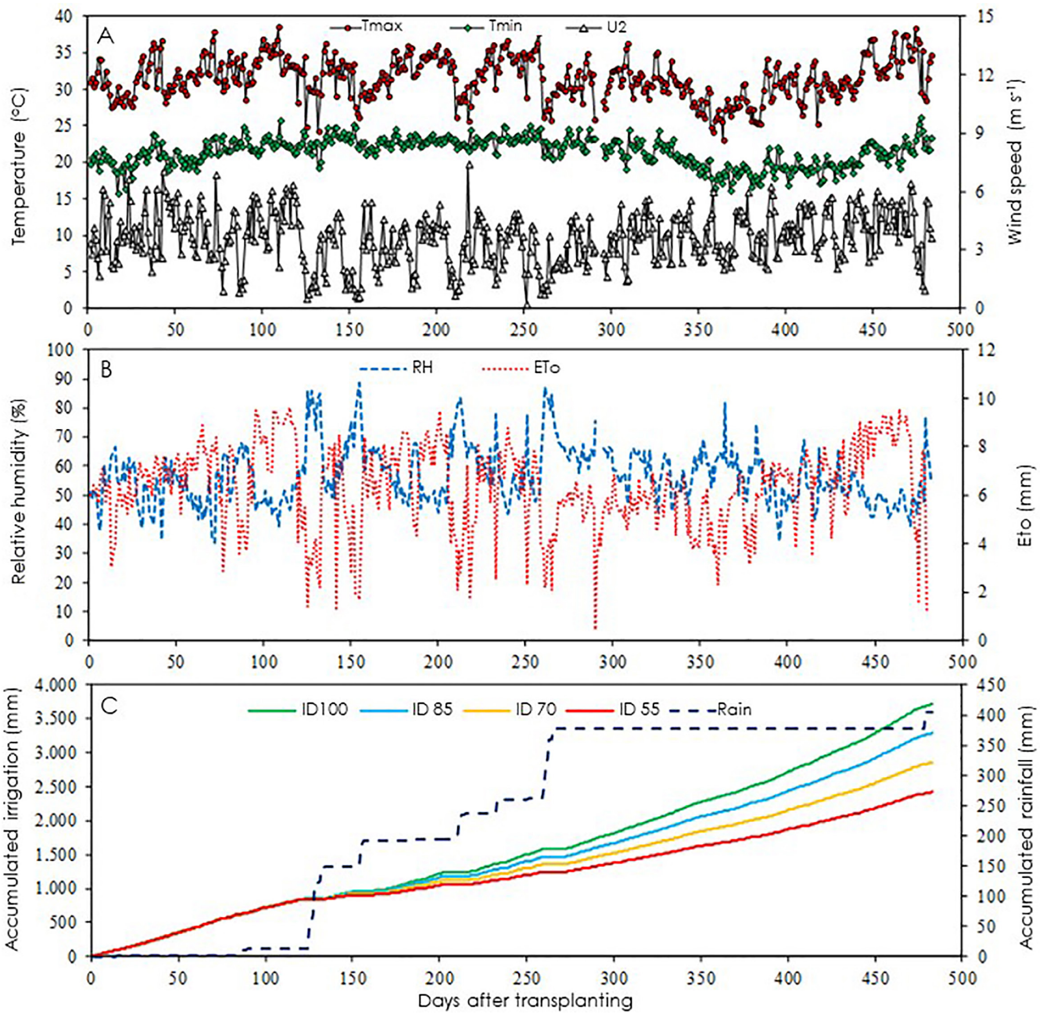

Figure 1. Maximum temperature – Tmax, minimum temperature – Tmin and wind speed – U2 (A); relative humidity – RH and reference evapotranspiration – ETo (B), accumulated irrigation depth for 100% ETc - ID100, 85% ETc - ID85, 70% ETc - ID70, 55% ETc - ID55 and accumulated rainfall (C) during the experimental period. Guanambi, Bahia, Brazil, 2018.

Prior to planting, soil samples were collected for chemical characterization of the area (Table 1). The soil is a Red Yellow Latosol, with medium texture, density of 1.59 kg dm^{-3}; 0.630 kg kg^{-1} of sand; 0.154 kg kg^{-1} of silt and 0.216 kg kg^{-1} of clay. The area was conventionally tilled (subsoiling, plowing and harrowing) and furrows were made at 2.5 m apart. Planting holes were dug using an auger attached to a tractor, at a spacing depending on the treatment. Micropropagated plantlets were transplanted to the area in July 2016. Crop practices followed recommendations for bananas (Rodrigues et al., 2015).

Table 1. Soil chemical properties at the experimental area prior planting.

Property	Depth (cm)	
	0.00–0.20	0.20–0.40
pH[1]	7.8	7.6
SOM[2] (dag kg^{-1})	2.1	0.7
P[3] (mg dm^{-3})	467.8	208.9
K[3] (mg dm^{-3})	598.5	351.8
Na[3] (cmolc dm^{-3})	0.2	0.2
Ca[4] (cmolc dm^{-3})	5.6	3.7
Mg[4] (cmolc dm^{-3})	2.5	1.8
Al[4] (cmolc dm^{-3})	0.0	0.0
H+Al[5] (cmolc dm^{-3})	0.7	0.8
SB (cmolc dm^{-3})	9.9	6.6
ECEC (cmolc dm^{-3})	9.9	6.6
CEC (cmolc dm^{-3})	10.6	7.3
V (%)	93	89
B[6] (mg dm^{-3})	0.9	1.0
Cu[3] (mg dm^{-3})	1.2	2.0
Fe[3] (mg dm^{-3})	15.6	16.3
Mn[3] (mg dm^{-3})	115.4	71.5
Zn[3] (mg dm^{-3})	30.6	12.4
P_{rem}[8] (mg L^{-1})	46.7	42.8
EC (dS m^{-1})	1.7	1.1

(1)pH in water; (2)Calorimetry; (3)Mehlich-1 extractor; (4)KCl 1 mol/L; (5)SMP buffer method; (6)$CaCl_2$; (7) Equilibrium P solution; SOM, soil organic matter; SB, sum of bases; ECEC, effective cation exchange capacity; CEC, cation exchange capacity at pH 7; V, base saturation; m, aluminum saturation; P-rem, remaining phosphorus; EC, electrical conductivity. dag kg^{-1} = %; mg dm^{-3} = ppm; $cmol_c$ dm^{-3} = 0,01 meg cm^{-3}.

If micronutrient deficiency was detected, fertilizer was applied via foliar applications until the flowering stage. After flowering, micronutrient fertilizers were applied via rhizome (pruned sucker) (Rodrigues et al., 2007). Plants were irrigated by micro-sprinklers with flow rate of 120 L h^{-1}. Emitters were spaced 4.0 m apart within a lateral line while lateral lines were placed 6.0 m apart. Application intensity of each micro-sprinkler was 5.0 mm h^{-1}, with overlapping wetted diameters and application efficiency at 83%. Irrigation water came from a tubular well and had an electrical conductivity of 0.65 dS m^{-1}.

The study was based on assessing the interaction or single effect of planting density and/or irrigation levels on root length density (RLD) as well as correlating crop yield with leaf area of ‘BRS Platina’ banana cultivated in the first production cycle.

A randomized block design was used. Treatments were arranged in split-split plots with three replications; the factor irrigation level was assigned to plots, planting density to subplots and distance from pseudostem or sampling depth to sub-subplots. Irrigation levels were 55%, 75%, 85% and 100% crop evapotranspiration (ETc); planting densities were 1,600 plants per hectare (2.5 m x 2.5 m), 2,000 plants per hectare (2.5 m x 2.0 m), 2,666 plants per hectare (2.5 m x 1.5 m) and 3,333 plants per hectare (2.5 m x 1.2 m); the distances from pseudostem were 0.10 m, 0.25 m, 0.50 m, 0.75 m and 1.10 m and sampling depths were 0–0.20 m, 0.20–0.40 m and 0.40–0.60 m deep.

Crop evapotranspiration (ETc) was the product of reference evapotranspiration (ETo) and crop coefficient (Kc). Reference evapotranspiration was indirectly determined by Penman-Monteith method, standard FAO Bulletin 56, based on climate data from a weather station installed near the experimental area. Crop coefficients were calculated according to Borges et al. (2011).

From transplanting to early stages of plant development, which corresponded to 120 days after transplanting (DAT), the same amount of water was delivered to each treatment, amounting to 836.31 mm. A Kc of 1 was used during crop establishment, which lasted for 97 DAT. From this stage on, Kc values ranged, approximately, from 0.60 to 1.40 until 300 DAT. Then, Kc remained at 1.40 until the end of the experiment, at 483 DAT. The total amount of water applied to plants irrigated with 100, 85, 70 and 55% ETc were 3723, 3290, 2857 and 2424 mm, respectively (Figure 1).

At the harvest of the first cycle, in November 2017, leaf area and yield were determined. After harvest, root samples were collected from December 2017 to January 2018.

Total leaf area (TFA), expressed in m², was estimated by a linear regression equation adjusted for ‘Prata-Anã’ banana (Zucoloto et al., 2008): TFA = 0.5187 (L x W x N) + 9603.5, R^2 0.89 ($p < 0.05$), where, L and W represent length and width of the third leaf, respectively; N is the number of living leaves; and 0.5187 is a correction factor.

Root samples were collected using a modified auger measuring 63 mm in inner diameter and 1.2 m in length and with 0.20-m external length markings. The roots were collected at five distances longitudinally to a row of plants: 0.10 m, 0.25 m, 0.50 m, 0.75 m and 1.10 m from pseudostem; and, at three depths for each distance: 0–0.20 m, 0.20–0.40 m and 0.40–0.60 m deep.

The samples were placed in plastic bags with labels indicating the corresponding block, irrigation level, planting density, sampling distance, and sampling depth. Then, soil was washed off the roots through a sieve. Roots were scanned to a computer as Tagged Image File Format (TIFF). Dark edges caused by the scanning process were edited out. Then, the images were analyzed using Rootedge software to determine diameter and length of each root (Kaspar & Ewing, 1997). The data were imported to Microsoft Excel® spreadsheets to classify the roots into diameter ranges. With root length values (cm), RLD was calculated for each sample. Soil volume was determined by multiplying the cross-sectional area of the circular base of the auger by the height of the sample within it, totaling 623.25 cm^3.

Root length densities were classified according to root diameter classes proposed by Bohm (1979): very fine roots, diameter lower than 0.5 mm (RLDvf); fine roots, diameter ranging from 0.5 to 2 mm (RLDf); small roots, diameter ranging from 2 to 5 mm (RLDs); medium roots, diameter ranging from 5 to 10 mm (RLDm); and total roots length density (RLDt).

Data on total root length density and diameter classes were subjected to Shapiro-Wilk normality test; when needed, the data were transformed to normal distribution. Initially, the data were tested for normality as a function of four factors: irrigation level, planting density, distance from pseudostem, and sampling depth. Triple interactions were also tested; however, data were not normally distributed. Then, in testing double interactions, data were found to be normally distributed and subjected to analysis of variance for comparing the following interactions: irrigation level x planting density; irrigation level x distance from pseudostem; irrigation level x sampling depth; planting density x distance from pseudostem; planting density x sampling depth; and distance from pseudostem x sampling depth. In case of significant interactions, surface response models were used. For main effects, regression analysis was performed at 5% significance level. Regression models were chosen based on the significance of beta coefficients by t-test, coefficient of determination, and how well the model fits the biological phenomenon. Additionally, total RLD, RLD for each diameter class, yield and total leaf area per plant were subjected to Pearson correlation analysis to verify associations between plant shoot, root system, yield, planting density and irrigation level.

Results and Discussion

Total root length density (RLDt) was significantly affected by interactions between irrigation level (IL) and planting density (PD), IL and distance from pseudostem (DPS), DP and DPS, and DPS and sampling depth (SD). Interactions between IL and PD, IL and DPS, and DPS and SD were significant for very fine root length density (RLDvf). Significant interactions between IL and PD, IL and DPS, and DPS and SD were observed for fine root length density (RLDf). Interactions between IL and PD, and PD and DPS significantly influenced small root length density (RLDs). Interactions between IL and PD, PD and DPS, PD and SD, and DPS and SD were significant for root length density of medium diameter roots (RLDm). The single factor SD was significant for all RLD classes. Distance from pseudostem was significant for RLDs and RLDm, and IL had a significant effect on RLDm.

Despite the significant IL x PD interaction for RLDvf and RLDm, no response surface model could be adequately fitted to the data because of a random variation. However, roots belonging to these classes were found to develop better at the highest irrigation level, 100% ETc, and with PD ranging from 2,000 to 2,666 plants ha^{-1}. For all root diameter classes, RLD decreases with increasing sampling depth, irrespective of irrigation level, planting density and distance from pseudostem (Figure 2). For every 10 cm deep, RLD decreased by 0.058, 0.002, 0.042, 0.012, and 0.027 cm cm^{-3} for the classes RLDt, RLDvf, RLDf, RLDs, and RLDm, respectively. A similar result was found by Santos et al. (2017) working with ‘BRS Princesa’ banana; the authors concluded that regardless of the distance from the pseudostem, a higher concentration of roots is found within 0.40 m deep, in the range of depth evaluated (0.00-0.60 m). The higher concentration of roots close to the soil surface may be attributed to the fact that the banana crop is a monocot having a fibrous root system, which is generally more superficial. Sant’ana et al. (2012) concluded that micro-irrigated ‘Prata-Anã’ banana crop roots are predominantly superficial, with 80% of roots within 0.51 m deep. On ‘Prata Gorutuba’, Santana Junior et al. (2020) concluded that the effective rooting depth ranged from 0.36 to 0.57 m.

Irrespective of the other factors, distance from the pseudostem influenced RLDs (small diameter roots) and RLDm (medium diameter roots), where roots were more abundant within 0.40 m of the pseudostem (Figure 2A, B). The response of RLDm to irrigation level was fitted to a quadratic model (Figure 2C). The lowest RLDs (0.17 cm cm^{-3}) was measured at a distance of 0.62 m from the pseudostem while the lowest RLDm (0.072 cm cm^{-3}) was at 0.65 m from the pseudostem. The increase in RLD from the distance 0.62 m on may be because a higher planting density results in plants with roots overlapping the neighboring plants’ roots, and, in this study, the factor planting density was not analyzed separately. The lowest RLDm (0.10 cm cm^{-3}) is found when using an irrigation level at 69% ETc.

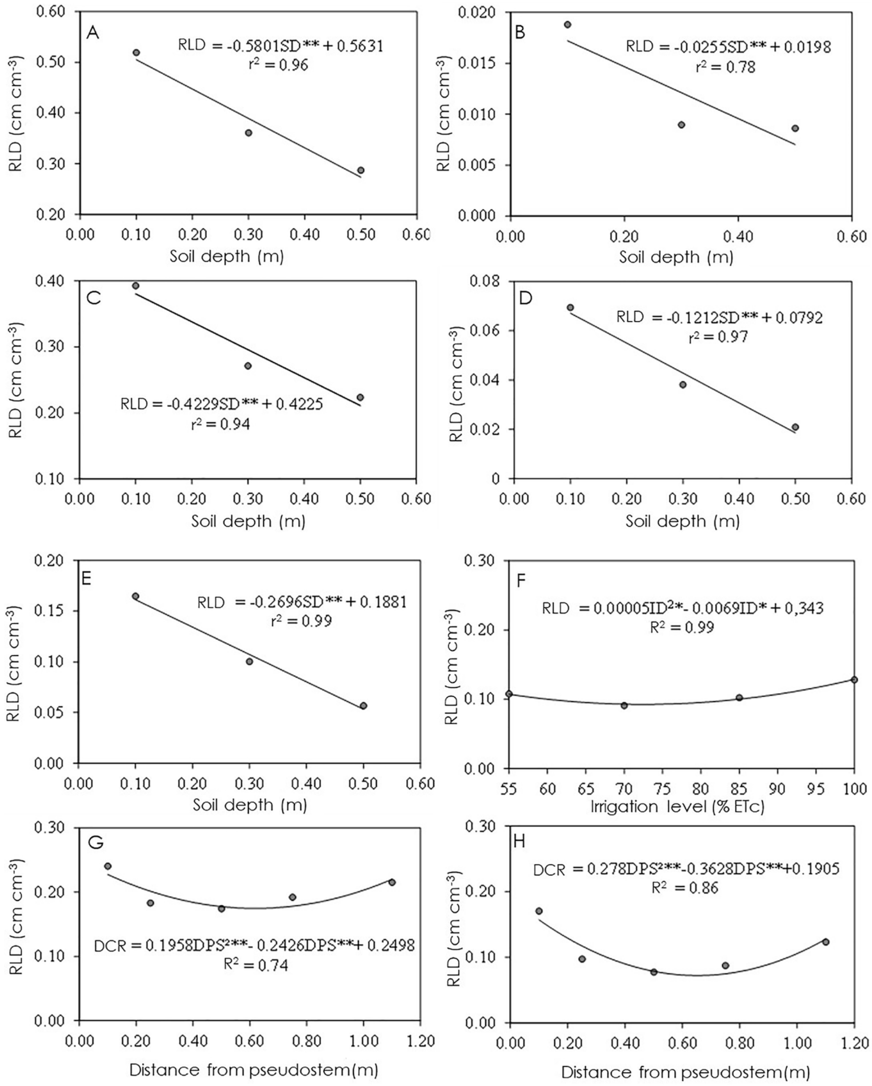

Figure 2. Total root length density (A), root length density of very fine roots with diameter lower than 0.5 mm (B), fine roots with diameter between 0.5 and 2 mm (C), small roots with diameter between 2 to 5 mm (D) and medium roots with diameter between 5 and 10 mm (E) as a function of irrigation level; root length density of small roots with diameter between 5 and 10 mm (F) as a function of irrigation level; and small RLD with diameter between 2 and 5 mm (G), medium roots with diameter between 5 and 10 mm (H) as a function of distance from pseudostem of ‘BRS Platina’ banana * significant at 5% and ** significant at 1% by t test.

The significant interactions, PD x IL for RLDt, RLDf and RLDs; IL x DPS for RLDt, RLDvf and RLDf; and PD x DPS for RLDt, RLDf and RLDs, are shown in Figure 3.

Root length density increases in a linear fashion when increasing irrigation level, but changes in planting density had little influence on RLDt (Figure 3A) and RLDf (Figure 3A); conversely, RLDs had considerable growth under intermediate plant densities (Figure 3C). Fully irrigated plants (100% ETc) had the highest RLD, but the IR x PD interaction had a different effect on RLD; RLDt and RLDf were highest at 3,333 plants ha^{-1} and RLDs was highest at 2,666 plants ha^{-1}. The lowest overall RLD values were found in plots receiving the least amount of water, 55% ETc, at the lowest planting density — 1,600 plants ha^{-1}. Root length densities for each diameter class were: RLDt ranged from 0.37 cm cm^{-3} to 0.61 cm cm^{-3}; RLDf ranged from 0.23 cm cm^{-3} to 0.39 cm cm^{-3}; and RLDs ranged from 0.032 cm cm^{-3} to 0.057 cm cm^{-3}.

Total root length density (RLDt), RLDvf and RLDf decreased with decreasing irrigation level at intermediate distances from pseudostem (Figure 3D, E and F). The lowest values, 0.12, 0.01 and 0.075 cm cm^{-3} for RLDt, RLDvf and RLDf, respectively, were found at the lowest irrigation level, 55% ETc, and at 0.50 m from the pseudostem. The highest RLDt, RLDvf and RLDf — 0.24, 0.016 and 0.13 cm cm^{-3}, respectively — were observed at full irrigation, 100% ETc, and at the distances of 0.1 m for RLDt and 1.1 m for RLDvf and RLDf. Fully irrigated plants have access to a greater volume of moist soil, which allows the roots to grow farther from the plant and deeper into de soil (Coelho et al. 2016).

Total root length density (RLDt), RLDs and RLDm are lowest at 1,600 plants ha^{-1} and at 0.50 m away from the plant for RLDt (0.14 cm cm^{-3}) and RLDs (0.022 cm cm^{-3}), and 0.75 m for RLDm (0.0031 cm cm^{-3}) (Figure 3G, H and I). The highest values, however, are found at higher planting densities: at 3,333 plants ha^{-1} for RLDt (0.20 cm cm^{-3}) and RLDm (0.028 cm cm^{-3}) and at 2,666 plants ha^{-1} for RLDs (0.065 cm cm^{-3}), all of which within 0.10 m of the pseudostem.

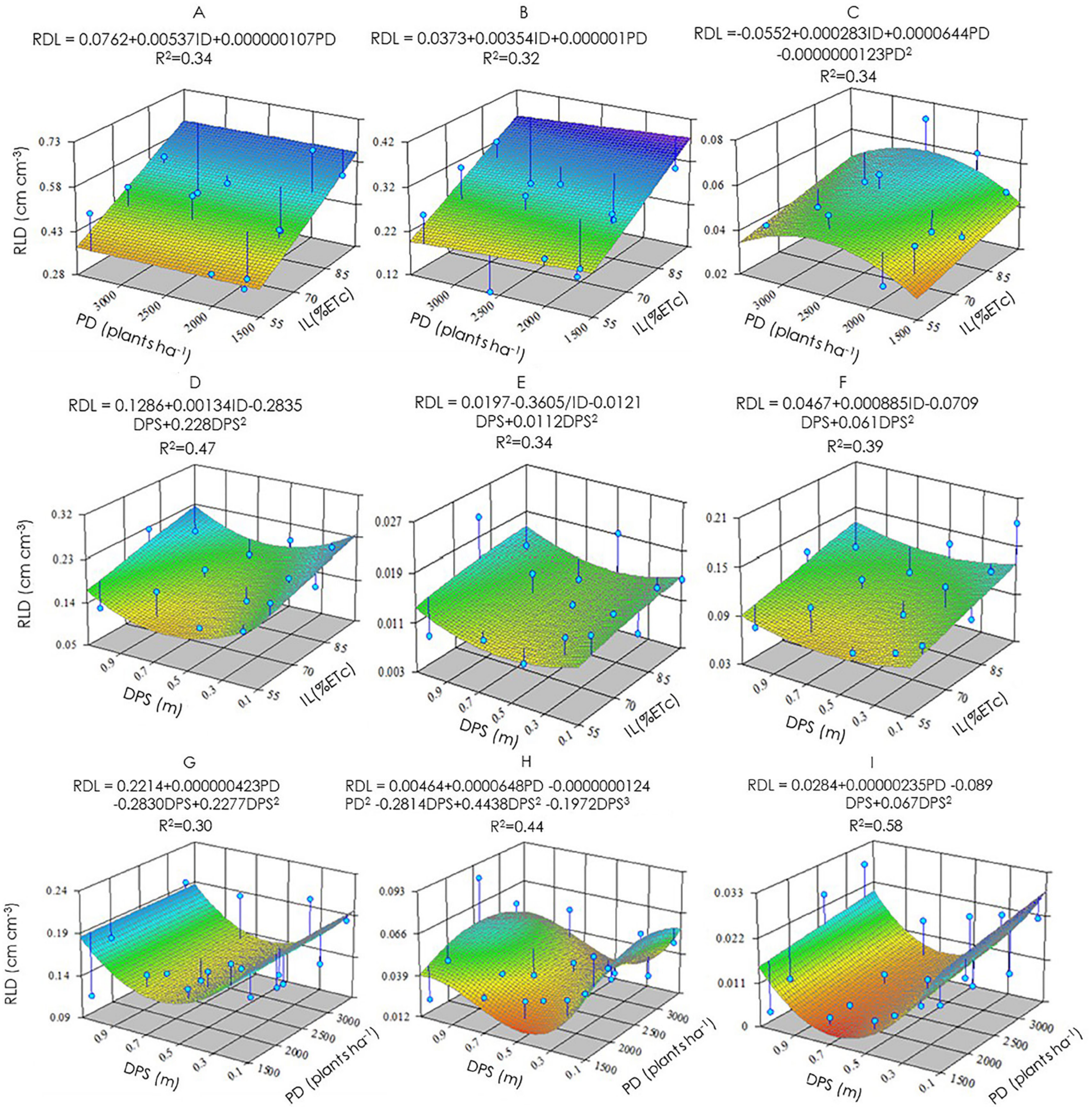

Figure 3. Total root length density (A), fine roots with diameter between 0.5 and 2 mm (B) and small roots with diameter between 2 to 5 mm (C) as a function of planting densities (plants ha^{-1}) and irrigation levels (% ETc); total root length density (D), very fine roots with diameter lower than 0.5 mm (E) and fine roots with diameter between 0.5 and 2 mm (F) as a function of distances from pseudostem and irrigation levels (% ETc); total root length density (G), small roots with diameter between 2 and 5 mm (H) and medium roots with diameter between 5 and 10 mm (I) as a function of planting density and distance from pseudostem of 'BRS Platina' banana. Planting density (PD), irrigation level (IL) and distance from pseudostem (DPS).

The results give us insight into how the banana plant's roots develop; thicker roots are concentrated at shorter distances from the pseudostem, while thinner roots spread through the soil to greater distances, and thus explore a larger area to absorb water and nutrients. Santos et al. (2016b) reported that RLD of fine roots (diameter between 0.5 and 2 cm) of 'Prata-Anã' and 'BRS Platina' bananas decreased as the distance from pseudostem and depth increased; this suggests that fine roots are associated with plant anchorage because they are mostly located close to the pseudostem, while the RLD of very fine roots (diameter less than 0.5 cm) had an opposite trend because they are mostly associated with absorption of water and nutrients (Sant’ana et al. 2012).

The DPS x SD interaction similarly affected RLDt, RLDvf, RLDf and RLDm (Figure 4) as the highest values are found in the topsoil and at a greater distance from the pseudostem, with the exception of RLDt and RLDm, which were highest (0.263 cm cm^{-3} and 0.094 cm cm^{-3}, respectively) at 10 cm away from the plant (Figure 4A and D). The highest values of RLDvf and RLDf were, respectively, 0.018 and 0.16 cm cm^{-3} for the depth of 0.10 m and distance of 1.1 m from the pseudostem. On the other hand, the lowest values, 0.0064 and 0.055 cm cm^{-3} for the RLDvf and RLDf, respectively, were found at 0.50 m deep and 0.10 m away from the pseudostem, whereas RLDt and RLDm were lower, 0.066 and 0.017 cm cm^{-3}, respectively, at 0.50 m deep and 1.1 m away from the pseudostem.

Length density of medium roots is directly proportional to planting density and inversely proportional to depth (Figure 4E). The highest root length densities found at the highest planting density may be associated with the greater root overlap between plants. The highest RLDm, 0.03 cm cm^{-3} was found at 10 cm deep in plots at the highest planting density (3,333 plants ha^{-1}); however, the lowest RLDm, 0.002 cm cm^{-3}, was found at the lowest planting density, 1,600 plants ha^{-1}.

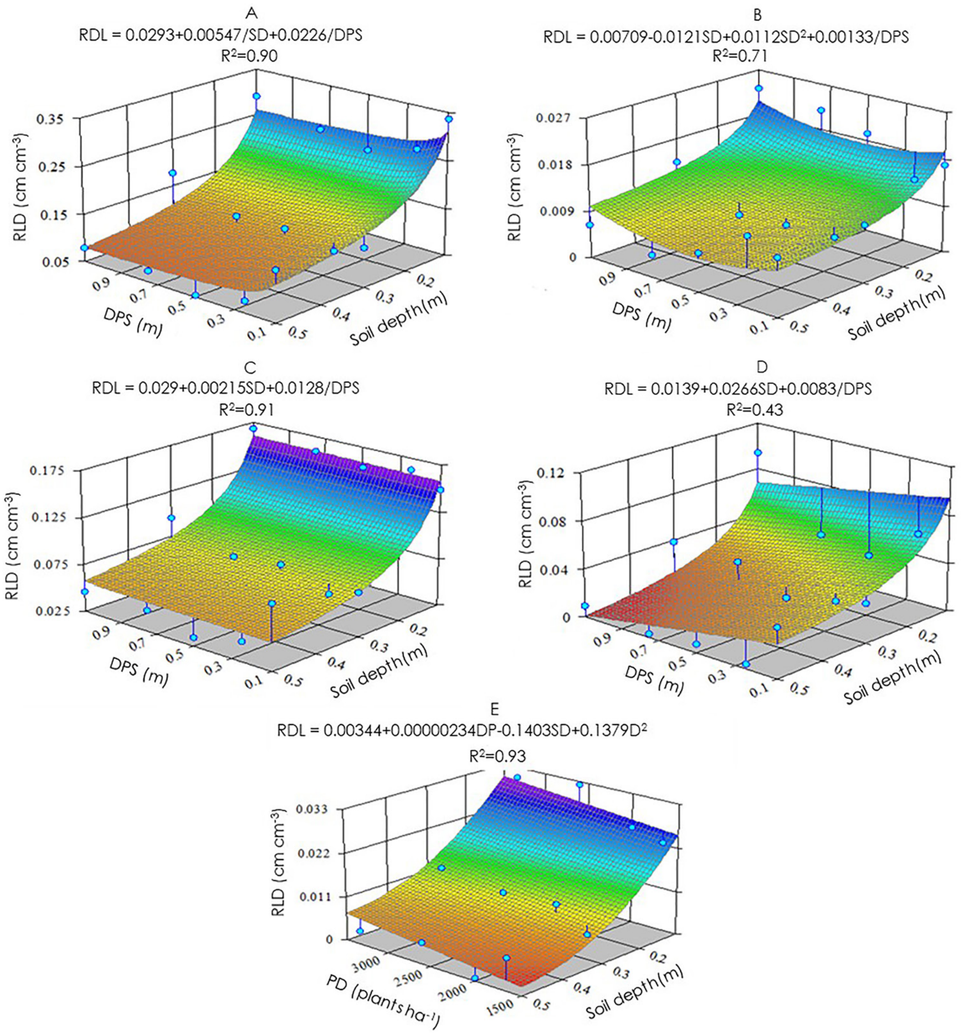

Figure 4. Total root length density (A), very fine roots with diameter lower than 0.5 mm (B), fine roots with diameter between 0.5 and 2 mm (C), medium roots with diameter between 5 and 10 mm (D) as a function of distance from pseudostem and depth (m); root length density of medium roots banana as a function of planting density (plants ha^{-1}) and depth (E), in ‘BRS Platina’ banana plants. Distance from pseudostem (DPS), soil depth (SD) and planting density (PD).

Root length density percentages of each root diameter (Figure 5A) show that fine roots with diameter between 0.5 and 2 mm and small roots with diameter between 2 and 5 mm account for more than 70% of total roots; these roots have the main function of anchoring the plant to the ground. Nutrient-absorbing roots (diameter lower than 0.5 mm) account for less than 10% of the total. Knowing how roots are distributed in the soil profile allows a more precise placement of soil moisture sensors, which in turn provide important data for improving the production system, particularly water delivery and side-dressing fertilizers.

Figure 5B shows that 80.36% of roots are within 0.31 m deep and 80.56% are within 0.78 m of the pseudostem; therefore, within this volume of soil lies the ideal place to apply fertilizer and install soil moisture sensors. Similar results were reported by Santana Junior et al. (2020) when evaluating the root distribution of ‘Prata Gorutuba’ banana irrigated by different micro-irrigation systems. The authors concluded that plants irrigated by a micro-sprinkler with flow rate of 70 L h^{-1} has 80% of its roots concentrated within 0.32 m deep and within 0.75 m of the pseudostem.

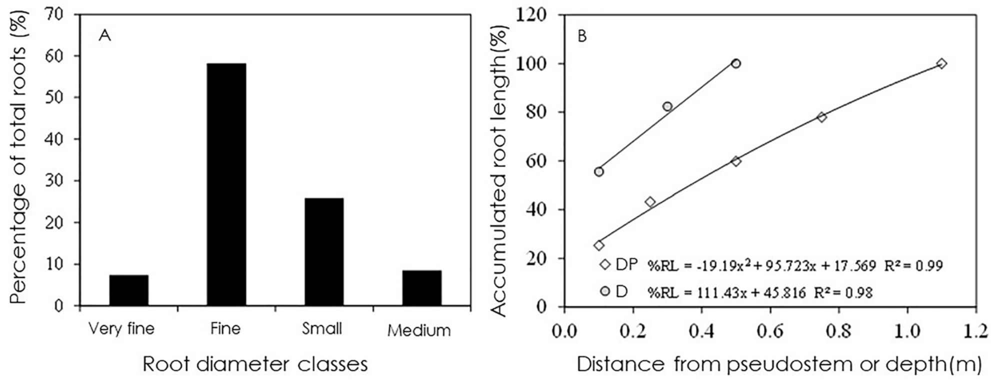

Figure 5. Overall percentage of total roots as to diameter (A) and percentage of accumulated root length (% CR) as a function of distance from pseudostem - DP and depth - D (B).

The following variables were correlated: irrigation level, planting density, crop yield, total leaf area, total root length density, and root length density of very fine, fine, small and medium diameter roots (Table 2). Pearson coefficients were classified according to Hopkins (2000) and showed a high positive correlation of irrigation level with RLDf, RLDs and RLDt. These correlations indicate increasing irrigation levels leads to greater root development. Planting density did not significantly correlate with total leaf area. Root length density of medium roots has a high positive correlation with yield while RLDvf has a moderate positive correlation with total leaf area. These results show that irrigation plays a major role in increasing RLD, which is associated with a further increase in yield of banana plants under higher planting density. Increased RLD of very fine roots correlates with increased leaf area, which indicates these roots are most associated with absorption of water and nutrients (Santos et al., 2017). Very fine roots have a significant, positive correlation with all root diameter classes, and correlate positively with crop yield.

Taiz et al. (2017) point out the greater investment in root development and decreased leaf area of plants under water deficit are the result of changes in shoot / root ratio and source-sink relationships, the degree of which depends on drought intensity. In this study, root distribution was positively affected by irrigation, even at lower levels, when planting density is higher. Increased planting density might have contributed to increasing overlapping roots and maintenance of soil moisture by reducing soil water evaporation due to increased shading, as well as protecting plants against wind, another factor that increases water loss (Donato et al., 2015).

Table 2. Correlation between irrigation level (IL), planting density (DP), crop yield (CY), total leaf area (TLA), root length density (RLD) of very fine (RLDvf), fine (RLDf), small (RLDs), medium (RLDm) and total (RLDt) roots.

Variable	IL	DP	CY	TLA	RLDvf	RLDf	RLDs	RLDm	RLDt
IL	1.00								
DP	0.00	1.00							
CY	0.14	0.89**	1.00						
TLA	0.28	-0.37	-0.26	1.00					
RLDvf	0.38	-0.10	-0.06	0.44*	1.00				
RLDf	0.56*	-0.06	0.14	0.29	0.79**	1.00			
RLDs	0.50*	0.14	0.25	0.03	0.36	0.69**	1.00		
RLDm	0.32	0.26	0.58**	-0.05	0.06	0.45*	0.56*	1.00	
RLDt	0.58**	0.01	0.21	0.25	0.74**	0.98**	0.81**	0.56*	1.00

*Significant at 5%, **significant at 1%.

Conclusions

Increasing irrigation level up to 100% ETc leads to increased root system development in 'BRS Platina' banana plants.

Planting densities ranging from 2,666 plants ha^{-1} to 3,333 plants ha^{-1} result in the highest RLD, particularly fine roots with diameter between 0.5 and 2 mm and medium roots with diameter between 5 and 10 mm.

80% of roots are concentrated within 0.31 m deep and within 0.78 m of the pseudostem, for the layer 0.00 – 0.60 m; within this portion of the soil lies the most appropriate place to install soil moisture sensors and to apply fertilizers.

Irrigation interacts with root system, and coupled with an increased planting density, contributes to the yield increase of 'BRS Platina' banana.

References

Amorim, M.S., Coelho, E.F., Melo, D.M., Lima, D.B., Lima, L.W.F. 2019. Cultivo orgânico da bananeira 'BRS Tropical' sob irrigação e uso de cobertura orgânica no solo. *Revista Brasileira de Agricultura Irrigada*, 13: 3487-3497.

Azevedo, M.C.B., Chopart, J.L., Medina, C.C. 2011. Sugarcane root length density and distribution from root intersection counting on a trench-profile. *Scientia Agricola*, 68: 94-101.

Böhm, W. 1979. *Methods of Studying Root Systems*. Ecological Studies (Analysis and Synthesis). Springer, Berlin, Heidelberg

Borges, A.L.; Coelho, E.F. Costa, E.L. 2011. Irrigação e fertirrigação na cultura da banana. In: Sousa, V. F. Marouelli, W. A. Coelho, E. F. Pinto, J. M. Coelho Filho M. A. (Ed.). *Irrigação e fertirrigação em fruteiras e hortaliças* Embrapa Mandioca e Fruticultura, Cruz das Almas-BA, Brazil.

Brasil. 2017. Resolução nº 107, de 27 de julho de 2017. Conselho Deliberativo da Superintendência do Desenvolvimento do Nordeste. Diário oficial da união: seção 1, Brasília, DF, n. 176, p.48, 13 set. 2017.

Coelho, E.F., Santos, M.R., Costa, E.L., Donato, S.L.R., Oliveira, P.M. 2016. Irrigation under different soil surface wetted areas and water depths for banana cv. Grand Naine. *African Journal of Agricultural Research*, 11: 3425-3432.

Donato, S.L.R., Coelho, E.F., Santos, M.R., Arantes, A.M., Rodrigues, M.G.V. 2015. Eficiência de uso da água em bananeira. *Informe Agropecuário*, 36: 46-59.

Donato, S. L. R., Lédo, A. A., Pereira, M. C. T., Coelho, E. F., Cotrim, C. E., & Coelho Filho, M. A. 2010. Estado nutricional de bananeiras tipo Prata sob diferentes sistemas de irrigação. *Pesquisa Agropecuária Brasileira,* 45(9), 980-988.

Faostat. 2019. Food and Agriculture Organization of the United Nations. http://www.fao.org/faostat/en/#data/QC<Access on 10 Apr. 2021>.

Hopkins, W.G. 2019. Correlation coefficient: a new view of statistics. 2000. https://www.sportsci.org/resource/stats/effectmag.html<Access on 07 Apr. 2019>.

Kaspar, T.C., Ewing, R.P. 1997. Rootedge: Software for measuring root length from desktop scanner images. *Agronomy Journal*, 89: 932-940.

Paltineanu, C., Coman, M., Nicolae, S., Ancu, I., Calinescu, M., Sturzeanu, M., Chitu, E., Ciucu, M. & Nicola, C. 2018. Root System Distribution of Highbush Blueberry Crops of Various Ages in Medium-Textured Soils. *Erwerbs-Obstbau*, 60 : 187–193.

Pramanik, S., Lai, S., Ray, R., Patra, S. K. 2016. Effect of drip fertigation on yield, water use efficiency, and nutrients availability in banana in West Bengal, India. *Communications in Soil Science and Plant Analysis*, 47: 1691-1700.

Rodrigues, M.G.V., Donato, S.L.R., Lichtemberg, L.A., Dias, M.S. 2015. Implantação e condução do bananal. *Informe Agropecuário*, 36: 27-45.

Rodrigues, M.G.V., Ruggiero, C., Natale, W., Pacheco, I.D. 2007. Nutrição e produção da bananeira 'Prata-anã' adubada com zinco e boro diretamente no rizoma, via muda desbastada. *Revista Brasileira de Fruticultura*, 29: 645-651.

Sant'ana, J.A.V., Coelho, E.F., Faria, M.A., Silva, E.L., Donato, S.L.R. 2012. Distribuição de raízes de bananeira 'Prata-Anã' no segundo ciclo de produção sob três sistemas de irrigação. *Revista Brasileira de Fruticultura*, 34: 124-133.

Santana Junior, E.B., Coelho, E.F., Cruz, J.L., & Reis, J.B.R.S. 2020. Trickle irrigation systems affect spatial distribution of roots of banana crop. *Revista Brasileira de Engenharia Agrícola e Ambiental,* 24: 325-331.

Santos, M.R., Coelho, E.F., Donato, S.L.R., Rodrigues, M.G.V. 2017. Distribuição de raízes e extração de água da bananeira 'BRS Princesa' sob diferentes configurações de irrigação. *Engenharia na agricultura*, 24: 513-522.

Santos, M.R., Donato, S.L.R., Lourenço, L.L., Silva, T.S., Coelho Filho, M.A. 2016a. Irrigation management strategy for Prata-type banana. *Revista Brasileira de Engenharia Agrícola e Ambiental,* 20: 817-822.

Santos, M.R., Donato, S.L.R., Magalhães D.B., Cotrim, M.P. 2019. Precocity, yield and water-use efficiency of banana plants under planting densities and irrigation depths, in semiarid region. *Pesquisa Agropecuaria Tropical*, 49: e53036.

Santos, M.R., Lorenço L.L., Donato, S.L. R., Silva B.L., Castro, I.N., Filho Coelho M.A. 2016b. Root system distribution and vegetative characteristics of Prata type bananas under different irrigation strategies. *African Journal of Agricultural Research,* 11: 3806-3815.

Santos, M.R., Martinez, M.A., Donato, S.L.R., Coelho, E.F.

2014. Fruit yield and root system distribution of 'Tommy Atkins' mango under different irrigation regimes. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 18: 362-369.

Segura, R.A., Serano, E., Pocasangre, L., Acuña, O., Bertsch, F., Stoorvogel, J.J., Sandoval, J.A. 2015. Chemical and microbiological interactions between soils and roots in commercial banana plantations (*Musa* AAA, cv. Cavendish). *Scientia Horticulturae*, 197: 66-71.

Silva, L.B., Nascimento, J.L., Naves, R.V., Braga Filho, J.R., Buso, W.H.D., Souza, E.R.B. 2017. Productive characteristics of banana genotypes submitted to different irrigation water depths under Cerrado conditions. *Semina: Ciências Agrárias*, 38: 2351-2361.

Taiz, L., Zeiger, E., Moller, I.M., Murphy, A. 2017. *Fisiologia e desenvolvimento vegetal*. 6th ed. Artmed, Porto Alegre-RS, Brazil.

Zucoloto, M., Lima, J.S.S., Coelho, R.I. 2008. Modelo matemático para estimativa da área foliar total de bananeira 'Prata-Anã'. *Revista Brasileira de Fruticultura*, 30: 1152-1154.

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