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Horticultural Science/ Original Article

Pineapple root growth and distribution with the use of plastic mulch and percolation barrier

Abstract – The objective of this work was to evaluate the effect of the use of plastic mulch and percolation barrier on the growth and distribution of pineapple roots. The BRS Imperial cultivar was cultivated using plastic as mulching material and a percolation barrier. The evaluated variables were: relative and absolute root growth rates, root length distribution, and root length density. The use of plastic mulch resulted in a greater accumulation of root dry matter, with or without the percolation barrier. Under drip irrigation, mulching promoted a greater root development. The highest root growth rate occurred from 360 to 450 days after planting. The amount of roots was from 64.1 to 66.7% on the stem, and from 34 to 36% distributed in the 0.10 and 0.20 m soil layer. Black plastic, as mulch or a percolation barrier, contributes to increase the root development of 'BRS Imperial' pineapple under drip irrigation.

Index terms: *Ananas comosus*, mulching, soil cover, water use efficiency.

Crescimento e distribuição de raízes de abacaxizeiro com uso de cobertura plástica e barreira de percolação

Resumo – O objetivo deste trabalho foi avaliar o efeito do uso de cobertura plástica e barreira de percolação no crescimento e na distribuição de raízes de abacaxizeiro. A cultivar BRS Imperial de abacaxizeiro foi cultivada com uso de plástico como cobertura do solo e como impedimento à percolação. As variáveis avaliadas foram: taxas de crescimento radicular relativo e absoluto, distribuição do comprimento das raízes e densidade do comprimento radicular. O uso do plástico como cobertura do solo resultou em maior acúmulo de matéria seca das raízes, com ou sem impedimento de percolação. Sob irrigação por gotejamento, o uso do plástico como cobertura do solo promoveu maior desenvolvimento das raizes. A maior taxa de crescimento radicular ocorreu dos 360 aos 450 dias após o plantio. A quantidade de raízes foi de 64,1 a 66,7% no caule, e de 34 a 36% distribuídas na camada de 0,10 a 0,20 m do solo. O plástico preto, tanto como cobertura do solo quanto como impedimento de percolação, contribui para aumentar o desenvolvimento radicular do abacaxizeiro 'BRS Imperial' sob irrigação por gotejamento.

Termos para indexação: *Ananas comosus*, mulching, cobertura do solo, eficiência do uso da água.

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Introduction

Pineapple [*Ananas comosus* (L.) Merr.] is widely grown in Brazil in an area of approximately 61,000 ha, with an average yield of 24,000 fruits per hectare (IBGE, 2022). For crop production, farmers have been using plastic mulch (Anjos et al., 2017), which reduces water loss both by decreasing soil evaporation and temperature (Pereira et al., 2015; Xiukang et al., 2015) and maintaining soil moisture at suitable levels (Santana et al., 2011; Bhargavi & Anusha, 2023; Coelho et el., 2024). Mulching also increases water use efficiency, reducing the need for irrigation, particularly in dry regions (Daryanto et al., 2017; Santos et al., 2022).

The strategy used for the cultivation of a crop depends, among other factors, on the knowledge about the root system of the plants. The distribution of roots at different depths and distances affects water and nutrient uptake, with consequences on crop production and water use efficiency (Fan et al., 2016). Besides increasing water use efficiency and yield, the use of plastic mulch, when installed below the effective root zone, reduces percolation and influences water and nutrient uptake, likely affecting root development and distribution (Coelho et al., 2024; Du et al., 2014). However, the information about pineapple roots regarding the use of mulch is still scarce in the literature (Chopart et al., 2015; Silva et al., 2021).

The methods used for crop fertilization (broadcasting and fertigation, for example) are also directly related to root distribution and development in the soil. Although fertigation is more adequate for drip irrigation (Kant & Kafkafi, 2013), in the case of pineapple, fertilizer application by spraying on the base of the leaves may be more favorable for yield due to the concentration of adventitious roots on the stem (Santos et al., 2022).

The objective of this work was to evaluate the effect of the use of plastic mulch and percolation barrier on the growth and distribution of pineapple roots.

Materials and Methods

The experiment was carried out in the experimental area of Embrapa Mandioca e Fruticultura, located in the coastal tablelands of the state of Bahia, Brazil (12°40'39"S, 39°06'23"W, at an altitude of 220 m). The climate of the region is humid hot tropical of the Aw to Am type, according to Köppen's classification, with an annual average rainfall, temperature, and relative humidity of 1,131.17 mm, 24.5°C, and 80%, respectively (Guimarães et al., 2016). The soil of the experimental area has a sandy loam texture, with 733 g kg^{-1} total sand, 94 g kg^{-1} silt, 173 g kg^{-1} clay, macroporosity of 11.9%, microporosity of 19.1%, and total porosity of 31.1%.

For the experiment, sucker-type plantlets of the BRS Imperial pineapple cultivar were planted in ridges at a spacing of 0.9x0.4x0.4 m, which corresponds to a planting density of 38,460 plants per hectare. Soil preparation, planting, and cultural practices followed Santana et al. (2013). A black plastic sheet with a 125 µm thickness was used to cover the soil (mulch) and installed at a depth of 0.4 m to prevent percolation (barrier).

Fertilization, based on the results of the soil analysis, was performed by fertigation every 15 days. The drip irrigation system was adopted, using inline drippers with a flow rate of 1.6 L h^{-1}, spaced at 0.30 m from each other. Each ridge was supplied by a lateral line, i.e., one for every two rows of plants, and irrigation was controlled by valves in the control head. The decision of when to irrigate was based on the soil water content determined by time-domain reflectometry through probes inserted at a 0.10 m depth in all plots. Soil water content data were also used to evaluate soil water availability over time (Santos et al., 2021). To standardize the production period, floral induction was performed at 360 days after planting (DAP), using an aqueous solution consisting of the Ethrel 720 ethephon-based product (Bayer Crop Science, São Paulo, SP, Brazil) and 2.0% urea.

Root growth and distribution throughout the crop cycle were analyzed as a function of different soil depths. The experimental design was a randomized complete block, with four replicates, in a 5x4x4 split-split-plot arrangement. The plots corresponded to different periods after planting (90, 180, 270, 360, and 450 DAP). The subplots stood for the following four cultivation treatments: WM-WI, with plastic mulch and with percolation barrier; WoM-WI, without plastic mulch and with percolation barrier; WM-WoI, with plastic mulch and without percolation barrier; and WoM-WoI, without plastic mulch and without percolation barrier. The subplots represented four depths: roots on the plant stem and roots at the soil depths of 0.00–0.10, 0.10–0.20, and 0.20–0.30 m.

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To evaluate the response of the root samples to the treatments, the following variables were analyzed: root dry matter, percentage of roots, absolute growth rate, relative growth rate, root length density, and total root length.

The distribution of plant roots in the flowering stage was evaluated in a crop row of each plot. Root dry matter was sampled in soil volumes of 0.4x0.4x0.4 m with one plant (Figure 1 A and B) and in three soil profiles corresponding to the directions from plant-plant, plant-dripper, and plant-ridge border in a same-size soil volume (Figure 2).

The distribution of roots around the plant in the flowering stage was evaluated using a randomized complete block design with four replicates, in a 4x3x3 split-split-plot arrangement, with the plots, subplots, and sub-subplots representing the four treatments, three directions (Figure 1), and three soil layers (0.00–0.10, 0.10–0.20, and 0.20–0.30 m), respectively. Root distribution around the plant was also analyzed using the experimental design in randomized complete blocks, with four replicates, but in a 4x3x2 split-split-plot arrangement, with the same aforementioned plots and subplots, but sub-subplots representing two lateral distances from the plant (0.00–0.10 and 0.10–0.20 m).

Treatment effects on the variables total root length, root length density, effective depth of root length, and effective distance were evaluated by the analysis of variance using the F-test. The means of the treatments and the decomposition of their interactions, when significant, were compared by Tukey's test (Ferreira, 2019). Isoline graphs for the distribution of root length density in the profile were generated based on the means of the treatments. Regression models for total root length, percentage of total root length, and percentage of total root length accumulated as a function of the plant-drip line distance and soil depth were evaluated.

To determine dry matter, the root system of the crop was collected every three months until the fruit-filling stage in the layers from soil surface to a 0.40 m depth, below which no root was found. Roots that surrounded or curled around the stem were identified and separated from those that branched out in the soil. The latter roots were collected in the 0.00–0.10, 0.10–0.20, and 0.20–0.30 m layers, with one collection in each layer in a 0.40x0.40 m area occupied by the plant and a soil volume of 0.016 m^3 (Figure 1 B).

The samples containing soil and roots were washed, and, then, the roots were separated from the soil. The material was dried in a forced-air circulation oven,

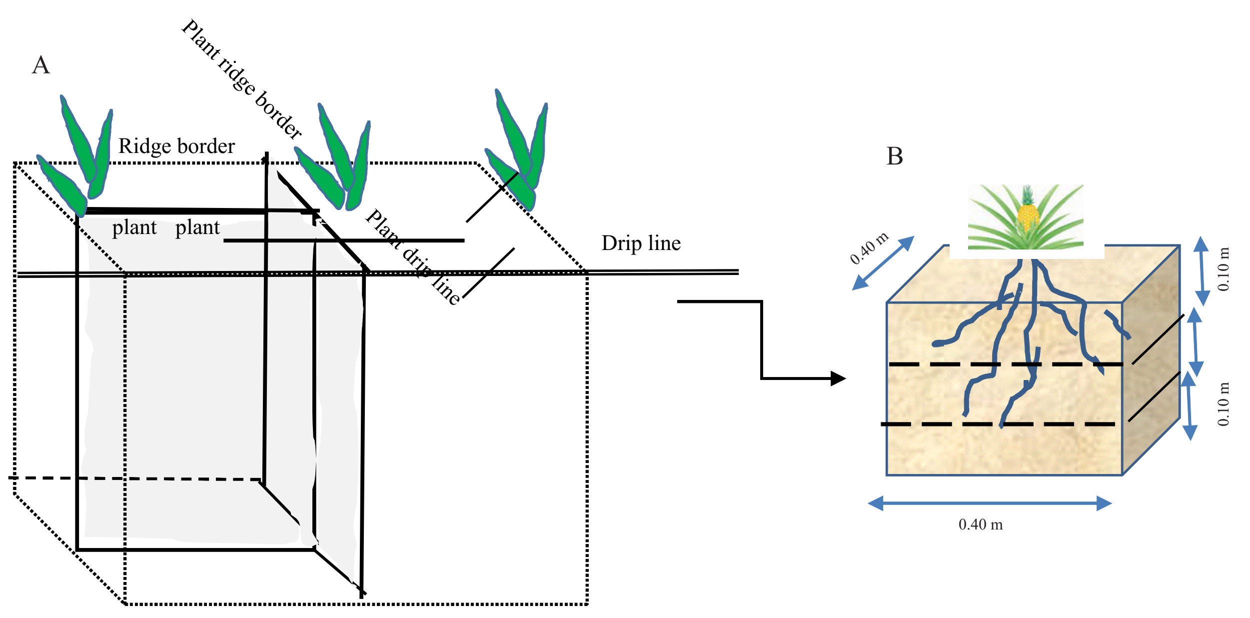

Figure 1. Directions (plant-plant, plant-drip line, and plant-ridge border) in relation to the plant (A) and soil layers (B) in which the data on pineapple (*Ananas comosus*) roots were collected.

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at 65°C, until reaching a constant weight, in order to determine root dry matter on a 0.01 g precision scale.

The absolute growth rate of the roots was determined based on the variation of total root dry matter over a period, according to Peixoto et al. (2011), as follows:

$$AGR = \frac{W_2 - W_1}{T_2 - T_1}$$

where AGR is the absolute growth rate (grams per day), and W_1 and W_2 refer to the dry matter weight (g) in two consecutive samples taken at times T_1 and T_2 (days).

The relative growth rate of the roots over time was determined by:

$$RGR = \frac{\ln W_2 - \ln W_1}{T_2 - T_1}$$

where RGR is the relative growth rate, and W_1 and W_2 also refer to the dry matter weight (g) in two consecutive samples taken at times T_1 and T_2 (days).

The root system of the pineapple plants was evaluated in the fruit-filling stage at 450 DAP in soil trenches with a length of 0.8 m and a depth of 0.4 m. The root samples were collected below the plant at the depths of 0.10, 0.20, 0.30, and 0.40 m, as well as at the distances of 0.10 and 0.20 m from the plant toward the drip line, toward the semi-space between double rows (border of the ridge), and toward another plant (Figure 2). Sample size was 0.10x0.10x0.10 m, corresponding to a soil volume of 0.001 m^3.

Soon after being collected, the samples were separated from the soil through washing and placed in plastic bags with a solution containing alcohol diluted in 50% distilled water for later storage, at 5°C, in a refrigerator (Santana Junior et al., 2020). The roots were removed from storage and placed on paper towels for natural drying. After the removal of impurities, such as leaves and roots from other crops, the roots were separated according to diameter and length and arranged on transparent sheets to be digitized into TIFF files (Coelho & Or, 1999). The digitized files were processed by the Rootedge software (Kaspar & Ewing, 1997), in order to determine the following geometric characteristics: root area, total root length, and root diameter. Root length density was obtained by the ratio between root length and sample volume according Santana Junior et al. (2020): $RGR = Lr/V$ where RLD is root length density (cm cm^{-3}), Lr is total root length (cm), and V is the soil volume of the sample (cm^{-3}). The ratio between the total root length at each distance and depth and the total root

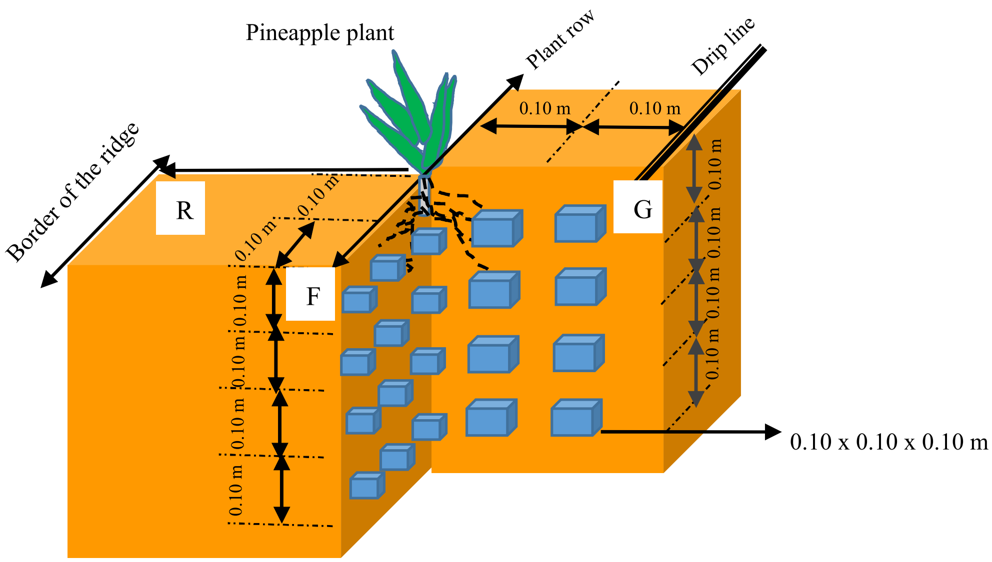

Figure 2. Points in the soil profiles where 0.10x0.10x0.10 m monoliths were collected to study the distribution of pineapple (*Ananas comosus*) roots. G, R, and F, distances toward the drip line, the semi-space between double rows (border of the ridge), and another plant, respectively.

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length of all positions of the soil profile resulted in the percentage of root length for each sampled position (distance from the plant and depth). Effective depth and effective distance from the roots were considered to be the regions where 80% of total root length was concentrated (Coelho et al., 2016).

Results and Discussion

The use of mulch had significant individual effects on plant root dry matter, absolute growth rate, and relative growth rate (Table 1). The WM-WI and WM-WoI treatments showed similar means for accumulated dry matter and absolute growth rate, whose values were significantly higher than those obtained for WoM-WI and WoM-WoI.

The use of plastic mulch favors the conservation of soil moisture, maintaining a high water availability to plants, i.e., near the upper limit of soil water availability or field capacity (Table 2), which is attributed mainly to the reduction of water loss by evaporation (Coelho et al., 2024). The soil water content near 100%-soil water availability contributes to increase plant photosynthetic rate and, consequently, dry matter production (Lamptey et al., 2020).

The accumulation of total root dry matter as a function of DAP showed a greater increase between 360 and 450 days (Figure 3), which correspond to the flowering and fruit-filling stages. The average cumulative dry mass during this period was 36.16, 23.65, 19.7, and 12.49 g for the WM-WI, WM-WoI, WoM-WI, and WoM-WoI treatments, respectively. This greater increase in dry matter accumulation is explained by the higher demand for photoassimilates during flowering and fruit development. These results are in alignment with those obtained by Pegoraro et al. (2014), who found that root dry mass increased until flowering and fructification. However, these authors observed a reduction in root dry mass, which was not verified in the present study due to the shorter growth evaluation time (until 450 DAP), with harvest at about 490 DAP.

The absolute growth rates of the roots ranged from 0.046 to 0.064 and from 0.028 to 0.047 g per day in the treatments with (WM-WI and WM-WoI) and without (WoM-WI and WoM-WoI) mulch until 180 DAP, continuing to increase from then onwards. The treatments with mulch reached rates of 0.100 to 0.120 g per day between 360 and 450 DAP (Figure 4), representing an almost constant difference over time of 0.010 to 0.013 g per day in relation to the treatments without mulch. The accumulated total root dry matter and absolute growth rate showed an exponential

Table 1. Effect of plastic mulching on the root dry matter, absolute growth rate, and relative growth rate of the BRS Imperial pineapple (Ananas comosus) cultivar(1).

Variable	Unit	Treatment(2)			
		WM-WI	WoM-WI	WM-WoI	WoM-WoI
Root dry matter	g	30.240a	20.800bc	28.200ab	18.960c
Absolute growth rate	g per day	0.092a	0.060c	0.089ab	0.064bc
Relative growth rate	g g^{-1} per day	0.047a	0.045a	0.047a	0.045a

(1)Means followed by equal letters, in the row, do not differ significantly by Tukey's test, at 5.0% probability. (2)WM, with mulch; WoM, without mulch; WI, with percolation barrier; and WoI, without percolation barrier.

Table 2. Water availability in soil cultivated with pineapple (*Ananas comosus*), with and without the use of plastic mulch, at different days after planting (DAP)(1).

Mulch	Water availability in the soil (%)				
	90 DAP	250 DAP	320 DAP	400 DAP	500 DAP
With	100.0a	100.0a	100.0a	99.0a	100.0a
Without	19.0b	59.0b	69.0b	30.0b	33.0b
CV (%)	21.4	8.1	8.9	43.2	69.2

(1)Means followed by equal letters, in the column, do not differ significantly by Tukey's test, at 5.0% probability. CV, coefficient of variation.

behavior as a function of time after planting. This result differed from the one obtained by Pegoraro et al. (2014), possibly because of the lack of data at the final growth stage (establishment of growth).

The treatments with plastic mulch did not significantly influence root distribution along the stem,

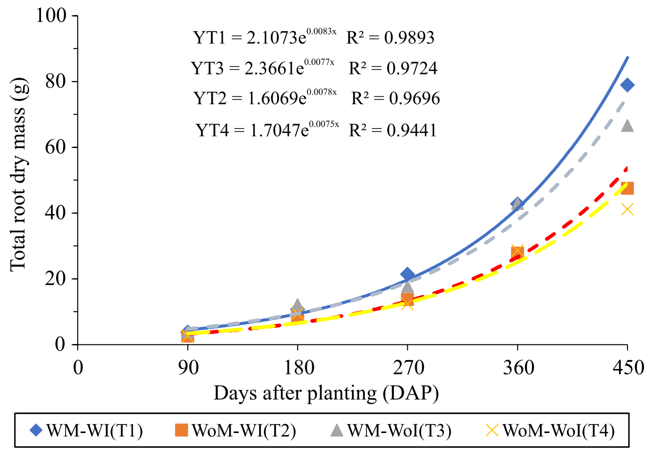

Figure 3. Total root dry matter of the BRS Imperial pineapple (*Ananas comosus*) cultivar on different days after planting as a function of treatments with and without mulch. Treatments (T1 to T4): WM, with mulch; WoM, without mulch; WI, with percolation barrier; and WoI, without percolation barrier.

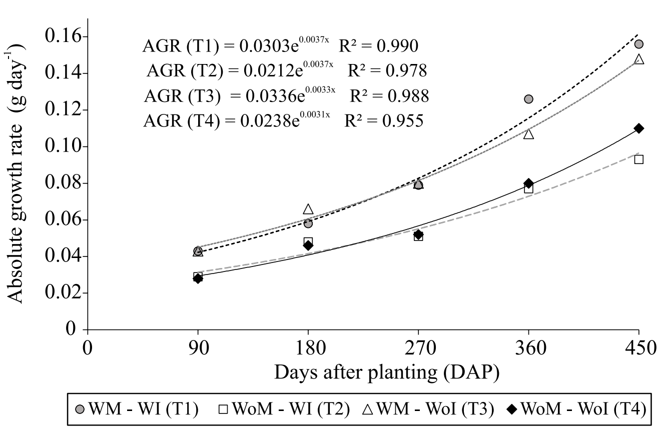

Figure 4. Absolute growth rate of the roots of the BRS Imperial pineapple (*Ananas comosus*) cultivar over time after planting, as a function of treatments (T1 to T4) with (WM) and without (WoM) mulch and with (WI) and without (WoI) percolation barrier. T1, WM-WI; T2, WoM-WI; T3, WM-WoI; and T4, WoM-WoI.

which showed a percentage of total roots (adventitious) between 64.1 and 66.7%. In the soil, 33 and 36% of total roots were distributed between the depths of 0.10 and 0.30 m (Table 3), and there was no significant difference in root percentage means at the depths of 0.10 and 0.20 m when plastic was used as a percolation barrier.

In the treatments with plastic, there were no roots in the layer below 0.20 m. Both as mulching and as a percolation barrier, the plastic contributed to increase root length density in the 0.00–0.10 m layer (Table 4). However, its use as a percolation barrier had a greater effect than as mulch in the 0.10–0.20 m layer, which is an indicative that soil moisture conditions up to a 0.20 m depth contributed to root development. Moreover, the percolation barrier prevented water flow below the latter depth and increased water storage in the 0.10–0.20 m layer (Coelho et al., 2024), maintaining

Table 3. Percentage of total roots of the BRS Imperial pineapple (*Ananas comosus*) cultivar at different depths for the treatments with or without plastic mulch in the post-floral induction period(1).

Depth	Total roots (%)(2)			
(m)	WM-WI	WM-WoI	WoM-WI	WoM-WoI
Stem	66.7aA	64.4aA	64.10aA	65.6aA
0.1	18.0bA	18.4bA	20.7bA	22.7bA
0.2	15.3bA	9.7cB	15.2bA	9.3cB
0.3	0.0cC	7.5cA	0.0cC	2.4dB

(1)Means followed by equal letters, uppercase in the row and lowercase in the column, do not differ from each other by Tukey's test, at 5.0% probability. (2)Treatments: WM, with mulch; WoM, without mulch; WI, with percolation barrier; and WoI, without percolation barrier.

Table 4. Root length density of the BRS Imperial pineapple (Ananas comosus) cultivar at different soil depths as a function of treatments with or without plastic mulch(1).

Depth	Root length density ($cm\ cm^{-3}$)(2)			
(m)	WM-WI	WM-WoI	WoM-WI	WoM-WoI
0.00–0.10	0.2652aA	0.2635aA	0.2177aA	0.1215aB
0.10–0.20	0.2128aA	0.1435bAB	0.1853aAB	0.1335aB
0.20–0.30	0.0465bA	0.0522cA	0.0294bA	0.0361bA

(1)Means followed by equal letters, lowercase in the columns and uppercase in the rows, do not differ from each other by Tukey's test, at 1.0% probability. (2)Treatments: WM, with mulch; WoM, without mulch; WI, with percolation barrier; and WoI, without percolation barrier.

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soil water availability near the upper limit (Table 2). This favors a more abundant distribution of the roots that are directly related to the water scenarios of a crop (Tardieu, 2012).

The percentage means of total roots at 0.10 m was significantly higher than that at 0.20 m in the absence of the percolation barrier. This difference is expected because of the downward water flow that contributes to a gradient of soil water content with depth and, consequently, to a reduction in root length with soil depth, corresponding to the root distribution pattern (Smith et al., 2005).

If only root distribution is considered, irrigation sprinkler systems (sprinkler and micro sprinkler, for example) should work better than drip systems for pineapple crops. In this sense, Carr (2012) recommend the use of sprinkler or micro sprinkler irrigation systems for pineapple, whose root distribution in the subsurface, mostly adhered to or around the stem, and leaf morphology, resembling gutters, favor the collection of water by the leaves, whether from rain, irrigation, or dew. The accumulated root growth over time, in percentage values (Table 5), highlighted the high concentration of roots in the stem, especially from 180 DAP. Throughout the crop cycle, more than 80% of the roots were located up to a 0.10 m depth, showing the shallowness of the pineapple root system. In the layer below 0.20 m, the presence of roots was very small, representing less than 6.0% of total roots, which decreased to only 2.94% on the last evaluation date, indicating little participation of this depth in the processes of soil water extraction. The evolution of these percentages throughout the crop cycle indicates that root growth continues during the flowering and fruiting stages (Table 5). Likewise, Pegoraro et al. (2014) also verified root growth during fruit filling. However, for Carr (2012), root growth is interrupted during this stage.

The mean values obtained for root length density and total root length in the soil profile, which corresponded to a two-dimensional plane with a depth of 0.40 m, were influenced by the distance from the plant (Table 6). The highest means were found within the distance of up to 0.10 m from the plant. A greater proportion of root length density and total root length at the shortest distances and shallower depths near the stem is expected due to plant architecture, as the root system below, on, and above soil surface is concentrated on the stem. The higher the root length density associated with total length, the more nutrients can be absorbed per unit and volume of soil (Donato et al., 2012). Therefore, root length density is an indicator of the ability of the root system to exploit a soil volume.

Root distribution, expressed by total root length and root length density, showed the highest means in the plant-drip line and plant-plant directions, which did not differ significantly from each other in comparison with the plant-ridge border direction (Table 7). The main reason for this behavior of the roots was the distribution of moisture in these planes (Figure 5). Furthermore, the highest root length density and soil moisture was found in the region between the plant rows and the lateral drip line (Figure 6). The lower means of root length density occurred between the plant rows and the ridge border, where soil water content was lower due to the distance from the drip line (Table 7 and Figures 5 and 6). These results are in agreement with those of Libardi & Van Lier (1999), who highlighted the presence of water as a preponderant factor for the development of a root system.

Table 5. Percentage distribution of the root dry matter of the BRS Imperial pineapple (*Ananas comosus*) cultivar at different soil depths throughout the plant cycle[1].

Depth (m)	Days after planting				
	90	180	270	360	450
Stem	3.42a	25.76a	44.61a	48.02a	64.06a
0.1	1.79a	2.96b	4.84b	6.67b	17.48b
0.2	0.18a	2.82b	4.74b	4.84bc	15.52b
0.3	0.00a	1.81b	0.81b	0.76c	2.94c
Total roots (%)	5.39	33.35	55	60.29	100

[1]Means followed by equal lowercase letters, in the columns, do not differ from each other by Scott-Knott’s test, at 1.0% probability.

Table 6. Distribution of the root length and root length density of the BRS Imperial pineapple (*Ananas comosus*) cultivar up to a 0.40 m depth, at distances of up to 0.10 m and from 0.10 to 0.20 m from the plant, under drip irrigation, at 450 days after planting[(1)].

Variable	Distances (m)	
	0.00–0.10	0.10–0.20
Root length (cm)	487.97a	365.62b
Root length density (cm cm^{-3})	0.1627a	0.1218b

[(1)]Means followed by equal letters, in the rows, do not differ from each other by Tukey's test, at 1.0% probability.

Table 7. Distribution of the roots of the BRS Imperial pineapple (*Ananas comosus*) cultivar in the soil in two-dimensional planes, from the plant toward the drip line, toward the neighboring plant in the row, and toward the border of the ridge at 450 days after planting[(1)].

Variable	Two-dimensional planes		
	Plant-drip line	Plant-plant	Plant-border
Root length (cm)	339.73a	299.33a	214.52b
Root length density (cm cm^{-3})	0.1698a	0.1497a	0.1073b

[(1)]Means followed by equal letters, in the rows, do not differ from each other by Tukey's test, at 1.0% probability.

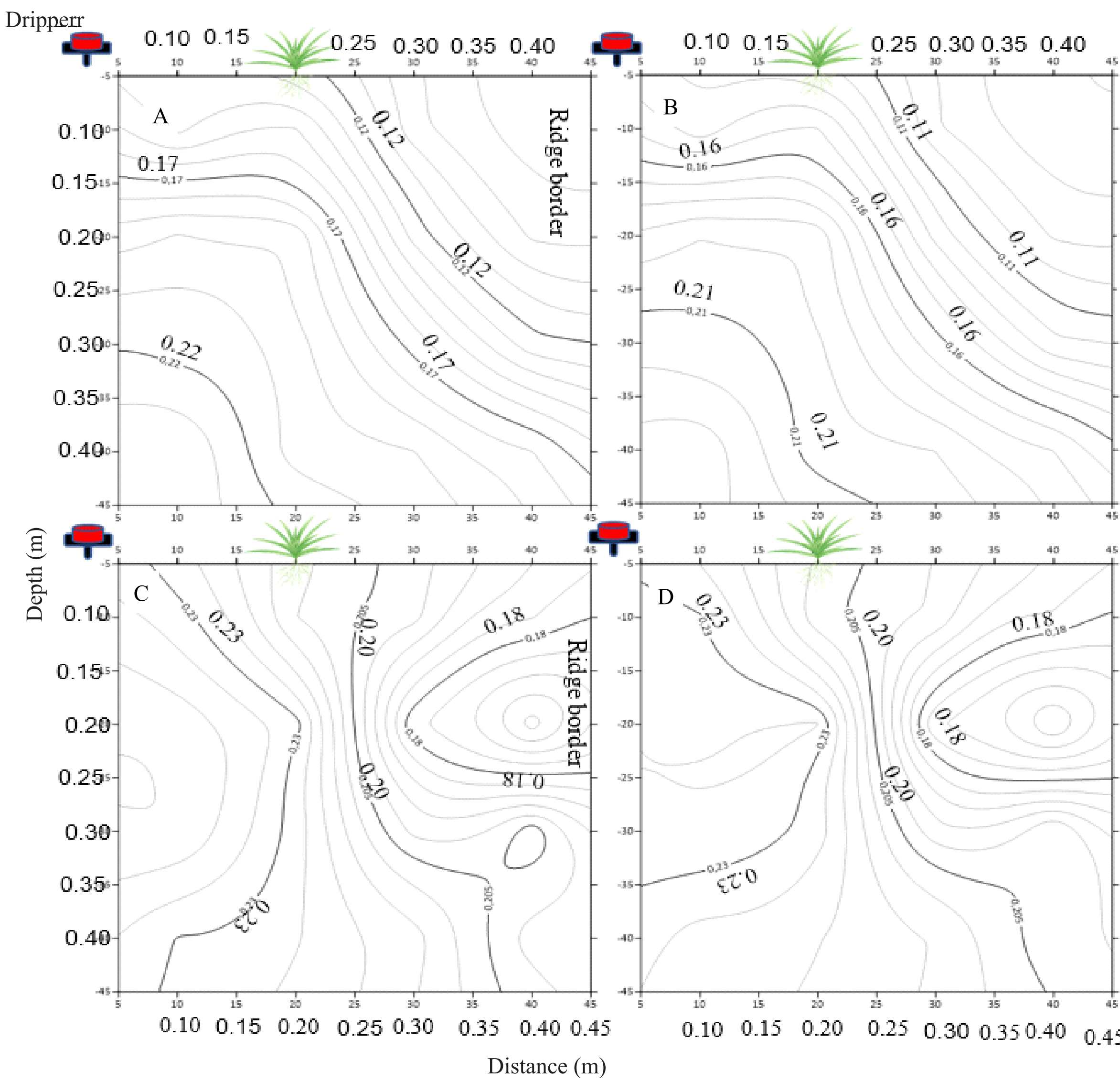

Figure 5. Water distribution in soil cultivated with the BRS Imperial pineapple (*Ananas comosus*) cultivar between 60 and 90 days after planting, without evaporation control at 5 (A) and 30 (B) hours after irrigation, and with evaporation control using mulch at 5 (C) and 30 (D) hours after irrigation.

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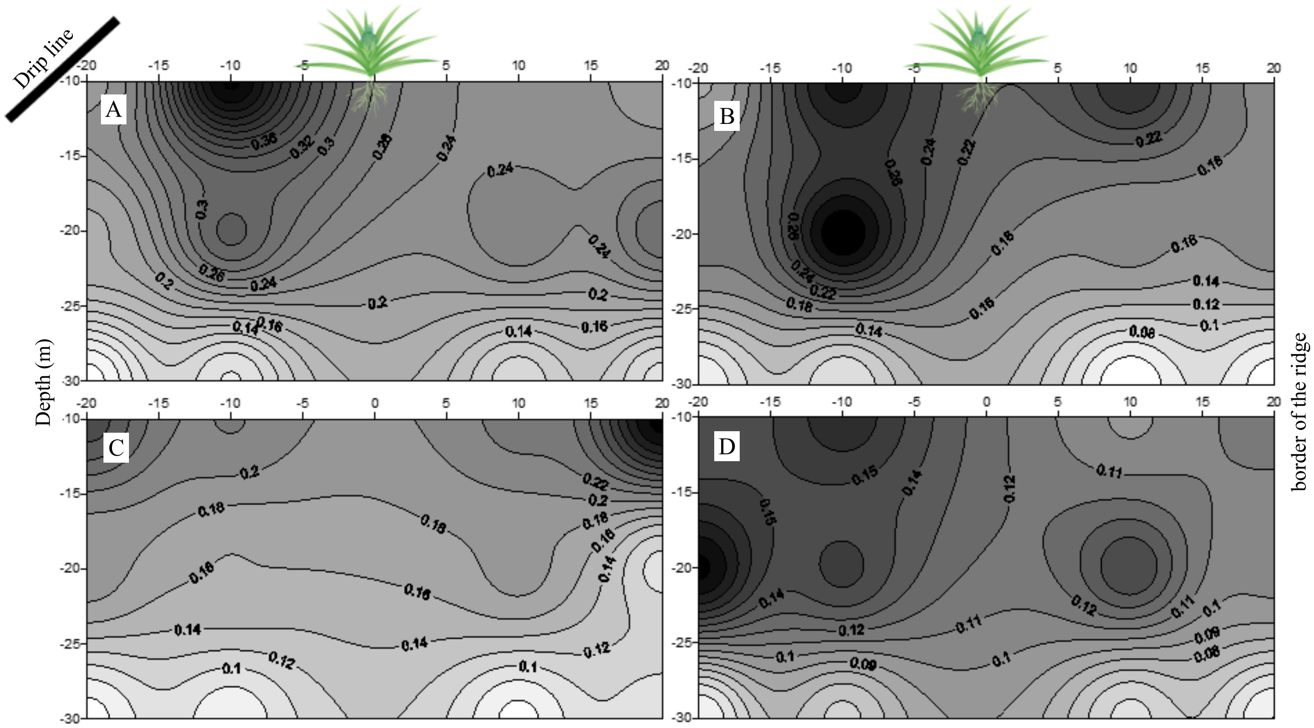

Figure 6. Isolines of the root length density (cm cm^{-3}) of the BRS Imperial pineapple (*Ananas comosus*) cultivar in the soil profile, under the following treatments with (WM) and without (WoM) mulch and with (WI) and without (WoI) percolation barrier: WM-WI (A), WoM-WI (B), WM-WoI (C), and WoM-WoI (D). The color scale from the darkest to the lightest tone represents the range from the highest to the lowest occurrence of root length density.

Conclusions

1. The use of black plastic, either as mulch or as a percolation barrier, contributes to increase the root development of the BRS Imperial pineapple (*Ananas comosus*) cultivar under drip irrigation.

2. The total root system of 'BRS Imperial' pineapple, under drip irrigation, using plastic as mulch and as a percolation barrier, has a high concentration of adventitious roots and reaches up to a 0.10 m soil depth.

3. The effective rooting depth of 'BRS Imperial' pineapple is 0.20 m for the calculation of irrigation depth for irrigation projects or irrigation water management, whereas adventitious roots should be considered for decision-making regarding the irrigation system and method of nutrient application.

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