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Camu-camu Root Distribution under Different Nitrogen and Potassium Doses through Drip Fertigation

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***Abstract*. Camu-camu is an native species in domestication processes. Therefore, studies related to the root system are necessary to evaluate the best cultivation practices for an orchard. Two trials were conducted, one with nitrogen (N) and the other with potassium (K), at doses of 0, 40, 80, 160, and 320 kg·ha^{-1}. Root distribution was determined using nondestructive analyses in which two-dimensional (2D) root images were obtained from trenches under the plants' canopy. Variables included width (measured in cubic millimeters), area (measured in square millimeters), and length (measured in millimeters, and were analyzed using Safira software (version 2010, Embrapa, Brazil). To have better spatial visualization of variable distribution in the soil profile, data were analyzed using the ordinary kriging technique with the geoR software package and R software (version 2016). Both N and K doses influenced positively the camu-camu root system with regard to length, volume, and area. Better root distribution was verified with 80 kg·ha^{-1} N and 160 kg·ha^{-1} K doses. The nondestructive analysis via 2D images allowed sound characterization of root spatial distribution.**

Camu-camu is an native species of the Amazon Basin that attracts attention as a result of its high content of vitamin C, reaching up to 7355 mg/100 g pulp in native populations of Roraima State (Chagas et al., 2015). It is currently considered functional food, with nutraceutical properties such as phenolic compounds and antioxidant substances such as ascorbic acid. These substances are capable of neutralizing excess free radicals caused by most degenerative diseases, such as diabetes, atherosclerosis, and osteoporosis, and those associated with cancer (Chatterjee et al.,1975; Damazio et al., 2017; Thomas, 2000).

The fruit tree is typical of humid tropical climates and is found naturally in the following countries: Peru, Colombia, Venezuela, and Brazil, along riverbanks, lakes, floodplains, and igapós (Pinedo et al., 2010; Smiderle and Sousa, 2010; Yuyama and Valente, 2011).

In Roraima, the northernmost state of Brazil, the occurrence of native camu-camu populations is significant, but the fruit availability is not continuous because of its seasonal production, which is influenced by edaphoclimatic factors (Abanto-Rodríguez et al., 2014). In addition, because the domestication process is still occurring, investigation of the development of agronomic techniques is needed for camu-camu adaptation in upland conditions.

The study of root distribution in the soil profile, with regard to depth and horizontal distance from the trunk, contributes to soil depth preparation, fertilizer and water application, the planning of moisture sensors and sampling sites, and the installation of the number of emitters in localized irrigation systems (Lourenção et al., 2004). Robinson and Sauco (2010) reported that root distribution is influenced strongly by a series of complex and dynamic processes, such as soil type, porosity, and compaction; toxicity of chemical elements; waterlogging and water availability; and nutrients.

Fertigation management in crops can be an alternative for optimal nutrient absorption and loss reduction. However, to verify the performance of the fertigation system it is necessary to evaluate its viability. One of the instruments that has been used to do this is root system distribution analysis. With the advancement of computing, methods and equipment have been developed and used to evaluate the spatial distribution of root systems in the soil profile. Among these methods is a nondestructive analysis, which is performed through digitalized root images in soil profiles obtained from trenches (kriging techniques). This method has less sample effort, lower cost, greater higher precision, and shorter analysis time (Carducci et al., 2014, Mairhofer et al., 2012).

The objective of our work was to determine the effect of different N and K doses applied via drip fertigation on the root distribution of camu-camu plants. The data were analyzed using nondestructive roots images obtained from trenches under the plant canopy.

Materials and Methods

Our research was carried out from Mar. to Oct. 2016 at the Água Boa Experimental Field, EMBRAPA-RR, Boa Vista, Roraima, Brazil (lat. 02°39'48.94''N; long. 60°50'30.39''W; altitude, 90 m). The local climate is tropical savanna (Aw) according to the Köppen classification, with an average annual temperature of 27.8 °C and average annual rainfall of ≈1.650 mm. The driest period occurs between the months of December and March (±9% annual rainfall), and the wettest months are

Fig. 1. (**A**) Trench. (**B**) Root painting. (**C**) Grid positioning.

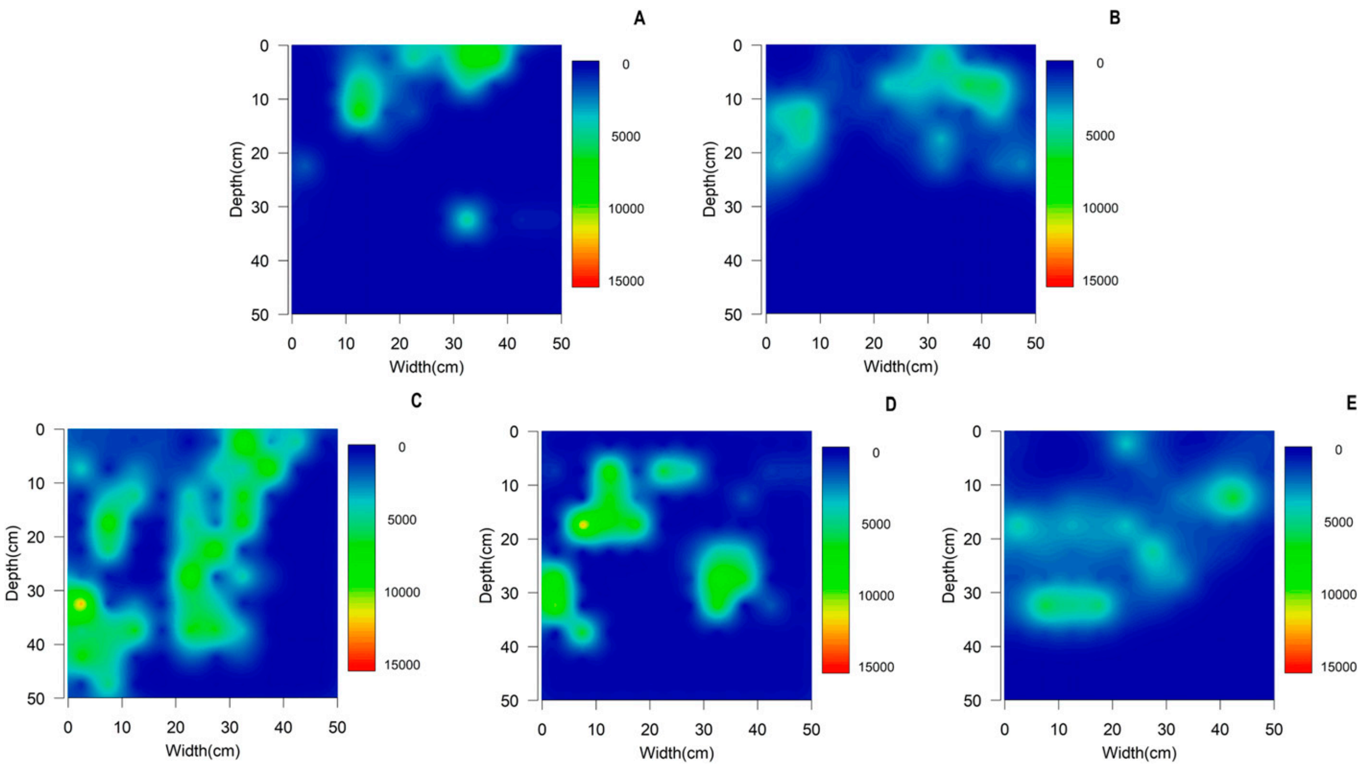

Fig. 2. Camu-camu root volume (measured in cubic millimeters) under fertigation with nitrogen doses of 0 (**A**), 40 (**B**), 80 (**C**), 160 (**D**), and 320 (**E**) kg·ha^{-1}.

between May and August (±70% annual rainfall) (Barbosa, 1997).

The soil of the experimental field is classified as Oxisol with a pH of 4.4, organic matter (OM; 10 g·kg^{-1}), P (3 g·kg^{-1}), K (0.2 Cmol$_c$·kg^{-1}), Ca (0.2 Cmolc·kg^{-1}), Mg (0.1 Cmolc·kg^{-1}), H + Al (2.4 Cmolc·kg^{-1}), SB (0.32 Cmolc·kgm^{-1}), CEC (2.8 Cmolc·kg^{-1}), according to soil chemical analysis manual of EMBRAPA.

Soil preparation consisted of applying dolomitic limestone (800 kg·ha^{-1}), and after planting, 10 g/plant FTE-BR12 (fritted trace elements) to provide micronutrients (9.0% to 9.2% zinc, 1.8% to 2.17% boron, 0.80% copper, 3.82% iron, 2.0% to 3.4% manganese, and 0.132% molybdenum). In addition, weed control was carried out monthly on the orchard.

The irrigation method was characterized by a drip system with a pump connected to a water container, with automatic activation by a RAIN BIRD® timer. The linear system flow was 6.8 L·h^{-1} (3.4 L·h^{-1} per dripper spaced every 50 cm). For injection of the fertilizers, a three-quarter-inch Venturi-type injector was used, with a 150-L·h^{-1} injection rate every week.

In this study, two experiments were conducted in a randomized block design with five doses of N and K (0, 40, 80, 160, and 320 kg·ha^{-1}) and four replicates. The experiments were installed in 2013, and root system data were measured in 2015, when plants were, on average, 1.50 m tall and had a trunk diameter of 25 mm. The plant spacing used was 4 m between rows and 1 m between plants.

For the root system analysis, 20 trenches were dug (Brasil et al., 2007) (10 for each experiment) at a 0.10-m distance from the trunk at 0.50 m wide × 0.50 m long × 0.50 m deep. Root distribution was visualized on the vertical wall of the trench under the plant canopy. The soil was scarified along the wall, removing a thin layer of soil (≈0.02 m), and then a water jet was used to expose the roots. After this procedure, the roots were sprayed with white paint to increase the contrast in relation to the ground of the trench wall, and then a metal grid with the trench dimensions was placed in perfect contact with the roots in the vertical wall for taking photographs. The grid consisted of one hundred 5- × 5-cm squares (Fig. 1).

The digital images were made with a semiprofessional digital camera with 32-megapixel resolution. To have a better quality image, the trench was covered with a black cloth to avoid contrast from reflected

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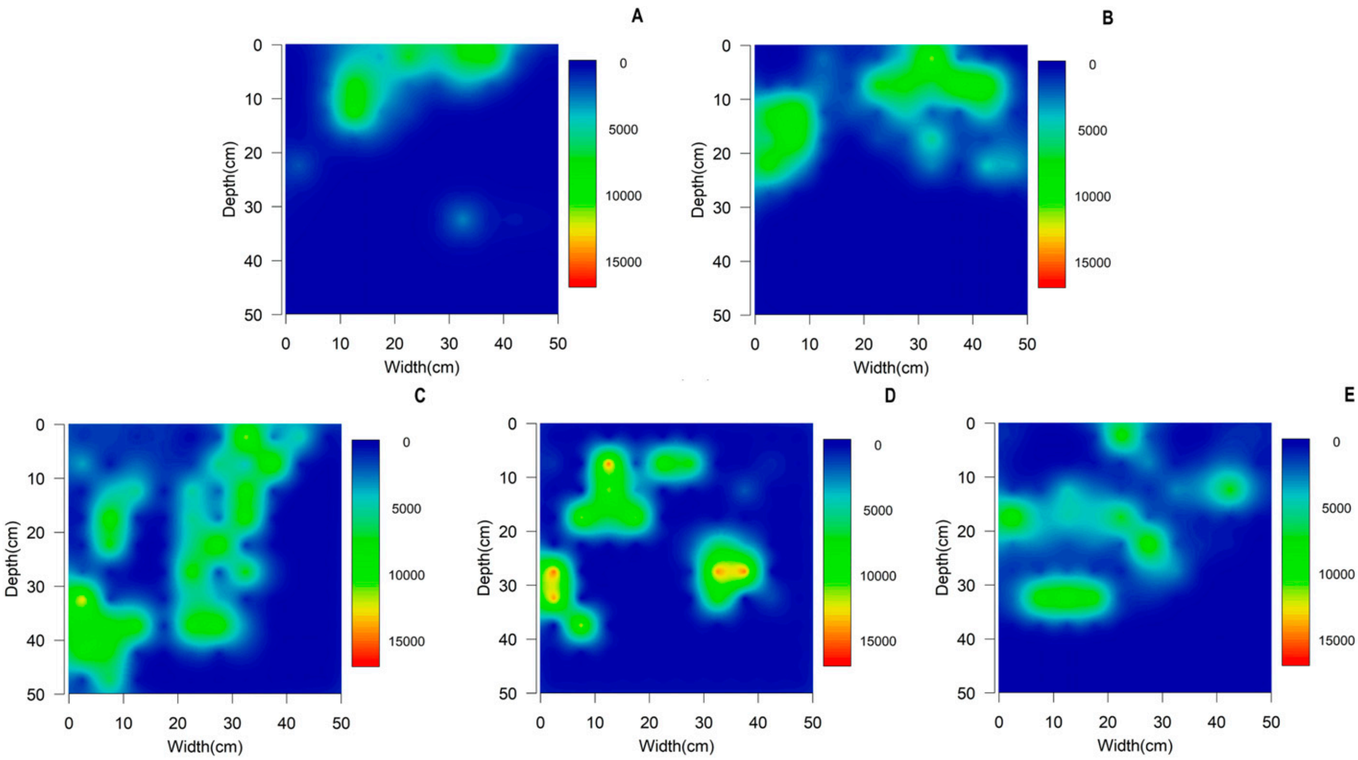

Fig. 3. Camu-camu root area (measured in square millimeters) under nitrogen fertigation doses of 0 (**A**), 40 (**B**), 80 (**C**), 160 (**D**), and 320 (**E**) kg·ha^{-1}.

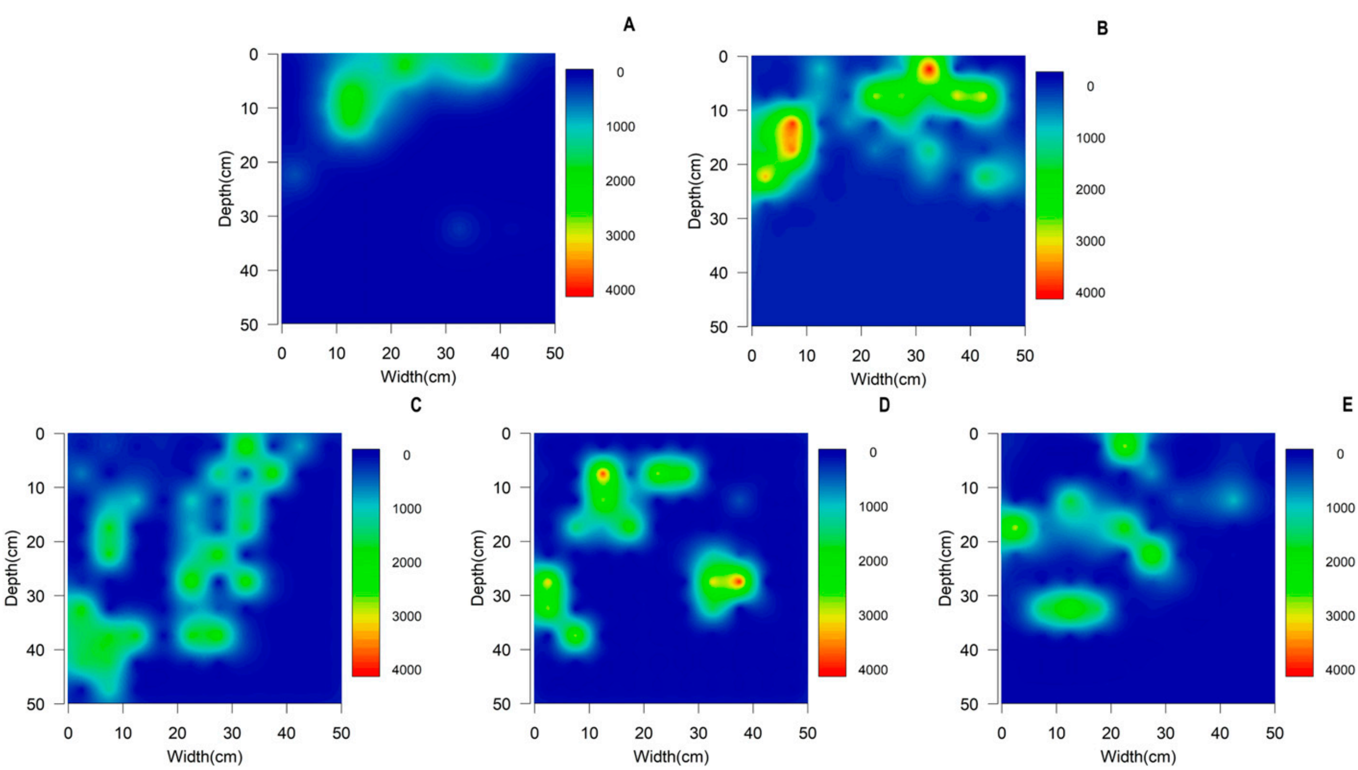

Fig. 4. Camu-camu root length (measured in millimeters) under nitrogen fertigation doses of 0 (**A**), 40 (**B**), 80 (**C**), 160 (**D**), and 320 (**E**) kg·ha^{-1}.

sunlight. Afterward, the images were corrected and aligned using Microsoft Office Picture Manager software (version 2013). Quantification of the root variables of volume (measured in cubic millimeters), surface area (measured in square millimeters), and length (measured in millimeters) was done using Safira software (Jorge and Silva, 2010).

With the results obtained for each grid unit, we proceeded to estimate the sample semivariance. For this purpose, the centroid of each plot was used, comprising 100 sample points.

After the model adjustment to the semivariogram, it was possible to estimate the

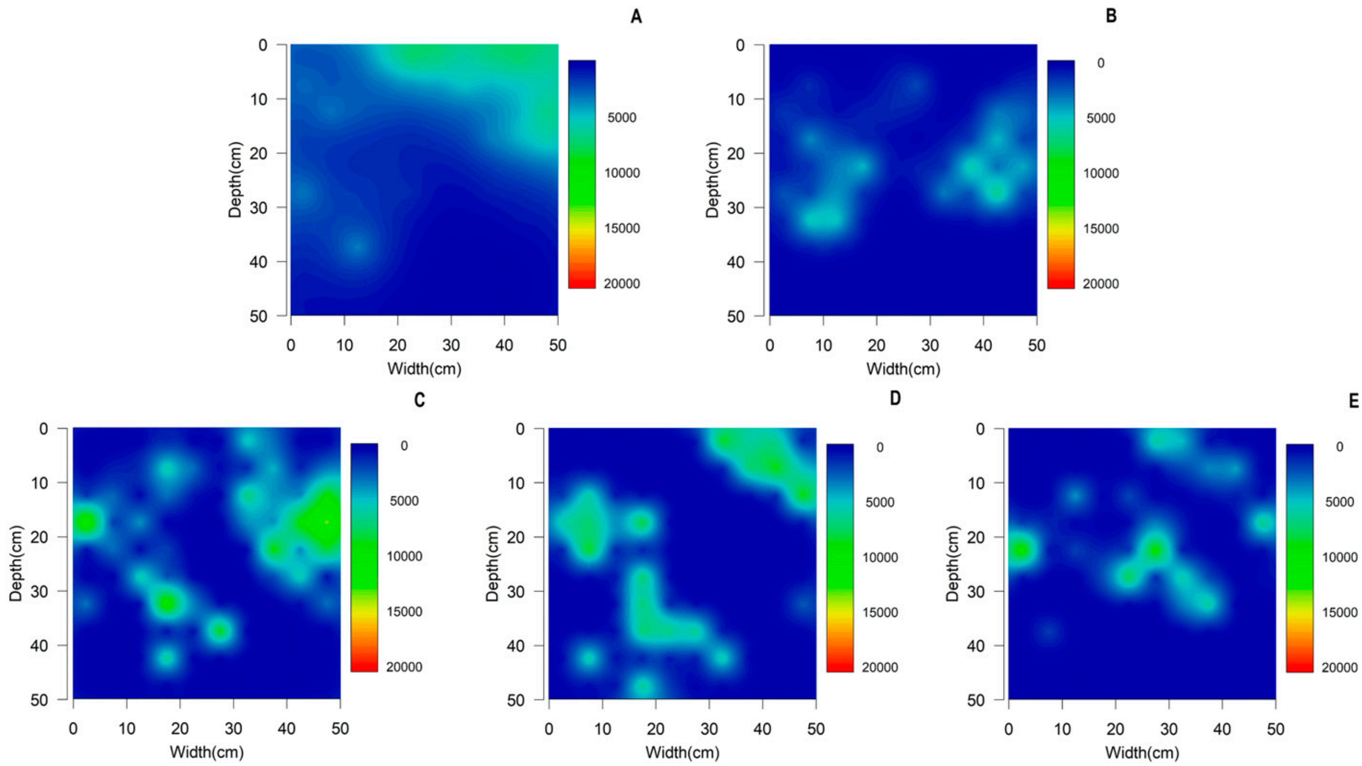

Fig. 5. Camu-camu root volume (measured in cubic millimeters) under potassium fertigation doses of 0 (**A**), 40 (**B**), 80 (**C**), 160 (**D**), and 320 (**E**) kg·ha^{-1}.

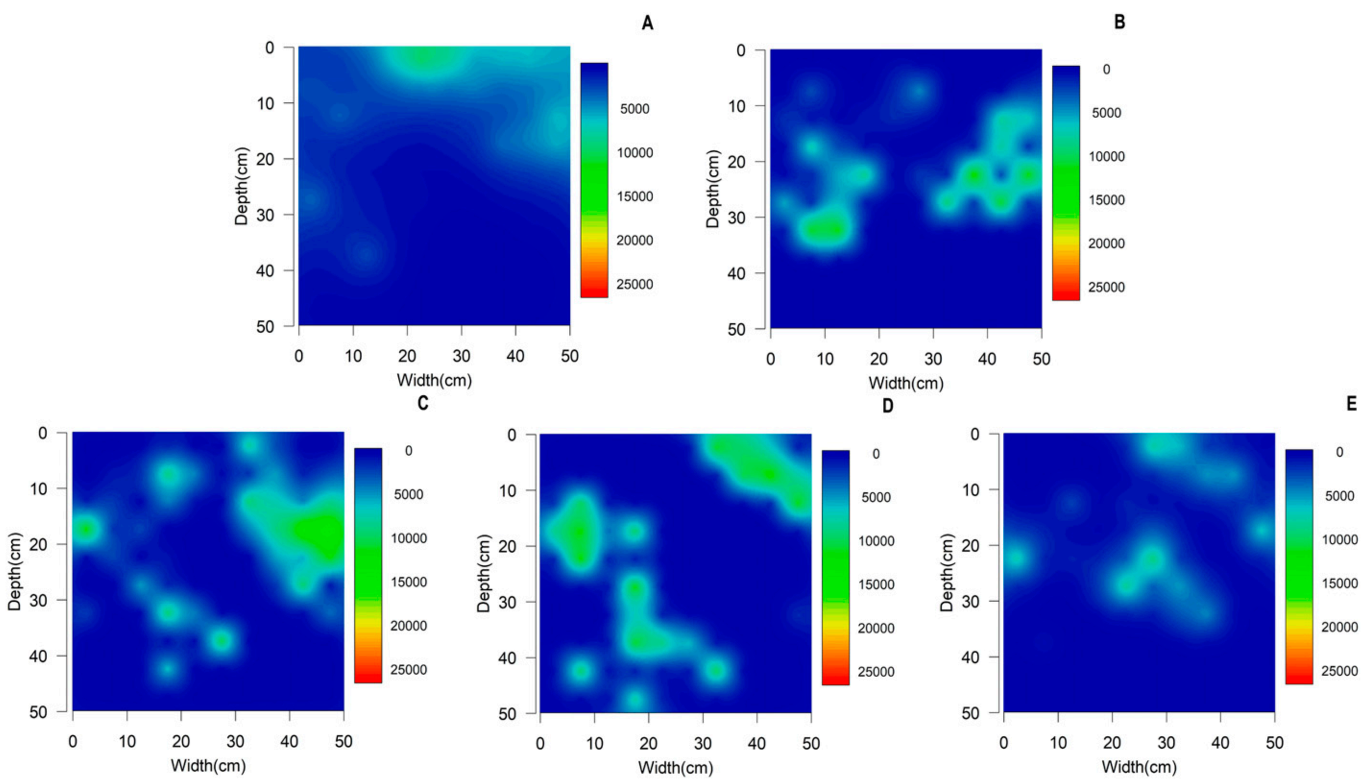

Fig. 6. Camu-camu root area (measured in square millimeters) under potassium fertigation doses of 0 (**A**), 40 (**B**), 80 (**C**), 160 (**D**), and 320 (**E**) kg·ha^{-1}.

unsampled points to obtain a better visualization of the root distribution in the soil profile. To do this, ordinary kriging using the geoR (Ribeiro and Diggle, 2006) and R (R Core Team, 2016) software packages was performed.

Results

The camu-camu root system distribution is presented in colored graphs based on digitalized photographs. In this sense, the red color represents the highest concentration of the root system followed by the green and blue color respectively.

Camu-camu root volume (mm^3), area (mm^2), and length with increasing N doses fertigation. The predominant root volume ranged from 4000 to 6000 mm^3 (green

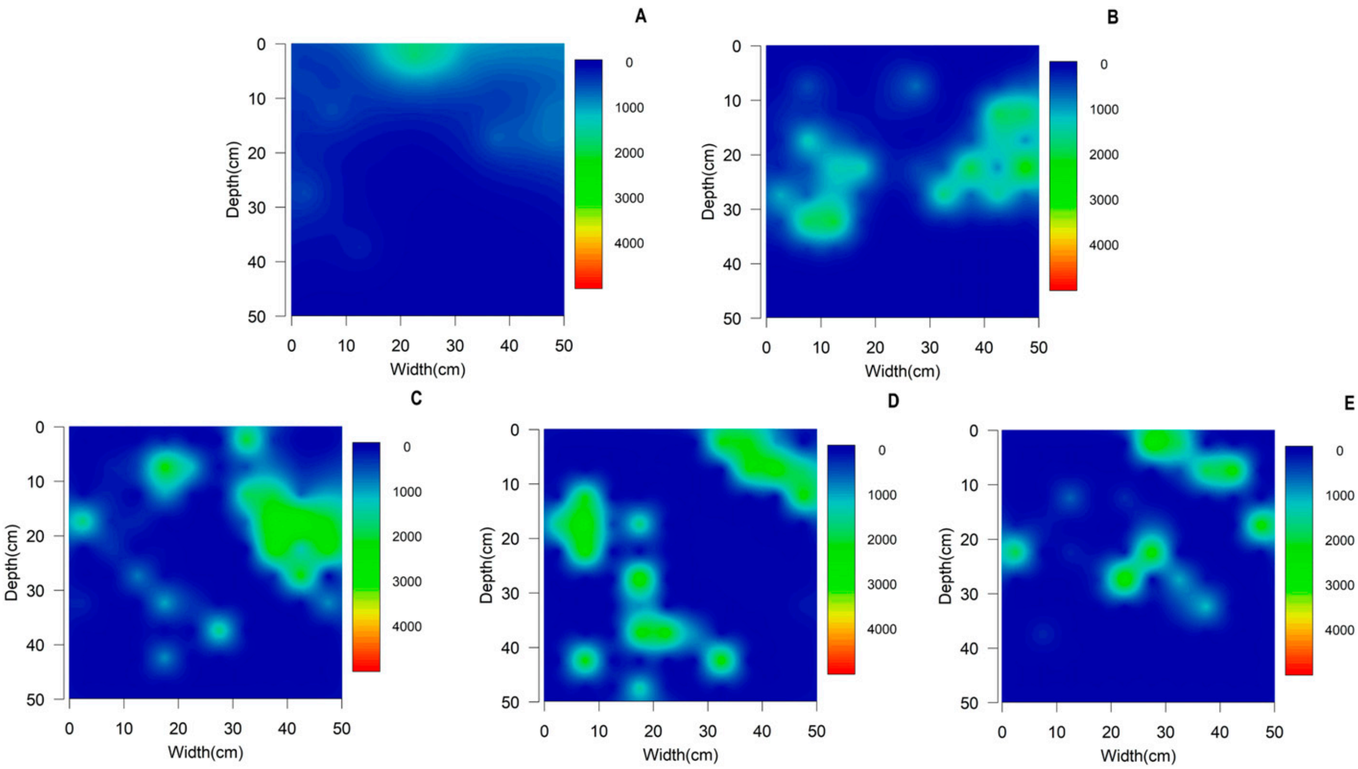

Fig. 7. Camu-camu root length (measured in millimeters) under potassium fertigation doses of 0 (**A**), 40 (**B**), 80 (**C**), 160 (**D**), and 320 (**E**) kg·ha^{-1}.

color) at a 0.40-m depth and close to a 0.30-m lateral distance at all N doses. Greater root volumes were noted in the profile (Fig. 2).

The greatest root volume (±12,000 mm^3; red color) was recorded near a 0.20-m depth at 160 kg N/ha N doses (Fig. 2D). In contrast, at 0 and 40 kg N/ha N, the root volume was recorded in the first layer of 0 to 0.10 m (±8000 mm^3), and at 80 and 320 kg N/ha N, the greatest volume was observed in the layer at 0.30 to 0.40 m (8000–10,000 mm^3) deep. In relation to the root area (mm^2), camu-camu plants presented variation according to increasing doses of N (Fig. 3). Thus, with 80 kg·ha^{-1} N, roots were better distributed in the profile, reaching deeper regions of up to 0.50 m (Fig. 3C).

Camu-camu root length ranged from 500 to 10,000 mm with increasing N doses (Fig. 4).

The 0 kg N/ha doses resulted in smaller root length indicating 2500 mm, located predominantly at 0.20 m deep. The 40 kg N/ha doses had a slightly increase in root length achieving 4000 mm and in the 80 kg N/ha dose roots were found 50 cm deep in profile with 2000 mm length. The 160 kg N/ha and 320 kg N/ha doses had almost the same the length, from 2000 to 3000 mm (Fig. 4E). However, those of smaller length (green color) were predominant in all profiles. In general, incremental N doses allowed for a greater comprehension of the roots distribution in the soil profile, indicating that higher doses (320 kg N/ha) did not promote root length.

Camu-camu root volume (mm^3), area (mm^2), and length with increasing K doses fertigation. The camu-camu root volume showed values ranging from 2000–12,000 mm^3, distributed up to 0.5 m deep, in response to different increasing doses of K (Fig. 5).

It was observed that 0 and 40 kg K/ha doses induced more superficial root distribution at a 0.35-m depth. However, the greatest root volume (12,000 mm^3) was observed with 80 kg K/ha doses, concentrated at a depth of 0.1 to 0.2 m. In addition, roots were better distributed in the soil profile at 2500 cm^2 (Fig. 5).

In Fig. 6, it is observed that the camu-camu root area (mm^2) was influenced by increasing doses of K. Thus, the doses of 0, 40, 80, and 160 kg K/ha showed a larger root area, with an approximate value of 10,000 mm^2. But, in the first two K doses, the root distribution had a greater concentration in the first 0.25-m depth.

At 80 and 160 kg·ha^{-1} of K doses, there was a better root distribution in depth that occupied almost the entire area of the soil profile. However, at 320 kg K/ha, the root area was less than with the other doses, with a maximum value of 8000 mm^2. Similarly, the root distribution at this dose was up to 0.35 m deep.

The greatest root length was recorded at 80, 160, and 320 kg K/ha, with values ranging from 2500–8000 mm. In addition, these doses induced better root distribution at depth and width, covering 80% of the 2500-cm^2 profile (Fig. 7).

Discussion

In relation to root volume (mm^3), it is evident that N doses up to 160 kg N/ha increased the root distribution, with a slight reduction in deeper layers. Similar results were verified by Eloi et al. (2004), who worked with different N doses in *Annona muricata* and found that the greatest concentration of roots occurred in the superficial layer with a 380-kg N/ha dose.

Therefore, the reduction and irregular distribution of roots at greater N doses (Fig. 1) can be explained by the excessive use of N. Dechen and Nachtigall (2006) describe that plants under these conditions reduce the development of the root system in favor of greater vegetative area.

It was also noticed that the greatest root concentration in the vertical soil profile was asymmetric in relation to the trunk. This fact was triggered by the increased availability of water and nutrients provided through fertigation concentrated on one side of the line. Similar results were obtained by Covre et al. (2015), who worked with *Coffea canephora* fertigation and discovered that the roots were closer to the drip irrigation line.

The root area variable (mm^2) with different N doses, was influenced by N soil mobility associated with soil moisture, promoting a greater number of roots and, consequently, the capacity to reach relatively deeper layers in search of nutrients and water.

Under these conditions, the camu-camu root system areas were close to 10,000 mm^2, but in the treatments without N and at 40 kg N/ha, the roots were concentrated in the first 30-cm depth, while in the other doses the roots exceeded this layer.

According to Marschner and Marschner (2012), the nutrient supply can influence root system growth and distribution, and this effect is marked mainly by N. In addition, Silveira and Monteiro (2010) reported that the N supply to the aerial part is dependent on a well-developed root system.

The results obtained in our work are in agreement with those of Abanto-Rodriguez et al. (2018), who evaluated the total dry weight of camu-camu plants under different N doses. They demonstrated that there was a greater increase in the total dry weight with about 80 kg·ha^{-1} and a growth decrease at greater doses. In this sense, the reduction and irregular distribution of the roots in the greater of N doses occurred, according to Dechen and Nachtigall (2006), because of the excess of N in the soil solution, which elevates the osmotic pressure, damaging the absorption of nutrients by roots and reducing vegetative growth.

On the other hand, the effect of K doses on root growth showed that distribution in volume was influenced by low nutrient supply. Thus, the nutritional imbalance or absence of K resulted in smaller root systems, concentrated in the superficial profile to take advantage of reduced K in soil.

According to the results, all K doses did not influence root system depth, probably because of the continuous availability of water on the surface by the irrigation system.

The smaller root area (mm^2) associated with lower K can be explained based on the work of Abanto-Rodríguez et al. (2014), who found less vegetative growth in the absence of or low K doses.

Root length was influenced positively by greater K doses, which is in agreement with the results of Freitas et al. (2009), who tested different levels of K in irrigated passionfruit plants, with the greatest doses increasing root length. The 0- and 40-kg·ha^{-1} K doses did not favor root development, and root length was less than 1500 mm and was distributed at a depth of ±0.35 m.

Conclusions

The N and K fertigation doses, separately, influence the distribution of root systems in terms of length, volume, and area. The best root distribution was achieved with 80 kg N/ha and 160 kg K/ha doses. Nondestructive analysis through 2D images made a complete spatial root system characterization possible. It is recommended to carry out further studies concerning the distribution of the root system of plants of different ages in function of the various types of agronomic management, in order to analyze the adaptation of camu-camu to the conditions external to its natural habitat.

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