Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.15, n.3, e8139, 2020
Recife, PE, UFRPE. www.agraria.pro.br
DOI:10.5039/agraria.v15i3a8139
Protocol 8139 - 09/01/2020 • Approved in 23/05/2020

Slow-release fertilizer and hydrogel on the initial growth of camu-camu under different water conditions in a Savannah soil

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ABSTRACT: During the process of adapting camu-camu on dry land, the fertilization management in local water conditions must be considered with tests of technologies available for cultivation. To that end, the objective was evaluating the effects of the fertilization with slow-release fertilizer (SRF) and hydrogel on the initial growth of camu-camu plants under different water conditions, in two consecutive experiments. In the first one, we evaluated the leaf mortality in two plant sizes (from 15 to 25 cm and from 35 to 45 cm), two hydrogel levels (presence and absence) and different hole fertilizations [A1 - conventional fertilization - FC - (313 g of super simple + 37 g of urea + 41 g of KCl), A2 (357 g of SRF + 35 g of KCl), A3 (268 g SRF + 26 g of KCl), A4 (179 g SRF + 18 g of KCl) and A5 (89 g of SRF + 9 g of KCl)], under water deficit conditions. In the second experiment, the initial growth of larger plants was evaluated by using the same treatments for two years with water availability. Under water deficit, fertilizers A2 and A3, associated with hydrogel, were very damaging to the leaf growth, especially in plants with height values lesser than 25 cm. With water availability, using FC and A2 associated with hydrogel, and A4 and A5 in the hydrogel absence, favored the plant growth and the supply of chlorophyll ‘b’. Applying SRF in adequate amounts is effective on the initial growth of camu-camu plants in the Savannah soil from Roraima.

Key words: fertilization management; *Myrciaria dubia*; Osmocote®; plant mortality; water management

Fertilizante de liberação lenta e hidrogel no crescimento inicial de camucamuzeiro sob diferentes condições hídricas em solo de Savana

RESUMO: No processo de adaptação do camu-camu em terra firme, o manejo da adubação nas condições hídricas locais deve ser considerado com testes de tecnologias disponíveis ao cultivo. Nesse sentido, objetivou-se avaliar os efeitos da adubação com fertilizante de liberação lenta (FLL) e hidrogel sobre o crescimento inicial de camucamuzeiros em diferentes condições hídricas mediante dois experimentos consecutivos. No primeiro, avaliou-se a mortalidade foliar de plantas de dois portes (15 a 25 cm e 35 a 45 cm), dois níveis de hidrogel (presença e ausência) e diferentes adubações em covas [A1 – adubação convencional - AC - (313 g de super simples + 37 g de ureia + 41 g de KCl), A2 (357 g de FLL + 35 g de KCl), A3 (268 g de FLL + 26 g de KCl), A4 (179 g de FLL + 18 g de KCl) e A5 (89 g FLL + 9 g de KCl)], sob déficit hídrico. No segundo, foi avaliado o desenvolvimento inicial das plantas de maior porte pelo uso dos mesmos tratamentos durante dois anos, e com disponibilidade hídrica. Sob déficit hídrico, as adubações A2 e A3 associadas ao hidrogel foram terminantemente danosas ao estabelecimento foliar das plantas, principalmente àquelas com altura inferior a 25 cm. Com disponibilidade hídrica, o uso da AC e da A2 associado a hidrogel, e da A4 e A5 na ausência de hidrogel, favoreceram o crescimento das plantas e o aporte de clorofila ‘b’. A aplicação de FLL em quantidades adequadas é efetiva no crescimento inicial de camucamuzeiro em solo de Savana de Roraima.

Palavras-chave: manejo da fertilização; *Myrciaria dubia*; Osmocote®; mortalidade de plantas; manejo hídrico

Introduction

Among the native fruit species that have high productive and economic potentials in the Amazon region, the camu-camu (*Myrciaria dubia* (Kunth) Mc Vaugh) has been drawing attention for having important nutraceutical properties that highlights it in both the national and international markets, such as its high vitamin C content (Chagas et al., 2015). These properties are also the main reason for studies on the domestication of plants for dry-land cultivation, since the fruits commercialized and studied are predominantly from plants found in rivers and streams of the Amazon.

Over the last ten years, the geographical, biological, propagative and post-harvest aspects have been researched in this region, especially in Roraima (Chagas et al., 2015; Grigio et al., 2017; Abanto-Rodriguez et al., 2018). However, studies inherent to the plant field establishment through soil fertility management under water restriction conditions, as it is during most of the year in the Savannah of Roraima, are necessary due to the low fruit supply from commercial dry-land plantations. Moreover, the camu-camu is a species that has a long period from its planting to the fruit production, thus justifying the need for correct plant management during this stage, when good results are expected in the production period.

Among the Brazilian Amazon states, Roraima has a peculiarity for it contains extensive Savannah areas inserted in a large part of its territory. These areas, currently scouted for future commercial plantations of camu-camu, have as main characteristics the predominance of naturally acidic and low fertility soils, as well as two distinct climatic periods, one dry (from October to March) and other rainy (from April to September) (Araújo et al., 2001). Thereby, understanding the camu-camu behavior in these conditions, by managing soil fertility, is part of the process of adapting the species to Savannah soils.

In general, the underway experiments with camu-camu in the Savannah area use conventional fertilizers according to the recommendation established by Viégas et al. (2004). However, this recommendation is for plantations predominantly inserted in the Amazon biome, where there is high rainfall availability almost during all year. Therefore, the efficiency of this fertilization in Savannah soils must be proved, as well as the plant behavior during the soil fertility management with use of potentially viable technologies regarding the agronomic efficiency.

Among these mentioned technologies, slow-release fertilizers (SRF), available in several formulations of N-P-K and micronutrients, are an alternative to the conventional fertilization when striving for minimizing nutrient losses by leaching, in addition to optimizing the use of fertilizers and reducing the production costs (Mendonça et al., 2008). According to Rossa et al. (2013), these fertilizers are formulated by being surrounded in a semipermeable membrane that expands due to the temperature effect, controlling the gradual and osmotic release of nutrients to the soil, tested in the growth of cultivated species, as well as in nurseries and in permanent field plantings.

As for the water availability, highly compromised during the low-rainfall months in the Savannah from Roraima, the agricultural hydrogels, soil conditioners that retain water and nutrients in quantities available to plants, can be an alternative during this period, as already reported in the obtaining of vigorous and productive stands of several cultivated species (Monteiro Neto et al., 2017).

Therefore, as part of the studies on the camu-camu adaptation in the Savannah area, the objective here was to evaluate the effects of fertilization with slow-release fertilizer (SRF) and hydrogel on the initial growth of camu-camu under different water conditions, by means of two experiments in a Savannah soil from Roraima.

Materials and Methods

Location, period and climate of the studied region

The research was conducted in the experimental area from the Agricultural Sciences Center of the Federal University of Roraima, located in the Savannah region of Roraima, from September 2016 to October 2018, through two consecutive experiments separately presented in this study. The region climate is of the Aw type, with annual mean rainfall, temperature and humidity corresponding to 1,678 mm, 27.4 ºC and 70%, respectively (Araújo et al., 2001).

Edaphic characterization of the studied area

The soil, having no cultivation history, was classified as a "Latossolo Amarelo" (Oxisol), with the following chemical characterization in its 0-15 cm layer, as according to Silva (2009): pH - 4.9 (determined by potentiometry, using proportions of 1:2.5 v/v of soil: solution); Ca^{2+} - 0.10 $cmol_c$ dm^{-3} and Mg^{2+} - 0.02 $cmol_c$ dm^{-3} (extracted in KCl 1 mol L^{-1} and determined by atomic absorption spectrometry); K^+ - 0.01 $cmol_c$ dm^{-3} and P - 0.48 mg dm^{-3} (extracted by the Mehlich-1 extractor, determining K by flame photometry and P by colorimetry); Al^{3+} - 0.51 cmolc dm^{-3} (extracted in 1 mol L^{-1} KCl and determined by titration with 0.025 mol L^{-1} NaOH); H + Al^{3+} - 2.56 $cmol_c$ dm^{-3} (determined after extraction with 0.5 mol L^{-1} calcium acetate at pH 7.0, by titration with NaOH). From these results, the following values were calculated: effective CEC - 0.64 $cmol_c$ dm^{-3}; Total CEC - 2.69 $cmol_c$ dm^{-3}; base saturation (V) - 4.9%; and aluminum saturation (m) - 79.7%. At 30 days prior to the transplantation, striving for V levels above 70%, 1.5 t ha^{-1} of dolomitic limestone was applied, determined by the base saturation method.

Experiment 1 - camu-camu establishment under water deficit

Seedling production

Before setting the experiment up, seedlings were produced in a protected environment, via semiiferous propagation and in polyethylene bags (0.15 x 0.225 m) filled with the standard substrate composed of soil and sand, determined by Chagas et al. (2013). Aiming evaluating two plant sizes in the research, the seedlings were produced in two groups of different ages and sizes: I) seedlings from 15 to 25 cm of height obtained at 90 days after emergence (DAE); and II) seedlings from 35 to 45 cm of height obtained at 180 DAE. For that, group II was sown first and, after growing for three months, group I was sown. This allowed using all plants at the beginning of experiment 1.

Setting up the experiment and treatments

In September 2016, the experiment was set up in four randomized blocks, with treatments arranged in subdivided plots, with three plants per experimental unit. We evaluated two plant sizes (plots: from 15 to 25 cm and from 35 to 45 cm), two hydrogel levels (subplots: presence and absence) and five types of hole fertilization by using slow-release fertilizer (SRF) [subplots: A1 - conventional fertilization (AC) (313 g of super simple + 37 g of urea + 41 g of KCl); A2 - (357 g of SRF + 35 g of KCl); A3 - (268 g of SRF + 26 g of KCl); A4 - (179 g of SRF + 18 g of KCl) and A5 - (89 g of SRF + 9 g of KCl).

The conventional fertilization used was the recommended by Viégas et al. (2004) for cultivating camu-camu, and the slow-release fertilizer employed was the Osmocote® (N-P-K = 14-14-14), acquired from local specialized stores. Hydrogel from the Hidroterragel® commercial brand was used in a hydrated form, by mixing 6 g of the powdered polymer to each water liter, applying 750 mL per hole at the transplanting.

Transplanting and application of the products were performed in holes of 40 cm in diameter and 40 cm high (0.05 m^3), obeying the following filling order: 1) 50% of the fertilizer - 2) part of the soil previously dug - 3) remaining 50% of fertilizer - 4) 375 mL of hydrogel - 5) plant - 6) remaining 375 ml of hydrogel - 7) hole closed. The same procedure was done in treatments with no hydrogel, however, not using the polymer this time.

Water management and leaf evaluation

For the water management in the first experiment, daily irrigations, which kept the soil at field capacity (FC), were performed during the first fifteen days after transplanting (DAT), a period necessary for the field establishment of plants. Afterwards, a three-day irrigation shift was adopted, by which the FC was established for each irrigation. At 35 DAT, the plant symptomatology was evaluated by counting severely withered leaves (dry and/or in abscission) of each plant, according to Navroski et al. (2014).

The drip irrigation system was used, with emitters having a flow of 3.4 L h^{-1}, distributed at every 50 cm. A tersiometry was used to monitor the FC, in which irrigations were held until the water in the soil had a tension between 6 and 10 kPa. For this, reference tensiometers were installed inside the holes under the drip lines outside the experiment useful area. This monitoring via tensiometry was performed only for experiment 1.

Statistical analyses

After verifying the normality of the data by employing the Kolmogorov-Smirnov test and the significant effect by the analysis of variance, the Tukey test ($p \leq 0.05$) was applied to compare the levels of each evaluated factor. The plant behavior only under the SRF doses effect was evaluated by using the regression analysis, admitting the doses applied in percentage of Osmocote® (A2 - 100%, A3 - 75%, A4 - 50% and A5 - 25%). The statistical program used was the Sisvar (Ferreira, 2011).

Experiment 2 - initial growth of camu-camu over two years of the transplanting

Treatments

After observing the treatments effects on experiment 1, the second experiment was conducted by evaluating the larger plants growth (35-45 cm) over the following two years. To that end, the same hydrogel levels (plots: presence and absence) and fertilizations (subplots: A1, A2, A3, A4 and A5) of experiment 1were used.

Conducting the experiments

During the two experimental years, the treatments were applied twice. The first application was only once (September 2016), at the transplanting. The second application was split into three parts (January/2018, March/2018 and May/2018), in holes around each plant. On the first application of the second year (January/2018), the entire hydrogel amount (0.75 L) was applied at once, thus having the fertilizer split into equal amounts.

Depending on the regime of treatment application and the biometric variation of the seedlings used in this experiment, the growth in two evaluation periods was evaluated, namely: from November/2016 to July/2017 (first evaluation period) and from January/2018 to August/2018 (second evaluation period), that is, two measurements in each time period, one at the beginning and the other at the end. It is noteworthy that camu-camu plants in this degrowth phase did not demonstrate the phenological stages defined in the literature. However, in the best treatments, plants were approximately 1.1 m tall in July 2017 (end of the first year from the transplanting) and 1.6 m in August 2018 (end of the experiment).

Irrigation management and cultural practices

The irrigations were performed by means of an automatic dripping system, with a flow of 3.4 L h^{-1} for each emitter, keeping the soil moistened. Over the two years of the experiment, irrigations were held only in periods with no rain and with high temperatures, as is characteristic in the studied region in the months from September to March (Araújo et al., 2001). Used as a reference for the water replacement through irrigation, evapotranspiration data collected in the same period of this study were used in experiments referring to the estimate of the crop coefficient (Kc) from camu-camu plants, currently reported by Rodríguez (2020). During the experimental period, there was no reference around the water requirement of the camu-camu in the edaphoclimatic conditions of the Savannah from Roraima.

Invasive plants were controlled by means of manual weeding, performed periodically over the two years of the experiment. There was no need in using pesticides to control the pests and diseases.

Analyzed variables

During the first evaluation period (from November/2016 to July/2017), the growth of the following variables was measured: plant height (PH), using a metrically graduated measuring tape; stem diameter (SD), using a digital caliper at 5 cm from the ground; number of branches (NB), by the total count of branches produced; and the plant height/ stem diameter ratio (PH/SD). In the last measurement of this evaluation (July/2017), the chlorophyll indices, stomatal conductance and leaf temperature were also taken. In the second evaluation period (from January/2018 to August/2018), the growth of PH, SD, NB, PH/SD and the largest branch length (LBL) were evaluated, and in the last measurement (August/2018), the plant chlorophyll indexes were also taken.

Chlorophyll-related evaluation were performed with an electronic chlorophyllometer from the ClorofiLOG® brand, model CFL 1030 (Falker index). Stomatal conductance and leaf temperature were determined with a LI-1600 LICOR "Steady State" porometer. In addition, for these evaluations, we used, between every 9h00min and 16h00min, three leaves exposed to the sun and randomly chosen in the central region of the plants of each experimental unit, following the methodology, with adaptations, from Oliveira et al. (2005).

Statistical analyzes

The data obtained in each evaluation, after determining the normal distribution, were subjected to analyses of variance, and the treatment means were compared by using the Tukey test ($p \leq 0.05$) in the Sisvar software (Ferreira, 2011). The correlations between treatments and analyzed variables were determined through the multivariate analysis of main components, with the aid of the Infostat statistical package. It is worth emphasizing that the data were analyzed using the lost plot method, since two experimental units were lost over the experiment.

Results and Discussion

Experiment 1 - camu-camu establishment under water deficit

A porcentagem de folhas severamente murchas variou em função da ação conjunta entre porte das plantas (P), hidrogel (H) e adubação (A), uma vez que o efeito da interação tripla foi significativo. Embora tenha existido tratamentos mais expressivos no aumento do número de folhas murchas, todas as plantas avaliadas apresentaram alguma porcentagem de folhas severamente danificadas, indicando que para a implantação de cultivos comerciais de camu-camu, como já reportado, o manejo da adubação deve ser terminantemente associado à efetiva disponibilidade hídrica às plantas (Abanto-Rodriguez et al., 2018; Pinedo et al., 2018; Pinto et al., 2020).

Após o desdobramento dos fatores entre si, elevados valores de mortalidade foliar foram observados nas plantas adubadas com as maiores aplicações de SRF (A2 e A3), principalmente nas de menor porte, que foram mais afetadas comparadas com as de tamanho maior em todos os níveis de hidrogel e adubação (Tabela 1). Nessas plantas (menor porte), observou-se também que o uso de hidrogel favoreceu o aumento dos danos quando usado as três maiores aplicações de SRF (A4, A3 e A2), que não diferiram entre si, mas foram superiores à A5 e à AC. Já na ausência de hidrogel, a adubação A2, seguida da A3 e da AC, foram as mais danosas ao estabelecimento foliar das plantas de menor porte (15-25 cm) sob estresse hídrico (Tabela 1).

In larger plants (35-45 cm), the highest SRF applications (A2 and A3) were more expressive in increasing the amount of severely withered leaves on the two hydrogel levels, but with values significantly lower than what was found in the smaller plants. In these plants (larger size), the CF had values lower than A2 and A3 fertilizations and higher than the A4 and A5 fertilizations, regardless of using hydrogel or not (Table 1).

When only the SRF doses were evaluated on leaf mortality in both plant sizes (Figure 1), they demonstrated a quadratic behavior with increasing doses in the hydrogel presence, with more expressive values in smaller plants, in which the SRF application of 84.0% resulted in a leaf mortality of 91.13%, more than twice the damage caused by the highest dose (A2 - 100%) on larger plants. In the hydrogel absence, the damage was relatively minor, with the increased SRF doses promoting a quadratic behavior in smaller plants and a linear one in larger plants, in which the 100% dose application (A2), although more harmful to smaller plants, was the most expressive on both sizes.

As the expected, due to the adopted water management, the plants demonstrated significant symptoms of water

Table 1. Percentage of leaves from camu-camu plants (*Myrciaria dubia*) severely withered in response to the fertilization with slow-release fertilizer (SRF) and hydrogel.

Treatments	Severely withered leaves (%)					
	Smaller size		m	Larger size		m
	NH	WH		NH	WH	
Conventional fertilization	25.6 Axcd	29.8 Axb	27.7	12.9 Ayb	10.7 Aybc	11.8
A2 - SRF 100%	75.2 Axa	81.2 Axa	78.2	34.3 Bya	42.1 Aya	38.2
A3 - SRF 75%	45.0 Bxb	76.7 Axa	60.9	32.3 Aya	20.2 Byb	26.3
A4 - SRF 50%	35.2 Bxbc	74.5 Axa	54.9	5.9 Ayb	3.9 Ayc	4.9
A5 - SRF 25%	21.5 Axd	18.2 Axb	19.9	2.7 Ayb	3.8 Ayc	3.3
m	40.5	56.1		17.6	16.1	

Means followed by the same letter, lowercase in the columns and uppercase in the rows, are statistically equal, with 'x' and 'y' comparing the plant sizes (x>y*), both by the Tukey test ($p \geq 0.05$). NH - no hydrogel, WH - with hydrogel, m - means of treatments.

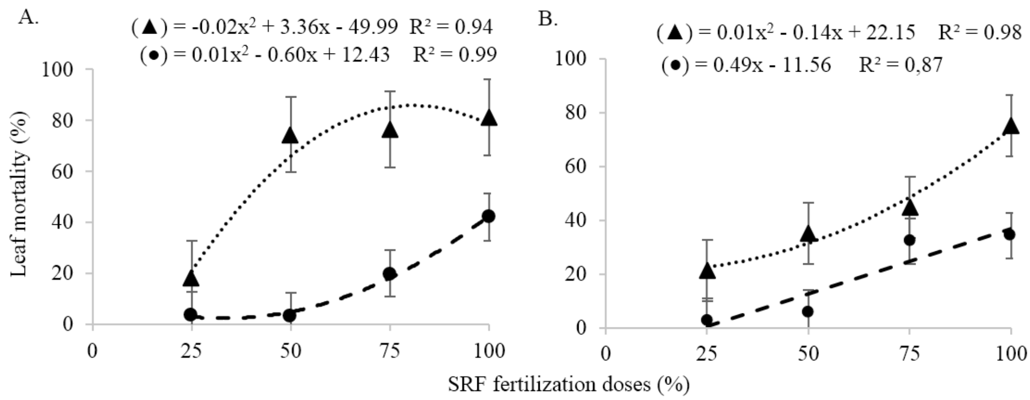

Figure 1. Effect of slow-release fertilizer (SRF) doses on leaf mortality in camu-camu plants. A: with hydrogel, B: no hydrogel, (▲): small-sized plants (from 15 to 25 cm), (●): large-sized plants (from 35 to 45 cm). Treatments: 25% - A5; 50% - A4; 75% - A3 and 100% - A2.

deficiency. These symptoms, however, were significantly increased with using SRF in the amount recommended by Viégas et al. (2004), a fact that possibly occurred due to the increased soil temperature in response to the low water availability. This must have accelerated the nutrient-release process in amounts toxic to plants, since the semipermeable membrane that coats this fertilizer type expands with the increasing temperature (Rossa et al., 2013).

These effects were more expressive in smaller plants when associated with the hydrogel use, probably because they are more susceptible to the stomatal deregulation caused by water deficit (Gonçalves et al., 2009) and adverse conditions of absorption, transport and ion distribution in plant parts (Natale et al., 2018).

Even though there are studies proving the efficiency of slow-release fertilizers and hydrogels in the initial development of several agricultural species (Monteiro Neto et al., 2017; Cruz et al., 2018), it is stated that these products must be managed under optimal water conditions and in cultivations containing camu-camu plants of the adequate size. This is because plants below 25 cm of height are negatively affected by the SRF doses associated with the hydrogel use in conditions of low water availability.

Experiment 2 - initial growth over two years of the transplanting

First evaluation period - vegetal growth between 11/2016 and 07/2017

The growth variables PH, SD, NB and PH/SD ratio varied according to the significant interaction effect (fertilization x hydrogel). For plant height (PH), using hydrogel associated with the fertilizations A2 (93.6 cm), A4 (79.1 cm) and the conventional one- CF (77.3 cm) promoted the highest plant growth values, differing from the values found in the hydrogel absence, in which the lowest SRF fertilization levels (A4 and A5) were the most efficient in increasing PH during this period (Table 2).

These results indicate that camu-camu plants, during their initial development stage, have a more expressive growth when the total application of the recommended conventional fertilization (FC) and the total SRF fertilization (A2) are used together with the hydrogel, and in a smaller fertilizer amount (A4 and A5) in soils without using the polymer.

For the stem diameter (SD), the FC and A2 fertilizations, in presence of hydrogel, continued to be the top contributors to the increased values observed, which were of 6.9 and 8.7 mm, respectively, over the evaluated growth period. In absence of

Table 2. Mean growth rates values of phytotechnical variables in camu-camu plants during their initial development stage from 11/2016 to 07/2017.

Treatments	CF	A2	A3	A4	A5
CV1 = 4.73%		*Plant height (cm)		CV2 = 14.55	
WH	77.3 Aab	93.6 Aa	35.0 Ac	79.1 Aab	23.7 Bc
NH	55.3 Bb	54.2 Bb	23.2 Ac	75.5 Aa	61.7 Aab
CV1 = 18.98%		*Stem diameter (mm)		CV2 = 20.19%	
WH	6.9 Aab	8.7 Aa	3.8 Ac	5.7 Abc	3.6 Ac
NH	5.0 Aab	2.2 Bc	3.1 Abc	6.4 Aa	4.6 Ab
CV1 = 24.24%		*Number of branches		CV2 = 10.06%	
WH	5.9 Ab	12.7 Aa	5.0 Bb	13.5 Aa	6.5 Bb
NH	8.0 Ab	5.2 Bc	7.7 Ab	11.2 Ba	11.4 Aa
CV1 = 18.82%		*PH/SD relation		CV2 = 18.40%	
WH	113.0 Aab	100.8 Bab	104.7 Aab	139.5 Aa	67.6 Bb
NH	111.6 Abc	249.6 Aa	73.3 Ac	127.0 Ab	132.7 Ab

Means with the same letter, uppercase in the columns and lowercase in the rows, are equal by the Tukey test (p ≥ 0.05). WH - with hydrogel, NH - no hydrogel, CF - conventional fertilization. * significant interaction.

hydrogel, using A4 (6.4 mm) and FC (5.0 mm) were the most significant treatments for increasing stem diameter (Table 2).

As for the produced number of branches (NB), with a mean of 12.7 and 13.5 per plant, fertilizers A2 and A4, in presence of hydrogel, were the most efficient treatments. In absence of the polymer, the smallest SRF applications (A4 and A5), as well as in the height increase (PH), were also the top contributors to the production of branches per plant.

When analyzing the levels of hydrogel within each fertilization, in the three growth variables evaluated, it is evident that using this polymer was decisive in increasing the values of each variable when applying A2 fertilization, the most efficient combination in increasing the growth of camu-camu plants during the evaluation period. The opposite effect was observed only in A5, in which the hydrogel absence favored the increase in PH and NB. In the other fertilizations, no statistical differences were identified among the hydrogel levels (Table 2).

The good results found with the A2 fertilization in presence of hydrogel, possibly, occurred due to the greater nutrient amount provided with this fertilization, gradually released to the soil solution after being retained by hydrogel, since this polymer is able to absorb and retain large amounts of water and nutrients through its hydrophilic, chemical and basically reticulated polymer networks (Brito et al., 2013). This, possibly, kept the quantities of available nutrients to the plants over the experimental period, since, under normal conditions, the SRF used has a release effect from 3 to 4 months of the application, as instructed by the manufacturer, a fact that would hardly occur on a smaller application of this fertilizer.

Among the nutrients provided by this fertilization, the greater potassium (K) supply, retained by the hydrogel, must have been one of the main factors responsible for obtaining these results, since the camu-camu in its initial growth stage has a high affinity for this nutrient during the first cultivation year (Abanto-Rodriguez et al., 2014), which also justifies the CF values in presence of hydrogel. Adding hydrogel helped increasing the K availability due to its decreased leaching (Navroski et al., 2015). Fernandes (2010), in a study using a polyacrylamide-based polymer in *Eucaliptus urophylla* individuals, demonstrated an increased shoot K content with increasing hydrogel doses, having almost double K values (2.08 g kg^{-1}) with using hydrogel compared to the zero dose (1.12 g kg^{-1}).

When comparing only the highest (A2) and the lowest SRF amounts (A4 and A5), the effects of the hydrogel were different from those expected concerning the saving of fertilizers. In presence of hydrogel, the most efficient application was A2, while in its absence, A3 and A5 were the ones that most influenced the plant growth positively (Table 2), diverging also from the results found by Navroski et al. (2015) in the Eucalyptus initial development, verifying a significant reduction in the need for fertilization with the hydrogel use.

These results may be linked to the nutritional characteristics of camu-camu and to the availability of macro and micronutrients offered by the tested treatments, since the balance between these is essential for the establishment of the species on dry land (Abanto-Rodriguez et al., 2014). According to Abanto-Rodriguez et al. (2018), camu-camu plants are highly demanding on N, Ca, K, Fe, Mn and B, having the following concentration order at leaf level: N>Ca>K>Mg>S>P>Mn>Fe>B>Zn>Cu.

For that matter, it is believed that the results found with A2 were due to the increase in the macronutrients levels by the hydrogel action; and the greater micronutrients accumulation offered by fertilizers A4 and A5 in absence of the polymer, since according to Navroski et al. (2015), using hydrogel increases soil macro levels and decreases its micronutrient levels due to increased pH. According to Vichiato et al. (2004), this may be due to the change in the cation exchange capacity provided by the hydrogel polymeric networks in function of the greater retention of basic cations.

Regarding the PH/SD ratio (Table 2), an index that provides indications of rusticity and vigor of plants during their initial growth stage, using hydrogel associated with A2 fertilization promoted the best balanced growth between shoot and stem diameter, since the lower the value of this relation is, the greater the uniform growth between the height and diameter of the plant stem will be.

It is noteworthy that the growth quality determined by this relation (PH/SD) must be associated with the individual values of the other variables (Monteiro Neto et al., 2016), since good results found by a given treatment in the individual growth of PH, SD and NB may not be repeated in the PH/SD ratio, as observed on A5 fertilization in absence of hydrogel (Table 2).

As for leaf variables, the interaction significant effect was observed in chlorophyll ‘b’, stomatal conductance and leaf temperature. For chlorophyll ‘a’ and total chlorophyll, the variations occurred only in function of the fertilization.

In the chlorophyll contents (Table 3), the isolated A5 application stood out compared to the others on the values of chlorophyll ‘a’ and total chlorophyll. However, regarding the chlorophyll ‘b’ levels, the results followed those observed on the variables PH, SD and NB (Table 2), in which the best values were found in the largest fertilizations (FC and A2) using hydrogel, and in the lower fertilizer applications (A4 and A5) in absence of the polymer. With this answer, it is believed that using hydrogel possibly decreased the nitrogen (N) loss by leaching, thus providing its greater absorption, which is a chlorophyll molecule ‘b’ constituent, which, in turn, is an accessory pigment associated with the protection of the photosynthetic apparatus from the effects of the intense solar radiation and temperature (Taiz & Zaiger, 2013).

It is known that, under high solar radiation conditions, as reported by Monteiro Neto et al. (2016) in the same region of this study, if there is no efficient supply of accessory pigments in the leaves, such as carotenoids and chlorophyll ‘b’, irreversible damage can compromise the field development of plants.

To that end, the experiment area environmental conditions, reaching up to temperatures and photosynthetically active

Table 3. Mean values of chlorophyll levels, stomatal conductance and leaf temperature of camu-camu plants during their first cultivation year.

Treatments	CF	A2	A3	A4	A5
CV1 = 10.3%		Chlorophyll 'a'		CV2 = 9.3%	
Mean	27.1 b	27.3 b	25.6 b	28.2 b	32.4 a
CV1 = 12.2%		*Chlorophyll 'b'		CV2 = 11.5%	
WH	6.6 Aa	5.6 Aab	4.1 Ac	5.4 Aab	4.4 Bbc
NH	4.4 Bcd	5.2 Abc	3.3 Ad	5.9 Aab	7.2 Aa
CV1 = 10.5%		Total chlorophyll		CV2 = 8.2%	
Mean	32.6 bc	32.7 bc	29.3 c	33.9 b	38.1 a
CV1 = 18.5%		*Stomatal conductance (mmol m^{-2} s^{-1})		CV2 = 9.2%	
WH	989.4 Aab	1142.5 Aa	1014.4 Aab	1082.3 Aa	832.3 Ab
NH	914.8 Ab	675.2 Bc	843.0 Bbc	1211.6 Aa	852.5 Abc
CV1 = 13.0%		*Leaf temperature (°C)		CV2 = 3.0%	
WH	34.4 Aab	33.6 Bab	33.4 Aab	32.3 Ab	34.9 Aa
NH	33.4 Ab	35.9 Aa	34.5 Aab	33.6 Ab	32.1 Ac

Means with the same letter, uppercase in the columns and lowercase in the rows, are equal by the Tukey test ($p \geq 0.05$). WH - with hydrogel, NH - no hydrogel, CF - conventional fertilization. * significant interaction.

radiation above 30 °C and 726.8 µmol s^{-1} m^{-2} (Monteiro Neto et al., 2016), respectively, must have directly influenced in the values of stomatal conductance and leaf temperature, which were higher in this study than those found by Fernandes et al. (2015), mainly in A2 and A3 fertilizations associated with the hydrogel presence (Table 3).

According to Shimada et al. (2017), the increase in temperature to levels not tolerated by plants promotes negative effects on the photosynthetic rates (gross and liquid), stomatal conductance, cell respiration and transpiration of different species, with these factors closely linked to vegetable tolerance increased heat. In a study comparing methods for determining heat injury levels, Xu et al. (2014) emphasized the damage caused by high temperatures to the chlorophylls fluorescence levels. The authors also report that the increased temperature minimizes the quantum electron yield, thus limiting in turn the photosystem II (FSII) efficiency due to the drop in photochemical 'Quenching' rates and the increase in non-photochemical levels. According to Shimada et al. (2017), the damage caused in FSII reduces the functions of the b6/f complex and, consequently, of photosystem I (FSI), culminating in the non-production of ATP and NADPH for the subsequent photosynthesis processes.

In addition to the direct influence on the plant photosynthetic complex, high temperatures can also affect the ion distribution in the different organs of the plants, directly influencing their ionic homeostasis (Dutra et al., 2011), in other words, the balance and conservation of physiological elements intrinsic to plant physiology can be deregulated by high temperatures. In this context, it is stated that the managements of both fertilization and water supply must be closely associated with the local climatic conditions in order to obtain homogeneous and productive orchards.

In the analysis of principal components (CP), the variance explained by the components was of 71.8%, efficiently discriminating the treatments. CP1 explained 44.5% of the data variability, correlating with the variables Cl. 'a', Cl. ''b', Cl. total, NB, PH, SD and CD , while CP2 explained 27.3% of the data variability, correlating to the variables PH/SD and LT. A positive correlation was observed among the variables PH, NB, Cl. 'b', EC, total Cl. and SD. Moreover, a negative correlation was demonstrated between TF and the vegetative plant development (PH, SD and NB), confirming the direct influence of ambient temperature on the plant growth (Figure 2). These results justify Shimada et al. (2017) and Xu et al. (2014) conclusions, that the significant increase in ambient temperature at high levels reflects the low performance of plant growth.

For the treatments, A5 fertilization with no hydrogel (A5+NH) had a strong correlation with chlorophylls. In a similar fashion, conventional fertilization with hydrogel (AC+WH), together with A5 with no hydrogel (A4+NH), had a correlation with NB and PH.

SD demonstrated a strong correlation with the A2 fertilization associated with hydrogel (A2+WH), and the EC was better correlated to A4 with hydrogel (50%+WH). The variables LT and PH/SD correlated positively with treatments A2+NH and A5+WH. The treatments A3+NH, A3+WH and CF+NH had low correlation with the studied variables (Figure 2).

Second evaluation period - vegetal growth between 01/2018 and 08/2018

During the growth period that comprises the second year of the plants in the field, the significant effect of the interaction was responsible for the variation observed in all growth variables. In this period, the main results found in the first growth evaluation (from 11/2016 to 07/2017) with the best treatments were repeated in terms of PH, SD and the largest branch length (LBL). However, using SRF proved to be more efficient in increasing all the analyzed variables, especially with no hydrogel.

On PH, fertilizations A2, A3 and A4 were the most effective in presence of hydrogel, with increments greater than 40 cm. In absence of hydrogel, A4 and A5 were the ones that most promoted the field increase of plants, but it still lower than when in presence of hydrogel (Table 4).

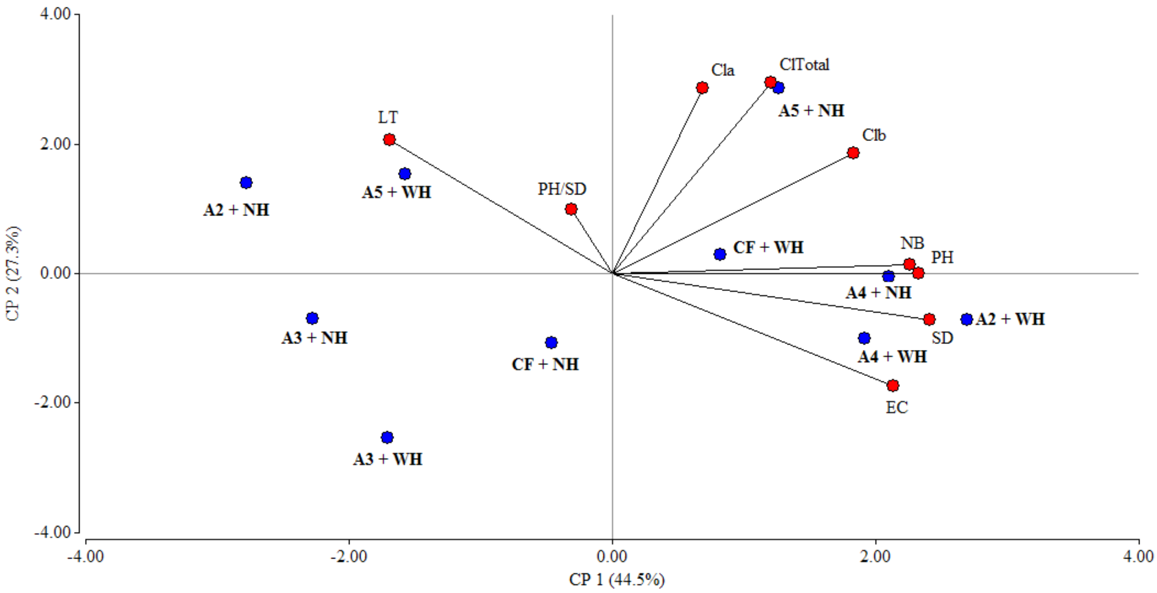

Figure 2. Projection of variables (SD - stem diameter; NB - number of branches; PH - plant heights; PH/SD ratio; Cla - chlorophyll 'a'; Clb - chlorophyll 'b'; and ClTotal - total chlorophyll; LT - leaf temperature and SC - stomatal conductance) and from the fertilization treatments (conventional fertilization (CF) and slow-release fertilizer (SRF): A2 - 100%; A3 - 75%; A4 - 50%; and A5 - 25%) and hydrogel (WH - with hydrogel; and NH - no hydrogel).

Table 4. Mean growth rates values of phytotechnical variables in camu-camu plants during their initial development stage from 01/2018 to 08/2018.

Treatments	CF	A2	A3	A4	A5
CV1 = 14.43%		*Plant height (cm)		CV2 = 12.06%	
WH	36.0 Ab	48.8 Aa	44.2 Aab	43.85 Aab	26.2 Ab
NH	24.8 Bbc	19.9 Bc	26.7 Bbc	36.9 Ba	31.0 Aab
CV1 = 11.72%		*Stem diameter (mm)		CV2 = 20.26%	
WH	2.3 Bb	5.2 Aa	2.6 Ab	6.0 Aa	5.4 Aa
NH	2.5 Ab	3.5 Bab	3.5 Aab	4.5 Ba	5.2 Aa
CV1 = 26.70%		*Number of branches		CV2 = 18.52%	
WH	5.0 Aa	1.4 Bc	3.1 Bb	5.8 Aa	3.2 Ab
NH	2.9 Bb	4.1 Aa	3.9 Aa	3.6 Bab	3.8 Aa
CV1 = 13.72%		*Largest branch length (cm)		CV2 = 11.29%	
WH	33.9 CF	54.6 Aa	46.6 Aab	45.7 Ab	33.2 CF
NH	28.2 Aab	24.0 Bb	28.0 Bab	33.8 Ba	36.3 Aa
CV1 = 31.31%		*PH/SD relation		CV2 = 27.44%	
WH	286.0 Aa	93.3 Ab	178.4 Aa	86.0 Aa	67.5 Aa
NH	109.9 Ba	61.8 Aa	79.4 Ba	73.2 Aa	59.9 Aa
CV1 = 15.31%		*Chlorophyll 'b'		CV2 = 12.12%	
WH	7.4 Aa	7.9 Aa	7.6 Aa	5.8 CF	5.7 CF
NH	6.8 Aa	5.0 Bb	6.4 Aa	6.6 Aa	6.4 Aa
CV1 = 16.22%		Total chlorophyll		CV2 = 13.41%	
Mean	39.9 a	38.4 a	37.4 ab	34.7 b	35.6 b

Means with the same letter, uppercase in the columns and lowercase in the rows, are equal by the Tukey test (p ≥ 0.05). WH - with hydrogel, NH - no hydrogel, FC - conventional fertilization. * significant interaction.

As for the SD increase, all SRF applications, except A3 in presence of hydrogel, were efficient in relation to CF, however, the presence of hydrogel favored increased values when using A2 and A4 fertilizers (Table 4).

In a similar fashion, in absence of hydrogel, all SRF fertilizations proved to be efficient in increasing the number of branches (NB). In this variable, an interesting result was identified with using the highest SRF amount (A2) in presence of hydrogel, which was one of the best treatments in the other variables. This treatment showed the smallest increase in the NB growth, averaging 1.4 branches produced since the first analysis (January/2018), yet it also promoted the greatest largest branch growth (LBL) (Table 4), indicating that the plants produced with this combination converted their nutritional reserves, preferentially, in growth rather than in branch production. Abanto-Rodrigues et al. (2014) also pointed this out when stating that, at some period, the plants stop producing new branches to invest in the growth of existing ones.

In general, the SRF proved to be efficient on the vegetative increment of camu-camu plants, depending on the combination between the quantity and the hydrogel presence or absence. Although these results are in agreement with the observed in the production of seedlings from various species, such as *Schinus terebinthifolius* and *Sebastiania commersoniana* (Rossa et al., 2013), as well as *Cedrela fissilis* (Navroski et al., 2016), studies comparing and confronting results are scarce when regarding the field vegetative growth of fruit plants. Therefore, the efficiency of the SRF quantities was possibly linked to splitting all fertilizers during this evaluated period, which, even in smaller quantities, must have made nutrients available to the plants throughout this growth period by replacing them every two months, unlike what happened in the first cultivation year (from 11/2016 to 07/2017).

As for chlorophyll levels, only Cl. 'b' suffered interference from the interaction, and Cl. total varied depending on fertilization. No statistical differences were identified for Cl. 'a'. With the results of comparing the treatments, illustrated by Table 4, it is believed that the highest fertilizer applications (CF, A2 and A3), associated with hydrogel, both in the contents of Cl. 'b' and isolated in total Cl. increase, possibly, stood out by the increment of N and Mg to the soil, as chlorophylls are essentially constituted by them (Taiz & Zaiger, 2013).

With the analysis of principal components (CP), it was observed that in this plant growth period, the variance explained by the components (CP) was 79.4%. From these, 47.3% were explained by CP1, and 32.1% explained by CP2. SD and NB correlate negatively with the other variables, however, the highest negative correlations were observed between NB and the variables LBL, PH and Cl. 'b', and between SD and variables Cl. 'a', PH/SD and total Cl., indicating that, among these correlations, when one variable increases the other decreases, and vice-versa (Figure 3).

Regarding the treatments, the applications of A4 and A5 with and without hydrogel (A4+WH, A4+NH, A5+WH and A5+NH) had a strong correlation with the SD variable. NB was better correlated to hydrogel treatments in A2 and A3 fertilizations. Conventional fertilization, regardless of hydrogel, demonstrated a strong correlation with the variables Cl. 'a', PH/SD and total Cl. Furthermore, fertilizations A2 and A3, without applying hydrogel, had a strong correlation with LBL, PH and CB (Figure 3).

In general, the data obtained with the analysis of principal components, in both evaluation periods, demonstrated that the best treatments and the relation between the analyzed variables followed a similar behavior of what was found in the means comparison tests (Tables 2, 3 and 4). This enables inferring that the CP analysis confirmed the data discussed about the vegetative growth of the camu-camu plants. Associated with this, according to Tobar-Tosse et al. (2015), the results found with the two principal components (CP1 and CP2) showed that the agronomic variables used in this study were considered important for determining the best treatments tested in the edaphoclimatic conditions of the experimental area.

In this study, important information inherent to the initial growth of camu-camu plants using hydrogel and slow-release fertilizer were generated as a contribution to the studies aimed at the domestication of camu-camu on dry land. To that end, we reaffirm the need of associating this fruit cultivation with the monitoring of local edaphoclimatic conditions, as these can be decisive for establishing plants after the transplanting.

We suggest that; as a function of the growth variability of camu-camu plants, even though they hail from a common seed lot; the biometric measurement of plants, when possible, is performed using the growth rate of the variables evaluated

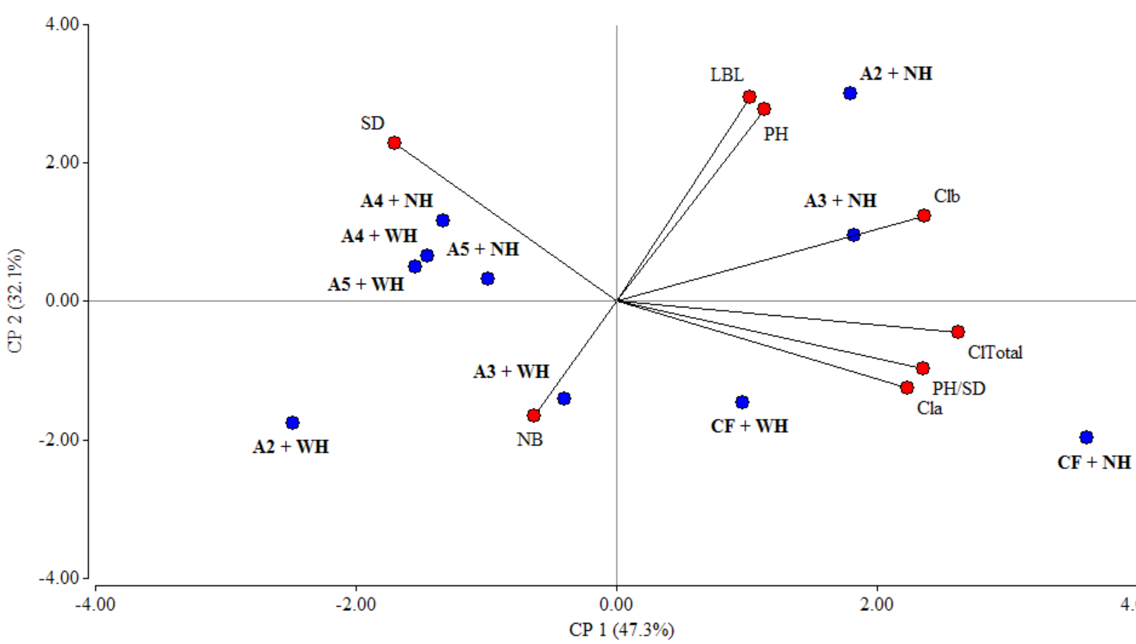

Figure 3. Projection of variables (SD - stem diameter; NB - number of branches; LBL - longest branch length; PH - plant height, PH/SD ratio; Cla - chlorophyll 'a'; Clb - chlorophyll 'b'; and ClTotal - total chlorophyll) and fertilization treatments (conventional fertilization (CF) and slow-release fertilizer (SRF): A2 - 100%; A3 - 75%; A4 - 50%; and A5 - 25%) and hydrogel (WH - with hydrogel; and NH - no hydrogel).

in multifactorial experiments of qualitative nature, as in this study. This, for statistical purposes, allowed the analysis of data normally homogenized by means of parametric analyzes (Analysis of variance and Tukey test), reflected in the acceptable coefficients of variation in the growth variables (Tables 2 and 4).

We also suggest that, before using hydrogel and slow-release fertilizers in large-scale commercial plantations, an analysis of the economic viability of these products should be held, especially in regions that have low commercial availability, since these raised significantly the cost of conducting this research.

Conclusions

Under water deficit, the conventional fertilization (CF) recommended for the crop does not affect the leaf mortality of camu-camu plants in irreversible levels. Under these conditions, using hydrogel associated to fertilization with slow-release fertilizer (SRF) A2 (100% of SRF) and A3 (75% of SRF) is very harmful to the leaf establishment of the plants, especially in those smaller than 25 cm.

Having water availability, camu-camu plants during their initial development stage respond positively to using hydrogel and SRF fertilization. In the first planting year (no fertilization split), using CF and fertilizer A2 (100% of SRF) associated with hydrogel, and fertilizers A4 (50% of SRF) and A5 (25% of SRF) in hydrogel absence, favored the vegetative growth and the supply of chlorophyll 'b' in camu-camu plants. SRF fertilizations A3, A4 and A5 are effective in the vegetative growth when performed in parts after the first transplanting year. Principal component analysis (CP) allowed inferring that SRF application is an efficient alternative in the vegetative development of camu-camu plants in the Savannah soils from Roraima.

Acknowledgements

The authors would like to thank CAPES (Coordination for the Improvement of Higher Education Personnel) - Brazil for promoting the research and CNPq (Brazilian National Council for Scientific and Technological Development) for the financial support via Universal Notice, process 408673/2016-8.

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