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Cassava productivity increased with the use of cassava wastewater as a fertilizer

A produtividade da mandioca aumentou com o uso de águas residuais da mandioca como fertilizante

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Cassava wastewater (CWW) is a residue highly rich in nutrients and compounds that can be used in plant nutrition. Cultivation of cassava in some communities on the outskirts of the Amazon is quite incipient due to the lack of technical assistance and technical-scientific information on the cultivation of the species in the region itself. With this, the cassava culture falls into traditionalism, being closed to innovations in these regions. The aim of study was to evaluate the use of CWW as fertilizer in cassava culture. The research was conducted in the field at the Science Center of Chapadinha, at the Federal University of Maranhão. The following doses of CWW were used: 0, 71, 144, 213 and 286 m^3 ha^{-1} CWW, where the biometric and productive parameters of cassava were evaluated. Except for stem length, all biometric and yield parameters responded significantly to doses of cassava wastewater. The biometric parameters showed an increase in their results until the optimal dose was reached. Root length and diameter increased with cassava wastewater. Stem diameter also increased when cassava wastewater was used as a biofertilizer. The same behavior was observed in the productive parameters, where the cassava root yield (t ha^{-1}) reached the best result with 144.3 m^3 ha^{-1} of CWW. Use of CWW positively influenced the growth, development and productivity of the cassava crop. However, its use must be done with caution to avoid unwanted results. The application 144.3 m^3 ha^{-1} of CWW is recommended to increase cassava root yield.
Keywords: *Manihot esculenta* Crantz, agro-industrial waste, sustainability.

A água residuária da mandioca (ARM) é um resíduo altamente rico em nutrientes e compostos que podem ser utilizados na nutrição de plantas. O cultivo da mandioca em algumas comunidades da periferia da Amazônia é bastante incipiente devido à falta de assistência técnica e informações técnico-científicas sobre o cultivo da espécie na própria região. Com isso, a cultura da mandioca cai no tradicionalismo, ficando fechada para inovações nessas regiões. Objetivou-se avaliar o uso da ARM como fertilizante no cultivo da mandioca. A pesquisa foi conduzida em campo no Centro de Ciências da Chapadinha, da Universidade Federal do Maranhão. Foram utilizadas as seguintes doses de ARM: 0, 71, 144, 213 e 286 m^3 ha^{-1} ARM, onde foram avaliados os parâmetros biométricos e produtivos da mandioca. Com exceção do comprimento do colmo, todos os parâmetros biométricos e de produtividade responderam significativamente às doses de água residuária da mandioca. Os parâmetros biométricos registraram um aumento em seus resultados até atingir a dose ótima. O comprimento radicular e o diâmetro aumentaram seus índices com as águas residuárias de mandioca. O diâmetro do caule também registrou um aumento ao utilizar as águas residuárias de mandioca como biofertilizante. O mesmo comportamento foi observado nos parâmetros produtivos, onde a produtividade de raízes de mandioca atingiu o melhor resultado com 144,3 m^3 ha^{-1} de ARM. O uso de ARM influenciou positivamente o crescimento, desenvolvimento e produtividade da cultura da mandioca. No entanto, seu uso deve ser feito com cautela para evitar resultados indesejados. Recomenda-se a aplicação de 144,3 m^3 ha^{-1} de ARM para aumentar a produtividade de raízes de mandioca.
Palavras-chave: *Manihot esculenta* Crantz, resíduos agroindustriais, sustentabilidade.

1. INTRODUCTION

Cassava crop (*Manihot esculenta* Crantz) production is a sector of agriculture of notorious relevance in food security worldwide, particularly in underdeveloped nations in Latin America and Africa. According to the United Nations (FAO), global production of cassava roots reached approximately 333,6 million tons [1], with FAO recognizing cassava roots as the food of the century, highlighting the need for a "Save and Grow" production approach, with practices that can sustainably increase crop productivity by up to 400% [2].

The ecologically sound and lucrative handling of cassava wastewater (CWW) is a contemporary industrial problem that is garnering much attention. This pale-yellow effluent with a milky viscosity is produced by combining root washing water, starch, and water released during cassava breakdown [3]. When untreated, it has a biochemical oxygen demand that exceeds the limitations for discharge into the environment [4] and is therefore harmful to soil and water resources [5]. The processing of one ton of cassava roots in a flour mill generates around 300 liters of cassava wastewater, while in starch mills, the average is 600 liters of cassava wastewater [6].

In that regard, CWW reuse strategies are being tested, such as its insecticidal potential [7], fungicide [8], nematicidal [9] and fertilizer [10]. Despite this, our current understanding of the use of CWW as a natural fertilizer in cassava cultivation is limited, since studies that have evaluated the potential of CWW as a fertilizer are limited to summer crops (e.g., maize and beans). Faced with the international scenario of constant increases in the prices of mineral fertilizers, farmers from traditional communities in the north-northeast region of Brazil use CWW empirically in cassava cultivation, due to its regional availability and low or no acquisition cost.

In this region, the quality of life of many farmers is marked by a deplorable poverty picture, social vulnerability, and disparities, in stark contrast to their human potential and natural wealth. The production system would be based on itinerant “slash-and-burn” agriculture, which would be characterized by low productivity indices, food insecurity, and the use of unsustainable agricultural practices, all of which would contribute to an increase in greenhouse gas emissions, biodiversity losses, and soil pollution [11].

Based on these arguments, it is opportune to suggest the hypothesis that the adoption of sustainable technologies, such as the use of CWW in cassava cultivation, can contribute to the ecological intensification of cassava crops, serving as an alternative to the use of fertilizers and reducing production costs and environmental impacts. To test this hypothesis and determine the levels tolerated by the crop, we evaluated the effects of CWW levels on the biometric and yield parameters of cassava.

2. MATERIAL AND METHODS

The research was conducted from January 2018 to January 2019, in the experimental field of the Centro de Ciências de Chapadinha, Universidade Federal do Maranhão, located in Chapadinha (107 m above sea level), Maranhão State, Northeastern region, Brazil (Figure 1).

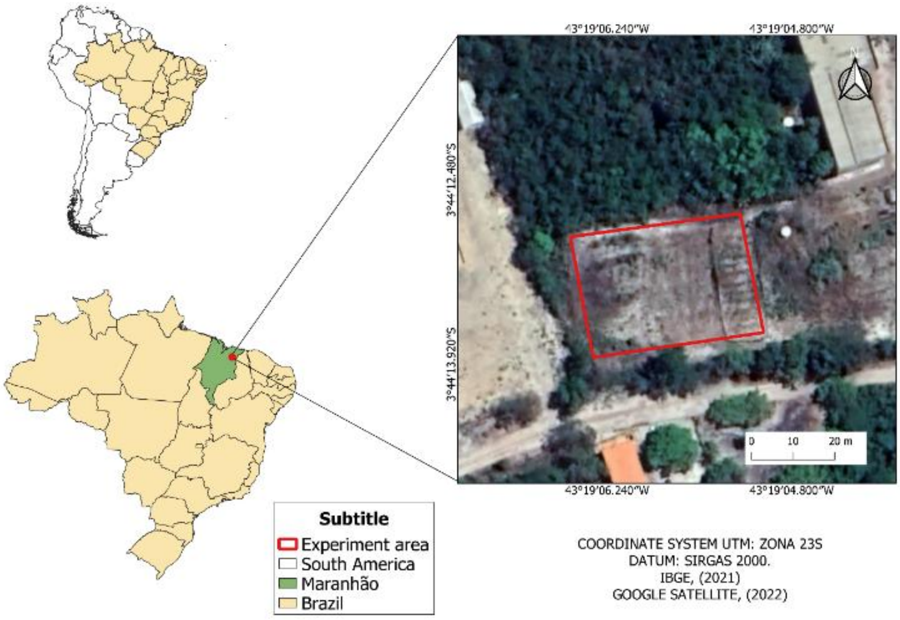

Figure 1. Map of the experimental study area in the Chapadinha, Maranhão, Brazil.

The soil used was classified as Oxisol (Yellow Latosol, according to the Brazilian Soil Classification System). The climate pattern of the region, according to Köppen, is type Aw, hot and humid equatorial. According to data supplied from stations of the Instituto Nacional de Meteorologia [12], the rainfall ranged from 0.2 to 379.1 mm, the temperature varied between 26.5 and 30.5 °C and the relative humidity ranged from 60.8 to 85.1% during the experimental period. The averages of the climatic conditions during the conduct of the experiment can be seen in Figure 2.

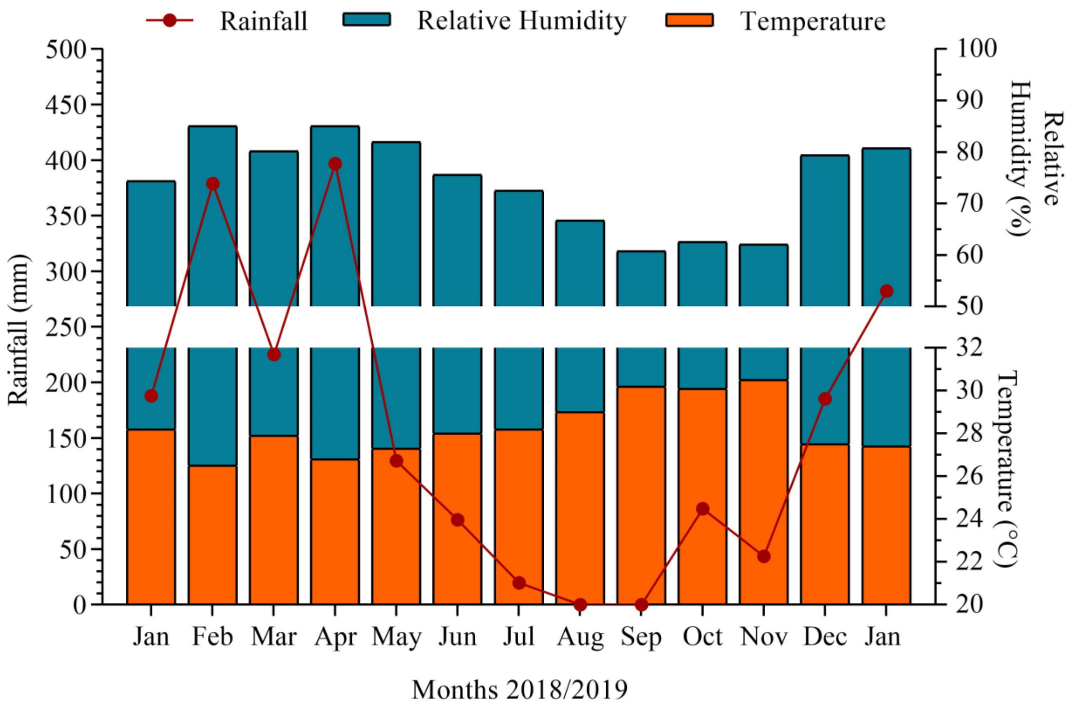

Figure 2. Average values of Rainfall, air relative humidity and air temperature in the municipality of Chapadinha, Maranhão, during the study period of experimental conduction, 2018-2019. Source: INMET, 2019.

In the present study, CWW was provided by the Association of Farmers of São Gonçalo, located in the municipality of Santana do Maranhão, state of Maranhão, northeastern Brazil (3º06'57" S and 42º24'43" W and altitude of 43 m), after processing the cassava roots, as shown in Figure 3.

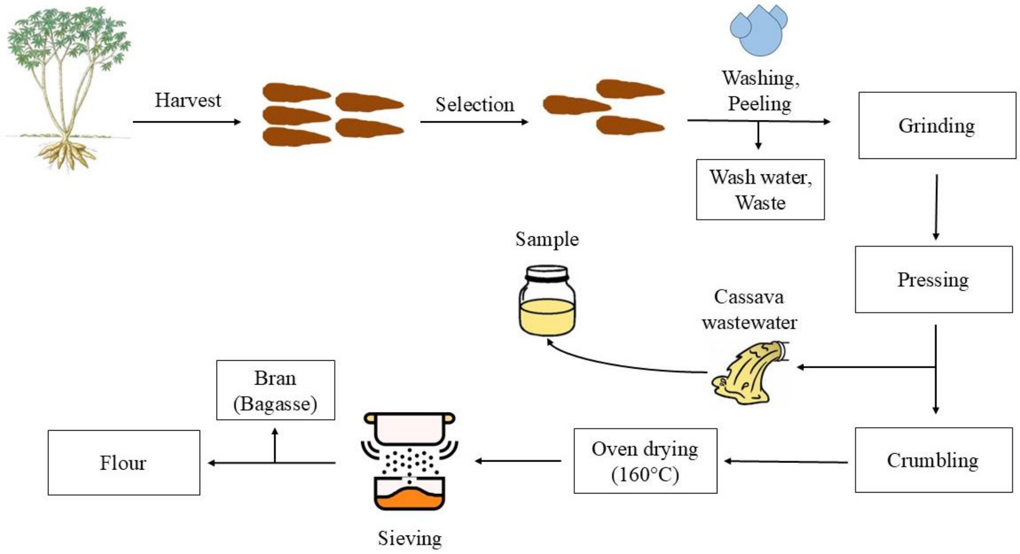

Figure 3. Stages of processing cassava roots and their respective products until flour production.

All CWW samples were stored for 60 days at room temperature (~26.6 °C) in 500 L polyethylene reactors until collection for analysis and field application. The room temperature storage aimed to stabilize the pH of the cassava wastewater (requiring 46 days for such stabilization); to reduce and stabilize the total cyanide content of this compound (requiring at least 60 days), for later use in soil as fertilizer; and to restrict the release of total cyanide, reducing the risk of contamination for processors [13]. After the storage period, the chemical characterization of CWW was carried out, following the methodological procedures of the American Public Health Association [14], obtaining: pH = 4.8; organic matter = 2.7%; N = 330.0 mg L^{-1}; P = 240.0 mg L^{-1}; K = 3450 mg L^{-1}; Ca = 228.0 mg L^{-1}; Mg = 1000.0 mg L^{-1}; S = 42.0 mg L^{-1}; Cu = 0.430 mg L^{-1}; Fe = 1740 mg L^{-1}; Mn = 0.4 mg L^{-1}; Zn = 0.39 mg L^{-1} and Na = 40 mg L^{-1}.

In December 2017, conventional soil preparation started with 20 cm plowing, followed by harrowing. The chemical parameters of the soil in the experimental area were characterized and the following data were found pH = 4.0; OM = 22.8 g kg^{-1}; P = 3.5 mg dm^{-3}; k = 0.14 $cmol_c$ dm^{-3}; Ca = 0.69 $cmol_c$ dm^{-3}; Mg = 0.53 $cmol_c$ dm^{-3}; Al = 0.51 $cmol_c$ dm^{-3}; H+Al = 6.12 $cmol_c$ dm^{-3}. Then, Soil acidity was corrected using the Base Saturation method and was applied 2 t ha^{-1} of calcitic limestone (PRNT: 100%, 4% MgO and 35% CaO) in the area and a new harrowing operation was carried out to incorporate the limestone. In January 2018, the experimental area was divided into four blocks of 70 m^2, within which forty plots of 2.8 m^2 were distributed, consisting of ten plants in two rows of five with a spacing of 1.0 × 0.7 m.

The study was implemented in the area using a randomized block design, containing five treatments (CWW levels: 0, 71, 144, 213 and 286 m^3 ha^{-1}) and eight replications. Fertilization was carried out according to soil analysis, where 91 kg of urea (40 kg of N), 111 kg of simple superphosphate (20 kg of P_2O_5) and 69 kg of KCl (40 kg of K_2O) were used, based on the state of Minas Gerais Soil Fertility Commission [15]. The experimental area had a drip irrigation system, consisting of a main line and twenty lateral lines with built-in drippers, with an average flow of 1.25×10^{-6} m^3 s^{-1}. Irrigation was carried out in a supplementary manner, in the period without rain.

Phytosanitary control was carried out based on the technical recommendations adopted in the region for cassava cultivation, using preventive applications of Neem oil (*Azadirachta indica*) at a dose of 20 L ha^{-1} against insect pests of the species (e.g., whitefly, mites and bedbugs), and monitoring during the crop cycle to control plants weeding weeds. At 30 days after emergence (DAE), thinning was performed, standardizing one plant per hole. CWW doses were applied in six periods throughout the crop cycle, namely, 45, 55, 65, 75, 85 and 95 DAE, always at 5 pm (local time, GMT − 03:00 am). The application was carried out by the same operator using a sprayer with a capacity of 20 L and pressure control.

At the time of harvest, plant height was measured from ground level to the terminal bud with a measuring tape graded in millimeters. In this study, an electronic digital caliper (MTX® 316119, MTXToolsWorld, Garulhos - SP) was used to measure the stem diameter of the plants, as well as the root diameter. The root length was measured with a millimeter measuring tape.

After 380 DAE, the cassava root yield (t ha^{-1}) was measured by weighing the roots of the experimental plot on a digital scale (B-MAX® BM-A06, So Paulo - SP). Similarly, shoot fresh weight (t ha^{-1}) was calculated by weighing the plant's aerial section in the experimental plot. Finally, the harvest index (%) was calculated using the ratio of root production to biomass production, according to Eq. 1.

$$\text{Harvest index (\%)} = \frac{\text{Cassava root yield}}{(\text{Cassava root yield + shoot fresh weight})} \times 100 \quad (1)$$

The hypothesis of normality of the residuals of the data was verified by the Kolmogorov test ($P < 0.05$) using PROC UNIVARIATE. ANOVA using the PROC GLM was performed according to Eq. 2. If the effect of fertilization with CWW was significant ($P < 0.05$) by the t test, the data were submitted to regression analysis by the PROC REG, testing the linear and quadratic models.

$$Y_{ij} = \mu + D_i + B_j + \varepsilon_{ij} \quad (2)$$

Where Y_{ij} - the dependent variable; μ - the overall mean; D_i - the fixed effect of the cassava wastewater level; B_j - the random effect of the block; and ε_{ij} - the residual effect which includes the other sources of variation.

Principal component analysis was performed using the PROC PRINCOMP procedure to characterize the investigated treatments. Initially, the dataset composed of the means of the variables of each treatment was standardized ($\mu = 0$; $s^2 = 1$), aiming to eliminate the influence of the different units of measurement of the variables. Then, a biplot was prepared by the PROC PRINQUAL procedure to analyze correlations and multivariate trends. All analyses were performed in the Statistical Analysis System [16].

3. RESULTS AND DISCUSSION

Table 1 shows the overall structure of variance and covariance of principal component analysis (PCA). The first principal component 1 (PC 1) explained 61.36% of the total variation between the biometric and productive parameters of cassava, after applications of 0, 71, 144, 213 and 286 m^3 ha^{-1} of CWW. The second principal component 2 (PC 2), explained 31.85% of this variation. As a result, PCA explained 93.21% of the overall variance and covariance structure, which can be considered reasonable. In the present study, greater weighting of root length, stem diameter and cassava root yield was observed in the PC1 extraction process, as well as greater weighting of plant height, root diameter, harvest index and shoot fresh weight for Can 2 extractions, suggesting a variation related to the root (PC 1) and aerial part of the cassava plant (PC 2).

Table 1. Coefficients and total variation explained by each principal component (PC).

Variables	**Principal Component***	
	PC1	**PC2**
Root length	0.48	-0.01
Shoot fresh weight	0.36	-0.42
Stem diameter	0.42	0.23
Plant height	0.18	0.59
Root diameter	-0.33	0.49
Harvest index	0.29	0.43
Cassava root yield	0.46	-0.31
Eigenvalue	4.29	2.23
Variation (%)	61.36	31.85
Accumulated Variation (%)	61.36	93.21

* Scores with high weighting in the construction of PC> 0.

The joint analysis of PC1 and PC2 using the biplot allowed a two-dimensional ordering of the multivariate characteristics of the treatments evaluated according to the measured variables, clearly dividing them into four groups (Figure 4). The treatments corresponding to the doses 144 m^3 ha^{-1} and 213 m^3 ha^{-1} of CWW were shifted to quadrant II by the axis of the principal components in the positive direction in the biplot. Therefore, these treatments showed similar multivariate characteristics, with a tendency toward high mean values for the variables plant height, harvest index, stem diameter, root length and cassava root yield. The usage of 286 m^3 ha^{-1} of CWW, on the other hand, tends to suppress variables. The application of the dose of 71 m^3 ha^{-1} of CWW is characterized by higher average values of biomass, since in the absence of CWW, higher values of root diameter tend to be observed.

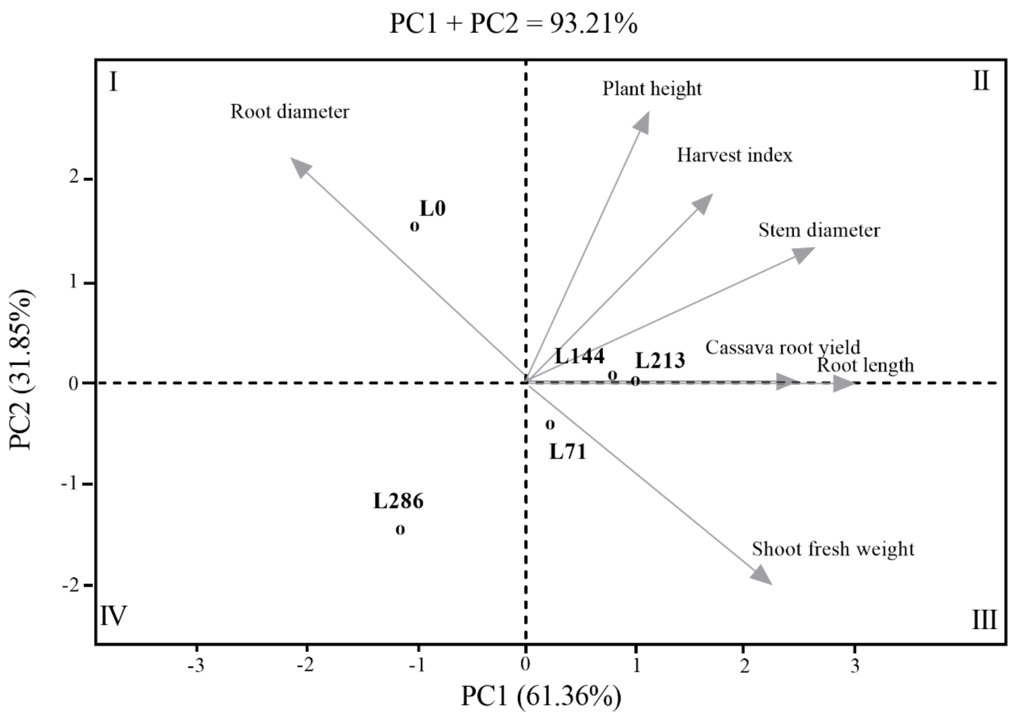

Figure 4. Principal component analysis (PCA) of the biometric and productive parameters of cassava, after applications of 0, 71, 144, 213 and 286 m^3 ha^{-1} cassava wastewater.

The results obtained with the doses of cassava wastewater for the biometric and productive parameters can be seen in Table 2. Our results indicated that the use of cassava wastewater (CWW) as fertilizer promoted an effect on stem diameter, root diameter, root length, and root productivity of cassava, which can be explained by the quadratic model ($P < 0.05$).

Furthermore, an influence of cassava wastewater on shoot fresh weight was recorded, explained by the linear effect ($P < 0.05$) (Table 2).

Table 2. Effects of increasing levels of cassava wastewater on biometric and productive parameters of cassava cultivation.

Variables	Doses of cassava wastewater ($m^3\ ha^{-1}$)					SEM[1]	Effects[2]	
	0	71	144	213	286		Linear	Quadratic
Biometric parameters								
Plant height (cm)[3]	1.62	1.64	1.72	1.73	1.66	0.01	0.45	0.18
Stem diameter (mm)[4]	13.78	14.11	16.51	14.88	12.86	1.08	0.61	0.04
Root length (cm)[5]	67.41	72.55	75.19	74.97	64.55	1.28	0.77	0.04
Root diameter (mm)[6]	62.78	57.53	56.67	55.73	58.05	0.34	0.52	<0.01
Productive parameters								
Cassava root yield ($t\ ha^{-1}$)[7]	15.56	18.79	21.58	25.35	14.46	1.04	0.82	<0.01
Shoot fresh weight ($t\ ha^{-1}$)[8]	10.71	11.97	12.86	13.92	15.7	0.41	0.02	0.04
Harvest index (%)[9]	66.85	68.46	68.46	66.03	55.93	1.43	0.46	0.05

[1]SEM = standard error of the mean
[2] Significant by the F test
[3] $\hat{y} = -0.002x + 1.6471$ (r=0.14) and $\hat{y} = 1.6091 + 0.0013x - 0.00006x^2$ ($R^2 = 0.48$)
[4] $\hat{y} = -0.0081x + 12.58$ (r=0.056) and $\hat{y} = 10.35 + 0.0706x - 0.0002x^2$ ($R^2 = 0.34$)
[5] $\hat{y} = -0.0047x + 71.607$ (r=0.007) and $\hat{y} = 66.756 + 0.1312x - 0.0005x^2$ ($R^2 = 0.53$)
[6] $\hat{y} = -0.0255x + 62.398$ (r=0.29) and $\hat{y} = 65.83 + 0.12x - 0.00033x^2$ ($R^2 = 0.66$)
[7] $\hat{y} = 0.006x + 18.289$ (r=0.018) and $\hat{y} = 14.385 + 0.1154x - 0.0004x^2$ ($R^2 = 0.54$)
[8] $\hat{y} = 0.00175x + 10.501$ (r=0.96) and $\hat{y} = 10.625 + 0.014x - 0.0005x^2$ ($R^2 = 0.96$)
[9] $\hat{y} = -0{,}034x + 70{,}067$ (r=0,30) and $\hat{y} = 66.36 + 0.06x - 0.00036x^2$ ($R^2 = 0.55$)

The stem diameter variable recorded an increase in its value up to the optimal dose (176.5 $m^3\ ha^{-1}$ CWW), where it recorded the best result (16.58 mm), showing an increase of 60.19% compared to the dose 0 $m^3\ ha^{-1}$ CWW (i.e., control treatment). Thus, doses above 176.5 $m^3\ ha^{-1}$ CWW inhibit the development of stem diameter.

For the root diameter, an increase was registered until reaching 76.74 mm with the dose 181.8 $m^3\ ha^{-1}$ CWW, representing an increase of 16.57% in comparison with the control treatment. Therefore, doses above 181.8 $m^3\ ha^{-1}$ CWW inhibit the development of root diameter. This behavior was also observed in root length, which increased as the CWW concentration increased up to the dose of 131.2 $m^3\ ha^{-1}$ CWW, where the best result was recorded (75.36 cm), with an increase of 12.89% when compared with the result obtained with the control treatment.

The cassava root yield obtained the best response (22.7 $t\ ha^{-1}$) with the dose 144.3 $m^3\ ha^{-1}$ CWW, which represents an increase of 57.8% compared to the control. After reaching the peak, cassava root yield values decreased as CWW doses increased.

Our findings contribute to the body of research supporting the use of CWW as a sustainable fertilizer. However, this study is the first to examine the impacts of CWW on the biometric and productive characteristics of cassava, paving the way for efficient management of this effluent. Other studies have shown the effect of this effluent on other commercial crops such as corn [17], sunflower [18], and papaya [19], as well as spontaneous vegetation [20]. We found that CWW doses did not affect the harvest index, but a quadratic effect was documented in most of the evaluated parameters (e.g., stem and root diameters, root length, and cassava root yield). Therefore, this finding provides evidence of the potential use of CWW as an alternative to the use of fertilizers, reducing production costs and environmental impacts.

The increases observed for most of the variables measured in the present study can be explained by the variety of nutrients (e.g., dextrose, fructose, sucrose, etc.), nitrogenous compounds and cations (e.g., magnesium, calcium, manganese, iron, zinc) present in CWW, which favor the rooting and growth of cassava shoots [3]. In addition to the effect of nutrient input, its use can promote beneficial changes in the physical properties of the soil, such as the reduction of density in oxisol [21], which, consequently, promotes increased porosity, in other words, better conditions for root development. However, However, a decrease in biometric and productive parameters can be observed in treatments with higher doses of CWW. This effect may be associated with the cyanide (HCN) present in its composition. Plants have a certain resistance to HCN, but the compound directly affects the Calvin-Benson cycle [22], as it hinders the supply of carbon by carbonic anhydrase, as this behavior was also observed in *Chlorella pyrenoidosa* when responding to the application of HCN [23]. Furthermore, it is estimated that it may inhibit the electron transport chain in photosystem II [24], which impairs photosynthetic activity and carbon fixation by the plant.

Additionally, the nutritional imbalance caused by CWW can have an additive effect on the documented results. According to the CWW analysis, this compound has high concentrations of potassium, which in large amounts impairs the absorption and assimilation of nutrients such as calcium and magnesium [25]. Low carbon assimilation was associated with a possible nutritional imbalance, which may have hindered root development. Previous studies have explained that CWW impairs the balance between nutrients and can increase salinity and reduce pH [26].

Despite the rusticity of the species under study and resistance to soil acidity, cassava also suffers from the effects of pH decrease, even if indirectly, considering that the decrease in soil pH affects the availability of nutrients in the soil solution and therefore affects plant nutrition. Considering salinity, it is known that soil salinity is one of the main factors that hinders the cultivation, development and production of cassava roots [27]. Soil salinity affects plant cells in two ways: water deficit caused by high concentrations of salts in the soil solution, which leads to reduced water absorption by the roots (osmotic stress); and the high accumulation of salts in the plant, which modifies the Na^+/K^+ ratio, which leads to a high concentration of Na^+ and Cl^- [28].

Although without significant differences, the harvest rates found are generally within the appropriate range (i.e., above 50%), according to the classification proposed by Peixoto et al. (2005) [29]. Regarding cassava root yield, the results obtained in the present study were above the world average productivity (10.6 t ha^{-1}) achieved in 2021 [1]. Values above 144.3 m^3 ha^{-1} of CWW reduced the cassava root yield, which raises an alert for the use of this effluent. This reduction specifically may be associated with the acidity of CWW, which interferes with the absorption of some nutrients [25]. This only reinforces again the need to establish specific doses for each particular species [30].

In the case of biometric parameters, it is important to highlight the increase in the seedling-seed formation capacity, that is, for the propagation of cassava, as well as an alternative for animal feed in the forage season, due to the high nutritional value and acceptability of the animals [31]. According to Lago et al. (2011) [32], the stem diameter suitable for seed cutting production is greater than 10 mm. This result can contribute to the food security and quality of life of many farmers from traditional communities in the Amazon region and its periphery. However, according to Sagrilo and Oliveira Junior (2008) [33], the appropriate diameter for producing seed cuttings must be at least 20 mm.

Although CWW has some potential as an organic fertilizer in cassava cultivation, clearly its excessive use can inhibit the development of biometric parameters of the plant, which leads us to conclude that this residue should not be used recklessly, as it can generate negative results. unsatisfactory. Thus, research increasingly reiterates the need for the correct disposal of CWW [34], as it has a high polluting potential [3], and its inappropriate use can negatively influence the initial development of crop commercials [35]. Therefore, further studies are needed in commercial crops, either in the field or in a greenhouse, to verify the viability of its use in agricultural cultivation and to determine which doses of this residue are adequate to be used as an alternative fertilizer in commercial crops.

In addition to the previously mentioned factors, Ogunyemi et al. (2022) [36] reported that CWW has a cytogenotoxic effect, being able to generate chromosomal aberrations, which cause disturbances in plant growth. The authors claim that this result comes from the HCN present in CWW. Regardless of the HCN concentration, all CWW treatments had a cytogenotoxic effect on Allium cepa, which generated certain growth restrictions, something that is confirmed by the literature [36, 37]. Such an effect may have occurred in cassava, since it presented growth restrictions in its biometric parameters (plant height, stem diameter and root diameter) with the highest dose of CWW (286 m^3 ha^{-1}) (Table 2).

However, the positive results obtained with the use of CWW in cassava cultivation point to an interesting alternative for the proper disposal of this residue. Although Brazil is among the largest producers of cassava in the world [1], there are no major investments in the sector and waste (i.e., cassava wastewater) is released in large quantities into the environment [38]. Therefore, the present work contributes to the development of increasingly sustainable agriculture and to the advancement of cassava culture. New research is needed to fully understand the use of cassava wastewater in agriculture and the environment impact.

4. CONCLUSION

The rational use of cassava wastewater as an alternative organic fertilizer positively influences the growth, development, and productivity of cassava roots.

Based on preliminary results, the recommended application rate is 144.3 m^3 ha^{-1} of cassava wastewater for an average cassava root production of 22.7 t ha^{-1}.

Amounts above this amount (144 m^3 ha^{-1}) inhibit cassava root productivity and biometric parameters.

5. ACKNOWLEDGMENTS

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