Production and quality of cassava (*Manihot esculenta* Crantz) organically and chemically fertilized and intercropped with sapodilla

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ABSTRACT

Objective: To evaluate the yield and quality of organically nourished cassava (*Manihot esculenta* Crantz) produced in an intercropping system with sapodilla.

Design/methodology/approach: A cassava crop was established in Veracruz, Mexico, under a completely randomized block design in split-plot arrangements. The large plot corresponded to sapodilla densities (156 and 312 trees/ha), and the small plot to mineral and organic fertilization and a control. The variables measured were: total plant height, aerial and root biomass, number of roots per plant, external and internal root color, average root diameter and length. Additionally, starch content was estimated by the specific gravity method.

Results: The results show that at low density, better-quality cassavas are obtained, and average yields of 13 roots/plant with an average total weight of 2.914 kg and a starch content of 29.58%. On the other hand, organic and mineral fertilization showed similar behaviors with the exception of root diameter, luminosity, internal hue angle and starch content, where organic fertilization showed values of 34.49 mm, 85.67, 87.36° and 29.71%, respectively.

Limitations on study/implications: The results obtained can be applied in tropical regions with vertisol soils with a sandy crumb texture with dark color, pH of 6.5 and good surface drainage; they also serve as a basis for further exploring these production systems.

Findings/conclusions: It is concluded that planting density and nutrition influence the quality and yield characteristics of cassava.

Keywords: Mandioca, Bokashi, Production systems.

INTRODUCTION

Cassava is a food of great nutritional importance. Around 330 million tons are harvested annually worldwide (Food and Agriculture Organization of the United Nations [FAO], 2024), making it the fourth staple food in the diet of 1 billion people, primarily those with limited resources (Díaz & López, 2021). The crop has grown since 2000, with a faster rate in Africa and Asia than in the Americas, where it originated, resulting in an annual per

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capita consumption of 60 kg by 2013 (Díaz & López, 2021; Howeler *et al.*, 2013; Suárez & Mederos, 2011). In Mexico, 24,000 tons are produced across seven states (Agricultural and Fisheries Information System [SIAP], 2024), with the roots primarily intended for food purposes.

Cassava is characterized by having a root capable of storing large amounts of starch, which can be harvested from eight months to three years after planting without losing its nutritional qualities (Díaz & López, 2021; Salvador *et al.*, 2014). This crop is consumed fresh, roasted, boiled, or fried, but it is primarily consumed as flour (Salvador *et al.*, 2014). This makes starch content an important parameter when defining the quality of this root.

Cassava cultivation is easy to manage, as it shows good tolerance to drought and low-fertility soils, making it accessible to subsistence farmers (Laranjeira *et al.*, 2023). However, it should not be overlooked that proper management can impact the quality and yield of cassava, such as genotype selection, fertilizer use, and the design of the production system to be employed (Laranjeira *et al.*, 2023; Souza *et al.*, 2024). Additionally, it should be considered that there is a continuous search at the international level for sustainable management practices that minimize environmental impact while supporting food security for families (Howeler *et al.*, 2013).

In Mexico, cassava is primarily cultivated in marginal areas and small plots, particularly in the state of Veracruz, where the average regional chemical nutrition is 146-46-60 kg of NPK/ha (Durán *et al.*, 2023). However, it is unknown how the use of alternative nutrient sources and intercropping with fruit trees may influence its yield and quality. Therefore, the objective of this study was to evaluate the yield and quality of cassava (*Manihot esculenta* Crantz) organically nourished and produced in an intercropping system with sapodilla.

MATERIALS AND METHODS

The experiment was conducted in the intercropping system orchard with sapodilla at the Cotaxtla Experimental Field of the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP) in Medellín, Veracruz, Mexico. The orchard is located at the geographic coordinates 18° 56’ 12” north latitude and 96° 11’ 32” west longitude, at an altitude of 16 meters (Google Earth, 2024). The region is characterized by an average annual precipitation of 1350 mm and an average annual maximum and minimum temperature of 31.8 °C and 21.8 °C, respectively (Martínez-Ruiz *et al.*, 2017). The soil of the orchard is vertisol with a sandy crumb texture and dark color, a pH of 6.5, and good surface drainage (Alemán, 2018).

The cassava crop (*Manihot esculenta* Crantz) of the San Andrés native variety was evaluated in an intercropping system with sapodilla (*Manilkara zapota* (L.) P. Royen) of the Betawi variety. The sapodilla was established in 2005 at two planting densities of 156 and 312 trees/ha, with spatial arrangements in real frame at distances of 8×8 m and 8×4 m, respectively. The sapodilla trees are maintained with crown pruning at a 2 m radius and 3 m height, leaving a 4 m space for intercropping.

In June 2023, a harrow was used in the available 4 m for intercropping, and three beds of 0.5 m in height were formed, with a center-to-center distance of 2 m. Cassava was planted in the beds using cuttings of 30 cm in length, which were collected from another orchard within the same Experimental Field. The cuttings were planted at a 45° angle, in a staggered pattern, and at a density of 6600 plants/ha. The cassava was managed as a rainfed crop; however, due to the uneven precipitation throughout the cycle, supplementary irrigation was applied every third day from June 13 to July 19.

Nutritionally, the NPK dose of 146-46-60 was applied using the mineral fertilizers DAP, urea, and potassium chloride at planting, or with bokashi at planting and five applications of efficient microorganisms (EM) at a dose of 50 mL per plant every 15 days starting on October 11.

The cassava was harvested in January 2024, seven months after planting. For the development of this study, the organic fertilizers "bokashi" and "Efficient Microorganisms" (EM) were prepared, both of which are obtained through fermentation processes. The former is used as a solid fertilizer, and the latter as a liquid fertilizer.

To prepare the bokashi, chicken and cow manure, pangola grass, soil, and sand were used in volumetric proportions of 2:2:2:1:1. The materials were mixed with a 1.5% molasses solution until a moisture content of 75 to 80% was reached.

The moisture content was verified using the fist test, as described by Méndez and Viteri (2007). The process continued as outlined by Rebolledo *et al.* (2012). After the fermentation process, an analysis was conducted, which showed that the bokashi was characterized by a pH of 6.5, a C/N ratio of 8.18, and a composition of: 20.04% organic matter, 11.62% C, 1.42% N_{total}, 0.23% $N_{nitrate}$, 1.47% P_2O_5, 1.42% K_2O, 3.64% CaCO, 0.8% MgO, 1.02% Fe^{2+}, 0.04% Zn^{2+}, 0.00% Cu^{2+}, 0.06% Mn^{2+}, and 0.03% B^{2+}.

The bio-input EM is a solution containing several beneficial microorganisms, so plant material with fungal strains must be collected from undisturbed areas. The preparation of 200 L of EM was carried out following the process of Rebolledo *et al.* (2012); the materials used were 2 kg of corn flour, 2 kg of bran, 0.5 kg of charcoal, and 1 kg of plant material with strains; the fermentation medium was a 10% molasses solution.

A completely randomized block design was used in a split-plot arrangement, where the main plot corresponds to the sapodilla planting densities with two levels, and the subplot corresponds to the nutritional management of cassava with three levels, with four replications. The experimental unit consisted of plots measuring 20 m^2. The resulting treatments can be seen in Table 1.

Table 1. Nutritional treatments evaluated in an intercropped cassava study with sapodilla.

Treatment	Sapodilla density plantation	cassava nourish
1	156 trees ha^{-1}	0
2	156 trees ha^{-1}	2 kg bokashi $plant^{-1}$
3	156 trees ha^{-1}	146-46-60 kg ha^{-1} of N P K
4	312 trees ha^{-1}	0
5	312 trees ha^{-1}	2 kg bokashi $plant^{-1}$
6	312 trees ha^{-1}	146-46-60 kg ha^{-1} of N P K

Regarding the evaluated variables, total plant height (m) was measured five months after establishment using a stadia rod from the base to the apex. The aboveground biomass (kg), consisting of stems, branches, and leaves, was weighed fresh with a hand scale accurate to the gram. The total root biomass (kg) of the sampled plants was also weighed in the field using a scale with gram precision, and the number of marketable roots per plant was recorded. These roots were then transported to the tropical fruit sample preparation laboratory at the Cotaxtla Experimental Field of INIFAP.

The internal and external color of the roots was measured using a WR10QC colorimeter. The L a b parameters were converted into hue and chroma values according to McGuire (1992). From the total roots per plant, a subsample of three representative roots was selected. The length (cm) and average diameter (mm) of these roots were determined, with the diameter measured at three points per root —upper, middle, and lower sections— using a vernier caliper.

The starch content was determined using specific gravity, a method employed to obtain the dry matter and starch content in roots through a standardized correlation (Aristizábal & Sánchez, 2007). This variable was measured according to the procedure described by Aristizábal and Sánchez (2007), where the selected roots were individually weighed both in air and submerged in water. The obtained values were applied in Equation 1.

$$SC = \frac{Pfr_{ai}}{Pfr_{ai} - Pfr_{ag}}$$

where SC is the specific gravity; Pfr_{ai} corresponds to the weight of the roots in air and Pfr_{ag} is the weight of the roots in water.

The percentage of dry matter was determined according to Equation 2.

$$\%MS = (SC \times 158.26) - 142.05$$

Finally, this value was used to calculate the percentage of starch with Equation 3:

$$\%AL = \%MS \times 0.875$$

where $\%AL$ is the starch percentage and $\%MS$ is the dry matter percentage (Aristizábal and Sánchez, 2007).

The statistical analysis was performed using Minitab 19 software. The assumptions of normality were verified with the Anderson-Darling statistic, autocorrelation was checked using the Durbin-Watson test, and homogeneity of variances was assessed with Bartlett's test for the studied variables. Subsequently, analysis of variance ($\alpha = 0.05$) was performed, and mean comparisons were made using Tukey's multiple range test ($p \leq 0.05$).

RESULTS AND DISCUSSION

The studied variables met the statistical assumptions of normality, independence, and homogeneity of variance ($p>0.05$). The descriptive statistics are shown in Table 2.

The results by factor of the studied variables, considering the planting density of sapodilla and the nutrition, are shown in Tables 3 and 4, respectively.

The aerial biomass is important in the livestock sector, where it has been considered a viable alternative to meet the forage demand that has been affected by climate variability (Gómez *et al.*, 2016). In the present study, the aerial biomass variable did not show

Table 2. Descriptive statistics of parameters evaluated in cassava nourished with different sources and intercropped with sapodilla established at two planting densities.

Parameter	Mean	SD	Mdn	Min.	Max.	Range	Kurtosis
Aerial biomass (kg/plant)	2.84	1.16	2.71	0.64	5.31	4.67	−0.56
Root quantity (number/plant)	10.75	4.36	10.00	4.00	23.00	19.00	−0.01
Root biomass (kg/plant)	2.43	1.16	2.35	0.56	5.50	4.94	0.35
Root length (cm)	30.85	10.87	30.10	9.50	73.00	63.5	0.94
Root diameter (mm)	32.91	5.15	33.05	16.37	43.97	27.6	0.29
External luminosity	41.02	3.09	41.38	32.85	48.51	15.66	0.16
External color saturation	21.91	1.89	21.45	18.10	27.24	9.14	0.16
External hue angle (°)	56.61	1.91	56.33	53.62	64.84	11.22	7.11
Internal luminosity	84.28	2.32	84.64	77.39	88.11	10.72	0.77
Internal color saturation	11.72	1.32	11.97	9.05	14.23	5.17	−0.73
Internal hue angle (°)	86.72	1.69	86.53	81.86	89.29	7.43	−0.01
Starch content (%)	26.85	8.09	29.57	14.18	44.58	30.4	−0.86

SD: standard deviation; Mdn.: median; Min: minimum; Max: maximum.

Table 3. Evaluated parameters in cassava grown as intercropped with sapodilla established at two planting densities.

Parameters	Low density[a]	High density
Aerial biomass (kg/plant)	3.31 a	2.36 b
Root quantity (number/plant)	13.11 a	8.38 b
Root biomass (kg/plant)	2.914 a	1.93 b
Root length (cm)	32.54 a	29.16 a
Root diameter (mm)	34.62 a	31.20 b
External luminosity	41.60 a	40.43 a
External saturation	22.66 a	21.15 b
External hue angle (°)	56.85 a	56.36 a
Internal luminosity	83.91 a	84.64 a
Internal saturation	11.51 a	11.93 a
Internal hue angle (°)	85.99 b	87.44 a
Starch content (%)	29.58 a	24.11 b

[a] Different letters between columns indicate statistically significant differences between groups. Low density: 156 trees per hectare, High density: 312 trees per hectare.

Table 4. Parameters evaluated in cassava cultivated with different nutritional sources.

Parameter	Inorganic[a]	Organic	Control
Aerial biomass (kg/plant)	3.55 a	2.93 a	2.02 b
Root quantity (number/plant)	11.66 a	10.75 a	9.83 a
Root biomass (kg/plant)	2.63 a	2.37 a	2.26 a
Root length (cm)	32.83 a	32.84 a	26.87 b
Root diameter (mm)	31.52 b	34.49 a	32.72 ab
External luminosity	40.82 a	41.61 a	40.62 a
External saturation	22.41 a	21.82 a	21.50 a
External hue angle (°)	56.95 a	56.32 a	56.54 a
Internal luminosity	83.05 b	85.67 a	84.11 ab
Internal saturation	12.33 a	11.44 a	11.39 a
Internal hue angle (°)	85.83 b	87.36 a	86.96 ab
Starch content (%)	24.90 b	29.71 a	25.94 ab

[a] Different letters between columns indicate statistically significant differences between groups. The nutrition treatment involved the application of 146-46-60 with Urea, DAP, and K_2Cl for the inorganic treatment, and bokashi with EM for the organic treatment. The absolute control had no additional nutritional sources other than those present in the soil.

interactions between plots (p=0.9453); however, it is observed that the sapodilla planting density (p=0.0041) and fertilization (p=0.0027) significantly affect this variable, producing a higher biomass when cassava is intercropped at a lower density and when a fertilizer is applied. The cassava crop intercropped with sapodilla at a density of 156 trees/ha shows an aerial biomass production of 21.8 t/ha. On the other hand, in the nutrition factor, the inorganic and organic treatments were statistically equal to each other and higher than the control, with an average production of 21.38 t/ha. The results obtained are higher than those reported by Gómez *et al.* (2016), who evaluated cassava at different densities, finding a production of 11.1 t/ha at a density of 70 thousand fresh aerial biomass of cassava, which was established in the Colombian Caribbean and harvested in the first months of the year. This difference is likely due to the fact that the cassava was harvested between 75 and 105 days.

The number of commercial roots did not show interactions (p=0.1127) or significant differences based on the nutrition factor (p=0.4654), but it did show significance regarding the sapodilla planting density (p=0.0004). The 152 trees/ha density presented a higher number of roots than the 312 trees/ha density (Table 3). The number of commercial roots found in this study (Table 2) is similar to those reported by Amara *et al.* (2024), who characterized a yam germplasm bank in Sierra Leona. The root biomass refers to the total yield of commercial roots. This variable did not show interaction (p=0.4642) nor was it significant regarding nutrition (p=0.7018), but it was significant in relation to its cultivation in an intercropping system at different densities (p=0.0116). The intercropped cassava cultivation in sapodilla at a density of 156 trees/ha yields 19.23 t/ha of commercial roots, while increasing the planting density of sapodilla results in significantly lower yields of 12.73 t/ha (Table 3). The plant weight obtained in the present study is lower than that reported by Amara *et al.* (2024), which could be attributed to multiple factors such as genotype, planting density, planting-to-harvest time, and harvest season. However, it is similar to the findings by Cohelo *et al.* (2017), who, when studying the spatial distribution of cassava, found that simple row plantations intercropped with beans produced 2.29 kg/plant.

The root length was not affected by the interaction of the studied factors ($p=0.7275$) or by planting density ($p=0.0991$), but it was affected by the applied nutrition ($p=0.0252$). The roots of cassava plants fertilized with both organic and inorganic sources were similar to each other and superior to the control, which showed values 18% lower (Table 4).

Root diameter shows an interaction between factors ($p=0.0441$), where lower density and organic nutrition result in thicker roots. The factors planting density of sapodilla ($p=0.0002$) and nutrition ($p=0.0291$) also showed significance in the model. The mean comparisons indicate that when the density is higher, roots are 10% thinner than those at the lower density (Table 3); moreover, organic nutrition (Table 4) results in thicker roots compared to those fertilized with inorganic sources. This is likely because the organic fertilizer acts as a soil conditioner, providing better conditions for the roots to thicken more easily.

Regarding the external color, the lightness and hue angle were not affected by the factors studied ($p>0.05$). However, the color saturation of the cassava peel was significantly affected by the sapodilla planting density ($p=0.0178$). At the lowest density, there is higher saturation, meaning the color appears with greater purity.

In the internal part of the cassava root, the luminosity parameter is affected by the nutrient source ($p=0.0199$), and the hue angle is affected by both density ($p=0.0052$) and nutrition ($p=0.0397$), while other factors did not significantly affect these variables ($p>0.05$). The color saturation was statistically similar across all studied conditions ($p>0.05$). The results indicate that the shades of white in the pulp vary, with a higher value at the lowest density, while these values of 87° can be reached with organic nutrition. It is also evident that organic nutrition provides a brighter pulp compared to inorganic sources, which result in more opaque tones.

Starch content is the quality variable linked to the use of cassava for flour production, as it is a carbohydrate that primarily provides its chemical and mechanical qualities. The factors studied showed that their interaction significantly affects the starch ($p=0.0003$) present in the cassava, as well as density ($p>0.0000$) and nutrient source ($p=0.0104$). A lower density allows for cassava to be obtained with a higher starch percentage (Table 3). On the other hand, organic nutrition was similar to the control and was statistically superior to inorganic nutrition. The results obtained are consistent with the values reported by Aristizábal and Sánchez (2007), who provide reference values for starch content ranging from 17.5% to 39.4%.

CONCLUSIONS

It is concluded that planting density and nutrition influence the quality characteristics and yield of cassava. A lower planting density in an intercropping system with cassava allows for greater production of aerial biomass, root biomass, and starch. Organic nutrition is a good option for cassava cultivation, as it provides the same benefits as inorganic nutrition in the morphological characteristics of cassava, but offers better qualities in starch content and internal coloration.

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