Article

Comparative yield of cassava under mineral fertilization and green manure

Wanderley Magaña Valenzuela[1]
José Jesús Obrador Olán[1§]
Eustolia García López[1]
Mepivoseth Castelán Estrada[1]
Eugenio Carrillo Ávila[2]

[1]Postgraduate College-*Campus* Tabasco. Peripherical Carlos A. Molina km 3.5 s/n, AP. 24. Cárdenas, Tabasco, Mexico. CP. 86500. (magana.wanderley@colpos.mx; rogarlopez@colpos.mx; mcastelan@colpos.mx). [2]Postgraduate College-*Campus* Campeche. Federal Highway Haltun-chén-Edzná km 17.5, Sihochac, Champotón, Campeche, Mexico. CP. 24450. (ceugenio@colpos.mx).

[§]Corresponding author: obradoro@colpos.mx.

Abstract

The use of legumes as green manures in agri-food crops is a cultural practice that reduces the excessive use of fertilizers, improves fertility and reduces soil erosion. The crotalaria (*Crotalaria juncea* L.) is a legume that is used as green manure due to its rapid growth and nitrogen contribution to the soil. The objective of the study was to evaluate the effect of the legume *Crotalaria juncea* L. as green manure on cassava yield and soil fertility at different plantation densities. The experiment was carried out from September 2018 to April 2019 in the Experimental Field of the Postgraduate College-Tabasco *Campus*. A completely randomized experimental design with a 2 x 2 factorial arrangement was applied, the statistical analyzes were performed in the Statistic program, 2003. The yield of cassava tuberous roots did not show significant differences due to the effect of green manure and the density of plantation, on average the yields in dry and fresh weight were 4.44 and 13.26 t ha^{-1}, respectively. Cassava with a density of 10 375 plants ha^{-1} presented the highest leaf yields (1.23 t ha^{-1}). Regarding the fertility of the soil, there was no significant difference between the treatments, the OM of the soil was not affected by the presence of *C. juncea* and the contents of N, P and K in the soil were 0.27%, 8.25 mg kg^{-1} and 0.32 cmol kg^{-1} respectively, which presented tendencies to increase due to the effect of green manure (*C. juncea*).

Keywords: *Crotalaria juncea* L., legume, plantation density.

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Introduction

Cassava (*Manihot esculenta* Crantz) is one of the most important crops in the subtropical regions of the world, as a source of basic food, animal fodder and primary commercial crop for small producers (Pinto-Zevallos *et al*., 2016). In Mexico, the national average yield is 13.01 t ha^{-1} and it is cultivated in seven states: Tabasco, Chiapas, Campeche, Yucatán, Oaxaca, Michoacán and Jalisco), with Tabasco being the state with the largest planted area (INIFAP, 2017). Tabasco has 476 617 ha with high edaphoclimatic potential (climate and soil), to produce potential yields of 48.3 t ha^{-1} from fresh cassava roots (tuberous roots) (Rivera-Hernández *et al*., 2012); however, the average yields are 11.78 t ha^{-1} (SIAP-SAGARPA, 2018).

The low yields are due, mainly to the low fertility of the soil, the low use of inputs, diseases and pests (McCallum *et al*., 2017). In Tabasco the soils are very varied and most of them are overexploited and have lost their natural fertility, particularly in the areas where cassava is grown, they have good amounts of organic matter (OM) but low availability of nutrients (Palma-López, 2019). In low fertility soils, the use of fertilizers is of great importance to obtain commercial yields and achieve profitability of the crop (FAO, 2002); however, excessive application affects the economy and produces imbalances in the soil, damaging its fertility (Yepis-Vargas *et al*., 1999).

In soils, degradation is only seen in the long term, since the progressive incorporation of a greater quantity of inputs (fertilizers, corrective, etc.) temporarily hides the negative effects, preserving the level of yields, but increasing production costs and deteriorating competitiveness (Amezquita *et al*., 2013). In cassava, doses of 60-120-60 kg ha^{-1} of NPK are managed, which are supplied with fertilizers such as urea, potassium chloride and triple 17, among others (INIFAP, 2017).

Due to the low yields due to low soil fertility, excessive use of pesticides (herbicides, insecticides) and the high costs of fertilizers (McCallum *et al*., 2017), it is necessary to seek management alternatives to obtain profitable yields and maintain fertility of soil. Achieving an optimal density per hectare in the crop (Silva *et al*., 2013) and implementing agroecological technologies such as the incorporation of green manures (AV), constitute a sustainable alternative (Prager *et al*., 2012).

The use of green manure consists of growing plants to be incorporated into the soil, due to its high content of water, sugars, starch and nutrients that crops require, among its many benefits is the contribution of organic matter and the improvement of chemical properties, physical and biological soils, as well as being able to help control pests, diseases and weeds (Cruz *et al*., 2014).

Commonly, legumes are used as green manure because they have the capacity to fix nitrogen (N) from the air through their association with microorganisms of the *Rhizobium* genus, which form nodules, where they fix considerable amounts of this nutrient, therefore, when they are incorporated into the soil, it is added (Saldaña, 2017).

C. juncea is one of the most widely used legumes as green manure, due to its ability to improve soil properties, rapid growth, high dry matter production, high nitrogen fixation, nutrient accumulation and adaptability to low fertility soils, that is why it is considered important to promote soil fertility and increase crop yields (Araujo *et al*., 2018). Therefore, the objective of the study was to evaluate the effect of the legume *Crotalaria juncea* L. as green manure on cassava yield and soil fertility at different plant densities.

Materials and methods

The study was carried out in the experimental field of the Postgraduate College, Campus Tabasco, located between coordinates 18° 01' north latitude; 93° 03' west longitude, at km 21 of the Federal Highway 180 Cárdenas-Coatzacoalcos, in the municipality of Cárdenas, Tabasco. The climate is tropical, the Köeppen system classifies it as Am(g)w" (warm humid with abundant rains in summer), it presents total annual precipitations of 2 324 mm, with dry months in March and April where less than 50 mm fall monthly and other rainy ones like September and October where the precipitation is close to 400 mm monthly. The annual average temperature is 26 °C. The soil is classified as ecutric Cambisol CMeu (Arcillic) (Palma-López *et al*., 2007), which has shown in its productive history a significant decrease in yield.

Cassava planting: planting was carried out at two distances: 1.2 x 0.5 and 1.2 x 0.8 m, which correspond to planting densities of 16 600 and 10 375 plants per hectare respectively, each experimental unit had a useful area of 38.4 m^2 with 2 m spacing between them (Figure 1). The cassava variety 'Sabanera' was used due to its tolerance to pests and diseases and high root yield (INIFAP, 2017).

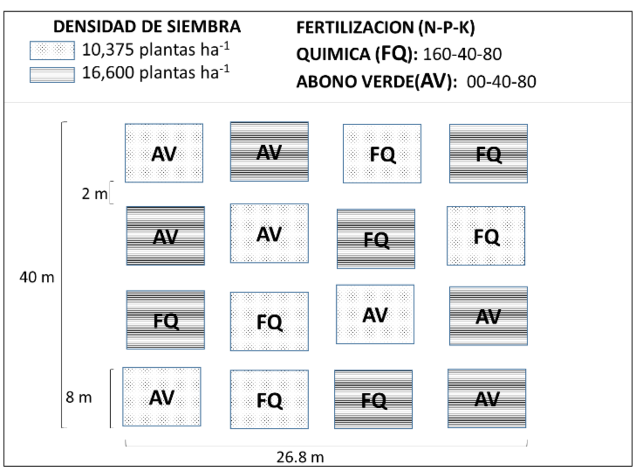

Figure 1. Field establishment of the experimental units studied using a complete randomized design.

Sowing of green manure: *C. juncea* was sown volley in an interleaved manner in the corresponding treatments applying 15 kg ha^{-1} of seed 30 days after sowing of the cassava and the yield was estimated (PCE-SD 150C field scale) , harvesting all the vegetative material in each of the plots and the green manure was incorporated in each corresponding plot, both activities were carried out 60 days after the germination of *C. juncea* (flowering stage) so that the availability of nutrients provided therefore, it coincided with the date of maximum development of the cassava crop.

Treatments: Figure 1 shows the distribution of treatments in the field based on the design of complete random blocks, Table 1 shows the description of each one of them. For chemical fertilization, fertilizers, triple 17, urea, potassium chloride and triple superphosphate were used.

Table 1. Description of treatments.

Treatment	Description
T1	Cassava with a density of 10 375 plants ha^{-1} + fertilization dose 160-40-80 kg ha^{-1}
T2	Cassava with a density of 10 375 plants ha^{-1} + fertilization dose 00-40-80 kg ha^{-1} + green manure
T3	Cassava with a density of 16 600 plants ha^{-1} + fertilization dose 160-40-80 kg ha^{-1}
T4	Cassava with a density of 16 600 plants ha^{-1} + fertilization dose 0-40-80 kg ha^{-1} + green manure

Variables and techniques to use: to estimate the tuber yield in cassava, the following variables were taken into account (Rojas *et al*., 2007).

Yield (t ha^{-1}): to estimate the yield of tuberous cassava roots, only commercial roots, length ≥ 25 cm and diameter ≥ 3 cm were considered. Using a field scale (PCE-SD 150C), the tuberous roots were weighed fresh, obtaining the total yield in kg ha^{-1}, and samples were then taken from six plants per plot, which were labeled and taken to the forced circulation oven of air to constant weight to calculate the yield of cassava tuberous roots in dry weight.

Yucca aerial biomass yield (t ha^{-1}): of the components of the aerial biomass (stem and leaves), on the day of harvest the fresh components of each plot were weighed using a field balance (PCE-SD 150C) and subsequently samples were taken from six plants per plot, which were taken to the forced air circulation oven to constant weight to calculate the dry weight.

Improvement in soil fertility: when establishing the experiment and the cassava harvest in the different treatments, soil samples were taken with a Dutch-type auger at a depth of 0-30 cm, the samples were made up of 15 subsamples per composite sample, taken randomly in a zig-zag, covering the entire terrain.

Statistical analysis: a completely randomized experimental design with a 2 x 2 factorial arrangement was applied to all the data. The first factor was the density, with two levels: 0.8 and 0.50 m between plants and the second factor consisted of the type of fertilization: with levels: 00-40-80 and 160-40-80 of N_2, K_20 P_2O_5, which generated four treatments. For those variables where significant differences were found, a multiple analysis of means was applied by the Tukey method, this in order to determine the best treatment. All the procedures were performed in the Statistic program, 2003.

Results and discussion

The results showed that there were no significant statistical differences in yield (dry and fresh weight) due to the effect of density and fertilization management. Nor was there for the yield components (leaf and stem) due to the effect of density; however, significant statistical differences were observed for leaf yield due to the effect of fertilization management (Table 2).

Table 2. Results of the analysis of variance for the components of yield of aerial biomass and yield of tuberous cassava roots.

Characteristics	Tuber yield		Aerial biomass yield	
	Dry weight (t ha^{-1})	Fresh weight (t ha^{-1})	Dry weight (t ha^{-1})	
Variation factor	Tuberous root	Tuberous root	Stem	Leaf
Density	ns	ns	ns	ns
Fertilization	ns	ns	ns	*
Mean	4.44	13.26	3.26	1.1
Coefficient of variation	7.07	1.73	6.7	12.14

*= indicates significant differences according to the Tukey test at 0.05%, ns= no significant differences.

Dry weight of *C. juncea*. Figure 2 shows the effect of planting density on dry weight (t ha^{-1}) of *C. juncea*. Statistical analysis did not show significant differences. Planting density did not influence the yield of the dry biomass of *C. juncea*. The yield of dry biomass showed a tendency to increase with the density of 10 375 plants ha^{-1}, which is attributed to the competition that one crop exerts over another in each of the treatments studied.

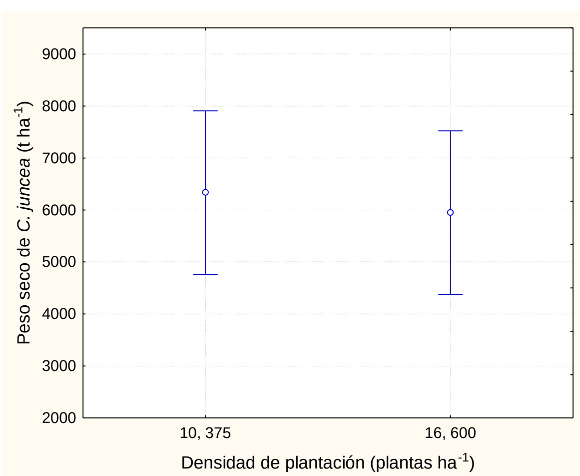

Figure 2. Effect of planting density on dry weight yield of *Crotalaria juncea*.

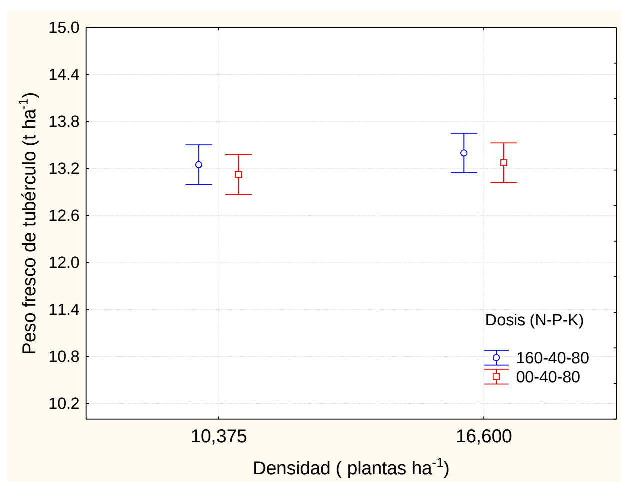

Figure 3. Effect of plantation density and fertilization dose on the yield in fresh weight of cassava tuber.

On average, the dry biomass yields were 6 142.56 kg ha^{-1}. These results are found in the range of dry biomass produced by *C. juncea* described by Brunner *et al*. (2009), but lower than those found by Almeida-Santos *et al*. (2019) of 7.16 t ha^{-1}. Studies such as that of Hinds *et al*. (2013) show values of dry biomass of *C. juncea* of 6 725 kg ha^{-1} slightly higher than those found, Gamez *et al*. (2019) for its part obtained between 3 000 to 4 000 kg ha^{-1} of dry matter; that is, 44.7% less dry biomass compared to the highest biomass value obtained in this work (6 142.56 kg ha^{-1}).

Fresh weight of tuberous roots. The fresh weight (t ha^{-1}) did not present significant statistical differences in any of the treatments. The yields of tuberous roots with green manure (*C. juncea* + NPK dose 00-40-80) were similar to those of chemical fertilization (NPK 160-40-80) in both densities (Figure 3), this is because the association of *C. juncea* with the *Rhizobium* bacteria in the soil, gives rise to specialized structures called nodules, where the biological fixation of atmospheric nitrogen (FBN) occurs, which was used by cassava cultivation when perishing (Adekiya *et al*., 2019). Due to the effect of the greater plantation density (16 600 plants ha^{-1}), the yields tended to increase slightly, Rojas *et al*. (2007) mention that a higher plantation density increases the yield per hectare.

On average, the fresh weight of tuberous roots of the treatments was 13.41 t ha^{-1}, which is higher than the state average (11.78 t ha^{-1}) and similar to the national average (13.01 t ha^{-1}) (SIAP-SAGARPA, 2018). The results obtained are similar to those obtained by López-López *et al*. (2018) that ranged between 8.7 and 13.4 t ha^{-1}, showing a notable difference with what was reported by Joao *et al*. (2017) who report high yields, up to 42 t ha^{-1}. Nitrogen fertilization promotes an increase in the yield of tuberous cassava roots (Kaweewong *et al*., 2013; Adekiya *et al*., 2019). In the present work, everything seems to indicate that *C. juncea* completed nitrogen fertilization to obtain similar yields to N-P-K 160-40-80 fertilization.

Yield of the aerial biomass of cassava (*M. esculenta*) with the use of green manure (*C. juncea*) and mineral fertilization

Leaf dry weight. For this yield component, a statistically significant difference was found in terms of planting density, but not, for the effect of managing the dose of fertilization and green manure. Leaf dry weight was higher at the lowest density (10 375 plants ha^{-1}) with average yields of 1.23 t ha^{-1} for NPK mineral fertilization (160-40-80) and the use of green manure (*C. juncea* + NPK dose 00-40-80), that is, the low density exerted a beneficial effect on leaf production compared to the high density (Figure 4), this effect is attributed to the fact that the low planting density increases the space between plants which causes plants to fully develop their biomass and there is no competition for essential elements such as light and water (Rojas *et al*., 2007).

Aristizabal and Sánchez (2007), point out that the amount of leaves is an important characteristic in the preparation of concentrates for animals, since it is known that the highest percentages of cassava protein, minerals and vitamin C are concentrated in the leaves and the stem. The results are slightly low compared to that reported by Bolivar and Molina (2007) whose yields range from 1.47 to 1.94 t ha^{-1}, but high compared to those reported by Cadavid and López (2015) of 0.2 t ha^{-1} of dry matter leaves.

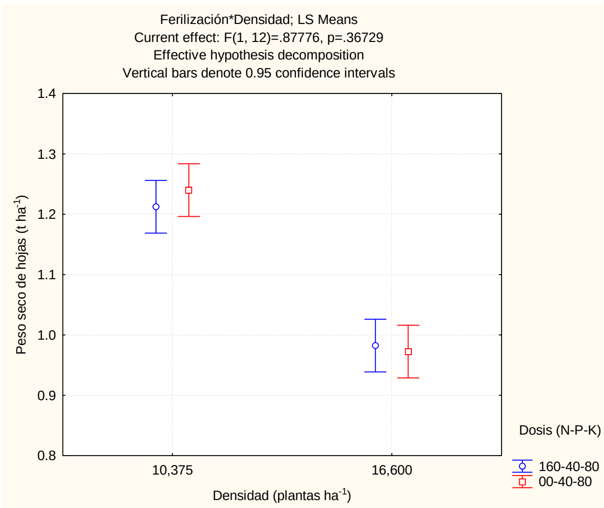

Figure 4. Effect of planting density and fertilization dose on the dry weight yield of cassava leaves.

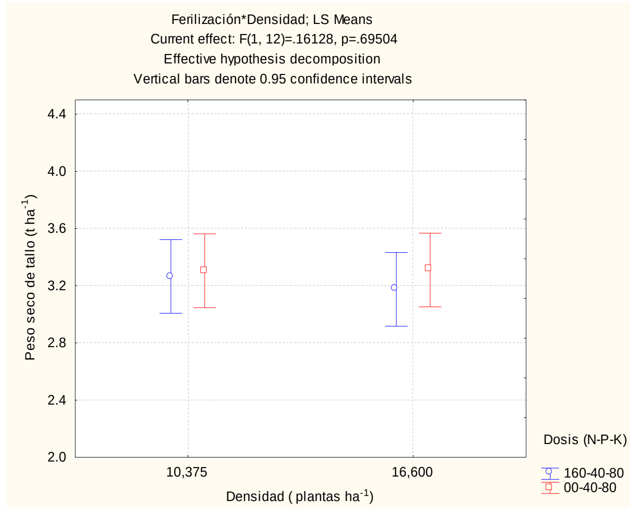

Figure 5. Effect of planting density and fertilization dose on the dry weight yield of cassava stem.

Stem dry weight. Stem dry weight yield did not show significant statistical differences due to the effect of the plantation density or the effect of the fertilization dose (Figure 5). The values of dry weight of stem with the use of green manure (*C. juncea* and doses N-P-K 00-40-80) showed tendencies to increase in the two planting distances. On average, the stem yields were 3.25 t ha^{-1}, which are high compared to those obtained by Bolivar and Molina (2007) of 1.05 and 1.39 t h^{-1}. N, P and K are the main nutrients that are related to the development of the cassava stem, the incorporation of green manures promotes soil fertility and the incorporation of nutrients through the recycling and mobilization of nutrients, in particular turning them into assimilable forms for plants (García *et al*., 2000; Cháves-González *et al*., 2018).

It is noteworthy that in the present study no statistical differences were observed in favor of the use of green manures; however, in fertile soils, the use of these or chemical fertilizers usually express similar responses regarding agronomic yield, given that the soil has the necessary nutrient elements, in other cases, low physical, chemical and biological properties, limit the positive effect of fertilizers or fertilizers by not allowing crops to express their maximum yield, the combined use of green manure and fertilizer is an alternative that favors increased yields and the sustainability of the system (Subaedah and Nirwana, 2015; Combatt-Cabellero *et al*., 2016).

Soil fertility under the use of green manure (*C. juncea*) and mineral fertilization

Next, the results of the chemical analyzes of the soil before sowing (Table 3) and after the incorporation of *C. juncea* as green manure are discussed. N0M 0-21 (2000) was considered to establish the nutritional diagnosis.

Table 3. Soil fertility analysis of the cassava plots under study before planting and after soil preparation (0-30 cm depth).

Sampling	pH (H_2O)	EC (dS m^{-1})	OM	Nt	P (mg kg^{-1})	K	Ca	Mg	Na	CIC	Ar	Li	Are	Classification Textural
			(%)			(cmol+ kg^{-1})					(%)			
ASC	5.87	0.05	2.1	0.15	8.2	0.09	10.16	0.27	0.12	21.76	56	42	2	Slimy-clayey

Nt= total nitrogen; P= phosphorus-olsen; Ar= clay; Li= silt; Are= arena; EC= electric conductivity.

The OM and N contents before sowing and after preparing the soil resulted in medium levels. The C/N ratio was 8.1, which indicates that there is a good mineralization of residues and therefore a prompt availability of organic N, although in insufficient quantities for cassava cultivation, being necessary to apply N as fertilizer (Gamarra *et al*., 2017). The P-Olsen value found was 8.2 ppm, which is classified as medium and coincides with the values reported by Pascual-Córdova *et al*. (2017) for this type of soil in which they vary mostly from medium to low.

The pH was moderately acidic, at this value most of the nutrients are available for the study plant (Salgado-Garcia *et al*., 2013). The CIC value was medium, which indicates that it is a soil of good fertility (Salgado-García *et al*., 2013) with significant clay content, the K content was 0.09 cmol+ kg^{-1}, it is classified as low and coincides with the values found by Palma-López *et al*. (2007) in Cambisol soils for sugar cane use. Mg and K are two elements of the exchange bases that show to be deficient in soils in the area (Pascual-Córdova *et al*., 2017), the values of 10.16 of Ca are classified as high and for Mg they are classified as very low (Salgado-García *et al*., 2013).

Effect on the chemical properties of the soil after the incorporation of *C. juncea*

Figures 6, 7 and 8 show the effect on soil properties 30 days after incorporating *C. juncea* into the soil in the different treatments.

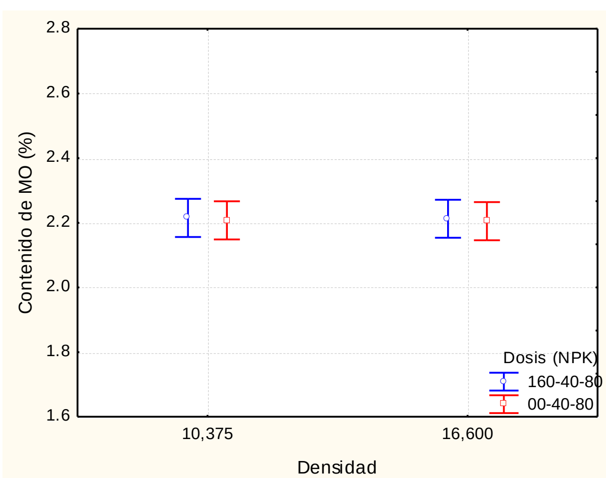

Figure 6. Organic matter of the soil under the effect of the sowing density and fertilization dose.

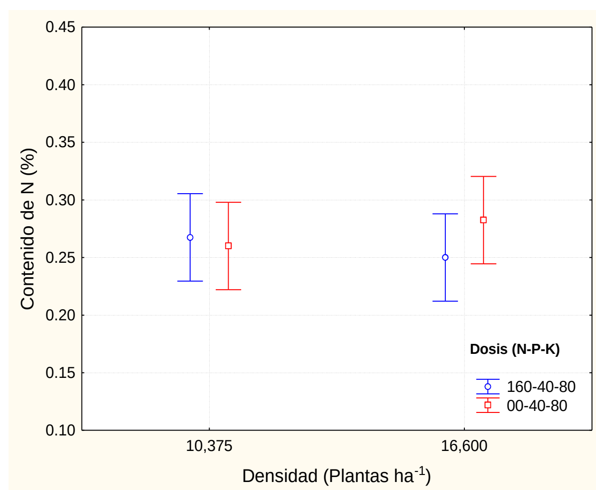

Figure 7. Behavior of total soil nitrogen by effect of planting density and fertilization dose.

Organic material

The statistical analysis did not show significant statistical differences between the treatments, on average the OM value was 2.21%, which are low compared to that reported by Palma-López *et al*. (2007), of 4.41% in soils Eutric Cambisols (CMeu). Treatments with T2 and T4 green manure (*C. juncea* + NPK dose 00-40-80) presented OM percentages statistically equal to treatments with T1 and T3 mineral fertilization (NPK dose 160-40-80) in both plantation densities, due to the ability of green manures to increase OM content in the soil (Cruz *et al*., 2014), the application of *C. juncea* as green manure contributes to a slight increase in OM percentage, the positive effects of the improvement of soil fertility are evident, studies such as that of Cháves-González *et al*. (2018) confirm this fact, where increases of 47% in OM content are shown in addition to the improvement of other nutrients, compared to the characteristics of the initial soil.

Nitrogen (N)

In Figure 7, the behavior of nitrogen after incorporating *C. juncea* (20 days) to the soil is shown, the statistical analysis did not show significant statistical differences due to the effect of fertilizer management and planting density, on average the percentage of total N remained between 0.26 and 0.28%.

The application of green manure (*C. juncea* + dose 00-40-80) together with the density of 16 600 plants ha^{-1} (T4), presented the highest value of total N (0.28%). Legumes contribute to nitrogen nutrition allowing a better use of nitrogen and higher productivity (Cháves-González *et al*., 2018). Legume residues can increase the mineral N in the soil and the amount of N stored in the microbial biomass.

In several experiments with green manure, contributions between 150 and 200 kg ha^{-1} of N are mentioned (Castro *et al*., 2018; Almeida-Santos *et al*., 2019). Among the various nutritive elements, nitrogen is the one required in higher amounts and directly influences productivity (López-López *et al*., 2018), the availability of this nutrient in the soil is determined by the conditions and the quantity from organic matter of the soil (Cookson *et al*., 2002), the microorganisms decompose the OM in the mineralization process to make nitrogen available in the soil. Harbans *et al*. (2005); Adenkule (2011) indicate that *C. juncea* as a soil improver has shown important results especially for the high contributions of organic matter, a property that is related to many parameters that confer properties for increasing soil fertility and crop yield (Almeida-Santos *et al*., 2019); however, this was not observed in the present study. Diacono and Montemurro (2010) indicate that organic amendments usually show their effects generally after several cultivation cycles.

P-Olsen (mg kg^{-1})

No significant statistical differences were found for phosphorus, although the effect of lower density (10 375 plants ha^{-1}) presented increasing tendencies (Figure 8). Fertilization with green manure (C. *juncea* + N-P-K dose 00-40-80) on average presented values of 8.7 mg kg^1 while chemical fertilization (N-P-K dose) 160-40-80 presented values of 7.7 mg kg^{-1}. Which are classified as medium (Salgado-García *et al*., 2013) and are superior to those reported by Cadavid and López (2015) of 4.8 mg kg^{-1} with *C. lencea* legume in Colombian soils.

90% of P is found in the soil, but only a small part is absorbed by the roots quickly, requiring it to be restored through organic residues or commercial fertilizers, allowing interaction with other elements (Fernández, 2007). The slight contribution of this nutrient in the treatment (*C. juncea* + dose 00-40-80) is due to the fact that the legume not only provides N; through its roots it also absorbs other nutrients such as P and K that accumulate in the biomass area to be returned to the soil (ECHO, 2017).

Potassium (K)

With regard to the content of the exchangeable cation K, it is observed in Figure 9 that there were no significant statistical differences in any of the treatments, on average the content of K for the treatments with green manure (*C. juncea* + dose NPK 00-40- 80) was 0.33 cmol kg^{-1} ha^{-1} slightly higher than nitrogen fertilization (160-40-80) in both densities, this content is classified as medium (Salgado-García *et al*., 2013).

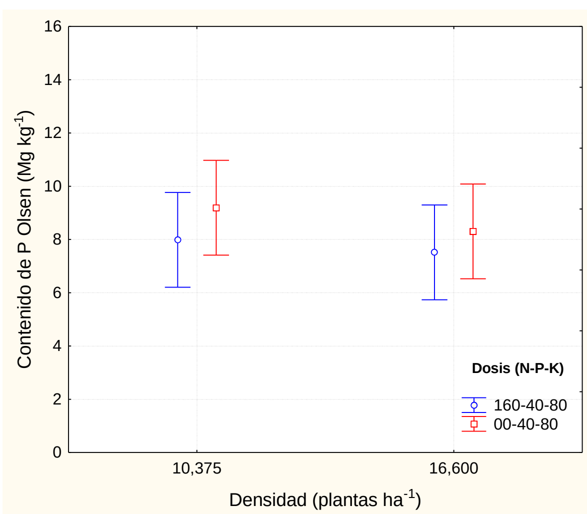

Figure 8. P Olsen behavior of the soil due to the effect of planting density and fertilization dose.

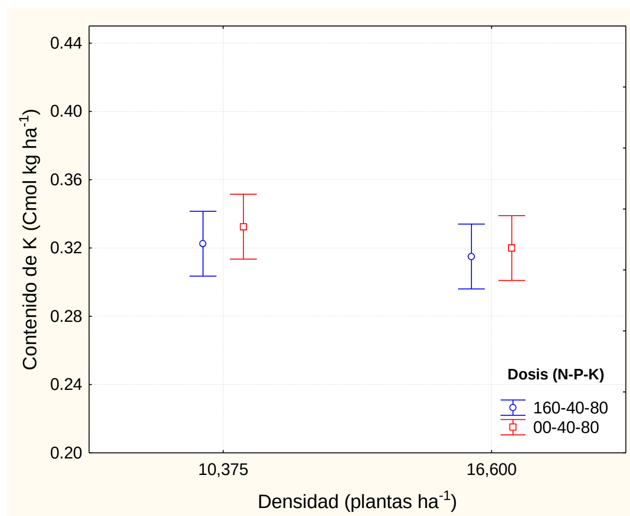

Figure 9. Soil behavior K due to the effect of planting density and fertilization dose.

K contents in soils are dependent on three factors; plant absorption, leaching to lower layers and fixation of clay minerals (Zúñiga-Estrada *et al*., 2010). Green manures can increase the content of P and K in the soil in the contribution of recycling and mobilization of nutrients, in particular turning them into assimilable forms for plants (García *et al*., 2000).

Conclusions

The application of *Crotalaria juncea* L. does not increase the yields of the tuberous roots of cassava, but it does maintain good yields without the need for the use of chemical nitrogen fertilization. Stem dry weight was similar in all treatments; however, at dry leaf weight, the lowest density produced the most. The chemical properties of the soil did not show significant statistical differences in any of the treatments.

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