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Scientific Paper

Effect of organic fertilization on morphological and agronomic indicators of two varieties of *Manihot esculenta* Crantz

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Abstract

Objective: To evaluate the effect of organic fertilization on morphological and agronomic indicators of two varieties of *Manihot esculenta* Crantz.

Materials and Methods: In 2019 a trial was conducted during nine months with two varieties of *M. esculenta* (INIVIT Y93-4 and Señorita). A randomized block experimental design was applied, with four treatments and three replicas: T1 control-mineral fertilization, T2-fertilization with 700 g/plant of enriched biochar, T3-fertilization with 700 g/plant of compost and T4-fertilization with 350 g of enriched biochar + 350 g of compost/plant. Morphological and agricultural yield variables were measured. Variance analysis and mean comparison through Duncan's test ($p \leq 0,05$) were carried out.

Results: During the 150 days of study, the morphological variables height and stem diameter, associated to the growth of *M. esculenta* in the varieties INIVIT Y93-4 and Señorita, did not show significant differences with regards to the control due to the effect of fertilization. The utilization of biochar, enriched or combined with compost, guaranteed between 3 and 4 kg/m^2 of *M. esculenta* yield in the varieties INIVIT Y93-4 and Señorita, without significant differences compared with the chemical fertilization.

Conclusions: The alternatives of organic fertilization stimulated plant growth during their vegetative phase and guaranteed *M. esculenta* yields, comparable with chemical fertilization in the varieties INIVIT Y93-4 and Señorita.

Keywords: biochar, IHPLUS®, compost, yield, soil

Introduction

Manihot esculenta Crantz (cassava) constitutes an important agricultural item in tropical countries and an excellent substitute of commercial concentrate feed for animal feeding. It stands out for its high production of roots, rich in starch and foliage, with high protein percentage. The stem and leaves of this plant can be used to produce protein meals aimed at poultry and fish feeding (Hurtado-Espinoza, 2019); the roots and peels for ensiling and feeding dairy cows (López-Herrera *et al*., 2019) and to obtain probiotics from their fermentation (Urbina-Orozco and Guerrero-Montenegro, 2018).

The potential of agricultural yield of *M. esculenta* is between 15 and more than 45 t/ha (Howeler, 1985). The crop extracts from the soil volumes of macroelements equivalent to 62 and 202 kg/ha of N, in the roots and the total plant; 23 and 73 kg of P_2O_5/ha; 197 and 343 kg of K_2O/ha; 36 and 179 kg of MgO/ha; 17 and 183 kg of CaO/ha; 3 and 15 kg of S/ha. According to the report by Paneque-Pérez and Calaña (2001), the nitrogen, phosphorus and potassium extractions (kg/t of agricultural product) correspond to 1,71 N; 1,43 P_2O_5 and 7,43 K_2O.

Biochar and its combination with compost constitute an option that could satisfy the nutritional and soil quality demands for the production of *M. esculenta*. The compost provides assimilable substances, such as minerals and degradation products, available as energy source (carbohydrates, lignins, proteins, tannins, fatty acids) in the presence of edaphic microorganisms of the labile faction.

In addition, it enriches the humic fraction, more stable, constituted by fulvic acids, humic acids and humins (Ballesteros-Trujillo *et al*., 2018). Biochar is a versatile material that has a high concentration of mineralization-resistant pyrogenic carbon (Ouyang *et al.,* 2016).

The biochar from sicklebush (*Dichrostachys cinerea* L.), mixed with the soil in a volumetric ratio 1:1, guarantees the storage and holding of more than 0,5 g of water per each gram of substrate during six days; while the soil lacking in fertilizer only stores 0,3 g (Milera-Rodríguez *et al*., 2020).

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The objective of this study was to evaluate the effect of organic fertilization on morphological and agronomic indicators of *M. esculenta* varieties.

Materials and Methods

Geographic location. The experiment was conducted in La Ceiba farm, site adjacent to the Pastures and Forages Research Station Indio Hatuey (EEPFIH), in the Perico municipality, of Matanzas province, Cuba. The farm is located between 22°, 48 'and 7' North latitude and 81° and 2' West longitude, at 19,9 m.a.s.l.

Climate characteristics. During the crop cycle, the agrometeorological conditions were characterized by typical seasonal differences between the first growth stages, which corresponded to the dry season (March to April) and the reproductive and agricultural maturity stage, which coincided with the rainy season (May to September).

Soil particularities. The soil corresponds to the genetic type ferralitic red (Hernández-Jiménez *et al.,* 2015). The topography is flat, with slope from 0,5 to 1,0 %, and depth to the limestone of 1,50 m.

The soil analysis was carried out in the Agrochemistry Laboratory of the Institute of Agricultural Sciences (INCA). For such purpose the following methods were applied: pH in H_2O, potentiometry, soil-water ratio: 1:2.5 (ONN, 1999a); OM, Walkley and Black (ONN, 1999b); exchangeable cations, extraction with NH_4Ac 1 mol L-1 at pH 7; determination by complexometry (Ca and Mg) and flame photometry (Na and K) (ONN, 1999c); P, Oniani (extraction with H_2SO_4 0.1N and determination by UV-visible spectrometry (ONN, 1999d).

According to the initial chemical analyses, from samples taken at a depth from 0 to 20 cm and the agrochemical interpretation table (Paneque-Pérez and Calaña, 2001), the soil pH in the experimental site was slightly acid (6,14). The values of K and exchangeable Na (0,09 cmol$^{(+)}$/kg and 0,14 cmol$^{(+)}$/kg, respectively) were low. The concentrations of exchangeable Mg (3,9 cmol$^{(+)}$ /kg) were high. The Ca values were moderate (11,1 cmol$^{(+)}$/kg). The OM concentration (2,94 %) was classified as low, with regards to most of the optimum soils for agricultural use.

Experimental design and treatments. In the trial a randomized block design, with three replicas, was applied. The evaluated treatments were four:

- T1 control: mineral fertilization, with 80 g of fertilizer/plant (complete formula 9-13-17), according to the soil characteristics and the cultivation technical norms, with productive potential of 30 t/h.
- T2: fertilization with 700 g/plant of enriched biochar.
- T3: fertilization with 700 g/plant of compost.
- T4: fertilization with 350 g of enriched biochar + 350 g of compost/ plant.

Experimental area. The planting area comprised 1 152 m^2, with 12 plots in total per *M. esculenta* variety. The rough area of the plots was 48 m^2, with 48 plants/plot and a planting frame of 1 x 1 m. the planting density corresponded to 10 000 plants/m^2.

Experimental procedure. The experiment was carried out during nine months of crop growth.

Table 1. Performance of the agrometeorological variables during the cultivation cycle of *M. esculenta*.

Variable		Dry season	Rainy season
Temperature, °C	Maximum	30,2	33,6
	Minimum	16,3	21,8
	Mean	22,8	26,8
Relative humidity, %	Maximum	98	97,8
	Minimum	45,4	50,8
	Mean	76,8	79,8
Rainfall, mm		77,9	191,3
Evaporation, mm	Night	1,4	1,5
	Day	4,8	6,0
	24	6,2	7,5

The planting moment was December, 2018. The experimental period comprised two evaluation stages: vegetative growth during the first 150 days and agricultural yield in the ninth month. The varieties INIVIT Y93-4 and Señorita were used in the study.

The soil was prepared by the conventional method. Planting, in December, was carried out by agamic seed. Irrigation was performed fortnightly during the first four months of growth.

The substrates used for the organic amendments were prepared from the mixture and total homogenization of the components, according to the proportion established for each treatment. The chemical fertilizer, as well as the manures, was deposited in the planting niche under each propagule, at the moment of sowing.

Compost. The compost was elaborated in the pilot plant of organic-mineral fertilizer of the EEPFIH, from the processing of cattle feces under aerobic conditions, spontaneous vegetation and gardening waste, enriched with IHPLUS®. It was applied with knapsack sprayer, at a rate of five liters per ton of compost at the moment of irrigation, with 15-day frequency.

IHPLUS® is a product constituted by a mixture of different organisms, aerobic as well as anaerobic, compatible from the physiological point of view, which are mutually complemented. This solution has a pH between 3,2 and 3,8. It was used as liquid inoculant, enhanced from a mixture of 1 kg of *Saccharum officinarum* L. final molasses and 1 kg of mother solution and 20 kg of water without chlorine. Its fermentation took place during 10 days (Milera-Rodríguez *et al*., 2020).

Biochar. The biochar was obtained through a pyrolysis process of the sicklebush (*D. cinerea*) stems, during two hours, in a pit kiln. For that purpose the Kon-Tiki technology (Schmidt and Taylor, 2014) was used. The biochar was submerged during 24 h in H_2O and cow urine + IHPLUS® at 50 % concentration. The proportion of inoculation in biochar consisted in IHPLUS® (1,5 kg) + cow urine (0,5 kg) + water (1 kg). Afterwards, it was rinsed during 24 h and the substrates were mixed and prepared.

The fertilizers used were in the adequate range of organic matter content for organic fertilizers, according to the criteria expressed by Paneque-Pérez (2010). In addition, the redox potential [Eh (pH7)] and the pH were in the optimum range, between +350 and +450 mV, and pH from 6,5 to 7,5, according to Husson (2012). The biochar was enriched with urine and IHPLUS®. Their Na and Mg content was higher with regards to the compost.

Evaluated indicators. Monthly, during the first five months after planting, measurements of plant height (cm), stem diameter (cm), branch length (cm) and branch diameter (cm) were done. In addition, the agricultural yield (t/ha of differentiated roots) was determined at nine months. The measurements were made in 12 plants, located at the center of each plot.

Statistical analysis. The normality of data distribution in all the variables was verified through the modified Shapiro-Wilk test and variance homogeneity, according to Levene's test. Variance analysis was carried out and the means were compared by Duncan's test ($p \leq 0,05$). The statistical program Infostat 2008 (Di Rienzo *et al*., 2008) was used.

Results and Discussion

Effect on the initial growth and agricultural yield of M. esculenta, INIVIT Y93-4 variety. The morphological variables associated to the growth of *M. esculenta,* INIVIT Y93-4 variety (fig. 1) did not show significant differences due to the effect of fertilization on the variables height and stem diameter during the 150 days of the study. Although differences were found in the diameter and branch length until 120 days after crop planting, they disappeared at the end of the evaluation.

The fact that the treatment with chemical fertilization did not exceed the organic fertilization alternatives indicates that, although synthetic fertilizers are efficient to guarantee the fast growth of crops, by injecting directly in the rhizosphere essential nutrients in assimilable form, such as nitrogen and potassium, plant roots cannot absorb

Table 2. Some agrochemical characteristics of organic fertilizers.

Fertilizer	Eh (pH7) (mV)	pH	Na	K	Ca	Mg	P, ppm.	OM, %
			cmol$^{(+)}$/kg					
Enriched biochar	363,3	7,77	2,39	1,22	34,5	20,25	1797	50,1
Compost + enriched biochar	374,0	7,17	0,82	1,17	35,5	14,0	5804	48,60
Compost	350	6,28	1,06	1,17	34,5	14,5	6407	42,30

them from aqueous solutions in the soil. In this study there were limitations of soil humidity, as a result of insufficient rainfall during the dry season, and this could have limited the effects of chemical fertilization.Nevertheless, organic fertilizers improve soil structure and properties, have regulating effect on temperature and prevent excessive evaporation, which helps to maintain effective humidity for the plants.

The soil/compost and biochar mixtures increase water holding, as consequence of the high proportion of meso- and macro-pores, and the increase of the surface area in the presence of biochar, where the strong capillary forces are effective to store high quantities of water (Teβin, 2016). Under this condition, plants have availability of the aqueous solutions with nutrients previously stored in the biofertilizer structure, which is characterized by a favorable cation exchange capacity and redox potential (Reyes-Pérez *et al*., 2016; Segura-Chavarría, 2018). Hence no differences were found between chemical and organic fertilization.

A similar performance to the one obtained in this study in the *M. esculenta* crop was reported by Iglesias-Abad *et al.* (2018) in *Zea mays* L., who applied organic fertilization from biochar elaborated from residual biomass of *Eucalyptus globulus* Labill, applied at the moment of planting on the row bottom, in doses of 5 t/ha. These authors found phenological characteristics of growth (height, leaf area index and stem diameter) comparable to the treatment of mineral fertilization recommended for corn.

These results in the growth of *M. esculenta* differ from the ones obtained by Reyes-Moreno (2018), who obtained higher growth and development of the leaf and stem part of *Acacia mangium* Willd in the treatments with presence of biochar compared with mineral fertilization. This author stated that one of the causes for which the fertilizer with biochar could cause an increase in the growth and development rate is the quantity of K it makes available for the plants, as a result of a higher photosynthesis capacity, an increase of assimilation in the phloem and a higher stomatal opening and increase in C. This is a characteristic of the fertilizers tested in this study, and explains the fact that the agricultural yield does not differ statistically between the treatments with organic and chemical fertilization (fig. 2).

The performance in the growth stage of the aerial organs and in root formation allowed to consider the response of the crop as indifferent to the various alternatives of organic and chemical fertilization. This indicates, in turn, the superiority of the treatments with organic fertilization, in terms of environmental sustainability, with regards to the mineral one, particularly of the fertilizers with presence of biochar.

The positive influence of organic fertilizers, besides the above-mentioned reasons, is determined, according to Sofo *et al*. (2014) and Díaz (2015), by the abundance of nitrogenous substances that exist in the compost and enriched biochar, in this case, there are cattle urine and IHPLUS® (used to enrich compost as well as biochar), which provides vitamins, organic acids, chelates and antioxidant substances which contribute to the fast decomposition of macromolecules, besides stimulating plant growth at rates comparable to inorganic fertilization.

Panwar *et al.* (2019) found that biochar, applied to 10 cm of soil depth, can decrease the denitrification potential and decrease N_2O emissions. This indicates that the amendment with biochar improves nitrogen transformation in the soil.

Effect on the initial growth and agricultural yield of M. esculenta, Señorita variety. Just like INIVIT Y93-4, the Señorita variety did not show differences in plant height and stem diameter during the first growth stages (fig. 3). Regarding branch length, significant differences were observed in favor of chemical fertilization from 120 days until the end of the evaluation. Meanwhile, in the variable branch diameter, although significant differences were found that favor the control until 120 days; they disappeared at 150 days of study.

Most of the analyzed variables did not differ significantly among treatments. Nevertheless, although a similar response of the crop to chemical fertilization and manure, the organic alternatives would guarantee higher efficiency and sustainability in agricultural systems because they allow to close nutrient cycles from the recycling of available waste in the same agroecosystem.

It is known that the replacement of mineral fertilizers (highly costly and environment contaminant) by organic fertilizers constitutes a challenge, because frequently the nutrient efficiency of chemical fertilizers is higher, and leads to a gap in the yield of crops between conventional and organic agricultural systems (Ponti *et al.,* 2012). In addition, the recycling of crop waste and manure in a conventional farm is not sufficient to maintain the balanced nutrient supply.

Hence the fertilizer obtained from compost with microbial activators IHPLUS® (T3) and enriched biochar combined with compost (T4) is comparable

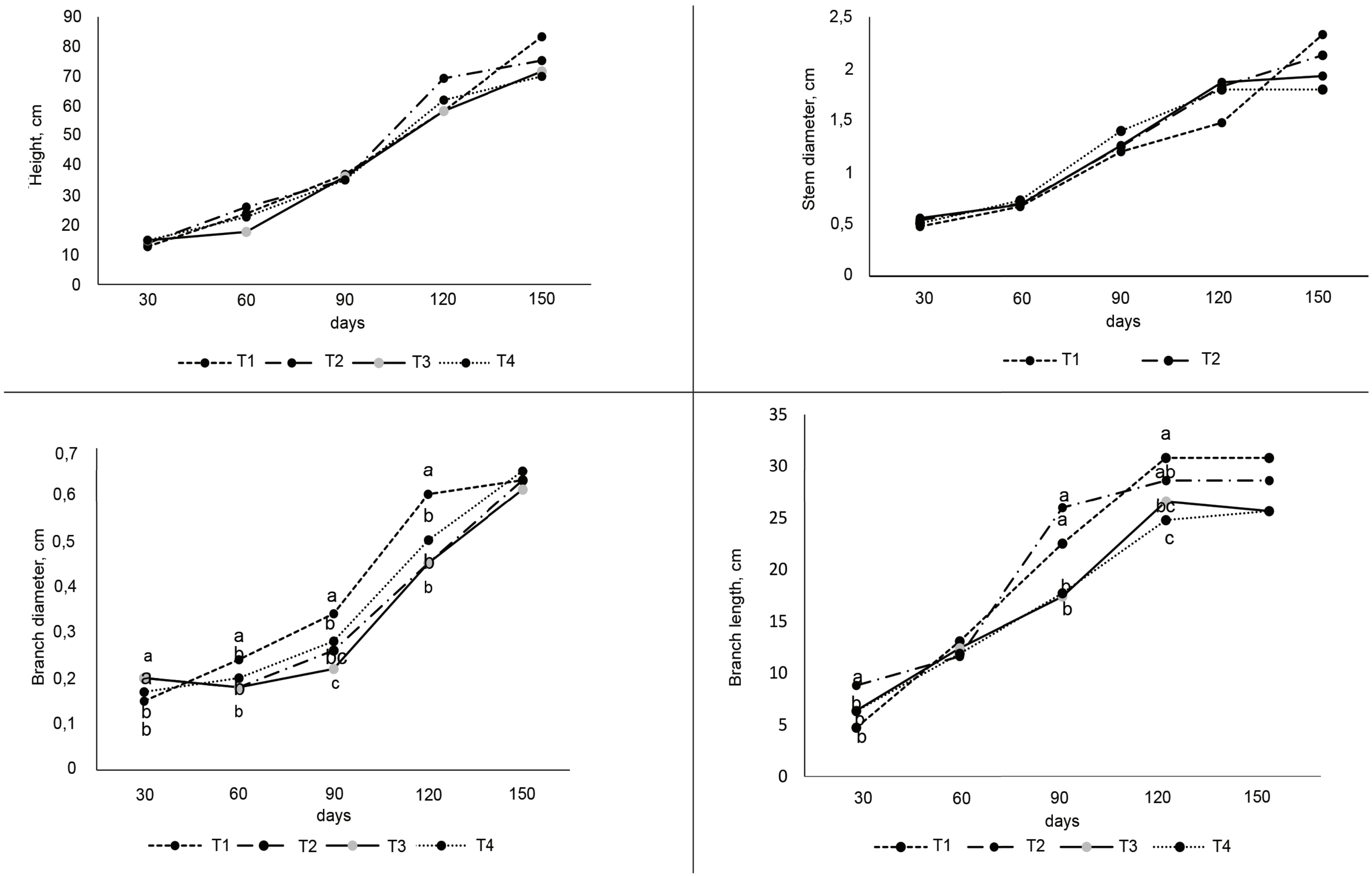

Figura 1. Crecimiento de *M. esculenta* variedad INIVIT Y93-4.
T1-control (mineral fertilization), T2-fertilization with 700 g of biochar, T3-fertilization with 700 g of compost, T4-fertilization with 350 g of biochar + 350 g of compost.
a, b, c: Means with different letter indicate differences at p < 0,05, according to Duncan (1955)

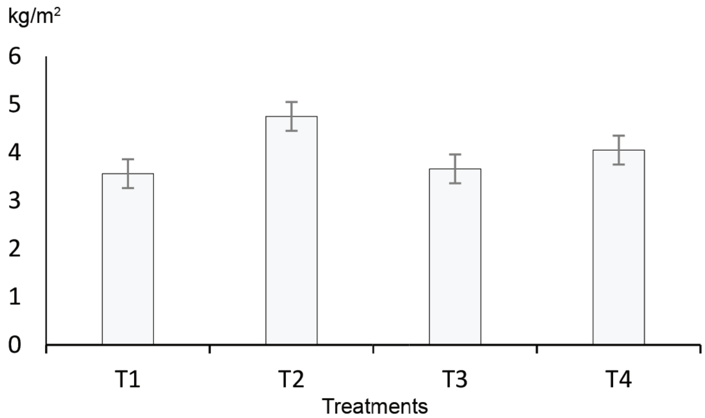

Figure 2. Agricultural yield of *M. esculenta* INIVIT Y 93-4 variety
T1-control (mineral fertilization), T2-fertilization with 700 g of biochar, T3-fertilization with 700 g of compost, T4-fertilization with 350 g of biochar + 350 g of compost.

to chemical fertilization, because it reduces losses by carbon and nutrient leaching in the recycling process. From the technological point of view, this would imply the integration of different agricultural and forestry productions in the same value chain, with the generation of coproducts in an agroecological concept, which places agricultural production in a more resilient and sustainable condition.

Biochar provides organic fertilizer with a new and important value, because it contributes to minimize the emission of greenhouse gasses, due to the high carbon contents that when entering the soil, increase the carbon/nitrogen ratio (Forero-Gutierrez and Navarro-Muñoz, 2019).

López-Molina (2018) showed that biochar can be a more stable soil amendment than bokashi and compost, due to its high content of recalcitrant carbon. The labile carbon fraction can stimulate mineralization of the soil organic matter, but in the long term biochar increases the stabilization of biogenic organic components through the adsorption and humification (Zimmerman, 2011). Forero-Gutierrez and Navarro-Muñoz (2017) observed that the content of organic carbon in the soil increased after the application of biochar (0,14 to 0,18 t/ha).

Torres-Sallan *et al*. (2014) studied biochar compared with compost and the combination of both at a rate of 5 t of C/ha. These authors found in the plots with biochar lower concentrations of oxidizable carbon, which contributes to lose less organic compounds due to leaching, and that the ones that can be solubilized are less reactive with metals and other elements.

The above-expressed arguments allow to explain that the agricultural yield of *M. esculenta*, Señorita variety, did not show statistical variations between chemical fertilization and the organic alternatives (fig. 4). This constitutes a defining element, regarding the possibility of substituting chemical fertilization by the evaluated fertilizers.

The effects of the fertilizers on the crop rhizosphere support the favorable results of the use of compost with enriched biochar. The pH of the soil solution is a critical factor for plant growth (Weil y Brady, 2010), and although the tolerance to acid and alkaline conditions varies considerably among crops, all of them have quite a narrow range of optimum conditions of pH.

M. esculenta is known for its capacity to grow under acid soil conditions. Yet, the acidity degree or highly alkaline conditions can affect its growth, mainly due to the influence the pH has on the availability of nutrients for the plant (Weil and Brady, 2010).

The fertilizers, elaborated based on compost and biochar, contribute to the reduction of nutrient leaching and acidity, which allows soil pH to increase (Forero-Gutierrez and Navarro-Muñoz, 2017). Biochar, enriched with the labile fraction of compost and with nutritional substances (cow urine and IHPLUS®), conditions a soil pH close to neutrality (Milera-Rodríguez *et al*., 2020).

Omondi *et al*. (2016) proved that the soil amendments with biochar contribute to reduce the soil apparent density by 7,6 %; while they increase porosity by 8,4 %, total stability by 8,2 %, available water holding capacity by 15,1 % and saturated water conductivity by 25,2 %.

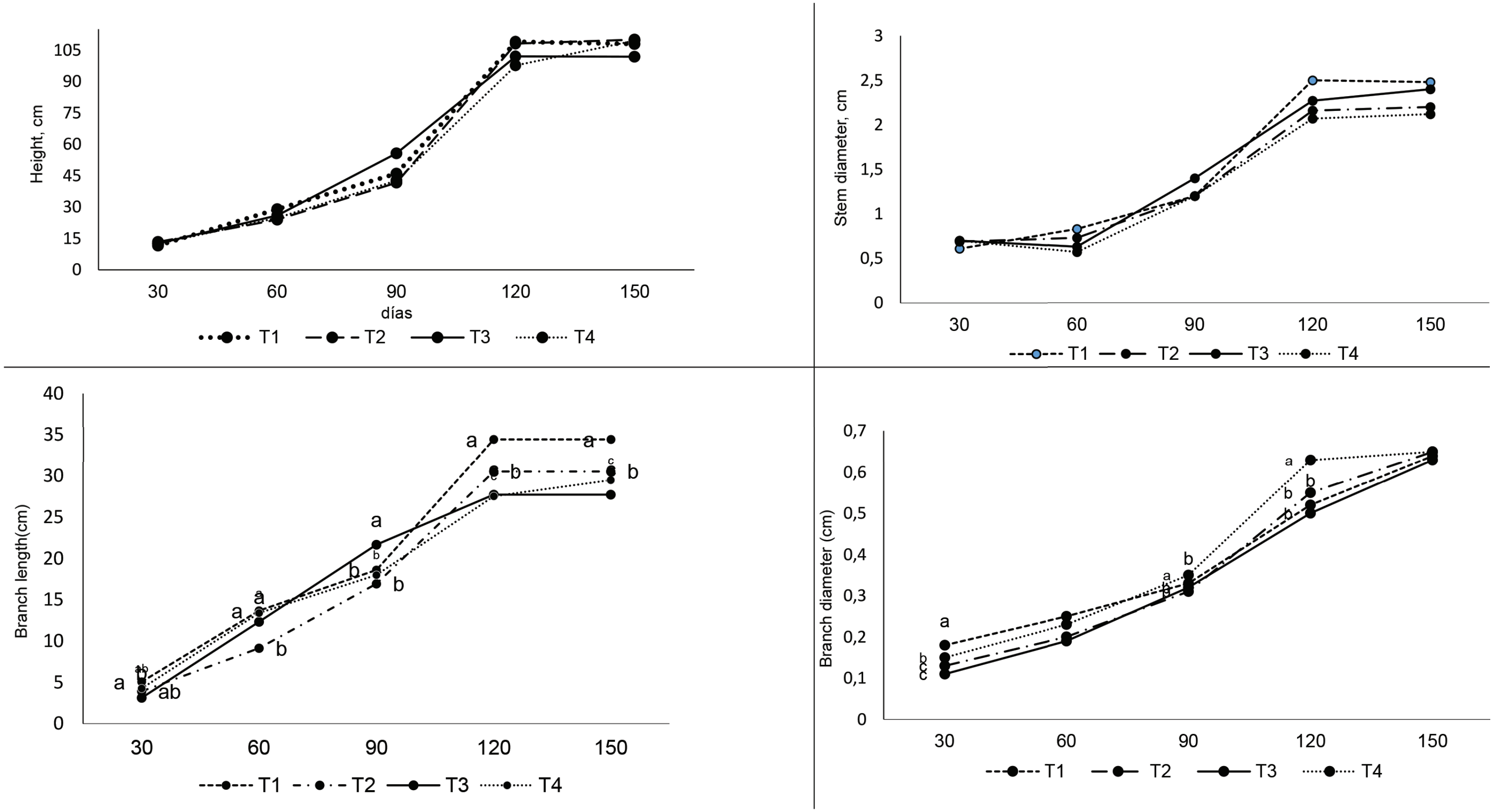

Figure 3. Growth of *M. esculenta* Señorita variety.
T1-control (mineral fertilization), T2-fertilization with 700 g of biochar, T3-fertilization with 700 g of compost, T4-fertilization with 350 g of biochar + 350 g of compost.
a, b, c: Means with different letters indicate differences at p < 0,05

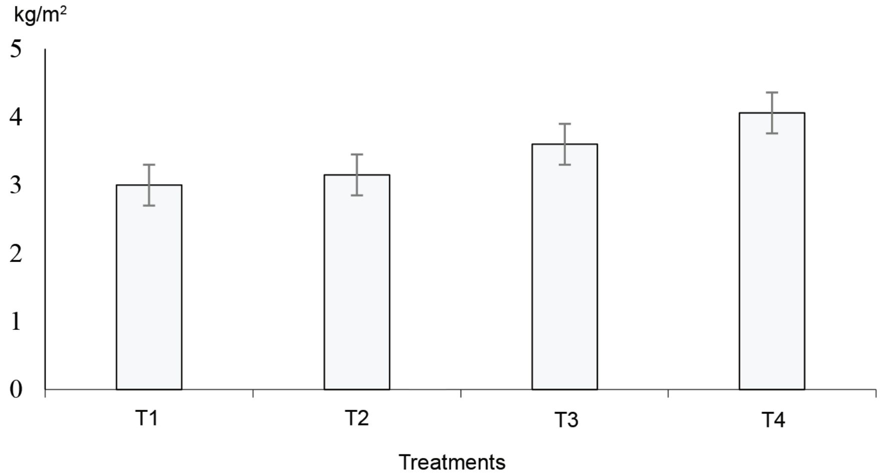

Figure 4. Agricultural yield of *M. esculenta*, Señorita variety

T1-control (mineral fertilization), T2-fertilization with 700 g of biochar, T3-fertilization with 700 g of compost, T4-fertilization with 350 g of biochar + 350 g of compost.

Conclusions

The organic fertilization alternatives stimulated plant growth during the vegetative stage and guaranteed yields of *M. esculenta* comparable to chemical fertilization in the varieties INIVIT Y 93-4 and Señorita.

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Authors' contribution

- Gertrudis Pentón-Fernández. Conceptualization of the idea and supervision of the research activity. Preparation of the manuscript for its publication.
- Giraldo J. Martín-Martín. Conceptualization of the research idea.
- Odelín Brea Maure. Statistical analysis and manuscript revision.
- Orilda Hernández-Santovenia. Conduction of the experiments and data collection.
- Hans Peter Schmidt. Supervision of the research.

Conflict of interests

The authors declare that there are no conflicts of interests among them.

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