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Evaluation of the *Genipa americana* L. / *Heliconia stricta* Huber agroforestry system and its effects on soil fertility

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ABSTRACT

Objective: To evaluate the plant development of *Genipa americana* L. and *Heliconia stricta* Huber associated as an agroforestry system, and their effects on soil fertility.

Design/methodology/approach: A completely randomized experimental design with three replications per treatment was used. *Genipa* plantations were established in July 2019 and *Heliconia* in September 2020. Soil samples and analyses were carried out based on the methodologies specified in NOM-021-RECNAT-2000 (SEMARNAT, 2002). Monthly measurements of height, stem diameter, number of leaves, photosynthetic rate were made for *Heliconia* and *Genipa*, as well as number of branches and canopy cover for the latter. Means were compared by Tukey's test at a 5% confidence level.

Results: Contents of organic material (OM), Phosphorus (P) and Manganese (Mn) in the soil did present significant differences because of the treatments, cultivated alone and/or associated, while the contents of Nitrogen (N), Potassium (K), Calcium (Ca), Magnesium (Mg), Zinc (Zn) and Copper (Cu) did not. The behavior and development of *Genipa* was the same in the treatments, while *Heliconia* did present variations.

Limitations on study/implications: It is recommended to continue the study.

Findings/conclusions: The treatments cultivated alone and/or associated improved the (OM) contents in the soil. *Genipa* is not affected by the effect of the treatments evaluated, while heliconias are.

Keywords: *Genipa*, *Heliconia*, Association, Soil, Organic Matter (OM).

INTRODUCTION

In the tropics, it is common to see combinations of timber-yielding trees as shade for perennial crops (coffee and cacao), disperse trees in agricultural fields and paddocks, as well as trees in lines and under the taungya system (Detlefsen & Somarriba, 2012). These systems can function as CO_2 sinks (Litynski *et al.*, 2006), for soil and water conservation, and for microclimate modification, among other natural services (CONAFOR, 2012). The tendency towards consumption of what is natural is increasingly stronger since there is a trend in developed countries to change the use of artificial for natural colorant, such as cochineal carmine (Lizárraga & Álvarez, 2019). The International Trade Center (2015) reports that imports in the European Union (EU) of natural dye of plant origin went from 21,842 t in 2006 to 45,876 t in 2015; that is, an increase of 110% in imports. In this sense, *Genipa americana* L. is a tree of economic and ecological importance, its fruit is edible fresh or used for the production of candy, jam, jelly and liquor; various medicinal uses are attributed to it, and the wood can be used for the elaboration of diverse articles and products (Strong and Fragoso, 2006; PIN, 2009; Quesada *et al.*, 2010). However, its greatest potential lies in that its immature fruit contains high levels of iridoids, such as genipin, which is essential for the formation of the blue color as a result of its reaction with primary sources of amines (Bentes & Mercadante, 2014; Fujikawa *et al.*, 1987). It is reported as a species of agroforestry use that contributes benefits to the soil. This is why in this study a new association is suggested as agroforestry system, with *Genipa americana* L. as tree combined with *Heliconia stricta* Huber, which has ornamental potential.

MATERIALS AND METHODS

The study was conducted in the open field of Colegio de Posgraduados, Campus Campeche (19° 50' 13.89" N, 90° 58' 61.11" W) and altitude of 20 masl, locality of Sihochac, municipality of Champotón, Campeche, Mexico. The climate is sub-humid warm with summer rains. The mean annual temperature of the place is 26 °C and the mean annual precipitation is 1,274.7 mm (INEGI, 2009). Planting the species was carried out in plots of 100 m^2.

Establishment of the plantation

Prior to planting, minimum tillage was conducted on the piece of land and three treatments with two repetitions were established in each plot of 100 m^2: associated plantation of *Genipa americana* L. with *Heliconia stricta* Huber (T1), monocrop of *Genipa americana* L. (T2), and monocrop of *Heliconia stricta* Huber (T3).

Planting *Genipa americana* L. (Ga) was carried out in July, 2019, at a distance of 3×2 m between furrows and plants, respectively (Figure 1). Planting *Heliconia stricta* Huber (Hs) was conducted in October 2019 at a distance of 2×1 between furrows and plants, respectively (Figure 1), and interspersed at 0.50 m of distance from the Ga lines (Figure 1). However, they did not survive because of lack of irrigation in the spring of that year. Therefore, the crop of this species was established again in September, 2020. The experiment was established in a completely randomized design (CRD) with three repetitions per treatment, planting date, to analyze the variables of height, stem diameter and number of leaves, photosynthetic rate in Hs and Ga, plus number of branches and green plant cover in Ga. The data were analyzed as a CRD with subsampling (Zamudio and Alvarado, 1994), using the statistical software InfoStat. The multiple means comparison test was carried out with Tukey's method with a significance level of 5%.

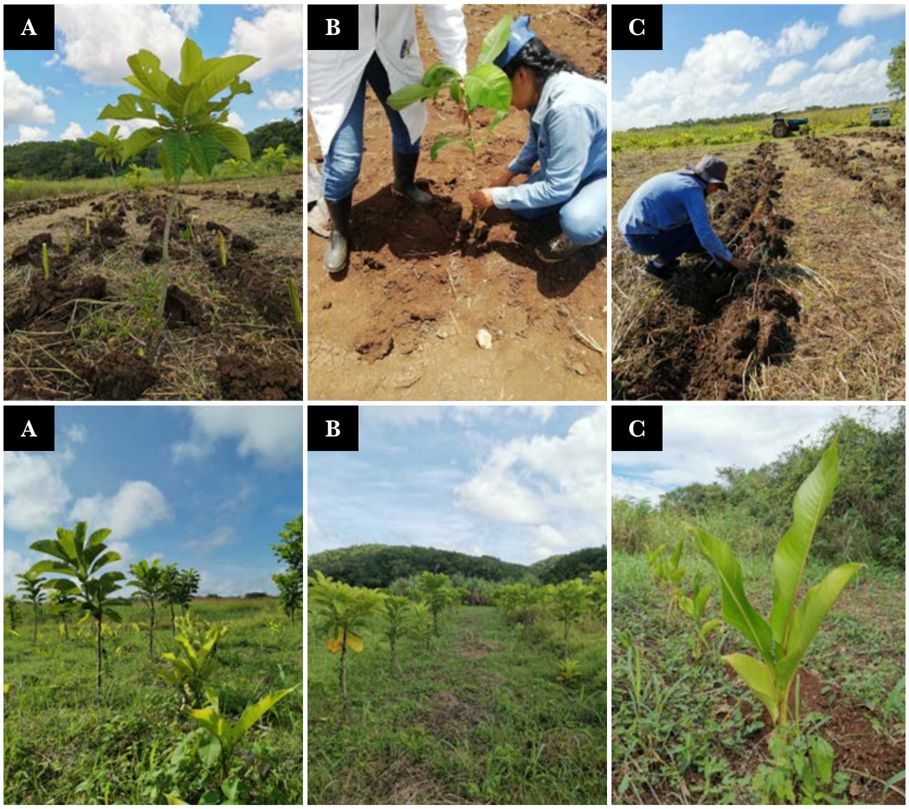

Figure 1. Establishment of the treatments: (T1) Plantation associated of *Genipa americana* L. with *Heliconia stricta* Huber, (T2) monocrop of *Genipa americana* L., and (T3) monocrop of *Heliconia stricta* Huber.

Soil sampling and analysis

The samples and analysis of the soil were obtained as described in NOM-021-RECNAT-2000 (SEMARNAT, 2002). A first sample of the entire plot was taken in July, 2019. The second sampling was carried out per treatment and the repetitions in March of 2021. The following were determined: pH, OM, N, P, K, Ca, Mg, Zn and Cu.

Sampling of the species in the treatments

Sampling in *Genipa americana* L.

Monthly measurements of the variables were carried out as follows: height of the plant's stem or shaft with the help of a measuring tape; stem diameter with a Vernier at the height of the base of the stem; number of leaves per plant, by counting considering all the true leaves on the plant; number of branches per plant considering all the branches on the plant; photosynthetic rate, which was determined using the LI-6400X equipment to measure photosynthesis (Carmona *et al.*, 2007); and canopy cover which was measured with the mobile phone application Canopeo (Jáuregui *et al.*, 2019).

Sampling in *Heliconia stricta* Huber

To understand the behavior of the development of *Heliconia stricta* Huber, the following variables were evaluated monthly: plant height, measured with a measuring tape, from the base of the plant to the tip; number of leaves per plant, counting the number of leaves considering all the true leaves on the plant; and photosynthetic rate.

RESULTS AND DISCUSSION

The soil, as a result of the effect of the *Heliconia stricta* Huber and *Genipa americana* L. crops

According to Table 1, the contents of N, K, Ca, Mg, Zn and Cu in the cultivated soil did not have significant differences as a result of the effect of treatments in single and associated crops; the contents of OM, P and Mn did present differences from the effect of such treatments, as well as the pH.

When it comes to the nutritional diagnosis of the soil in the treatments (T_i, T1, T2 and T3) according to what was established in SEMARNAT (2002), a high content was found in bases exchanged (K, Ca, Mg), which coincides with studies carried out by Fernández-Ojeda *et al.* (2016) in the systems they evaluated. In terms of the content of micronutrients (Mn, Zn, Cu), normal levels were found, in contrast with what was reported by Méndez (2013), who found medium levels when he evaluated similar treatments in the field.

The organic matter had an increase, going from a medium to a high percentage, which can be attributed to the contributions of fallen leaves, root fragments, and other plant components incorporated into the soil of the treatments (T1, T2 and T3) in the growth process. Studies carried out in the soil with agroforestry management show that in the superficial layer of the soil there are larger amounts of OM (Arévalo-Gardini *et al.*, 2015), due to residues from pruning, weeding and other factors (Hameed *et al.*, 2018). Regarding the content of phosphorus, it went from medium to low levels, results that agree with what was found in the systems evaluated by Fernández-Ojeda *et al.* (2016), who reported a low

Table 1. Chemical diagnosis associated to soil fertility before and after the treatments.

Determination	Unit	Treatment			
		T_i	T1	T2	T3
pH		6.97 a	7.83 a	7.64 a	7.51 a
MO	(%)	3.32 b	4.80 a	4.12 a	4.17 a
N		0.17 a	0.19 a	0.17 a	0.17 a
P	(mg kg^{-1})	6.95 a	2.01 b	1.44 b	2.68 b
K	(Cmol (+) kg^{-1})	0.63 a	0.77 a	0.99 a	0.88 a
Ca		26.77 a	33.85 a	33.34 a	29.06 a
Mg		4.25 a	3.79 a	4.49 a	4.59 a
Mn	(mg kg^{-1})	285.30 a	35.43 b	54.36 b	40.85 b
Zn		1.00 a	0.38 a	1.24 a	0.44 a
Cu		2.11 a	1.94 a	2.15 a	2.14 a

Means followed by the same letter in each line do not show significant differences as a result of the effect of treatments (Tukey, α=0.05). T_i=Initial condition of the soil before establishing the treatments (capacity of nutritional supply for the crops exhibited by the soil). T1=Condition of the soil containing the treatment of the association *Genipa americana* L./*Heliconia stricta* Huber. T2=Condition of the soil containing the treatment of *Genipa americana* L. T3=Condition of the soil containing the treatment of *Heliconia stricta* Huber.

content of this nutrient as a result of the effect of the cultivation systems evaluated, due to the demand of this element by those cultivars, since it requires being mineralized to be used by plants, under the influence of temperature, pH, aeration, the nature of organic matter, and the rate of carbon/phosphorus (Alcántar-González *et al.*, 2016). When it comes to the content of Manganese, a decrease was found as a result of the effect of treatments T1, T2 and T3 compared to T_i; however, the content of that nutrient in the cultivated soil continues to be adequate (SEMARNAT, 2002).

The soil pH showed changes in values considered as neutral in the conditions of T_i to moderately alkaline in the cultivation systems established (T1, T2 and T3), showing the influence of the pH on the availability of soil nutrients for the plant and the functions that it has in the chemical and biological activity of the soil (Larson and Pierce, 1991; Doran and Parkin, 1994). It is important to highlight the importance of this chemical property on the availability of soil nutrients for the plants cultivated, which is why Alcántar-González *et al.* (2016) mention that in neutral or alkaline pH, the decomposition of the OM from bacteria and actinomycetes predominate; that alkalinity promotes the deficiency of Mn, since it favors its chemical and bacterial oxidation, reducing its exploitation as could happen in certain stages in flooded soils (Silva, 2007); it also fosters the mineralization of organic P in the soil to a greater extent (Tabatabai and Dick, 1979). This behavior of the soil pH as a result of the effect of treatments applied in the field is of great relevance in agricultural systems of the Yucatan Peninsula, if it is considered that soils of this peninsular region are calcareous in much of the eco and agro ecosystems, because of their geological nature.

Growth and development of *Genipa americana* L.

No significant differences were found in the variables evaluated in *Genipa americana* L. from the effect of the treatments evaluated (Table 2), since in both treatments the plants develop in the same proportions, so it can be said that they are apt for their plant association in agroforestry management, as mentioned by García and Islas (2018).

Growth and development of *Heliconia stricta* Huber

As Table 3 shows, the variable plant height of *Heliconia stricta* Huber presented significant statistical differences, where the greatest height was in T1=16.84 compared to T3=15.63 as a result of the effect of treatments. Therefore, it is inferred that the sum of diverse factors, among them the shade favored by *Genipa americana* L. to the *Heliconia stricta* Huber plants, have an effect on the growth of the latter, as well as on the availability of nutrients present in the soil, among other effects.

Table 2. Statistical averages of the variables evaluated in *Genipa americana* L.

Treatment	Height (cm)	Diameter (mm)	Number of branches per plant	Number of leaves per plant	Photosynthesis (mmol CO_2 $m^{-2}S^{-1}$)	CANOPEO
T1	96.40 a	20.45 a	1.75 a	22.00 a	15.64 a	59.52 a
T2	95.88 a	20.80 a	1.71 a	22.58 a	13.40 a	59.97 a

* Means followed by the same letter by column (plant age) do not show significant differences from the effect of treatments (Tukey=0.05). T1=Agroforestry association *Genipa americana* L. / *Heliconia stricta* Huber. T2=Monocrop of *Genipa americana* L.

Table 3. Statistical averages of the variables evaluated in *Heliconia stricta* Huber.

Treatment	Height (cm)	Diameter (mm)	Number of leaves per plant	Photosynthesis (mmol CO_2*m^{-2} *S^{-1})
T1	16.84 a	11.19 a	2.95 b	7.67 b
T3	15.63 b	10.81 a	3.52 a	9.23 a

* Means followed by the same letter by column do not show significant differences as a result of the effect of treatments (Tukey=0.05). T1=Agroforestry association *Genipa americana* L. / *Heliconia stricta* Huber. T3=Monocrop of *Heliconia stricta* Huber.

According to Uc-Ku *et al.* (2019) and Baltazar-Bernal *et al.* (2020), mycorrhizal colonization in *Heliconia stricta* improves plant height, which is very similar to what was found in Pinto (2007) where two species of heliconias presented a greater height when organic fertilization was applied, in contrast with the application of mineral fertilizer, showing the same development than the control treatment. On the other hand, the stem diameter for *Heliconia stricta* Huber did not present statistically significant differences as a result of the effect of treatments, since they developed equally in both treatments. When it comes to the number of leaves, there were statistically significant differences in treatments T1 and T3, with a larger number of leaves in T3=3.52 compared to T1=2.95, which could be due to competition over nutrients in T1.

Authors like Neto *et al.* (2011) point out that under open field conditions and the application of chemical fertilization, *Heliconia stricta* is favored in plant development, although at the same time it reduces the production of inflorescence, and that without fertilization there is a better inflorescence; therefore, we can relate it with the good content of OM in the soil. Concerning the photosynthetic rate in the months evaluated, statistically significant differences were found as a result of the effect of the treatment, where the highest photosynthetic rate was found in T3=9.23 compared to T1=7.67 (Table 4). On the other hand, Uc-Ku *et al.* (2019), in their evaluation of photosynthesis in *Heliconia stricta* Huber in different samples of the effect of mycorrhizal inoculation, obtained lower values of photosynthesis in the species without inoculation under greenhouse conditions, and therefore, it can be noted that the species increases its photosynthetic activity at plain sunlight.

CONCLUSIONS

Both the association and the establishment of each plant species as monocrop did not affect the contents of N, K, Ca, Mg, Mn, Zn and Cu in the soil. The contents of OM improved, and the P suffered a decrease from the demand of the plants cultivated. It is feasible to associate *Genipa americana* L. in agroforestry management. More studies are required in *Heliconia stricta* Huber on its management in agroforestry systems.

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