Article

Characterization of tree species associated with coffee cultivation

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Abstract

Coffee cultivation in Mexico occurs under shade with various trees, including some nitrogen-fixing species, in systems called agroforestry. The present study was carried out in 2018 in the municipality of Huatusco, Veracruz and the objective was to characterize the agroforestry systems of *Inga vera* and *Erythrina poeppigiana* (a young and an adult plantation) in association with coffee; through the measurement of their physical characteristics, such as age of the trees, height, thickness of coffee plants, percentage of shade and the chemical characteristics of the soil and foliar. Subsequently, the results were compared with a system of coffee-*Juglans pyriformis*, to observe the nutritional differences between plantations with legumes and non-legumes. With these data, the use of *Erythrina poeppigiana* was proposed as coffee shading, which contributes to improving the microclimate and soil fertility through biological nitrogen fixation.

Keywords: nitrogen fixation, nutritional diagnosis, shade in coffee.

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Introduction

In the state of Veracruz, coffee cultivation is carried out under the shade of some leguminous forest species. These interact with the cultivation of coffee, on a physical level by means of the percentage of shade and nutritionally through the biological fixation of nitrogen (FBN). Agroforestry coffee systems must comply with a shade percentage of 55% to reduce water stress, which can be achieved with proper tree spacing and through periodic pruning (Cisneros and Sánchez, 2015). The present study aims to describe the physical and chemical interactions of four agroforestry systems by measuring the percentage of shade, as well as the analysis and interpretation of their nutritional values to propose a nutritional arrangement and management that allow maximum yields to be obtained.

Materials and methods

Description of the study area

The present study was conducted in a Luvisol in the town of 'La Patrona', in the municipality of Huatusco, Veracruz. The plots of interest are between 19° 09' 21'' and 19° 09' 31'' North latitude, and between 96° 55' 50' and 96° 56' 03'' west longitude, at an average altitude of 1 170 meters above sea level, average annual temperature of 17.2 °C and average annual rainfall of 1 69.9 mm per year and have a climate of type (A)C(w_1); (FAO, 2008). The agroforestry systems of the region the main crop is coffee, planted at 2∗1 m, fertilized in the drip area in May and August with 200 g of a mixture of phosphonitrate and potassium chloride and a foliar fertilization in February.

At 15 shade trees in each agroforestry system, the diameter, height and shade they cast were measured, while at 20 coffee plants chosen at random the soil and leaves were sampled for analysis. Soil and tissue analyze were performed according to NOM-021 (NOM, 2000). The diagnosis of the tissue analysis was made with the diagnosis and recommendation system (DRIS), Kenworthy Balance Indexes and optimal percentage deviation (DOP) (Kenworthy, 1961; Montañes *et al*., 1991; Bhaduri and Pal, 2013). The systems studied were:

Coffee-*Inga vera* system: This system is 12 years old; it is a tree legume widely used as a shade in coffee trees. The trees had a distance of 7∗6 m, density of 238 trees ha^{-1}, height 8.3 m and 21.6 cm in diameter and cast a shadow of 47% to coffee, while coffee plants measured 1.81 m high and 4.75 cm diameter.

Café-*Juglans pyriformis* system: the *Juglans pyriformis* species is not leguminous, it is 12 years old, planted at 6∗6, with a density of 277 ha, height of 6.9 m and the diameter of 18.8 cm, cast a shadow of 68.6%, being the witness regarding nitrogen fixers. Coffee plants measure an average of 1.97 m high and 5.04 cm in diameter.

Caffe system-*Erythrina poeppigiana-Grevillea robusta*

This system has *Erythrina poeppigiana* and *G. robusta*, they are 4 years old. The density of shade trees was 69 of *Erythrina poeppigiana* and 208 of *G. robusta*, which provide 53.6% shade for coffee cultivation. The crop had an average height of 2 m and a diameter of 4.7 cm.

Coffee system-*Erythrina poeppigiana*

This woodland is 24 years old, planted at 7∗6 m, resulting in a tree density of 238 trees ha^{-1}, which provides 61% shade to coffee, which on average measures 1.92 m height and 4.1 cm in diameter at the base.

Results and discussion

Evaluation of physical interactions

Table 1 shows the characteristics of the four agroforestry systems, such as spacing and tree age, percentage of shade and height of coffee trees.

Table 1. Description of the agroforestry systems under study.

Description	Coffee-*Inga vera* (IV)	Coffee-*E. poeppigiana* y *G. robusta* (EG)	Coffee-*E. poeppigiana* (EP)	Coffee-*Juglans pyriformis* (JP)
Surface (ha)	1.21	1	1.14	0.15
Age (years)	12	4	24	12
Tree density (trees ha^{-1})	238	69 *E. poeppigiana* 208 *G. robusta*	238	277
Shadow (%)	47	53.6	61	68.6
Coffee height (m)	1.81	2	1.92	1.97
Coffee diameter (cm)	4.75	4.7	4.1	5.04

System IV has a lower shadow percentage than that proposed by Franck and Vaast (2009), which could influence the size of coffee plants, which presented the lowest size of the systems analyzed. The JP and EP systems exceed 55% shade, very close to the ideal of 53.6%, important for leaf growth and fruit production. In the EP system, the age of the woodland promoted a higher percentage of shade. In the EG system the coffee trees had greater height and with greater diameter those of the EP system. According to Francesconi and Montagnini, 2014 the growth is related to the production of leaves, photosynthetic capacity, production of flowers of the following cycle with fruit buds highly sensitive to radiation.

Nutrient diagnosis of the soil by agroforestry system

Table 2 shows the soil analysis with a pH between 4.61 and 5.16, which is consistent with Audate *et al*. (2016) and decreases the availability of N, P, K, Ca, Mg, S and Mo, which must be supplied through fertilization to ensure an adequate nutritional balance.

Table 2. Concentration and interpretation of soil analyzes.

Attributes	EG	IV	JP	EP
pH	4.61	5.03	5.16	4.99
EC (µS cm^{-1})	94.9	79.1	99.2	101.2
MO (%)	5.16	6.37	5.9	5.43
CIC ($cmol^{+}$ kg^{-1})	17.65	17.65	18.37	14.25
N inorg. (mg kg^{-1})	3.5	7	21	24.5
P-Olsen (mg kg^{-1})	11.4	1.7	14.9	10.3
K (mg kg^{-1})	484.51	316.19	469.05	343.12
Ca (mg kg^{-1})	671.41	1064.12	1187.38	1072.36
S-SO_4 (mg kg^{-1})	101.14	54.09	62.95	81.36
Mg (mg kg^{-1})	110.07	137.1	214.92	182.52
Fe (mg kg^{-1})	58.13	30.45	20.96	21.43
Mn (mg kg^{-1})	18.16	34.63	48.08	71
Cu (mg kg^{-1})	0.34	0.74	0.8	0.86
Zn (mg kg^{-1})	0.83	1.18	1.08	1.22
B (mg kg^{-1})	3.81	2.8	2.55	3.76

EG= treatment of *Grevillea robusta* and *Erythrina poeppigiana*; IV= treatment with *Inga vera*; JP= treatment with *Juglans pyriformis*; EP= treatment with *Erythrina poeppigiana*.

All the systems showed a low and adequate EC for the development of the crop, as well as, 5.16% of organic matter derived from the accumulation of pruning residues, which promotes the recycling of nutrients, increased microflora and microfauna in the layer soil surface.

The JP and EP systems showed high concentrations of N greater than 20 mg kg^{-1}, while EG and IV had lower concentrations in a deficit range. System IV had a low level of P and very high K, while EG had the lowest concentration of Ca, Mg, Cu and Zn due to the accumulation of Al^{3+} which generates antagonisms with cations and fixation of P.

Ca and Cu was low in the 4 systems and Mg was very high, while Fe was very high in the EG and IV systems and medium in JP and EP. The Mn was low in EG, high in IV and JP and excessive in EP. In the EG system the concentration of Zn was very low, while in IV, JP and EP were low. The B is of utmost importance for the longevity of the pollen was very high (Ankerman, 1977).

Nutritional diagnosis of coffee by agroforestry system

Kenworthy balance index

To calculate the Kenworthy balance index, the data reported by Fonseca *et al*. (2018), with which the results presented in Table 4 were obtained.

Table 4. Initial nutritional diagnosis using the Kenworthy balance index for the four systems under study.

Systems	N	P	K	Ca	Mg	B	Cu	Fe	Mn	Zn
	(%)					(mg kg^{-1})				
Initial nutritional diagnosis of coffee with *Erythrina poeppigiana* (EP)										
CN	1.95	0.4	1.21	0.29	0.29	0.26	21.23	61.43	53.05	4.75
IBK	69	138	61	29	87	17	216	57	82	48
C	B	A	B	MB	N	MB	MA	B	B	MB
ORN	B> Ca> Zn> Fe> K> N> Mn> Mg> P> Cu									
Initial nutritional diagnosis coffee with *Inga vera* (IV)										
CN	1.85	0.38	1.32	0.26	0.31	0.26	17.48	95.18	72.05	4.6
IBK	65	130	66	27	92	17	172	81	96	47
C	B	A	B	MB	N	MB	MA	B	N	MB
ORN	B> Ca> Zn> N> K> Fe> Mg> Mn> P> Cu									
Initial nutritional diagnosis of coffee with *Juglans pyriformis* (JP)										
CN	1.41	0.31	1.32	0.27	0.29	0.22	14.23	55.85	96.2	5.53
IBK	51	104	66	28	87	17	135	53	134	53
C	B	N	B	MB	N	MB	A	B	A	B
ORN	B> Ca> N> Fe> Zn> K> Mg> P> Mn> Cu									
Initial nutritional diagnosis of coffee with *E. poeppigiana* and *Grevillea robusta* (EG)										
CN	1.81	0.4	1.38	0.28	0.26	0.38	10.33	23.58	62.55	5.25
IBK	64	138	69	29	79	17	94	31	89	51
C	B	A	B	MB	B	MB	N	MB	N	B
ORN	B> Ca> Fe> Zn> N> K> Mg> Mn> Cu> P									

CN= nutritional composition; IBK= Kenworthy balance index; C= condition: MB= very low; B= Low; N= normal; A= high; MA= very high; ORN= order of nutritional requirement.

The nutritional diagnosis of agroforestry systems indicated that B, Ca, Fe, Zn, N, K and Mg were the most deficient, while Mn always remained in the normal range, Cu and P were located at the level above normal.

Kenworthy's balance indicated that, despite the high content of N in the JP soil, the foliar concentration was lower compared to the other systems. It can also be observed that, in all systems, the most deficient elements were B and Ca, which coincides with Millan *et al*., (2010), who report high levels of Al^{3+} in acidic soils in Argentina.

When correcting the deficiency mentioned, the plants will have greater height, root system development, number of leaves, branches and resistance to pests and diseases. On the other hand, the most abundant elements are Cu and P. The P reduces its availability in soils with pH less than 6.5 but an unnecessary application P is observed.

Percent Optimal Deviation (DOP)

The diagnosis determined by the DOP method is presented in Table 5.

Table 5. Initial nutritional diagnosis with the DOP index for the four systems under study.

Systems	N	P	K	Ca	Mg	B	Cu	Fe	Mn	Zn
	(%)					(mg kg^{-1})				
Initial nutritional diagnosis of coffee with *Erythrina poeppigiana* (EP)										
-CN	1.95	0.4	1.21	0.29	0.29	0.26	21.23	61.43	53.05	4.75
DOP	-33	33	-42	-78	-15	-99	89	-50	-32	-64
ORN	B> Ca> Zn> Fe> K> N> Mn> Mg> Cu> P									
Initial nutritional diagnosis of coffee with *Inga vera* (IV)										
CN	1.85	0.38	1.32	0.26	0.31	0.26	17.48	95.18	72.05	4.6
DOP	-36	27	-36	-80	-9	-99	56	-22	-7	-64
ORN	B> Ca> Zn> K> N> Fe> Mg> Mn> Cu> P									
Initial nutritional diagnosis of coffee with *Juglans pyriformis* (JP)										
CN	1.41	0.31	1.32	0.27	0.29	0.22	14.23	55.85	96.2	5.53
DOP	-51	3	-36	-79	-15	-100	27	-54	24	-58
ORN	B> Ca> Zn> Fe> N> K> Mg> Mn> Cu> P									
Initial nutritional diagnosis of coffee with *E. poeppigiana* and *Grevillea robusta* (EG)										
CN	1.81	0.4	1.38	0.28	0.26	0.38	10.33	23.58	62.55	5.25
DOP	-38	33	-33	-78	-24	-99	-8	-81	-20	-60
ORN	B> Fe> Ca> Zn> N> K> Mg> Mn> Cu> P									

CN= Nutritional composition; DOP= deviation from the optimal percentage; ORN= order of nutrimental.

With both diagnostic systems it was found that the most limiting elements were B, Ca, Fe, Zn, N, K and Mg, but especially, in both methods, Kenworthy Balance and DOP shows that the elements with the greatest shortage are B and Ca and those that are in excess are Cu and P, corroborating the deficiencies in the nutritional management of the systems.

Conclusions

The major problem in agroforestry systems was the acidity of the soil that decreased the availability of Ca, Cu and Zn and the consequent deficiency of these in the plants. The level of Fe in the soil was very high in EG and IV, but average in JP and EP. While the Mn was low in EG, high in IV and JP and excessive in EP. The B which is a very important element for pollen longevity concentrations were found to be very high. In general and independently of the agroforestry system the analyzes indicated that the elements B, Ca, Fe, Zn, N, K and Mg were the most limiting being among the most deficient in the respective order, while Mn always remained in the normal range and Cu and P were located at the level above normal.

The use of *E. poeppigiana* is recommended as shading for coffee, because, by pruning, an ideal shade percentage for the crop can be maintained (55%); however, to increase efficiency in nodulation, the use of inoculums is necessary, since *E. poeppigiana* is an introduced species, as well as nodulation activators (Co, Mo, Fe) to ensure that the FBN is carried perform properly and reduce the need for nitrogen fertilization.

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