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Cover crops affect the mineral nutrition of cocoa trees in full-sun cultivation system

Jonas Olimpio de Lima Silva[1], Jaqueline Dalla Rosa[1]*, João Carlos Medeiros[1], George Andrade Sodré[2], Paulo Cesar Lima Marrocos[2,3], Luiz Roberto Martins Pinto[2], Carlos Eduardo Pereira[1]

[1]Universidade Federal do Sul da Bahia, Centro de Formação em Ciências Agroflorestais, Itabuna, Bahia, Brazil
[2]Universidade Estadual de Santa Cruz, Ilhéus, BA, Brazil
[3]Comissão Executiva do Plano da Lavoura Cacaueira, Ilhéus, BA, Brazil

***Corresponding author:** jaqueline.rosa@ufsb.edu.br

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Abstract: Cover crops improve physical, chemical, and biological quality of the soil. However, in full-sun cocoa cultivation, this practice still requires evaluation. This study evaluated soil fertility and mineral nutrition of cocoa trees in full-sun system intercropped with cover crops in the initial phase of implementation. The experiment was conducted in full-sun cocoa cultivation system, with two years of implementation of the clone of cocoa trees CEPEC 2002. The soil of the experimental area is a Typic Hapludalfs. The climate of the region, is hot and humid tropical forest without dry season and the regional relief is characterized as undulating, with altitude of 60 m. The study evaluated cover crops (brachiaria, fabaceas, spontaneous vegetation, and uncovered soil (desiccated)) in two experimental years, 2020 and 2021. Soil sampling was carried in layer of 0-20 cm and cocoa leaves were collected in 2020 and 2021 for nutritional composition evaluation (macro and micronutrients). The brachiaria treatment increased potassium levels in the soil approximately 3 times compared to initial levels. The use of cover crops in cacao full-sun cultivation systems decreased foliars nitrogen and zinc and increased potassium levels in the evaluated years. But, the potassium remained below the appropriate levels for the crop. The study still needs a longer period to comprove the results observed, at this early stage, by use of the cover crops in soil fertility and nutrition of cocoa trees, in full-sun systems.

Keywords: *Theobroma cacao* L., nutrient cycling, green manure, soil cover

Introduction

The cocoa tree (*Theobroma cacao* L.) is a plant native to the Americas and is considered one of the main crops of worldwide economic interest, mainly due, to the high added value of its beans and its importance in the chocolate industry, the most important market for this crop (Souza Junior, 2018). Global production is concentrated in a few countries such as Ivory Coast, Ghana, Indonesia, Nigeria, Ecuador, Cameroon, and Brazil, which together account for approximately 88% of global production, with Ivory Coast being the largest producer alone, accounting for approximately 39% of this total (ICCO, 2023).

Brazil is the 7th largest producer of cocoa beans in the world (ICCO, 2023), with 280,000 tons produced in 2021 and a planted area of 617,000 hectares. The largest cultivation areas are in the states of Bahia (440,000 hectares), Pará (149,000 hectares), and Espirito Santo (17,000 hectares). The highest national production of cocoa beans occurs in the same order, with Bahia in first place, followed by Pará, producing 160,000 and 74,000 tons, respectively, in the 2021/2022 harvest season (AIPC, 2023). However, despite having the largest planted area, Bahia's average yield is low at 286 kg/ha, compared to 950 kg/ha obtained in the state of Pará (IBGE, 2021), which is mainly due to the lack of management of production systems and nutrient replenishment.

The main cocoa cultivation systems in Brazil can be differentiated into shaded cultivation and cultivation with little or no shade (Piasentin and Saito, 2014). Shaded cultivation occurs under Agroforestry Systems and is adopted in various regions of the world, such as southeastern Cameroon, southwestern Nigeria, and eastern Ghana (Schroth et al., 2004). It is the predominant form of cultivation in the southern region of Bahia. However, in other locations (most of Ivory Coast, western Ghana, Malaysia, and Indonesia), cultivation occurs in systems with little or no shade (Schroth et al., 2004), also known as cocoa in full-sun or monoculture. The monoculture of cocoa trees has been gaining ground in Brazil, even in non-traditional cultivation regions. Therefore, evaluations are needed regarding the system implementation arrangements, use of clones, and aspects related to soil management.

The cocoa tree is a nutrient-demanding crop and should be cultivated in soils with medium to high fertility to achieve good productivity. However, in less fertile soils, this can be achieved through the use of fertilizers (Souza Junior, 2018). According to Santos et al. (2020), soil fertility has been one of the main limiting factors for the expansion and development of cocoa farming in Brazil. Therefore, maintaining soil quality and proper management are fundamental practices for increasing productivity.

One way to improve soil quality is through the use of cover crops, intercropped with perennial crops have provided improvements to production systems, such as weed control, nutrient cycling, increased root density and depth, soil microbial biomass, among others (Delonzek et al. 2019, Pires et al. 2020, Sousa et al. 2023). Soils kept covered by the vegetative remains of cover crops have resulted in higher fruit production, as observed in citrus crops (Lucena et al., 2017). One of the factors is the increase in root system density, due to soil protection from high temperatures and daily variations in moisture and temperature, as well by increasing the infiltration and storage of water in the soil (Moraes et al., 2016). The use of cover crops intercropped with banana crops in Cerrado soils resulted in increased productivity (Maia et al., 2019). Similarly, with the use of calopogonium and kudzu in the inter-rows of banana trees in the Brazil semi-arid region, there was an increase in soil water retention and nutrient cycling (Quaresma et al., 2017). The association of perennial fruit trees with cover crops is already a consolidated agricultural practice, however, it has not been studied in cocoa full-sun system. Therefore, the hypothesis of the present study is that cover crops increase soil fertility and favor cocoa tree nutrition. Thus, the present study was developed with the aim of evaluating soil fertility and cocoa tree nutrition in a full-sun cultivation system intercropped with cover crops in the initial phase of implementation.

Results and Discussion

Dry mass (DM) production of cover crops

In 2020, the highest DM production was observed in the Crotalaria treatment (14 t ha^{-1}), followed by Brachiaria with 11.2 t ha^{-1} and spontaneous vegetation with 6.2 t ha^{-1} (Figure 1A). The higher DM production by Crotalaria can be attributed to both the large growth of plants in the period and production, as well as the higher fraction of semi-woody stem component, which contributed to the increase in dry mass. It should be noted that the production of DM by cover crops is related to the study site, regional climatic conditions, soil fertility and plant cutting age (Silva et al. 2010, Pacheco et al. 2011).

In 2021, the highest DM production occurred in the Brachiaria treatment (11.9 t ha^{-1}), followed by spontaneous vegetation (10.3 t ha^{-1}) and pigeon pea (7.9 t ha^{-1}) (Figure 1B). An increase in DM production was observed in the second year of the study in the Brachiaria and spontaneous vegetation treatments, possibly due to the stabilization of vegetation in these treatments in the experimental area. The high biomass production is an important requirement for the adoption of a species in conservation systems (Tyler, 2020). DM produced by in our study is considered adequate for maintaining a conservationist system, such as no-tillage, which recommends a minimum amount of dry mass of 6 t ha^{-1} (Alvarenga et al. 2001, Calegari and Donizeti, 2014).

Soil chemical attributes

For the soil chemical attributes, there was an effect of cover crops only for the K, and effect of year for pH, Mg, Fe, and B. There was no interaction between the cover crop and year factors (Supplementary data I).

The highest K content in the soil was observed with Brachiaria cultivation (212.5 mg dm^{-3}), which differed from the other treatments (Figure 2). The treatments with spontaneous vegetation, Fabaceas, and uncovered soil presented contents of 113, 74, and 73 mg dm^{-3}, respectively, classified as very good and medium, respectively, for the development of cocoa culture, according to Souza Junior et al. (2018). Compared to the spontaneous vegetation treatment, Brachiaria incorporated twice as much K^+ into the soil. There was also an increase in soil K^+ content compared to the content measured at the beginning of the study (78 mg dm^{-3}) in the two years after intercropping with Brachiaria (212.5 mg dm^{-3}) and spontaneous vegetation (113 mg dm^{-3}), indicating the potential of these treatments in K^+ cycling.

Some studies have reported the importance of forage grasses in cycling K to the soil after desiccation (Brito et al., 2023). Grasses, especially Brachiaria, are important for nutrient input in the surface layers of the soil, resulting in significant increases in P and K contents in no-tillage systems because they extract these leached nutrients at depth through their deep root system and return them to the soil surface after the decomposition of plant residues (Silveira et al. 2010, Rosolem et al. 2019, Resende et al. 2021, Brito et al. 2023), making them available to successor or perennial crops.

Brachiaria has a high potential for nutrient cycling, however, this potential depends on the species used, as evidenced by Vivian et al. (2017) in a study on the potential of Brachiaria, *Panicum* as covers crops in no-tillage systems in the state of Santa Catarina, Brazil. The authors reported greater release of potassium to the soil and nutrient cycling was observed with *Urochloa ruziziensis*. Similarly, in study evaluating cover crops alone or intercropped and their effects on cotton grown in succession in Brazilian Cerrado, Ferreira et al. (2023), report that straw from the single cultivation of *Urochloa ruziziensis* and its intercropping with corn, *Crotalaria spectabilis*, *C. ochroleuca* or pigeon pea show a higher K contente. Pacheco et al. (2013), in a study conducted with rice and soybeans in Goiás, also observed a high concentration of potassium accumulated in the dry matter and higher rates of release of this nutrient to the soil when using *Urochloa ruziziensis*.

Potassium is a nutrient rapidly available to the soil during decomposition, since it does not integrate any structural component of plant tissues, and its mineralization, unlike most nutrients, is not a prerequisite for its transfer to the soil (Teixeira et al., 2011). Therefore, in the case of intercropping cover crops with perennial crops, as soon as K^+ is released from plant tissue, it can be absorbed by the crop, favoring its nutrition. The others evaluated chemical attributes did not show effect of cover crops (Supplementary data II). The contents of Ca, Mg, and P were classified as very good, as well as the SB and CEC parameters (Supplementary data II). The contents of OM and S were considered as medium for cocoa cultivation (Souza Junior et al., 2018). Among the micronutrients, only B was classified with a medium content, while the others were classified with a good to high content (Souza Junior et al., 2018).

There was a difference in soil pH for the two years studied, with a slight increase in the second year, and both values are within the ideal range (5.7 to 6.2) for the good development of the crop, according to Souza Junior et al. (2018). For Mg and Fe, there was a reduction in the average of the years, with lower values in the second year (Table 1).

According to Resende et al. (2016), an increase in Mg content in the soil solution is usually observed when organic matter is added. However, both the reduction of Mg and Fe from one year to the next may be associated with the absorption of these nutrients by the cocoa crop. It should be noted that in the second soil sampling period, the cocoa trees had already started the fruiting phase, and consequently, the demand for these nutrients increased.

The increase in B content in the second year compared to the first may be related to the increase in organic residue input from the cover crops in the system, since it is through soil organic matter that this nutrient is mainly made available in the soil (Tomicioli et al. 2021).

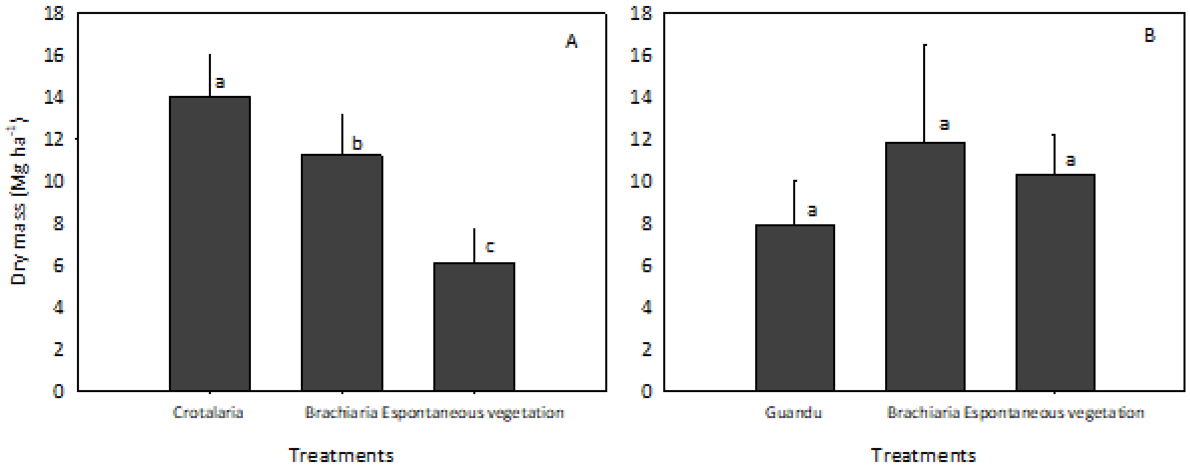

Figure 1. Dry mass (DM) production of cover crops intercropped with cocoa trees in full-sun cultivation system in 2020 (A) and 2021 (B) years. Different lowercase letters indicate differences between treatments by Tukey test ($p<0,05$). Bars refers to the standard error.

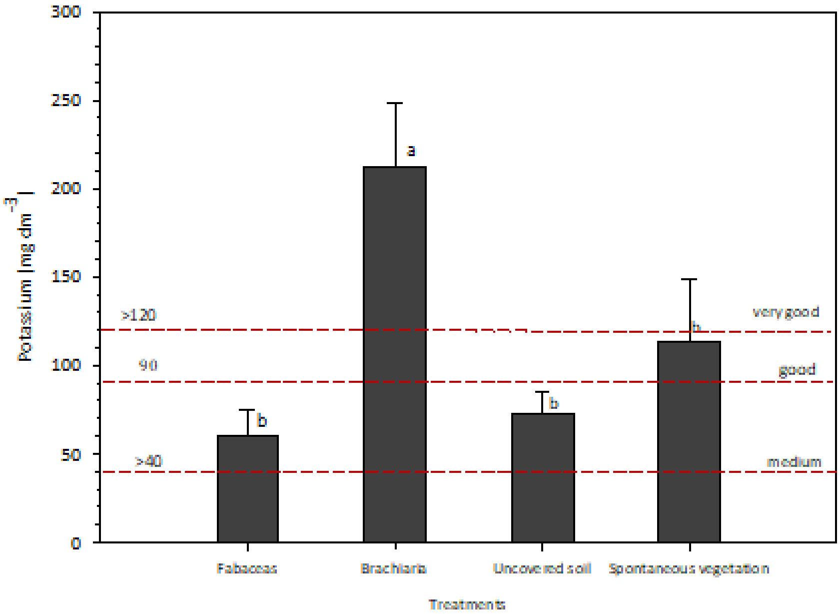

Figure 2. Available potassium content in the 0-20 cm layer of soil cultivated with cocoa trees in-full sun and intercropped with cover crops and uncovered soil. Different letters indicate differences between cover crops by Tukey's test ($p <0.05$). Bars indicate standard error. Red lines indicate classification of soil potassium by Sousa Junior et al. (2018).

Table 1. Magnesium (Mg), pH, iron (Fe), and boron (B) in the 0-20cm layer of soil cultivated with cocoa trees in full-sun intercropped with cover crops and uncovered soil in two years study.

Year	pH		Mg		Fe		B	
			$cmol_c\ dm^{-3}$		------mg dm^{-3}----			
2020	6.0	b	2.4	a	124	a	0.34	b
2021	6.3	a	2.1	b	96.4	b	0.51	a

Different letters indicate differences between the evaluated years by the F test ($p <0.05$).

Foliar nutrition of cocoa trees intercropped with cover crops

There was an interaction between the treatment and year factors for the nutrients N, K and Zn. Treatment effect was observed for N, P and Zn, as well as year effect for all evaluated nutrients (Supplementary data III).

In the interaction between treatments and production year, N did not show a difference between cover crops in the first year of the study. However, in the second year of evaluation, the highest foliar N contents were observed in treatments with uncovered soil and Brachiaria, and the lowest values in treatments with Fabaceas and spontaneous vegetation. When comparing the two years of evaluation, there was a reduction in foliar N contents in all treatments analyzed (Table 2).

All foliar N contents observed in the treatments of the first year were considered adequate for cocoa crop, however, in the second year, treatments with Fabaceas and spontaneous vegetation had values below the adequate range (18 - 31.2 g kg^{-1}) according to Souza Junior et al. (2018). In addition, the reduction in foliar N contents in all treatments between the first and second year of study may be related to the addition

Table 2. Interaction between cover crops and cultivation year on foliar nitrogen (N), potassium (K) and zinc (Zn) contents in cultivated cocoa trees in full sun intercropped with cover crops and uncovered soil.

Treatments/Foliar nutrientes	N				K				Zn			
	----------------------g kg-1----------------------------								mg kg-1			
Treatments/Year	2020		2021		2020		2021		2020		2021	
Fabaceas	24.7	Aa	17.6	Bb	6.1	Ba	9.4	Aab	209.8	Ab	90	Ba
Brachiaria	22.7	Aa	20.3	Bab	5.7	Ba	11.5	Aa	250.3	Aa	98.3	Ba
Uncovered Soil	23.8	Aa	22.5	Ba	6.1	Ba	8.7	Ab	193.0	Ab	89	Ba
Espontaneous vegetation	22	Aa	17.7	Bb	6.2	Ba	10.1	Aab	244.8	Aa	95.5	Ba

Uppercase letters compare year effect (in the row) and lowercase letters compare treatments effect (in the column) by Tukey's test ($p < 0.05$). Adequate levels for adult cocoa trees in the southern region of Bahia: N (20 – 24 g kg^{-1}); K (18-23 g kg^{-1}) and Zn (60 -140 mg kg^{-1}) by Sousa Junior et al. (2018).

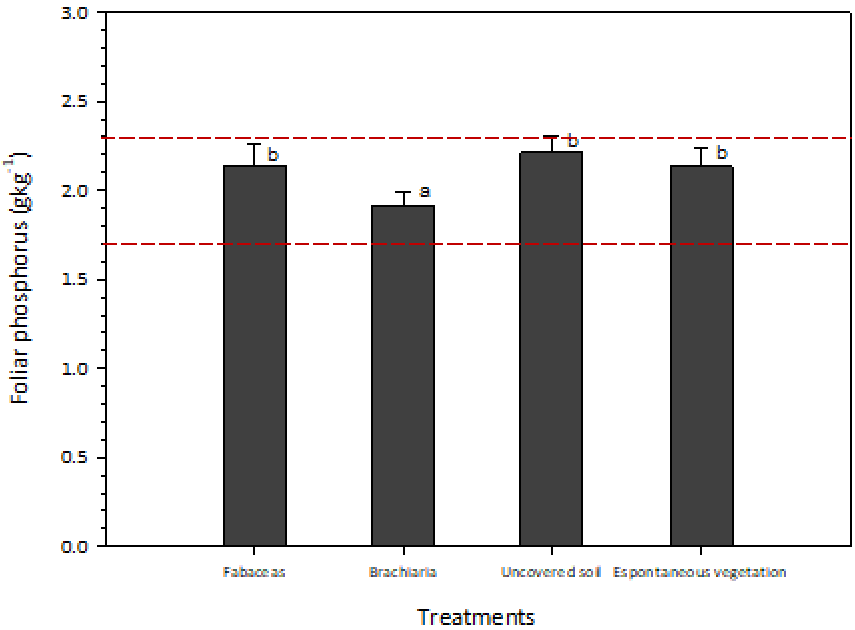

Figure 3. Foliar phosphorus contents in cocoa trees cultivated in full-sun intercropped with cover crops and uncovered soil. Different letters indicate differences between tretaments by Tukey's test ($p < 0.05$). Bars indicate standard error. Values between red lines (1.7 – 2.3 g kg^{-1}) indicate adequate leaf levels for adult cocoa trees in the southern region of Bahia by Sousa Junior et al. (2018).

of organic material from cover crop residues to the soil, suggesting immobilization of N by soil microorganisms. Even though nitrogen fertilization was applied twice a year, it was not sufficient to meet the demand of both the main crop and cover crops for N, causing this reduction from one year to another.

For foliar K, there was no difference between treatments in 2020. However, in the subsequent year, the Brachiaria treatment stood out among the others, with the highest foliar contents, but did not differ from the spontaneous vegetation and Fabaceae treatments. It is noteworthy that, as in the soil, the highest K contents were observed in the aerial part of cocoa trees in the Brachiaria treatment, suggesting that the increase in soil contents reflected an increase in this nutrient in the aerial part (leaves) of cocoa trees. All treatments showed an increase in K contents from one year to another, but the values are still below the adequate range for the crop, which is 18 - 23 g kg^{-1} (Souza Junior et al. 2018).

Zn was found in higher contents in the Brachiaria and spontaneous vegetation treatments in 2020, and all treatments had values above the adequate range (60 - 140 mg kg^{-1}) for the crop (Souza Junior et al., 2018). In 2021, treatments did not differ from each other, and there was a reduction in foliar contents in all treatments compared to the previous year, but they remained within the adequate range for the crop.

Regarding the P element, the highest foliar contents were found in the uncovered soil treatment when compared to the Brachiaria, but did not differ from the other treatments, spontaneous vegetation and Fabaceas (Figure 3). However, it is noteworthy that all treatments had adequate contents (1.7 to 2.3 g kg^{-1}) for cacao trees in sul Bahia region, according to Souza Junior et al. (2018).

In a similar study conducted with orange and green manure, higher P contents were found compared to those in this study with the Brachiaria treatment (Ragozo et al., 2014), suggesting that the absorption of phosphorus by cocoa trees may be related to the rate of release of this nutrient by cover crops. It should be noted that each cover crop species acts differently on the population of phosphorus-solubilizing organisms and also by its mycorrhizal character or not (Casali et al., 2016), thus promoting differentiated increases in soil P.

Some crops potentiate the increase in the quantity of phosphate-solubilizing microorganisms, such as pigeon pea (Carneiro et al., 2004), favoring its accumulation in the soil. The absorption of phosphorus by cocoa trees may be related to the rate of release of this nutrient by cover crops, as verified by Carvalho et al. (2021) in an orange orchard, where the highest contents occurred for legume, spontaneous vegetation, and grass, respectively.

There was a year effect for the nutrients phosphorus, calcium, magnesium, sulfur, iron, copper, manganese and boron (Table 3). Among the mentioned nutrients, a reduction

Table 3. Mean foliar nutritional composition of cocoa trees in full sun cocoa production system intercropped with cover crops and uncovered soil.

	P		Ca		Mg		S		Fe		Cu		Mn		B	
Year	----------------------g kg^{-1} --------------------								-----------------------mg kg^{-1}------------------------							
2020	2.3	a	22.5	b	9.4	a	1.8	a	122.6	a	7.5	b	1129	a	51	a
2021	1.9	b	26.5	a	8.6	b	1.7	b	47.6	b	9.0	a	493	b	42	b

P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; S: sulfur; Fe: iron; Zn: zinc; Cu: copper; Mn: manganese; B: boron. Different letters indicate differences between the evaluated years by F-test (p <0.05).

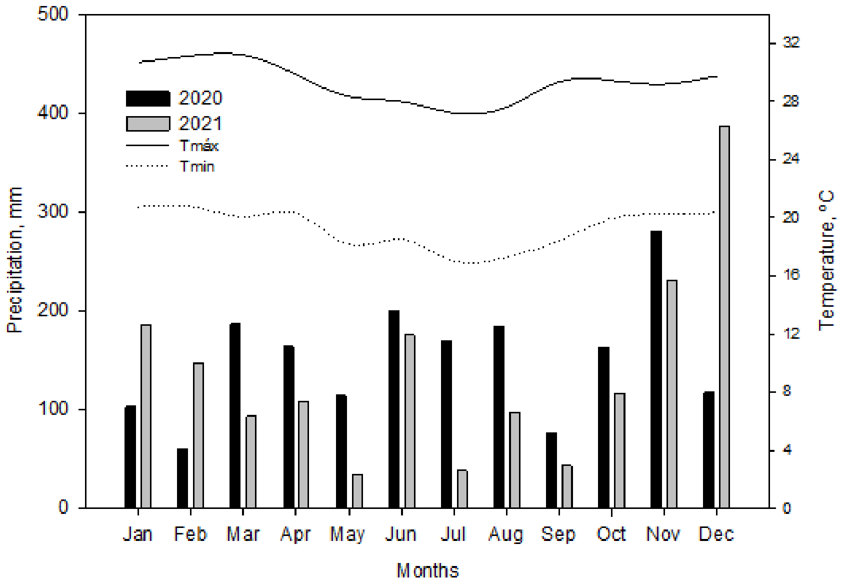

Figure 4. Meteorological data for the study period (2020 and 2021). Source: weather station CEPLAC/CEPEC/SERAM.

in macronutrients P, Mg, and S, and micronutrients Fe, Mn, and B, was observed from 2020 to 2021. The nutrients that increased in foliar content were Ca and Cu. P, S, Fe, and B were considered at adequate levels in both years of evaluation (P: 1.7-2,3 g kg^{-1}, S: 1- 2 g kg^{-1}, Fe: 50 - 150 mg kg^{-1} and B: 30 - 70 mg kg^{-1}).

The macronutrient Ca (adequate values: 8 to 12 g kg^{-1}), Mg (adequate values: 4 to 7 g kg^{-1}) and Mn (adequate value: 100-400 mg kg^{-1}) were in excess in both years, same with reduction of Mg and Mn in the second year. The appropriate values presented are for adult cocoa trees, of the Southern region of Bahia, Brazil, described by Souza Junior et al. (2018).

Deficiency of Ca, Mg, and S is less common than P, being more common in soils with high acidity and/or highly weathered, although cocoa is a crop that demands Mg. The micronutrient Mn showed a considerable reduction in the cocoa leaves in the second year of study, however, the value remained high. The high Mn values are related to the soil parent material of the study area, which is rich in this nutrient. In the case of cocoa trees, adequate levels of Mn are important to increase disease resistance (Nakayama and Andebrhan, 2000a).

In addition to nutritional aspects, Mn is one of the elements that most interferes with the cocoa tree's tolerance to the fungal disease witches' broom (Aguilar, 1999).

Materials and Methods

Study location

The experiment was conducted at CEPLAC (Comissão Executiva do Plano da Lavoura Cacaueira) in Ilhéus, BA. The climate of the region, according to the Köppen classification, is type Af, hot and humid tropical forest without a dry season, with precipitation above 1,300 mm distributed throughout the year, average temperature of 23℃ and relative humidity of 80%. The regional relief is characterized as undulating, with an altitude of 60 m. The soil of the experimental area is a Typic Hapludalfs (Santana et al., 2002). The soil chemical attributes before the experiment's implementation in the 0-20 cm layer were: pH in water: 6.0; H+Al: 4.2 $cmol_c$ dm^{-3}; Al: 0 $cmol_c$ dm^{-3}; Ca: 7.5 $cmol_c$ dm^{-3}; Mg: 2.1 $cmol_c$ dm^{-3}; SB: 9.9 $cmol_c$ dm^{-3}; T: 9.9 $cmol_c$ dm^{-3}; P: 40 mg dm^{-3}; K: 78 mg dm^{-3}; S: 7 mg dm^{-3}; Cu: 4.9 mg dm^{-3}; Fe: 84 mg dm^{-3}; Mn: 489 mg dm^{-3}; Zn: 10 mg dm^{-3}; B: 0.65 mg dm^{-3}; V: 70%; m: 0%. The granulometric distribution of the soil is 320 g kg^{-1} of sand, 338 g kg^{-1} of silt and 342 g kg^{-1} of clay.

Climatic data for the study period are described in figure 4. The total precipitation was of 1,820 mm and 1,657 mm for 2020 and 2021 year, respectively.

History of the experimental area

The experimental area was maintained in an agroforestry system (cocoa trees with erythrina *Erythrina velutina*) for at least 40 years. In 2016 year was clear-cut for the implementation of a monoculture system, or full-sun cultivation system. All vegetative remains (aerial part and roots of cocoa and erythrina trees) were removed from the site, and subsoiling was performed up to 50 cm depth, followed by harrowing for the incorporation of phosphate fertilization (144 kg ha^{-1} of P_2O_5) applied in the form of single superphosphate. Liming was not used due the low soil acidity and adequate levels of Ca and Mg. The area remained fallow until 2019, with of the spontaneous vegetation growth, especially *Panicum maximum* L. (colonial grass) and *Sorghum arundinaceum* (wild sorghum). In July 2019, all vegetation was cut and mantened about soil surface. Seedlings (6 months old) produced by cuttings from plagiotropic branches of the cacao CEPEC 2002 clone, were planted in holes with dimensions 0.40 x 0.40 x 0.40 m. The spacing between plants and interrows was of 1.5 x 4 m, respectively. Each plot had an area of 9 x 12 m, totaling 108 m^2, with 18 cocoa trees.

The full-sun cultivation system consists in the growing cocoa without shading. Only in the initial phase of cultivation, (~1 year), do the seedlings remain under shade, after the remainder of the cycle occurs in full-sun.

Experimental design and treatments

The experiment was implemented in March 2020, using a randomized block design with four replications. The variation factors evaluated were: cover crops and years. The cover crops evaluated were: (1) Brachiaria (*Urochloa decumbens*); (2) Fabaceas (*Crotalaria breviflora* and *Cajanus cajan*, for the first and second year respectively); (3) spontaneous vegetation; and (4) uncovered soil (desiccated). The two years evaluated were 2020 and 2021.

In March 2020, one harrowing was performed in all interrows of the cacao trees, followed by hand sowing and incorporation of cover crops. The following seed quantities were used in 2020: Brachiaria (*Urochloa decumbens*): 3.5 kg ha^{-1} and Crotalaria (*Crotalaria breviflora*): 15 kg ha^{-1}. In 2021, the Fabaceae treatment was Pigeon pea (*Cajanus cajan*): 45 kg ha^{-1}. There was no need for replanting Brachiaria in 2021, as the plant persisted in the plots. The spontaneous vegetation treatment consisted of local native species, predominantly including: *Commelina benghalensis* L.; *Bidens pilosa* L.; *Cyperus ferax*; *Euphorbia heterophylla* L. (amendoim bravo); *Rhynchospora nervosa* (tiririca branca); *Panicum maximum* L. (capim colonião); *Sorghum arundinaceum* (sorgo selvagem), with greater occurrence of the last two.

The uncovered soil (desiccated) treatment was maintained constantly without cover, by eliminating vegetation in the area of the plot with desiccation, using glyphosate potassium (dose of 2.0 L ha^{-1}).

Dry mass (DM) sampling and cover crop management

After development of the cover crops (flowering), in both evaluated years (2020 and 2021), DM production was determined using a 0.5m x 0.5m metal square, which was randomly released on the plot. All plant material that remained within the square was cut close to the ground and dried in a 65°C oven for 72 hours to obtain the DM produced by the cover crops.

After DM sampling, the cover crops was managed through mowing, which was repeated every two months, totaling six mowings each year. Two nitrogen fertilizations were applied each year, after the cover crop mowing, with rate of 50 kg ha^{-1} of N/application, in the form of urea. No other fertilizations were applied to either the cocoa trees or the cover crops.

Soil and leaf sampling and analysis

In December 2020 and 2021, soil sampling was carried out for chemical analysis in the 0-20 cm layer. Six samples were collected in each plot, in the cocoa tree row, which were mixed to form a composite sample for each plot.

The air-dried and sieved soil with 2 mm mesh was used to determine soil pH in water and $CaCl_2$, macronutrients (Ca^{2+}, Mg^{2+}, S, P, and K^+), micronutrients (Fe, Zn, Cu, Mn, and B), and soil fertility parameters (Al^{3+}, H+Al, SB, T, V, CTC, m, and organic matter), according to the methodologies described by Teixeira et al. (2017).

At the time of soil sampling, five cocoa trees were randomly selected in each plot, from which eight healthy leaves were collected per plant, totaling 40 leaves per plot. Foliar nutrient contents (N, P, K, Ca, Mg, S, Fe, Zn, Cu, Mn, and B) were determined. N was extracted by hot acid digestion, and the other nutrients were extracted by nitro-perchloric digestion, followed by titration according to Teixeira et al. (2017).

Statistical analysis

The data analysis was carried out considering the following factors of variation: cover crops, year, and interaction between these factors. Homogeneity of variances test was performed, followed by analysis of variance, and for significant cases, Tukey's test ($p<0.05$) was applied for mean comparison.

Conclusions

Two years afer the intercropping of brachiaria with cocoa trees in full-sun system increased soil potassium levels approximately three times compared to initial levels of this element in the soil. The use of cover crops in full-sun system, after two years, decreased foliar nitrogen and zinc levels and increased potassium levels. In the case of potassium, the increase was not sufficient, because foliar levels remained below of the adequate for cocoa crop. The study still needs a longer period to comprove the results observed, at this early stage, by use of the cover crops in soil fertility and nutrition of cocoa trees, in full-sun systems.

Acknowledgments

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