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EFFECTS OF BIOCHAR AND HUMUS ON THE MORPHOLOGICAL DEVELOPMENT OF COCOA PODS UNDER ACID SOIL

EFECTOS DEL BIOCHAR Y HUMUS EN EL DESARROLLO MORFOLÓGICO DE MAZORCAS DE CACAO EN UN SUELO ÁCIDO

Salomón Barrezueta-Unda
E-mail: sabarrezueta@utmachala.edu.ec
ORCID: https://orcid.org/0000-0003-4147-9284
Yaritza Chavez Gallegos
E-mail: ynchavez_est@utmachala.edu.ec
ORCID: https://orcid.org/0000-0001-8256-8350
Universidad Técnica de Machala. Ecuador.

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ABSTRACT

The cocoa soils with acid pH can be recovered by organic amendments, but it is necessary to know the effect of these fertilizers on the fruits in different proportions. In this aspect, the aim of the research was: to measure the effect of an organic amendment composed of biochar, worm humus and Biol in an acid soil cultivated with CCN51 cocoa. Five treatments were formed with doses of: 25 g of biochar + 50 g of humus+biol (T1); 10 g of biochar + 100 g of humus+biol (T2); 50 g of biochar+biol; 100 g of humus+biol (T0). Records were at 15 days (R1), 30 days (R2) and 90 days (R3) after the last application. Significant differences ($p \leq 0.05$) were obtained in R1 and R3 in the number of floral bearings (CF) and healthy harvested ears (MS). The treatments with the highest CF values were T0 in R1 and T2 in R2. The ANOVA did not indicate significant differences ($p \leq 0.05$) for the values of ear diameter and length, but did indicate significant differences in the weight of 100 dry cocoa seeds, with the highest average in T2 (895.2 g) and T3 (783.7 g).

Keywords:

Organic amendment, earthworm humus, acid soils, cocoa pods.

RESUMEN

Una forma de recuperar suelos cacaoteros con pH ácido es mediante enmiendas orgánicas, pero es necesario conocer su efecto de estos abonos sobre los frutos en diferentes proporciones. En este aspecto, el objetivo de la investigación fue: medir el efecto de una enmienda orgánica conformada por biochar, humus de lombriz y Biol en un suelo ácido cultivado con cacao CCN51. Se conformó cinco tratamientos con dosis de: 25 g de biochar + 50 g de humus+biol (T1); 10 gr de biochar + 100 g de humus+biol (T2); 50 g de biochar+biol; 100 g de humus+biol (T0). Los registros fueron a los 15 días (R1), 30 días (R2) y 90 días (R3) de la última aplicación. Se obtuvieron diferencias significativas ($p \leq 0,05$) en R1 y R3 en el número de cojinetes florales (CF) y de mazorcas sanas cosechadas (MS). Los tratamientos con los valores más altos de CF fueron el T0 en R1 y T2 en R2. El ANOVA, no indicó diferencias significativas ($p \leq 0,05$), para los valores de diámetro y largo de mazorca, pero si en el peso de 100 semillas secas de cacao, con el mayor promedio en T2 (895,2 g) y T3 (783,7 g).

Palabras clave:

Enmienda orgánica, humus de lombriz, suelos ácidos, mazorca de cacao.

INTRODUCTION

In the exploitation of *Theobroma cacao* L., those that stand out for their organoleptic properties are perceived and identified as having fine aroma and flavor in international markets (Barrezueta Unda & Paz González, 2018). Ecuador occupies the first place in the world in the production of cocoa with fine aroma and flavor, however, cocoas of low organoleptic quality, but with high productivity such as the CCN51 clone (Castro Naranjal tree 51 Collection) are also cultivated in the country. Between 2011 and 2019, cocoa production in Ecuador had an annual growth of over 6% per year, but this positive growth is limited by the soil resource (Sanchez-Mora et al., 2014).

One of the problems of cocoa farming in Ecuador is the indiscriminate use of chemical fertilizers and pesticides for pest control, which has caused soil degradation (Barrezueta Unda & Paz González, 2018). In this context, there are several effects of soil degradation due to excess fertilizers, such as soil acidification (Meyer et al., 2018). This change in pH causes low nutrient availability and, consequently, affects plant productivity (Pinzon-Nuñez et al., 2022). Other effects include the reduction of soil macro and microbiota, compaction of the first 15 cm of soil, and other negative factors (Meyer et al., 2018).

Soils can become unhealthy and need to be recovered. Scientists are using organic matter, like biochar, to help improve the health of soils. Biochar is made by burning biomass in an air-tight container at a high temperature for a few hours. The burning process makes gas, oil and a solid residue that helps soils (Ferry et al., 2022). Biochar is a type of charcoal that people can use to help make soils better. It comes from burning plants in a special way, using a lot of heat for a few hours. It can help make the soil healthier, by increasing the nutrients and helping fight against diseases (Barrezueta-Unda., 2022).

Biochar is made by burning biomass in a special way. The burning takes place at a specific temperature and time and produces gas, oil, and a solid material called biochar. The amount of each material depends on the type of biomass and how long it is burned (Milian-Luperón, 2020). Otherwise, mixing biochar with worm humus or cow manure helps make the soil better for plants. It helps plants grow better and this is especially helpful for small farmers (Agegnehu et al., 2016). Biochar and humus with manure increases the water holding capacity of soil and improves soil fertility, nutrient content and cation exchange capacity. It also improves soil aeration and helps to reduce soil compaction (Ferry et al., 2022). Biochar can also reduce the leaching of nutrients from the soil, helping to maintain soil fertility Finally, biochar can also help reduce soil acidity, which can be beneficial for certain types of plants. Therefore, the aim of this research was to measure the effect of an organic amendment composed of biochar, worm humus, and Biol in an acidic soil planted with CCN51 cocoa in the province of El Oro.

Metodology

Study area

The present work was carried out with a cocoa cultivar CCN51, located in the canton El Guabo, province of El Oro, in the geographical location: latitude 3°12'22.8" S and longitude 79°44'12.4" W, at 15 m above sea level. The climate in the area is humid tropical, with an average temperature of 24°C and an annual rainfall of 1750 mm. The soils in the area are of alluvial formation and are categorized in the Entisol order. The predominant texture is sandy loam to loam in the top 15 cm. On the farm where the trial was conducted, pH values fluctuated between 5,1 and 5,5 (highly acidic and acidic, respectively).

Organic manures

Biochar was obtained in a double-bottom furnace (inner and outer tank), a process that was carried out in a cleared area, following the instructions of Gaona-Chanalata et al., (2022). The biomass used for incineration was dried cocoa shells, which were introduced into the inner tank, being the heat source pieces of firewood, which were placed at the base of the outer tank. The temperature for this process was one hour at 300 °C. It was then allowed to cool for several hours to extract the product, which was then crushed and sieved with a 2 mm mesh.

Earthworm humus was bought from a retailer and the product was recorded at a pH of 7,9 and 75 % humidity, which was dried at room temperature for several days. The 10 kg of humus was then sprayed with 1 liter of biol obtained from alfalfa, moringa, whey and manure, which was fermented for 30 days. The humus sprayed with the biol was left covered with black plastic for 21 days.

Experiment design

The experimental consisting of 4 plots (treatments) of 50 x 50 m, where 15 cocoa plants were identified as the study units for data collection. In each plot, different amounts of cocoa biochar (BCC), earthworm humus and biol were applied to all plants, doses that are detailed in Table 1.

Table 1. Treatments and doses applied

Treatments	Doses/plants
T1	25 g cocoa biochar + 50 g Earthworm humus +biol
T2	10 g cocoa biochar + 100 g Earthworm humus + biol
T3	50 g cocoa biochar
T0	100 g de Earthworm humus +biol

Source: created by the authors

In addition to the organic fertilizers applied in each treatment, 50 g of lime and 150 g of triple superphosphate per plant were added to the soil one month before the trial.

Application of treatments

Two applications were made (June 12, 2021 and July 10, 2021) every 20 cm around the cocoa plant. Data recording was carried out 15 days after the first application and three months after the last application.

Variables measured in treatments

In the research, the variables were taken from the 15 selected plants and the measurement process was carried out as follows:

Number of floral: The inflorescences in cocoa trees are cauline and cymose, formed by pentamerous flowers with floral peduncle between 1 to 3 cm, therefore, the floral bearings (CF) located on the branches and stem at a height greater than 1.30 m were recorded in all plants for each treatment.

Number of cocoa pod: The total count of cocoa pods greater than 10 cm in length and that did not show signs of disease was made in all plants for each treatment.

Weight, diameter, length of the cocoa pod: 5 cocoa pods were chosen from each treatment at the end of the trial to measure weight (g), diameter (cm) and length (cm), using a scale and a tape measure.

Number of seeds per cocoa pod: The cocoa pod selected to measure the morphological variables were those that were later used to count the seeds.

Fresh and dry seed weight: From the pods selected for each treatment, groups of 100 seeds were ma*de,* fermented and dried for several days, and then weighed.

Statistical análisis

All data were entered into the Excel program. The variables were treated with the mean and standard deviation. An analysis of variance (ANOVA) with a significance level of 5% was used to establish differences between treatments. Tukey's test ($P < 0.05$) was also performed on the variables that showed differences between means. All data were analyzed with SPSS version 23 (SPSS, 2013).

RESULTS AND DISCUSIÓN

Effect of biochar on soil

Figure 1, shows how the pH of the soil changed when different treatments were put on it. The plot with the lowest pH corresponded to treatment two (10 g of BC+ 100 g of humus+biol) with a pH value of 5,04 (acid soil), which increased to pH 6,95 (neutral soil). The doses of 25 g of BC+ 50 g of humus+biol and 50 g of BC, corresponding to treatments T1 and T3, had an initial record of pH 5,65 (acid soil), then increased to pH 7.05 and 7.26, values that are categorized as slightly alkaline, respectively (Gaona-Chanala et al., 2022). These values indicate a change in the optimum soil reaction for the availability of nutrients such as N, P, K, Ca, but makes B, Zn and Fe less available (Quintana-Fuentes et al., 2015; Ramírez-Huila et al., 2016). This increase in soil pH increases biological activity and improves the long-term physical property of moisture retention and lower bulk density of soil (Barrezueta Unda & Paz González, 2018). On the other hand, Meyer et al., (2018), recommends the application of fertilizers with biochar in acid soils, because of the potential to improve the availability and absorption of nutrients in the root zone.

Treatment two made the soil more acidic, while treatments one and three made the soil slightly more alkaline. This change helps the soil hold more moisture and makes it easier for plants to get the nutrients they need. Adding biochar to acid soils also helps plants get the nutrients they need.

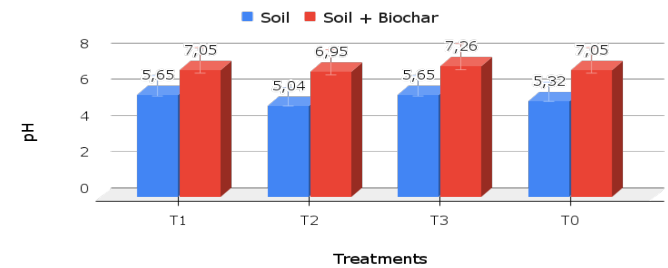


Figure 1. Average pH measured in the soils by treatment before and after applying the treatments

Source: created by the authors

Analysis of flower and healthy pods

The analysis of variance of CF (Table 2) showed significant differences ($p \leq 0,05$) in the first record (R1) and the third record (R3). CF values per treatment varied in the three logs. In R1, the highest averages were recorded in T0 (18 CF), followed by T2 (15 CF), T3 (9 CF) and T4 (4 CF). But in R2, values decreased in all treatments (T2=10 CF; T0=10 CF; T3= 8 CF; T1= 3 CF). While in R3, the values increased significantly only in T2 (16 CF), in T0 the CF value continued to decrease with respect to the other records. The difference in CF in R1 could have been associated with factors of low temperatures and high humidity in the area (Vera-Chang et al., 2016). Scientists studied cocoa trees in Ecuador and found that the number of flowers on the trees changed during different seasons and with different treatments. They noticed that the number of flowers changed a lot in the spring and that the pollinating insects also affected the number of flowers.

Although the number of CF is a factor related to the productivity of cocoa trees, but having a high fecundity of flowers is also dependent on the population of pollinating insects in the plots (Vásquez et al., 2020). On the other hand, the period in which the three observations were recorded corresponds to the spring season, a period of low flowering in the Ecuadorian coast (García et al., 2014).

Data related to the number of CF in cocoa fertilized with biochar were not found, but the greater increase in T2 can be explained by the neutral pH of this soil, where nutrients such as B and Zn, which affect the flowering of cocoa, would be available, while in slightly alkaline soils their availability to plants is limited (Barrezueta Unda & Paz González, 2018). Lim et al., (2015), analyzed the elemental composition of cocoa biochar and found high levels of

N, P, K, Ca, Mg, but low levels of B and Zn, elements that in the doses of T1, T3 and T0 can be absent, but available in the soil in a pH range between 5,5 to 6,5.

Table 2. Analysis of variance of floral bearings (FC) by record and treatments

	Treatments	Mean (DS)	Máximum	F	Si. 0,05
R1	T1	4 (5,6)	18	3,50	0,02
	T2	15 (17,8)	72		
	T3	9 (7,4)	29		
	T0	18 (14,9)	50		
R2	T1	3 (1,8)	6	2,06	0,12
	T2	10 (10,1)	35		
	T3	8 (7,9)	30		
	T0	10 (12,6)	48		
R3	T1	5 (6,2)	25	5,17	0,01
	T2	16 (10,5)	35		
	T3	8 (6,3)	19		
	T0	9 (7,1)	25		

R1= record 1; R2= record 2; R3= record 3.

SD= standard deviation

Source: created by the authors

The number of healthy pods presented in Table 3 shows significant differences (p≤0,05) among treatments in R3. The values of healthy ears in R1 ranged from 3 to 7 between T1 and T0, respectively. In R2, averages decreased from 2 to 4 DM, between T1 and T2, respectively; while maximum values ranged from 6 to 8 DM. In R3, the highest value was 2 DM recorded at T2. The averages are low compared to other studies and is related to the harvest season, which reaches its highest yield between February-April in the cocoa-growing areas of Ecuador (Quintana-Fuentes et al., 2015; Sánchez-Mora et al., 2014).

Table 3. Analysis of variance of healthy cocoa pods by treatments

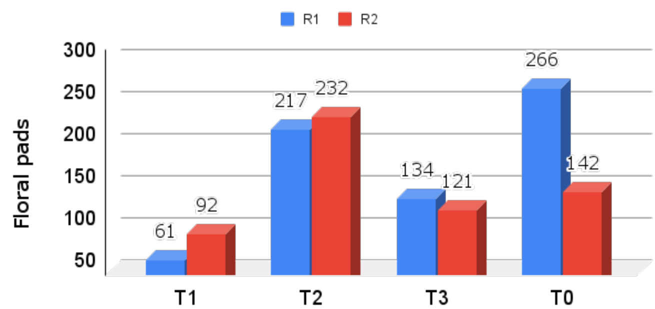
	Treatments	Mean (DS)	Máximum	F	Sig. 0,05
R1	T1	3 (2,9)	10	2,40	0,78
	T2	5 (3,1)	10		
	T3	6 (5,9)	23		
	T0	7 (5,9)	21		
R2	T1	2 (1,7)	6	2,61	0,60
	T2	4 (2,5)	8		
	T3	2 (2,2)	7		
	T0	3 (1,9)	8		
R3	T1	1 (0,6)	2	6,93	0,00
	T2	2 (1,36)	4		
	T3	1 (1,2)	4		
	T0	1 (0,6)	2		

R1= record 1; R2= record 2; R3= record 3

SD= standard deviation

Source: created by the authors

Figure 2A, the CF values (R1) from lowest to highest were: 61 (T1), 64 (T3), 217 (T2), and 266 (T0) In R3, a decrease in CF was observed in the control treatment (142 CF), but increased from lowest to highest in the following order: 92 (T1), 121 (T3), and 232 (T2). T2 values were close to the average obtained by Pérez Garcia & Freile Almeida (2017), for CCN51 clones and superior to the results for flowers without directed pollination (Vera-Chang et al., 2016). On the other hand, Figure 2B shows the decrease in the number of pods counted between R1 and R3. The highest peak in R1 was 166 DM corresponding to T0, followed by 114 DM (T3), 90 DM (T2) and 49 DM (T1). In R3, the treatments with the greatest difference with respect to the first record were: T0 (17 DM) and T3 (22 DM), while the lowest value was 6 DM corresponding to T1. The fluctuation between the number of CF and DM is not related, but it is observed that the effect of biochar has a positive incidence in T2, unlike T0 where the values decrease in greater proportion. Barrezueta et al, (2022) express that amendments with biochar in combination with other fertilizers increase the number of pods due to the improvement in the availability of nutrients in the soil.



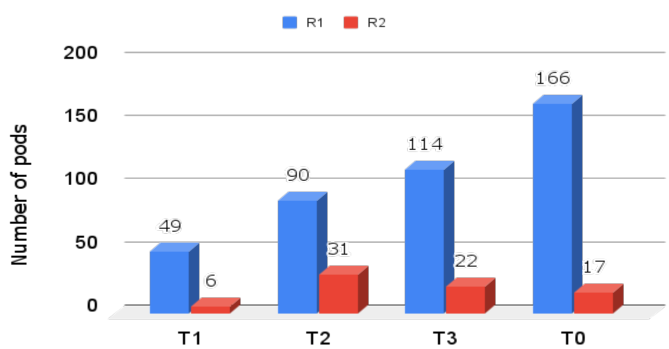


Figure 2. Comparison between record of the total sum of values per treatment of: A) mean number of flower cores per treatment between R1 and R2; B) means of number of healthy ears per treatment between R1 and R3

Source: created by the authors

Analysis of cocoa pod morphological variables

On the other hand, from the ANOVA of the number of seeds per cob, significant differences (p≤0,05) were obtained in the number of seeds and seed weight between T2 and the rest of the treatments (Table 3). The range of the number of seeds counted was from 17 (T3) to 56 (T0 and T2) and the averages from lowest to highest were: 38,8 (T3), 40,4 (T1), 45,1 (T4) and 46,9 (T2). The values are in the estimated range of (Estivarez Copa & Maldonado Fuentes, 2019) in several national cocoa hybrids (24 to 44 seeds per cob). The values of the dry weight of 100 dry cocoa seeds ranged from 271 (T3) to 1298 (T2) and the highest average was 895,2 g (T2), followed by 783,7 g (T3), 771,2 g (T0) and 633,8 g (T1). These values are higher than those obtained by (Pérez Garcia & Freile Almeida, 2017) in Nacional and CCN51 cocoa clones, but lower than those recorded by (Barrezueta., 2022).

Meyer et al., (2018), explains that soils with low pH and rich in Fe and Al oxides, the macronutrient P is often limiting in the soil due to its immobilization by these metals In this case, biochar can improve P availability due to its negative polarity induced adsorption mechanism that allows a better cation exchange (Meyer et al., 2018). As P is available, the plant absorbs it for different physiological processes such as fruit formation (Quintana-Fuentes et al., 2015; Ramírez-Huila et al., 2016).

Table 3. Descriptive statistics and Tukey's test (sig. 0.05) of the morphological variables of the cocoa pod: diameter, length, number of beans and weight of beans

Variables	Treatments	Mínimum	Mean (standard Desviation)	Máximum
Diameter (cm) of pod	T1	23	28,5 (2,9) a	34
	T2	25	30,9 (2,5) a	35
	T3	20	28,7 (3,4) a	33
	T0	25	30,4 (2,6) a	35
Length (cm) of cob	T1	19	22,2 (1,7) a	25
	T2	20	25,0 (3,1) a	33
	T3	18	24,1 (2,8) a	29
	T0	17	23,6 (5,9) a	43
Number of beans	T1	29	40,4 (7,3) ab	51
	T2	37	46,9 (6,5) a	56
	T3	17	38,8 (8,8) b	52
	T0	29	45,1 (7,9) ab	56
weight (g) of benas	T1	400	633,8 (175,4) b	1079
	T2	600	895,2 (174,0) a	1298
	T3	271	783,7 (206,4) ab	1071
	T0	448	771,2 (200,8) ab	1098

Source: created by the authors

CONCLUSIONS

Researchers did a study to see how adding biochar to soil would affect cocoa plants. They found that the soil changed from acid to neutral, which helped the plants grow better and produce more flowers. They also found that the plants produced the same size fruit and the same amount of seeds as plants grown in different soil. They want to do more testing to see if adding biochar to other types of soil helps plants grow better. Likewise, the number of healthy pods was related to the harvest season.

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