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Physical-chemical indicators of soil and cocoa yield with organic and conventional management

Indicadores físico-químicos del suelo y rendimiento del cacao con manejo orgánico y convencional

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ABSTRACT

The research evaluated the effect of organic and conventional management on soil physicochemical indicators and performance indicators of CCN-51 cocoa (*Theobroma cacao* L.). A completely randomized block design was applied, with four treatments: T1 (control), T2 (compost), T3 (NPK) and T4 (compost + NPK) and four repetitions. Physical indicators were evaluated: DA10 and DA20 bulk density and resistance to penetrability RP10 and RP20 (strata from 0.00 to 0.10 m and 0.10 to 0.20 m), chemical indicators: pH, MO, P, K, Ca, Mg, Al and CEC and performance indicators: number of fruits, fruit index and yield per hectare. The results did not show differences in DA and RP in both strata; Differences were found in the indicators pH, MO, P, Al and CEC, T2 and T4 had a greater effect on pH and CEC. Differences were found in the fruit index, in addition, the highest yield per hectare was presented by T2 (1125 kg/ha), although it did not show differences. In conclusion, there were significant chemical changes, except in physical indicators and performance indicators, showing organic production as a viable alternative by not showing differences and exceeding almond yield to chemical treatment.

Keywords: CCN51; compost; cob index; NPK; yield.

RESUMEN

La investigación evaluó el efecto del manejo orgánico y convencional sobre indicadores fisicoquímicos del suelo e indicadores de rendimiento del cacao CCN-51 (*Theobroma cacao* L.). Se aplicó un diseño de bloques completamente al azar, con cuatro tratamientos: T1 (control), T2 (compost), T3 (NPK) y T4 (compost + NPK) y cuatro repeticiones. Se evaluaron los indicadores físicos: densidad aparente DA10 y DA20 y resistencia a la penetrabilidad RP10 y RP20 (estratos de 0,00 a 0,10 m y 0,10 a 0,20 m), indicadores químicos: pH, MO, P, K, Ca, Mg, Al y CIC e indicadores de rendimiento: número de frutas, índice de fruta y rendimiento por hectárea. Los resultados no mostraron diferencias en la DA y RP en ambos estratos; se encontró diferencias en los indicadores pH, MO, P, Al y CIC, el T2 y T4 tuvieron mayor efecto sobre pH y CIC. Se encontró diferencias en el índice de fruta, además, el mayor rendimiento por hectárea lo presento T2 (1125 kg/ha), aunque, no mostró diferencias. En conclusión, hubo cambios químicos significativos, excepto en indicadores físicos e indicadores de rendimiento, mostrando a la producción orgánica como una alternativa viable al no mostrar diferencias y superar en rendimiento de almendras al tratamiento químico.

Palabras clave: CCN51; compost; índice de mazorca; NPK; rendimiento.

1. Introduction

In our country, cocoa production has stood out in the sector, as of 2017, it reached an extension of 199 thousand hectares (Ministry of Agriculture and Irrigation-MINAGRI, 2018); This increase in world production implies new areas dedicated to cultivation (Quintero and Diaz, 2004). Also, the world yield of cocoa bean production is on average 485 kg/ha, Peru presents average yields of 720 kg/ha, above the world average (MINAGRI, 2018).

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However, there are some countries with high productivity, such as Guatemala and Thailand, which in 2013 exceeded 3 thousand and 2.6 thousand kilograms per hectare (MINAGRI, 2016). The most used system is the conventional one, which is responsible for the loss of productivity, lower yields and greater environmental problems (Torres *et al*., 2006). Therefore, it is recommended to apply sustainable systems that make it possible to maintain high yields and provide ecosystem services (Jacobi *et al*., 2014), this can be achieved through organic production systems that offer long-term advantages, compared to conventional systems (Jacobi *et al*., 2014). For this reason, it requires evaluating production systems that allow comprehensive improvement of performance under local conditions. Faced with this, organic production is an alternative, to which multiple benefits are attributed to the soil and crops (Ahmed *et al*., 2020; Abreu *et al*., 2018; Cortes *et al*., 2016; Firme *et al*., 2014), contrary to the use of formulating fertilizers (NPK), which can impact soil properties and affect plant growth (Abreu *et al*., 2018; Orozco *et al*., 2016; Chaves *et al*., 2013; López *et al*., 2007).

The physical indicators of the soil are affected by the applied system, reduced tillage, conservation, and all agroecological systems are the ones that best conserve the physical properties of the soil (Navarro *et al*., 2019; García *et al*., 2018; Gracia, 2012); changes do not occur in the short term, they occur in the long term (Arévalo, 2014) unless organic fertilizers are applied in large quantities (Ramírez *et al*., 2015). In this context, sustainable production systems were sought, which make high production possible and maintain the productive potential of the agroecosystem. Therefore, the research aimed to evaluate the effect of organic and conventional management on physical soil indicators and performance indicators in CCN-51 cocoa plantations (*Theobroma cacao* L.), in Nuevo Progreso-Padre Abad, Ucayali region.

2. Materials and methods

2.1 Study area

The research was carried out in 2018 at the “Florida & Cárdenas” farm. Politically, the populated centre of Nuevo Progreso belongs to the district and the province of Padre Abad, Ucayali-Peru region. Geographically, the plot is located at latitude 8°54'23"S and longitude 75°29'34" W. According to Holdridge (2000), Padre Abad belongs to the very humid forest ecosystem - Tropical Premontane (bmh-PT) and the average climatic conditions are as follows: average annual temperature is 27 ºC, relative humidity is 84% and annual precipitation is 2,000 mm. For Pulgar (2014) the area is classified as the Omagua or lowland ecoregion. The area is located on non-flooding medium terraces, of ancient alluvial origin; taxonomically corresponds to an Inceptisol soil (Ucayali Regional Government-GOREU, 2017). The experimental units are 9 x 6 m that include 6 cocoa plants (4 selected for evaluation) and a total experimental area of 1,287 m^2.

2.2 Treatments

The treatments were applied following the recommendations of Puentes *et al*. (2014), based on soil analysis. Based on these results, the indicated amount of compost (according to the technical data sheet) and NPK (in the form of urea, triple superphosphate and potassium chloride; a dose of 84-161-35) were calculated. The total application was carried out in three stages (January, May and September) and contour of the tree canopy, with partial amounts of 54.8 g/N plant, 52.1 g/P plant and 96.7 g/potassium plant in each application.

2.3 Indicator evaluation

The evaluation of performance indicators was measured through several ears, ear index and almond yield per hectare; For this, the ears of labelled plants were collected in each experimental unit every month basis during the 2018 campaign. By counting the ears and recording the dry weight of the grain per plant, treatment and repetition, this allowed determining the average number per tree, the index ear (N ° pods/kg dry cocoa) and almond production (kg /ha/year). The evaluation of the physical indicators was made 60 days after the third application of the treatments (November), under the guidelines of the USDA (2014), evaluating resistance to penetrability (cone Penetrometer), texture (Bouyoucos), bulk density (cylinder method), methodologies described by Bazán (2017).

2.4 Analysis of data

Shapiro Wilk and Shapiro France normality tests were performed to verify the normality of the data. Also, analysis of variance and Duncan multiple comparisons were performed at a significance level of 5% for the comparison of means between treatments and repetitions. The data were analyzed with the free statistical program IBM SPSS 25.

3. Results and discussion

3.1 Physical indicators

Table 1 shows the means for DA10 and DA20, with no statistical differences found between the treatments for the evaluated strata and soils with acceptable DA (1.4 ≤ DA <1.6 g/cm^3) and ideal (DA <1.4 g/cm^3) according to the Food United Nations-FAO (2012). Likewise, regarding the RP in strata of 0.0 to 0.10 m and strata of 0.10 to 0.20 m, there are no differences between the treatments in both strata and these soils are considered as soft (1-2 kg/cm^2) according to Hosokay (2012). The results correspond to one year of evaluation, both physical indicators do not present statistical differences; Similar results were found by García *et al*. (2018) with AD of 1.52 g/cm^3 for reduced tillage and 1.27g/cm^3 for conservation tillage and Gracia (2012) found no significant changes in the physical properties of the soil, compared to the application of compost. These references show that changes in the physical properties of the soil do not occur in the short term, they occur in the long term; In this regard, Arévalo (2014) in Agroforestry and conventional cocoa production systems, in 10 years of evaluations, found statistically different means in the physical properties of the soil. Although in the short term, they can find differences if large amounts are applied, as Ramírez *et al*. (2015) applied doses of 9 t of earthworm humus and 60 t of manure, found a significant effect on the physical properties of the soil. According to the references, the results of the work are consistent since 3 t of compost was applied and evaluated for one year.

3.2 Chemical indicators of the soil

The results of Table 2 present significant statistical differences for the chemical indicators pH, OM, P, Al^{+3} and CEC; According to FAO (2012), these values correspond to a soil with strongly acidic pH levels, medium to high OM, medium P, low CEC and high Al level.

The behavior of compost treatments in T2 and T4 to raise pH levels and CEC have been evidenced by other authors, among them, Torres (2018) applying chicken manure and heifer increased pH values from 4.58 to 4.83 and CEC of 3.35 to 4.26 Cmol (+) / kg; Alvarado (2016) applying organic and inorganic fertilizer evidenced a significant effect on the variables of pH, organic matter, and phosphorus; Ramírez *et al.* (2015) with doses of 9 t of earthworm humus and 60 t of manure, found a positive effect and increased the contents of P, K, Ca, Mg and OM, and a noticeable increase in pH; Gracia (2012) applied different urban solid waste compost and found changes in the content of OM and macro and micronutrients; Orozco and Thienhaus (1997) treatment with 1,362 g of chicken manure increased the pH, CEC and OM; Orozco and Thienhaus (1997) found trends of increasing OM, pH and decrease of Al. These references corroborate the potential of compost to improve these chemical indicators.

According to Table 2, compost (T2) and compost + NPK (T4) presented the highest pH means, this behavior was reported by Ramírez *et al*. (2015) when applying 9 t of earthworm humus and 60 t of manure, he found a noticeable increase in pH; Contrary results can be found with the application of chemical treatments, according to Orozco and Thienhaus (1997) acidification of the soil is caused. The pH of T3 (NPK) in this research are lower than T2 and T4, which showed an increase in MO, CICe and a reduction in Al. However, some works show positive effects of NPK, Soto (2015) applied NPK and increased The levels of OM, P, K, CEC and changeable Bases increased as the NPK dose increased, this is not sustainable over time, according to Alvarado (2016) and Puentes *et al*. (2014) CCN-51 presents higher yield with low doses, the excess of NPK to the natural content of the soil, can present long-term negative yields to fertilization, due to the decrease in pH and the increase in changeable acidity.

3.3 Performance indicators

Table 2 shows the mean of the performance indicators with their standard deviation, and in cases where there is a significant difference, different letters appear, followed by the standard deviation of all the indicators evaluated according to the treatments applied.

Table 1
Analysis of physical indicators according to treatments

Indicators	Treatments				Statistics	
	T1	T2	T3	T4	SEM	Sig.
AD10 (g/cm^3)	1.36±0.05a	1.41±0.03a	1.372±0.07a	1.4±0.05a	0.132	0.892
AD20 (g/cm^3)	1.43±0.08a	1.53±0.10a	1.43±0.09a	1.5±0.05a	0.089	0.27
RP10 (kg/cm^2)	1.13±0.18a	0.96±0.1a	1.02±0.15a	0.91±0.25a	0.391	0.381
RP20 (kg/cm^2)	1.82±0.19a	1.53±0.19a	1.73±0.19a	1.58±0.19a	0.459	0.193

T1 Control. T2 compost. T3 NPK, T4 composts + NPK, SEM mean square of the error, Sig. Significance, * significant p < 0.05, ** significant p < 0.01, mean values in the same column followed by different letters indicate significant differences (p <0.05) between treatments.

Table 2
Analysis of chemical indicators according to treatments

Indicators	Treatments				Statistics	
	T1	T2	T3	T4	MSE	Sig.
pH	4.11±0.1a	4.39±0.1bc	4.26±0.08ab	4.42±0.06c	0.11	0.003**
OM %	2.32±0.4a	4.13±1.2b	4.41±1b	3.86±0.6b	8.52	0.019*
P (ppm)	9. 38+0.84a	10.10±0.5a	10.61+0.28a	8.68+0.56a	4.05	0.004**
K (ppm)	139.5±8.96a	145.25±24.4a	146.75±10.8a	131.5±10.9a	2729.5	0.498
Ca (Cmol/kg)	2. 62±0. 24a	2.62±0. 21a	2.33±0.14a	2.52±0.08a	0.373	0.125
Mg (Cmol/kg)	1.38±0. 21a	1.45±0. 24a	1.25±0.06a	1.46±0.08a	0.324	0.288
Al (Cmol/kg)	3.92±0.08b	3.28±0.45a	3.02±0.07a	3.31±0.25a	0.843	0.003**
CEC Cmol/kg	9.45±0.27c	8.78±0.81bc	7.87±0.36a	8.60±0.4ab	3082	0.007**

T1 Control, T2 compost, T3 NPK, T4 composts + NPK, MSE mean square of the error, Sig. Significance, * significant $p < 0.05$, ** significant $p < 0.01$, mean values in the same column followed by different letters indicate significant differences ($p < 0.05$) between treatments.

In Table 2, it can be seen that T2 (compost) presents the highest averages in almond production (1125 kg/ha) and T3 (NPK) presents the highest averages in the indicated number of ears (19.19 ears/plant) and ear index (20.36 ears/kg); finding significant differences only for the ear index.

The results of Table 3 present statistical differences between the treatments for the fruit index. Is an indicator that expresses the number of fruits per unit of weight, allowing a better interpretation of the behaviour of the treatments. The work found that the application of NPK (T3) had the highest index, that is, the largest number of fruits to obtain 1 kg of almond, which is not very favorable; In contrast, compost (T2) presented the lowest fruit index, indicating a lower number of fruits to obtain 1 kg of almonds, this is very favorable for the producer, it reflects that the compost improved the size of the fruits and grains and increased yield per fruit. This behaviour of chemical fertilizers has already been noted by Montes (2016) when applying DI ammonium phosphate + ammonium sulfate 60+40 kg/ha reports an index of 25.16 fruit/kg, which reflects a low yield per fruit.

Statistically, the treatments do not show differences for the number of fruits per plant and yield in almonds, being compost (T2) the one with the highest yield, there are two things to highlight based on this result: first, it explains the behaviour of the index of fruits. Of the T2 (lower index) and second, the treatments that contain compost, both the T2 and the T4 have the same behaviour as the fertilization with NPK.

Although the results, in general, are relatively higher than those of Castro (2015) in CCN-51, in the Santa Rosita estate in Irazola-Padre Abad, he found the almond yield of 607.61 kg /ha; Also, they are higher than the average yields for our country, 720 kg/ha and above the world average of 485 kg/ha (MINAGRI, 2018). How to explain this high yield in almonds, according to Recalde *et al.* (2012) the clone CCN51 develops the sink of nutrients and other compounds early in the growth cycle, which ensures higher yields, because, in the second year of production with chicken manure, it found 428 kg/ha, in our case the evaluated plot is in its third year of production, which would explain the higher performance found.

Organic production or combined with chemistry is a viable alternative, our result shows it, there are no statistical differences and the references contrast this behaviour; In this regard, Huera (2018) applying Full cocoa (organic + chemical) presented dry almond yields of 2 727.45 kg/ha and 1982.05 kg/ha for bio compost; Also, Gómez (2017) found yields of 1350 kg/ha for chemical fertilization and 1270 kg/ha for organic fertilization; Montes (2016) with diatomic phosphorus + ammonium sulfate (30+40 k/ha), obtained 1539 kg/ha; Álvarez *et al.* (2015) found similar responses between chemical and organic treatments, with averages of 2730 kg/ha for conventional and 2521.43 for organic, and Ludeña (2015) in Jaén found yields of 1298.3 kg/ha with organic treatment. and microelements. Finally, Abreu *et al.* (2018) state that in the first harvests, 100% chemical fertilizer gives the best results, however, the application of humus improves from the second harvest, which suggests that organic fertilizers outperform chemical fertilizers in the long term.

Table 3
Analysis of performance indicators according to treatments

Indicators	Treatments				Statistics	
	T1	T2	T3	T4	SEM	Sig.
Number of fruits	12±5.61	12.38±3.64	19.19±9.92	15.63±5.37	42.99	0.409
fruit index	15.60±0.5ab	12.83±2.3a	20.36±3.1c	16.22±1.7b	52.441	0.002**
Almonds (kg/ha)	860.41±412a	1 125.13±439a	1 080.1±674a	1057±296a	2711511.8	0.865

T1 Control, T2 compost, T3 NPK, T4 composts + NPK, SEM mean square of the error, Sig significance, * significant $p < 0.05$, ** significant $p < 0.01$, mean values in the same column followed by different letters indicate significant differences ($p < 0.05$) between treatments.

It is necessary not to exaggerate with the excessive use of fertilizers, thus Sánchez *et al.* (2005) applied fertilization with NPK 50, 100, 200 and 400% additional to the laboratory dose, the production of the control was statistically equal to that of the rest of the treatments. Although the cultivation of cocoa has a potential for nutrient extraction that translates into good yields, when this limit is exceeded, it causes a nutritional imbalance and consequently low yields (Puentes *et al*., 2014). Besides, the clone must be taken into account, the CCN-51 is highly productive and profitable (Carrión, 2012). Furthermore, according to Puentes *et al*. (2014) CCN-51 has a higher yield than other clones with only 25% additional NPK to the natural content of the soil. Additional doses may present negative yields to fertilization (Alvarado, 2016), a situation observed in T2 of the work since compost has a low but varied nutritional composition and presented the highest yield

4. Conclusion

There are significant differences in chemical indicators and in the ear index. The physical indicators of the soil and the yield of almonds per hectare do not show significant differences. Therefore, it shows organic production as a viable alternative for the area under study, as it does not present statistical differences and exceeds the yield of almonds per hectare to chemical treatment.

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