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Original article

Alternatives for agroecological soil management in agroecosystems of *Theobroma cacao* L

Alternativas para el manejo agroecológico de suelos en agroecosistemas de *Theobroma cacao* L.

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ABSTRACT: The research was carried out during the period 2016 - 2018 in farms of the UBPC "José MaceoGrajales", Baracoa municipality, Guantánamo Province with the aim of evaluating the effect of different alternatives for agroecological soil management in the fragile mountainous agroecosystem of Theobroma cacao L. Four treatments were studied, with four replications in a Random Block Design. The treatments were: 1. Live barriers + dead barriers, 2. Live barriers + dead barriers + organic matter, 3. Live barriers + dead barriers + organic matter + organic fertilizer generated from the *Canavalia ensiformis* and 4. Control without conservation measures. Evaluations such as chemical analysis of the soil (pH, organic matter, phosphorus and potassium), soil losses and cocoa crop yields were carried out in 2016, two years later the same evaluations were repeated. The results obtained show that the application of agroecological management alternatives significantly influences the improvement of the studied chemical properties of the brown sialitic, ochric soil and the reduction of soil losses to permissible limits in the cocoa agroecosystem. The most efficient alternative in agroecological soil management for *Theobroma cacao* L., was the combination of living and dead barriers plus organic fertilizers generated from the legume Canavalia species, with agricultural yields of 1, 18 t ha^{-1}, higher than the national average.

Key words: erosion, conservation, yield, alternatives.

RESUMEN: La investigación se realizó durante el período 2016 - 2018 en fincas de la UBPC "José Maceo Grajales", municipio Baracoa, provincia Guantánamo, con el objetivo de evaluar el efecto de diferentes alternativas de manejo agroecológico de suelo en agroecosistema frágil montañoso de cacao, *Theobroma cacao* L. Se estudiaron cuatro tratamientos, con cuatro réplicas en un Diseño en Bloques al Azar. Los tratamientos fueron: 1. Barreras vivas + barreras muertas, 2. Barreras vivas + barreras muertas + materia orgánica, 3. Barreras vivas + barreras muertas + materia orgánica + abono orgánico generado de la C*anavalia ensiformis* y 4. Testigo sin medidas de conservación. Se realizaron en el año 2016 evaluaciones tales como análisis químico del suelo (pH, materia orgánica, fósforo y potasio), pérdidas de suelos y rendimientos del cultivo del cacao, dos años después, se repitieron las mismas evaluaciones. Los resultados obtenidos demuestran que la aplicación de las alternativas de manejo agroecológico influye de manera significativa en el mejoramiento de las propiedades químicas estudiadas del suelo Pardo sialíticoócrico y la disminución de las pérdidas de suelos hasta límites permisibles en el agroecosistema cacaotero. La alternativa más eficiente en el manejo agroecológico de suelo para *Theobroma cacao* L. fue la combinación de barreras vivas y muertas con los abonos orgánicos generados de la especie leguminosa Canavalia, con rendimientos agrícolas de 1,18 t ha^{-1}, superiores a la media nacional.

Palabras clave: erosión, conservación, rendimiento, alternativas.

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INTRODUCTION

In tropical regions, water erosion is the most important soil degradation process (1). It has been reported that soil erosion has been influenced by climate change, mainly by changes in temperature and precipitation patterns that have impacted plant biomass production, infiltration rates, soil moisture, and changes in crop use and management (2). This, together with world population growth and the estimated 50 % increase in food demand in the coming years, make climate change an additional risk for soil degradation and depletion of water reserves, due to the expansion of cultivation areas and intensification of production (3).

In this regard, it has been pointed out that, although it is a fact that climate change is a natural and inevitable process and is not under human control, poor management of soils and the environment by man can accelerate erosive processes. Therefore, if land use could be properly managed, soil loss could be controlled and even decreased, even under the influence of climate change (4).

On the other hand, soils are also deteriorating rapidly due to nutrient depletion, loss of organic carbon, and compaction. However, this phenomenon can be reversed provided that initiatives are taken to promote sustainable management practices and the use of appropriate technologies (5).

It is a recognized fact that soil conservation is a pressing and urgent need that cannot be postponed. An average loss of 0.3 % of annual crop yields is occurring due to erosion, which, if continued without positive changes, could lead to a 10 % reduction in annual yields by the year 2050. This would mean the annual loss of 4.5 million hectares of agricultural soils, with Asia, Latin America and the Caribbean, the Near East and North Africa being the regions with the highest tendency to such deterioration (6).

Soil deterioration reinforces the importance of soil conservation, which implies considering fundamental aspects such as food security, resilience to climate change and geosocial stability (7). Particularly in Cuba, as a consequence of the above, more than 40 % of the soils are affected by erosion with potentials up to 56 %, which is alarming if we consider that the first sign of the chain reaction unleashed by these factors, the decrease in agricultural yields (8) in several crops, among these, cocoa, which is developed, fundamentally, in the pre-mountain range of the Nipe-Sagua-Baracoa and Sierra Maestra mountain massifs, in addition to the growing development in the Central and Western zones of the country (9), with an average yield that does not exceed 0.39 t ha^{-1}(10).

Mountainous regions are considered fragile ecosystems, in which agricultural development depends on sustainable alternatives to avoid breaking the balance between man and nature, since they are given the conditions for the occurrence of phenomena such as soil erosion caused by heavy rainfall and undulating relief, whose slopes without conservation measures cause runoff, which means the dragging of soil particles by the energy of water circulation before a lack of protection of the same.

Faced with this scenario, there is a need to gradually improve sustainability in the management of local natural resources such as soil, in order to achieve sustainable development through agroecological management alternatives that allow its conservation and improvement, in addition to achieving potential crop yields. Therefore, the present research work aimed to evaluate agroecological soil management alternatives in a fragile mountainous agroecosystem planted with *Theobroma cacao* L. in Baracoa municipality, Guantánamo province, Cuba.

MATERIALS AND METHODS

The research was conducted during the period 2016 - 2018, in agroecosystems of the UBPC “José Maceo Grajales”, located in the town of Jamal, Baracoa municipality, located at 20°16'34.65“north latitude and 74°25'32.35” west longitude, at 23 meters above sea level. It was developed in a cocoa plantation 20 years old, established with grafting of clone UF 650, with mixtures of forest species as shade, on a soil with sialitic brown grouping, brown type, ochric subtype (11), undulating relief and average slope of 15 %.

For the characterization of the climate, the existing information of the last five years was recorded, provided by the Meteorological Station, belonging to the Institute of Meteorology (INSMET) located in the area of Jamal (Figure 1). With the data described above, a climodiagram was drawn up showing the average temperatures and rainfall in the study area.

A randomized block design was used, with four treatments and four replications. The treatments were:

1. Live barrier + dead barrier
2. Live barrier + dead barrier + organic matter.
3. Live barrier + dead barrier + organic matter + organic fertilizer from *Canavalia ensiformis* L.
4. Absolute control (without any conservation measure). Application of technical standards (21)

Aralia plants (*Aralia elegans*) were used as a living barrier, established in spring by stakes with an approximate length of 0.40 m at a distance of 12 m between barriers (9). Stakes were placed in holes traced following the contour line for each treatment. Plants were pruned to maintain a minimum height of 0.80-1 m. All plant residues and biomass from the cocoa agroecosystem were used as dead barriers, such as banana stems, palm stalks, trunks and branches from pruning the crop itself. These were cordoned off at a distance of 12 m (9) and secured with stakes to ensure stability and uniformity.

The source of organic matter used was decomposed cocoa shells from the harvest pits of the plantation itself. Individual terraces were made up of small circular platforms around each cocoa plant and protected with banana pseudostems. Organic matter was applied every six months, at a rate of 10 kg per plant. On the other hand, the seeds of the species *Canavalia ensiformis* L. were sown around the cocoa plants and between rows at a planting frame of 0.20 m between plants and 0.50 m between rows. After homogeneous flowering, the biomass was incorporated into the soil for decomposition and use as organic fertilizer.

Two soil samplings were carried out per treatment with the objective of evaluating the nutritional behavior of the soil, one at the beginning (first evaluation, January 2016) and the other at the end of the research (second evaluation, December 2018). To carry out the two samplings, soil subsamples were taken per treatment, which were mixed and a final sample of 1 kg per treatment was obtained.

The chemical analysis of the soil samples was carried out and the contents of organic matter (by the Colorimetric method), phosphorus (Oniani method by Colorimetry), potassium (Oniani method by flame photometry) and pH were determined, whose methods were described in the Manual of analytical techniques for soil analysis, foliar, organic fertilizers and chemical fertilizers (12). The evaluation of their content in the soil was categorized as high, medium, low and very low, as described in the same manual.

Soil losses were determined by the improved method of nails and washers (13), for which four random points were evaluated by means of graduated and buried rods where the treatments were located, in plots without application of measures and with application of measures per treatment, to determine the level of eroded soil layer, based on the following formula:

$$P = h . A . Da$$

Where:

P= soil loss in (t ha^{-1} year).

h= height of the soil sheet lost by erosion (cm).

A= measured area (m^2).

Da= bulk density (g cm^3).

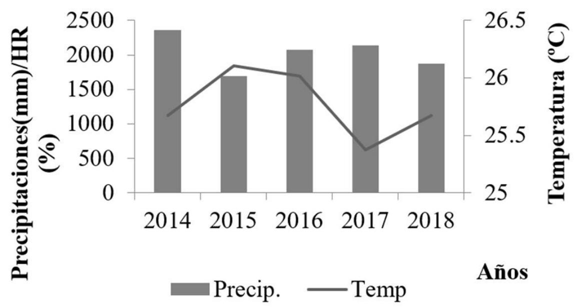
Soil losses were determined from the monthly recording of the height in cm of the eroded soil sheet in each of the graduated rods per treatment and per plot with and without the application of the management alternatives, whose average values signified the soil loss for each treatment. The dynamics of the soil loss register was compared with the local pluviometric information, which allowed the analysis and interpretation of the results due to the direct relationship that precipitation has with soil loss in mountainous relief.

During the research, evaluations of the agricultural yield (t ha^{-1}) of the crop per treatment were carried out in two harvest years that included four seasons (two cold harvests and two spring harvests). At the end of the research, the average agricultural yield of the crop years was determined from the number of ears harvested in a total of 22 plants per treatment, which were 100 % of plants per plot.

For all the research, the data were processed with the use of the statistical program STATGRAPHICS plus ver. 5.1, where an analysis of variance of simple classification and the comparison of the means with the application of Duncan's Multiple Range Test, for a 95 % probability of error, were carried out.

RESULTS AND DISCUSSION

In correspondence with the historical climatic characteristics of the region under study (Figure 1), the mean annual precipitation was between 1500-1800 mm, with higher values during the rainy season and the temperature between 25.7-30 ºC (14).



Precip.: Precipitations (mm) y Temp.: Temperature (°C)

Figure 1. Climogram of the area under study during 2014-2018, in El Jamal town, Baracoa municipality

Therefore, it is considered a very rainy area within the Nipe Sagua Baracoa mountain massif, with the possible effects of precipitation on the soil by causing soil deterioration, due to the constant runoff due to the effect of the slope, and with it the loss of organic matter that potentially causes low yields in the *Theobroma cacao* L. crop, when conservation and soil improvement measures are not applied. Thus, soil deterioration caused by natural phenomena or anthropogenic origin, shows the need to pay special attention when studying the impacts of high rainfall on unprotected soil and, at the same time, on production, in this case of cocoa. Thus, the need to look for sustainable soil management alternatives.

The chemical analysis of the soil at the beginning of the research (first evaluation) showed that the pH was acidic in the plots where all the treatments were located (Table 1), which was an aspect of agricultural interest due to the negative effects of this soil condition on the productive potential of the soil. However, in the second evaluation, after the application of soil conservation and improvement measures, unlike the control treatment, in all treatments the pH improved from a very acid to a neutral state, which was considered appropriate for agricultural crops (23).

Therefore, these changes in pH after integrated agroecological soil management were significant, with T3 performing better and 1.38 times better than the initial state. Similar results, although lower, were found for T1 and T2, (0.93 and 0.99) respectively to T3, but significant with respect to the first evaluation, which showed the influence of the measures applied in the improvement of soil acidity by increasing the pH and improving the productive yields of the cocoa crop. This is corroborated by (25) that cocoa productivity increases when the Al^{3+} concentration is decreased and the pH is increased to values between 5.5 and 7.5, independently of other characteristics: deep

Table 1. Results of soil chemical analysis before and after the application of soil conservation measures, first and second evaluation

		First evaluation (2016)		
Treatments	**pH**	**O. M**	**P_2O_5**	**K_2O**
T1	5.47	4.26	9.96	31.92
T2	5.48	4.36	9.96	31.90
T3	5.47	4.24	9.98	31.94
T4	5.46	4.26	9.96	31.91
Standard Error	0.024 ns	0.074 ns	0.12 ns	0.34 ns
		Second evaluation (2018)		
T1	6. 40b	5.23c	31.61b	43.61b
T2	6.47b	5.62b	31.79b	48.00a
T3	6. 85a	6.04a	34. 90a	49.71a
T4	5.12c	2.37d	8.97c	31.5c
Standard Error	0.07*	0.35*	0.69*	0.78*

T1. Live barrier + dead barrier, T2. Live barrier + dead barrier + organic matter, T3. Live barrier + dead barrier + organic matter + *Canavalia ensiformis* L., T4. Absolute control (without any conservation measure). Means with equal letters do not differ from each other (Duncan's Multiple Range Test, p≤0.05), ns: not significant for p≤0.05

soils, good drainage, moisture retention and good organic matter content.

On the other hand, according to the classifications of the manual of analytical techniques for the analysis of soil, foliar, organic fertilizers and chemical fertilizers, with the application of the treatments, the levels of phosphorus changed from very low to medium levels (12), in the second evaluation made for this element, with a significant difference between the treatments with the highest values in treatment 3; on the contrary, it resulted in the control treatment, with the lowest values. In general, tropical countries are characterized by insufficient phosphorus content, which is related to clay content, since clay tends to absorb a large amount of phosphorus (22), so it is necessary to apply organic matter to increase and sustain the availability of this element in the soil for cocoa cultivation.

On the other hand, high potassium contents were evaluated in all treatments (first evaluation) with an increase in its content after the application of one or another soil conservation and improvement measure, with the exception of the control, where the content of this element decreased, which could be due to soil dragging by erosion when soil conservation measures were not applied. For this reason, soil conservation practices and the use of organic matter and incorporation of green manures induce biochemical, physical and biological processes that enhance soil sustainability (23).

Incidentally, the greatest increases in potassium were found in treatment 3, followed by treatment 2. This increase in potassium may be due to the application of conservation measures by incorporating organic fertilizers from cocoa shells (rich in this element) and organic matter generated by the decomposing biomass of *Canavalia ensiformis* L., in the cocoa agroecosystem, which represented a better use and availability of this element.

With respect to organic matter in the first evaluation, in all treatments it showed average levels, with no significant difference between treatments. At the end of the evaluation, in the treatments where one or another soil protection and improvement alternative was applied, the organic matter content was high, with the highest values in treatment 3, followed by treatments 2 and 1, but in the soil where the control treatment was established, the organic matter content decreased.

In several areas of the world, inadequate land use has caused different erosion processes and a decrease in the organic matter content of soils, a phenomenon that has increased due to climate change and, therefore, increased vulnerability (15). In this context, lands devoid of vegetation cover are more vulnerable to degradation (16); therefore, taking into account what was stated by the above authors, in the present research the use of cover and conservation barriers have made the cocoa agroecosystem less vulnerable to soil losses, so that the use of alternatives facilitated the reduction of erosion and runoff, contributing to improve soil sustainability and crop productivity.

Thus, the results of the chemical analysis of the soil in each treatment highlighted the importance of green manures and the source of organic matter from cocoa shells as part of agroecological management in improving the chemical properties of the soil. In this way, management can be sustainable through the use of local sources of these materials, produced in situ, which gives greater importance to the alternatives applied. Hence, green manures are an agronomic practice that consists of the incorporation of a non-decomposed vegetal mass of cultivated plants, with the purpose of improving the availability of nutrients and the properties of the soil (17,18), so that this constitutes an alternative to be used for the agroecological management of soils dedicated to the cultivation of cocoa.

In general, it is evident that the application of living and dead soil protection barriers and sources of organic matter originating from the agroecosystem itself improve the quality, sustainability and agroproductivity of the soil resource (19), due to crop nutrition that will result in higher yields.

The slope of the land, together with the abundant rainfall in the study area, are the possible causes that have produced constant dragging of the superficial soil layer, through hydric erosion, causing the loss of the productive capacity, gradation and fertility, by evidencing a decrease in the content of the main limiting factors in crop yields: N, P_2O_5, K_2O, OM and pH (26).

The greatest soil loss, from the beginning to the end of the research period, occurred in the control treatment (Figure 2). On the contrary, due to the effect of the treatments: T1, T2 andT3, soil losses decreased, although with significant difference among them, highlighting treatment 3 with the best result. Therefore, the positive effect of soil conservation, protection and improvement measures in the cocoa agroecosystem as part of integrated agroecological management was evident.

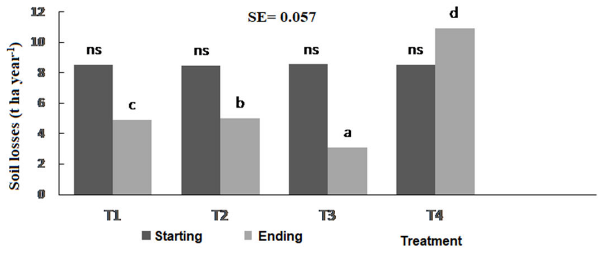
Different authors have reported losses of more than 20 t ha^{-1} year when soil conservation measures are not applied. Losses higher than 30 t ha^{-1} year have been reported in the Brown Sialitic soils of the North of Havana in a natural way and by anthropic effect, in spite of the high anti-erosion resistance of these soils (20). The intensive and continuous use of soils, without applying good agroecological practices in the locality where the research was conducted, constitute threats that limit the productivity of soils and reduce the sustainability of cocoa cultivation.

It is evident that further loss of productive soils would severely damage food production and food security. This loss can be restricted through sustainable soil management, using local, scientific knowledge and appropriate technologies.

Regarding productive yields, Figure 3 shows significant differences between treatments, in favor of treatment 3, whose average yield (1.18 t ha^{-1}) followed by treatments T1, T2 (0.87 t ha^{-1} and 0.90 t ha^{-1}, respectively), higher than the local average (0.40 t ha^{-1}). On the other hand, the lowest yield value was obtained by the control treatment, which result could be related to the constant soil losses and thus the degradation of its physical, chemical and biological properties.

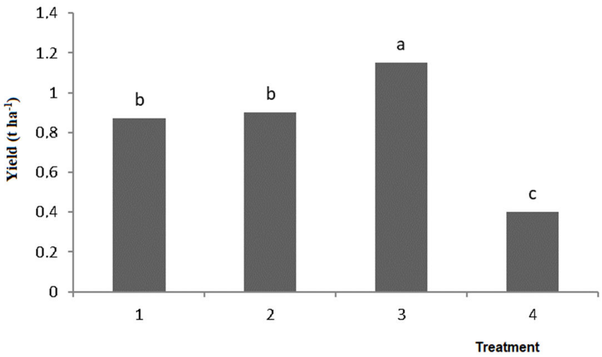
Soil is an exhaustible resource, which means that its loss and degradation is a threat to food security. But, soil loss can be greatly reduced with sustainable soil management practices such as live and dead barriers or cover crops that protect the soil surface from loss through erosion and degradation. Therefore, providing information to land managers about erosion processes and their consequences based on a reliable assessment of vulnerability and risk levels is a necessary step for prevention and control (17).

For this reason, agroecological soil management alternatives acquire significance in the face of deterioration due to the effect of rainfall and intensity in the region. At the same time, these measures are indispensable for the support and supply of nutrients and sustainability of the cocoa production agroecosystem, within the framework of ecological and sustainable agriculture, which can only be achieved through integrated soil management.



T1. Live barrier + dead barrier, T2. Live barrier + dead barrier + organic matter, T3. Live barrier + dead barrier + organic matter + organic fertilizer from *Canavalia ensiformis* L., T4. Absolute control (without any conservation measure). Starting: results of the stage at which the first soil loss assessment was initiated. End: results of the stage at which the last soil loss assessment was concluded. Means with equal letters do not differ from each other (Duncan's Multiple Range Test, $p \leq 0.05$), ns: not significant for $p \leq 0.05$

Figure 2. Effect of treatments on soil losses due to erosion



T1. Live barrier + dead barrier, T2. Live barrier + dead barrier + organic matter, T3. Live barrier + dead barrier + organic matter + *Canavalia ensiformis* L., T4. Absolute control (without any conservation measure). Means with equal letters do not differ from each other (Duncan's Multiple Range Test, $p \leq 0.05$)

Figure 3. Average cocoa yields for the two years for each treatment

CONCLUSIONS

- The application of agroecological management alternatives had a significant influence on the improvement of the chemical properties of the sialytic brown and ochric soils studied and the reduction of soil losses to permissible limits in the cocoa agroecosystem.
- The most efficient alternative in agroecological soil management for *Theobroma cacao* L. was the combination of live and dead barriers plus organic fertilizers generated from the leguminous species *Canavalia ensiformis* L., with agricultural yields of 1.18 t ha^{-1}, higher than the local and national average.

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