SCIENTIFIC PAPER

Effect of the application of sustainable practices on the physical, chemical and microbiological characteristics of degraded soils

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ABSTRACT: The objective of the study was to evaluate the effect of the application of sustainable practices on the evolution of the soil properties, in deteriorated areas of the Cesar department. The experimental design was complete randomized blocks and variance analysis was applied. Two treatments were evaluated: control, based on the traditional management of the farmer, without applying soil amelioration practices (prevailing system in the zone); and experimental, which consisted in the application of inorganic amendments and sustainable practices to the soil: adequate tillage, incorporation of green manure (*Vigna unguiculata*) and establishment of plant cover with associated grasses and legumes (*Bothriochloa pertusa*, *Leucaena leucocephala* and *Clitoria ternatea*). During three years, a comparative evaluation was made of the physical, chemical and microbiological characteristics of the soil. There was a trend towards the improvement of the physical and chemical characteristics of the soil, due to the decrease of the apparent density (from 1,68 to 1,53 g cm^{-3} in the first 30 cm of depth), as well as to the increase of the soil porosity (from 33,28 to 41,2 %), basic infiltration (from 0,5 to 1,3 mm h^{-1}), organic matter (from 0,97 to 1,40 %) and sulfur (from 8,57 to 40,35 mg kg^{-1}). Likewise, neither the sodium concentration nor the electric conductivity was increased. The treatments did not generate considerable alterations in the microbial populations (bacteria, actinomycetes and fungi), which allows to infer that the applied practices did not cause negative impacts on the soil microbiota.

Key words: grasses, green manure, legumes, soil compaction, zero tillage

INTRODUCTION

It is considered that 90 % of the soils in the Cesar department which have agricultural potential has undergone a process of deterioration of their physical, chemical and biological characteristics; this has affected their productive capacity and the production potential of the main agricultural systems of the region, which has affected the rural producers' incomes. As a solution to this problem the convenience of implementing integral practices of soil management as strategies for the amelioration and recovery or maintenance of their properties and productive capacity, has been stated.

In the livestock and agricultural production activities, one of the physical limitations shown in the soil is compaction; which –through time and with the persistence of its causes– can reach the deeper layers if no corrective actions are performed. For such reason it is stated that the biotic and abiotic processes constitute the organic amendments, while the physical treatments applied to the soil are effective methods to recover this property (Boivin *et al*., 2006; Zhang *et al*., 2006).

The negative impact of compaction consists in the alteration of porosity, which reduces the saturation of hydraulic conductivity and permeability to air (Boivin *et al*., 2006). The modifications occurred can generate processes of plant cover loss and trigger erosion. In addition, they alter the soil habitat and reduce the biological activity of the flora and fauna (Nevens and Reheul, 2003; Boivin *et al*., 2006). As final result, the loss of the soil productive capacity occurs, which has negative implications on the environment (Soane and Van Ouwerkek, 1995).

The soil, environment and productivity are benefitted when the edaphic potential is sustainably managed. The good management of the soil promotes healthier, less susceptible to diseases, and more productive crops and animals (Sullivan, 2007), which increases incomes and improves the living standards of farmers (Soto, 2008).

The objective of this study was to evaluate the effect of the application of sustainable practices on the evolution of the soil properties, in deteriorated areas of the Cesar department.

MATERIALS AND METHODS

Location. The trial was conducted at the farm Dominó, located to the southwest of the municipal main town of Valledupar (Cesar, Colombia), at 18 km on the road that leads to Bosconia, in a representative area of the problem (12 ha).

Physical, chemical and microbiological analysis of the soil

The physical, chemical and microbiological characteristics were determined through the laboratory and/or field methods, in the different stages of the study: initial or organic and inorganic amendment stage; intermediate or grass and legume establishment stage; and final stage or stage of exploitation of the experimental lots under grazing conditions.

The following physical properties were determined: texture, apparent density, porosity and infiltration, at two depths (0-30 cm and 30-60 cm). Texture was determined by the hydrometer method, and the apparent density, through the cylinder of known volume method.

The infiltration tests were performed with infiltrometric rings and four repetitions were made. A regression analysis was applied to the field results, to obtain the equations of the cumulative and basic infiltrations.

Porosity was obtained through the formula that comprises the apparent and real density. To estimate the real one, the density average that prevailed in the zone was taken (2,60 g/cm^3).

Likewise, the chemical characteristics were determined at two depths (0-30 cm and 30-60 cm), using the methods described in the *Manual No*. 47 of the *Programa de Suelos del ICA* (1980).

The organic matter was determined with the use of the Walkley-Black method (1934); nitrogen, by means of the Kjeldhal technique (USDA, 1996); and the minor elements, through the modified Olsen extraction method (USDA, 1996). The cation exchange capacity and electric conductivity were determined according to the NTC 5298 and NTC 5596, respectively (ICONTEC, 2008; 2008a).

On the other hand, the microbiological characteristics were determined from the recount on dish of seriated soil dilutions, according to the protocols of the laboratory of soil microbiology of CORPOICA, for counting bacteria, fungi and actinomycetes.

Selection of the tillage system

The selection of the adequate tillage system was made from the diagnosis of the soil properties. Tables 1 and 2 describe the criteria that were taken into consideration for the selection, according to the physical and chemical conditions of the soil (Castro and Amézquita, 1991; Bonilla and Murillo, 1998).

Experimental treatments. Application of sustainable practices

From the 12 ha chosen for conducting the study, six were selected for the control treatment and six for the experimental one. The first one (prevailing in extensive livestock productions of the zone) consisted in the non-application of inorganic amendments or the implementation of sustainable practices in the soil. While in the second treatment several amendments were made in the soil, which started with an initial pass of chisel at 60 cm of depth, and the drilling sowing of *Vigna unguiculata* L. Walp, in rows separated by 0,70 m; it was incorporated to the soil in two consecutive harvests, in

Table 1. Critical range of the physical properties in soils with compaction problems.

Physical property	Critical range		
	Sandy	Loamy	Clayey
Apparent density (g/cm^3)	> 1,8	> 1,6	> 1,5
Porosity (%)	< 31	< 38	< 42
Infiltration (mm/hour)	< 63	< 20	< 5

Source: Castro and Amézquita (1991).

Table 2. Selection criteria of the tillage system, according to the soil properties.

Soil Property	Deep tillage			Minimum tillage			Zero tillage		
	Texture			Texture			Texture		
	Heavy	Medium	Light	Heavy	Medium	Light	Heavy	Medium	Light
Apparent density (g/cm^3)	> 1,5	> 1,6	> 1,8	1,3-1,5	1,4-1,6	1,6-1,8	< 1,3	< 1,4	<1,6
Porosity (%)	< 42	< 38	< 32	42-50	38-46	32-40	> 50	> 46	> 40
Infiltration (mm/hour)	< 5	< 20	< 63	5-10	10-20	20-63	> 10	> 20	> 63
Organic matter	Low	Low	Low	Moderate	Moderate	Moderate	High	High	High

Source: Castro and Amézquita (1991).

the stage of pod formation (75 days after its germination), with the use of a harrow.

Afterwards, the legumes *Clitoria ternatea* and *Leucaena leucocephala*, associated to the grass *Cynodon nlemfuensis*, were established. In the case of leucaena, nursery plants were used from seeds inoculated with *Rhizobium* sp., which were sown at a distance of 4 m between rows and 1 m between plants.

Likewise, a total of 80 kg of kieserite and 75 kg of urea per hectare were incorporated, at two moments: before planting the star grass and 20-25 days after that.

The grass *C. nlemfuensis* was sown between the *L. leucocephala* rows, at a distance of 1,0 m between rows and 0,50 m between plants, and separated by 1,0 m from the leucaena. *C. ternatea* was sown broadcast, within the grass rows, with a planting density of 5 kg/ha.

In order to evaluate the soil response to animal trampling, the two areas were divided into 12 paddocks of 0,5 ha each, in which a rotational grazing system was established, with eight growing calves –130 kg of initial live weight as average– per treatment; the occupation period was 6 and 4 days and the resting time was 66 and 44 days, in the dry and rainy seasons, respectively.

The chemical, physical and microbiological analyses were carried out before and after the establishment of the treatments: control (T_1) and application of sustainable practices (T_2). A complete randomized block design and two replications were used. The analyses were made between the variables of the initial and the intermediate stage, as well as between the intermediate and final stage. The information obtained was subject to variance analysis and the means were compared through the DMS test, with a level of 5 % probability.

RESULTS AND DISCUSSION

Chemical analysis of the soil

Two consecutive incorporations of green manure were performed in the soil (3 352 kg DM/ha), which was obtained from the *Vigna unguiculata* crop and had the following dry matter composition: 3,26 % of nitrogen; 0,49 % of phosphorus; 2,93 % of potassium; 3,7 % of calcium; 0,55 % of magnesium; 0,84 % of manganese; 25,3 mg kg^{-1} of zinc; 7,2 mg kg^{-1} of copper; 80,2 mg kg^{-1} of iron; 17,1 mg kg^{-1} of boron and 967,9 mg kg^{-1} of sulfur.

In the initial analysis of the soil, a neutral pH and low contents of organic matter (1,32-0,97 %), sulfur (2,46-8,57 mg kg^{-1}) and sodium saturation (3,09-8,28 %) were obtained. The phosphorus content was moderate(16,97-36,45 mg kg^{-1}); while those of calcium (9,99-10,0 cmol^{+} kg^{-1}), magnesium (2,43-3,07 cmol^{+} kg^{-1}) and potassium (0,75-0,69 cmol^{+} kg^{-1}) were high, for T1 and T2, respectively. According to the electric conductivity, this soil is non-saline.

In the different stages there were no significant differences ($p > 0,05$) between the treatments, in most of the analyzed elements. In the sulfur content there was a significant increase ($p< 0,05$) in the three stages of T_2 with regards to T_1, which indicates that the use of amendments and the establishment of grasses and legumes had positive effect on the availability of this element. Such increase (21,40-40,35 mg kg^{-1}) possibly came from the inorganic amendment, the contribution of the green manure incorporated, as well as from the feces and urine of cattle. The cation exchange capacity (CEC) as well as the sodium percentage was also observed to have moderate values during the experiment, in both treatments, which shows that the soil does not pose risk of sodicity.

Likewise, it can be inferred that the chemical and nutritional characteristics of the soil were benefitted with the implementation of the two treatments –which involved the variations in the tillage system and the addition of organic amendments (green manure)–, by controlling its salinity and maintaining the organic matter content. It is important to state that the soil recovery by means of the incorporation of organic materials and the use of appropriate tillage systems can only be detected during longer time periods than the one used in this study; thus, the results obtained are preliminary, although important trends are shown.

The organic matter is involved in the water retention in the soil, which helps to decrease compaction. When the adequate quantity of organic matter is maintained as green manure, the soil structure is stabilized, because it becomes more resistant to degradation and to its excessive aggregation (Hamza and Anderson, 2005).

This application of green manure and compost as amendments is a practice that favors the recovery of the soil physical properties. In this sense, Reddy (1991) observed a decrease in the apparent density of 0,02 mg m^3, as well as an approximate increase of 11,8 KPa in the soil strength after the application of 10 t ha^{-1} of green manure. In turn, the infiltration can be increased in 0,4 cm ha^{-1} (Hamza and Anderson, 2005).

Other authors suggest that the C/N ratio is important for the adequate decomposition of organic matter by microorganisms (Marin, 2004). For such reason, the addition of organic matter in compacted or saline soils plays an important role and has a positive effect on the microbial and enzymatic activities, such as: urease, alkaline phosphatase and dehydrogenase (Tejada *et al*., 2006).

Soil physical analysis

Before performing the practices, a loamy clayey texture was appreciated in the soil. According to the physical analysis (table 3), the average value of the apparent density was over 1,5 g/cm^3 in the evaluated horizons; while the porosity average was lower than 42 %, and the infiltration, lower than 5 mm/hour. This, together with the low organic matter content (< than 1,5 %), indicated the critical status of soil compaction (Castro and Amézquita, 1991).

Through the diagnosis it was determined that the soil showed the characteristic affectation of degradation; this was shown by observing the landscape, in which the areas with scarce vegetation or without plant cover stood out. According to these results, it is considered that the appropriate technology to face such problem is the application of deep tillage, complemented with the incorporation of green manure (Bonilla and Murillo, 1998).

On the other hand, to conduct the statistical analysis the information obtained in: the initial and intermediate stage, and the intermediate and final stage, was compared.

When comparing the initial physical conditions of the soil with the ones existing after the application of the sustainable practices, it was observed that regarding the apparent density there were significant differences (p<0,05) between the treatments at the depth of 0 to 30 cm of the soil. In the intermediate stage, a lower average was obtained in T_2 (1,53 g/cm^3), compared with T_1 (1,71 g/cm^3), which can be ascribed to the effect of the applied practices.

In the depth from 30 to 60 cm no significant differences were found between T_1 (1,74 g/cm^3) and T_2 (1,70 g/cm^3), possibly due to the fact that the

Table 3. Physical analysis of the soil in the initial and intermediate stages.

Analysis	Treatment	Apparent density (g cm^{-3})$^{\Delta}$		Porosity (%)$^{\Delta}$		Infiltration (mm h^{-1})$^{\Delta}$
		0-30 cm	30-60 cm	0-30 cm	30-60 cm	
Initial	T1	1,70 ± 0,125^a	1,80 ± 0,025^a	34,60 ± 3,554^a	30,80 ± 0,851^a	0,52 ± 0,187^a
	T2	1,68 ± 0,033^a	1,75 ± 0,035^a	33,28 ± 0,338^a	29,92 ± 0,321^a	0,50 ± 0,108^a
Interme-diate	T1	1,71 ± 0,067^a	1,74 ± 0,049^a	34,20 ± 2,123^a	33,00 ± 1,920^a	0,61 ± 0,049^a
	T2	1,53 ± 0,060^b	1,70 ± 0,034^a	41,20 ± 2,328^b	34,40 ± 1,310^a	1,30 ± 0,428^b

$^{\Delta}$Average of three repetitions.

Different letters vertically indicate significant differences at p < 0,05 incorporation of organic matter in this horizon was lower than in the surface one.

In the indicator porosity significant differences were found ($p< 0,05$) between the treatments in the depth from 0 to 30 cm. The treatment where the sustainable practices were applied showed a higher soil porosity (41,20 %), with regards to the control lot (34,20 %), which can be ascribed to such practices, mainly tillage and incorporation of green manure. In the profile from 30 to 60 cm there were no sensible changes and the differences were not significant (table 3).

After cattle grazing, there was a slight reduction of the apparent density in the horizon from 0 to 30 cm, in T_2 with regards to the control. However, the difference was not significant ($p< 0,05$), for which it is inferred that the change was not due to animal trampling, but maybe to the continuity of the effect of sustainable practices, which was prolonged until grazing was over (table 4).

Animal trampling did not influence such indicator in both treatments, which could be due to the low stocking rate (initial-final): 0,34 LAU/ha-0,75 LAU/ha when the sustainable practices were applied, and 0,34 LAU/ha-0,62 LAU/ha in the control. It can also be ascribed to the scarce time passed during the experiment, as well as to the long drought period recorded in the zone and the low soil moisture.

The action of the *L. leucocephala* and *C. ternatea* roots, in addition to the cover that reduces the impact of the animal trampling, could contribute to the reduction of the density in the sustainable treatment.

In the horizon from 30 to 60 cm, the differences were not significant ($p > 0,05$) and the density remained stable. On the other hand, in T_2 there was a slight increase in porosity after grazing, in the depth from 0 to 30 cm, as consequence of the slight decrease of density; but the difference between the treatments was not significant ($p > 0,05$).

In the intermediate analysis an increase of infiltration was also found in T_2, but there were no significant differences between the treatments (table 4).

According to Nevens and Reheul (2003), the adequate management of the soil compaction – especially in arid and semiarid regions–can be achieved through the adequate application of one or several techniques: the addition of organic matter in the form of green manure; the control of the traffic of agricultural machinery and of the excessive grazing; the separation tillage methods; the adequate crop rotation and the use of pasture plants that show a deep and strong root growth, capable of penetrating and separating compacted soils.

Microbiological analysis of the soil

The microbial populations (bacteria, fungi and actinomycetes) did not show significant differences, which proved that there was no variation since the beginning until the end of the study.

Nevertheless, in the inter-subject tests there was a slight difference in the performance of the bacteria population, in general ($p = 0,029$), regarding the sampling event, because in the comparison of estimated marginal means (fig. 1) an increase was found of the bacterial populations, compared with their initial concentration. In contrast, the populations of fungi and actinomycetes remained stable in both sampling events, without considerable changes in their population (figs. 2 and 3).

Soils have an inherent quality, given by their chemical, physical and biological characteristics. The biological properties can reflect the changes that occur due to the environment, which shows the effect of certain management practices on the health status of the soil; for such reason, these properties can be used as bioindicators. Several authors state that the microbiological properties of the soil could show the existing differences between the appropriate management practices, in order to preserve the quality of the agroecosystems in time (Bending and Lincoln, 2007).

Table 4. Physical analysis of the soil at the intermediate and final moments.

	Treatment	Apparent density (g cm^{-3})$^{\Delta}$		Porosity (%)$^{\Delta}$		Infiltration (mm h^{-1})$^{\Delta}$
		0-30 cm	30-60 cm	0-30 cm	30-60 cm	
Intermediate analysis	T_1	1,71^a	1,74^a	34,20^a	33,00^a	0,61^a
	T_2	1,53^a	1,70^a	41,20^a	34,40^a	1,30^a
Final analysis	T_1	1,68^a	1,71^a	35,40^a	42,30^a	0,58^a
	T_2	1,50^a	1,67^a	33,80^a	35,90^a	2,15^a

$^{\Delta}$Average of three repetitions.

Different letters vertically indicate significant differences at $p < 0,05$.

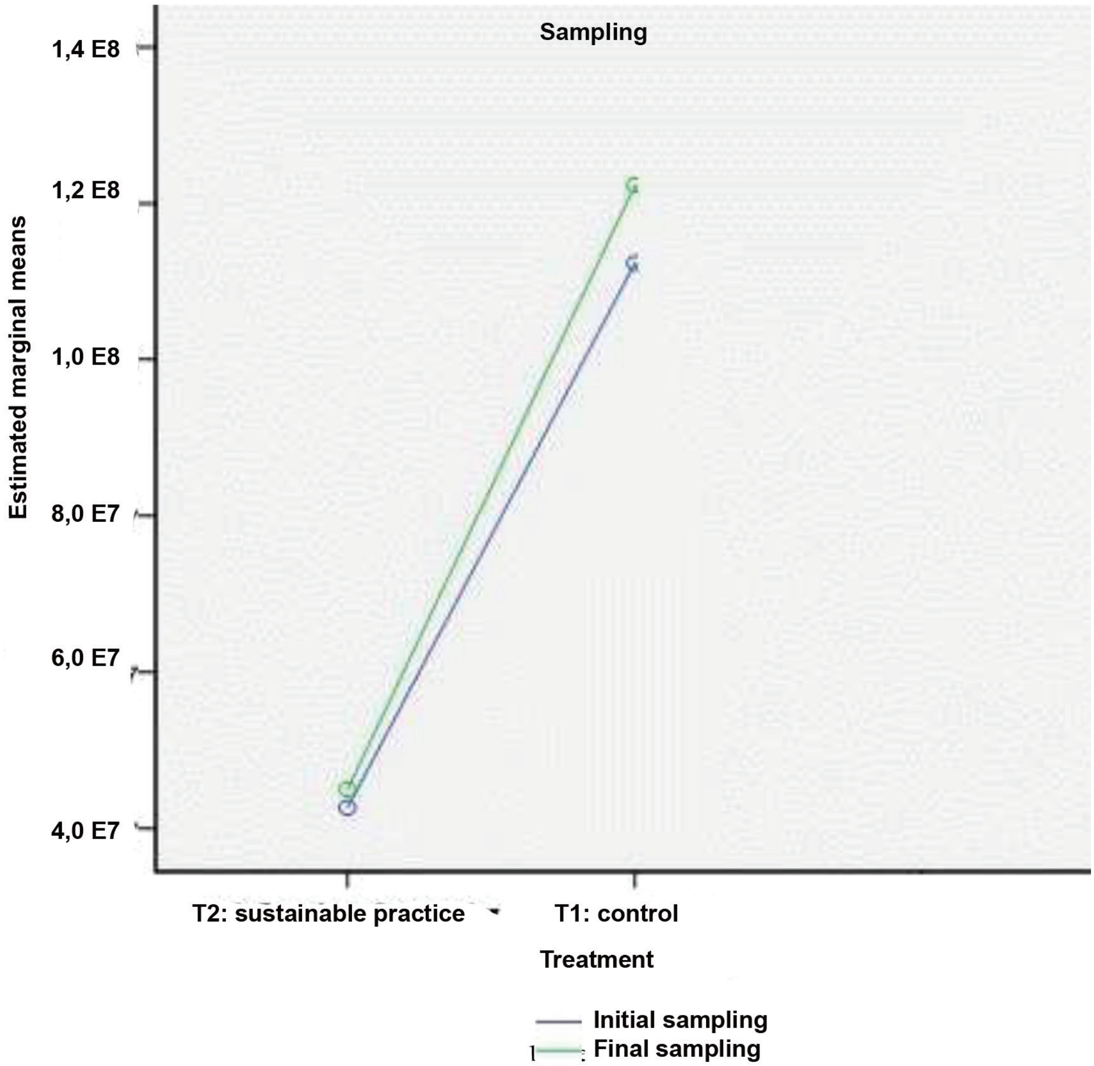

Figure 1. Marginal means per treatment and sampling event in bacteria.

The biological indicators or bioindicators have gained strength due to their higher sensitivity and fast response to the disturbances and/or variables introduced in the soil ecosystem and, especially, due to their integrating character. That is why the microbial populations of the soil can respond rapidly to the changes introduced in the system –caused by the management practices–, for which they constitute adequate indicators. Alkorta *et al.* (2004) and Breno *et al.* (2009) determined that the inadequate soil management, with inappropriate tillage systems, leads to the decrease of edaphic microorganisms.

The long-term maintenance of agroecosystems is an essential condition for the preservation of the soil resource. In fact, to improve its quality the development of the microbial communities that inhabit it should be favored, which is achieved through the adequate combination of cultural practices (Pérez *et al.*, 2010).

CONCLUSIONS

The application of sustainable practices tended to improve the physical and chemical characteristics of the soil, which is appreciated in the decrease of the apparent density, higher porosity, increase of infiltration and organic matter and sulfur contents; without increasing the sodium and salt contents.

The applied treatments did not generate considerable alterations in the microbial populations (bacteria, actinomycetes and fungi), which allows to infer that these practices did not cause negative impacts on the soil microbiota.

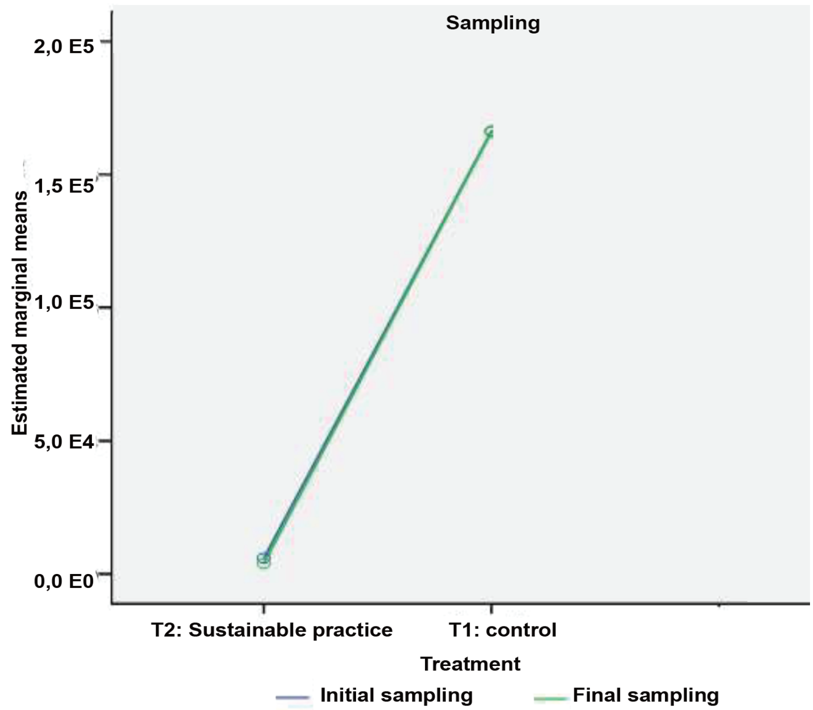

Figure 2. Marginal means per treatment and sampling event in fungi.

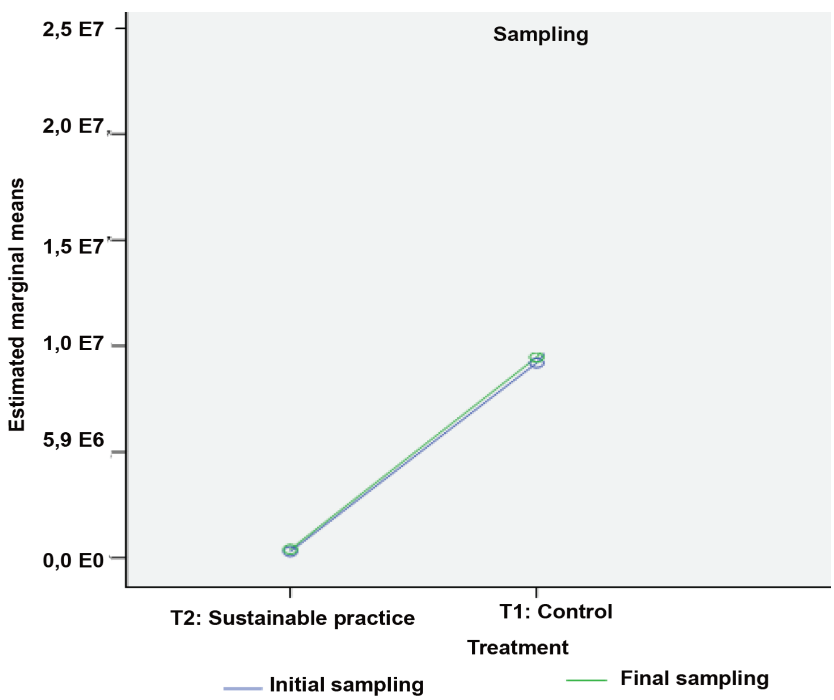

Figure 3. Marginal means per treatment and sampling event in actinomycetes.

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