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A Preliminary Study on Effectiveness in the Implementation of Bioengineering Works in Eroded Tropical Soils

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Abstract

This paper shows an assessment of effectiveness in the implementation of bioengineering works on eroded tropical soils (Bojacá, Colombia) through three indicators of soil quality: pH, electrical conductivity (EC), and microbiological abundance (MA). This study was conducted based on the guide for assessment of soil quality and health (USDA), the colony forming units' method (CFU) in aerobic-anoxic sowings, and the serial dilution method. Three erosion strata were distinguished: Stratum 1 (erosion gullies), Stratum 2 (lichens), and Stratum 3 (bioengineering works: benches). The results showed that there were significant differences between the three strata in relation to soil quality indicators (pH, EC, and MA). We observed the existence of a relationship between pH, EC, and MA, and the effectiveness of bioengineering works implemented in the study area. There was evidence of a decrease in pH to a range of beneficial magnitude for the increase of soil microorganisms (pH = 5.2). There was also a decrease of EC possibly by the increase of organic matter and stability of soil aggregates generated by the implementation of these bioengineering works (EC = 64.3 µS/cm). Finally, the microbiological abundance (CFU: bacteria, fungi, and yeasts) increased between 3.91 and 162 times through these bioengineering works (benches).

Keywords: Bioengineering, Tropical soil, Erosion, Benches.

INTRODUCTION

Inadequate land use and disorientated agricultural practices are the main human cause of desertification, erosion or alteration of soil characteristics [1, 2]. Hence, these phenomena influence soil properties such as infiltration, erosion, transport, and sediment deposition [3, 4]. An eroded soil has reached this state product of a deficit of organic matter and its low decomposition. Therefore, it is evident the relationship between composition of the bacterial communities and the amount of carbon existing within the soil [5]. However, microbiological diversity is not the only factor that varies; properties such as pH and electrical conductivity (EC) also vary within the soil [6].

Bioengineering is among the main alternatives for the integral recovery of a soil. This is a tool that consists in the construction of both stronger vegetation fences (e.g. benches), which serve as reinforcement, as hydraulic drains and barriers to contain the erosion and mass movements [7]. Among the parameters that allow evaluating the effectiveness of bioengineering works are pH, EC, and microbiological abundance (MA) [6]. In this way, it is of great importance to study the variation of these parameters under different erosion strata to evaluate the effectiveness of bioengineering works implemented in a specified area.

There are indicators of soil quality that allow to evaluate their status, and to identify the critical points in relation to the sustainability of this one as a productive medium or as an important natural resource for the life quality and maintenance of the biodiversity. The chemical indicators (e.g. pH and EC) refer to the conditions affecting the soil-plant relationship, and to the quality and availability of water and nutrients for plants and microorganisms. Biological indicators (e.g. MA) incorporate many factors that allow assessing the soil quality in relation to the abundance and by-products of microorganisms, including bacteria and fungi [8]. The biological activity acts in the solubilization, mobilization and availability of nutrients for plants, and is an indicator of the early changes that modify the dynamics of nutrients before they can be detected by chemical analyses [9].

The main objective of this paper is to analyze through three indicators of soil quality (pH, EC, and MA) the effectiveness of bioengineering works implemented on eroded tropical soils. Specifically, the effectiveness of the benches bioengineering technique in improving soil quality is analyzed. This study will deepen the knowledge about possible parameters of soil quality and health to evaluate the effectiveness of future bioengineering works on eroded tropical soils.

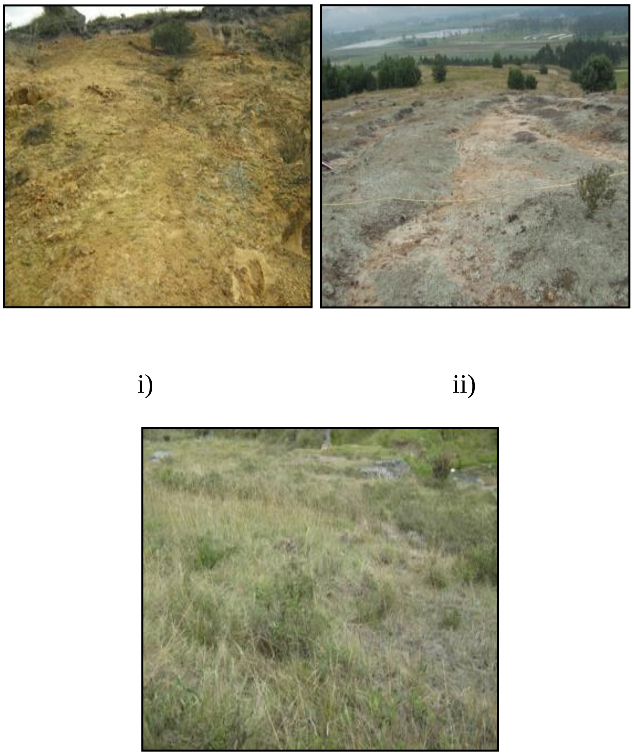
MATERIALS AND METHODS

Study area

Bojacá is a municipality located to 40 km from Bogota (capital of Colombia), which has a total area of 10277 ha. A large part of the territory shows an aridity index higher than 0.3, and between 26-55% of the municipal area evidence intense erosion [10]. The study area was on a mountain and hillside area that suffered the extractive exploitation of quarries and brick industries. It has alluvial plains with flat relief sets and a slope range between 1%-50%. It also has an average elevation of 2598 masl and an average temperature of 14 °C. The life zone prevalent in the study area was of low tropical humid mountainous forest.

Sampling system

The sampling system was based on the criterion of plant-desertification relationship [11]. Three study sites with different erosion degree were considered: (i) Stratum 1, erosion gully or non-vegetated area; (ii) Stratum 2, lichens, manifesting symbiosis between mycobiont and fycobiont; and (iii) Stratum 3, a bioengineering work (benches) with the presence of grasslands and moderate vegetation (Figure 1). Each soil stratum had a sampling area of 81 m^2 (9 m x 9 m) on which were defined ten analysis points using zig-zag technique (average distance between points: 1.9 m) [12]. At each analysis point, four soil samples were collected (50 g each) at a depth of 10 cm. Fifty percent of the samples collected at each analysis point were used for determination of pH and EC, and the remaining 50% were used for microbiological counting. The soil samples were preserved in a refrigerator for 12 h before the microbiological count [13].



i) ii)

iii)

Figure 1. Soil strata in the study area. (i) Stratum 1 = erosion gullies; (ii) Stratum 2 = lichens; (iii) Stratum 3 = bioengineering works (benches).

Laboratory analysis

pH and EC: Soil samples were previously sieved in dry (size fraction < 2000 µm) [12]. Ten grams of each soil sample was taken, then add 10 ml of distilled water. With the resulting mixture of soil-water (ratio 1:1, V/V) was determined pH and EC based on the guide for assessment of soil quality and health (USDA) [14]. Twenty soil samples were analyzed for pH and EC in each stratum under study.

MA: Ten soil samples of each stratum were homogenized and from this mixture, 50 g of soil was carried to a volume of 50 ml of sterile peptonized water at 0.1% (ratio 1:1, V/V). Then, three dilutions were carried out in series to make surface sowings (aerobic conditions) in nutritive agar (NA) and potato dextrose agar (PDA); and deep sowings (anoxic conditions) in NA and sabouraud dextrose agar (SDA) [15]. For each sowing a replica was made. The medium for the growth of bacteria (NA) was incubated for three days at 37 ºC. The medium for the growth of fungi and yeasts (PDA and SDA) was incubated for three days at 25 ºC [16]. Finally, the colony forming units (CFU) were counted for each medium, and the macroscopic morphology of the resulting colonies was recorded for bacteria (form, elevation, and margin) and fungi (color and texture) [15].

RESULTS AND DISCUSSION

pH

Figure 2 shows the existence of higher pH values for Stratum 1 (erosion gullies). As noted, there were comparatively differences in pH data between the tropical soil strata. Stratum 1 showed the highest pH values and a trend toward the neutrality of them (average pH = 7.2). This stratum also showed a lower pH variation (standard deviation, SD = 0.179) in relation to the other soil strata under study. In contrast, Stratum 3 (benches) tended to show lower pH values (average = 5.2) and a greater variation of this one (SD = 0.394) in relation to the other soil strata under study. Stratum 2 (lichens) exhibited intermediate pH values in relation to the strata 1 and 2.

A Shapiro-Wilk test showed a normal distribution of pH data in the three soil strata (df = 20; p-values > 0.278). An Anova test suggested the existence of significant differences for pH between the soil strata under study (df = 20; p-value < 0.001). In this regard, a Tukey test allowed evidence that the biggest difference in pH data was evident between the strata 1 and 3 (df = 20; p-value < 0.001).

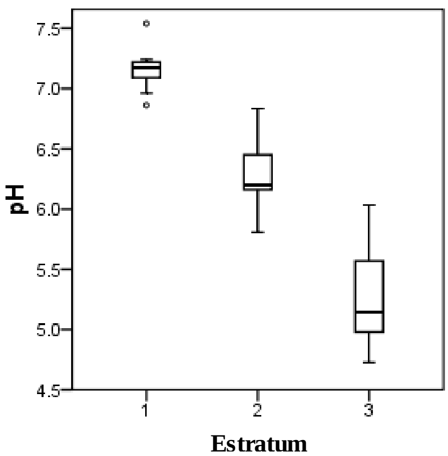


Figure 2. pH variation for the three soil strata. Stratum 1 = Erosion gullies, Stratum 2 = Lichens, and Stratum 3 = Benches.

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Therefore, the results suggested that pH tended to increase with the degree of soil erosion (Figure 1). Namely, the implementation of bioengineering works (benches) generated a reduction in pH. This trend was probably associated with a low concentration of iron and sulphates, and to the presence of humic acids in the soil. pH values for Stratum 2 were in an intermediate range in relation to the strata 1 and 3, suggesting a moderate concentration of iron and sulphate. [6] reported similar results in studies of soil erosion on the Lusatian mining area in east central Germany.

Electrical conductivity (EC)

Stratum 1 (erosion gullies) showed the highest EC values (average EC = 421 µS/cm). This stratum of soil also showed a greater EC variation (standard deviation, SD = 481 µS/cm) in relation to the strata 2 and 3. In contrast, the stratum where bioengineering works were developed (Stratum 3) showed the lowest EC values (average EC = 64.3 µS/cm) and a lesser variation in its magnitude (SD = 8.93 µS/cm). Stratum 2 showed intermediate EC values (Figure 3).

A Shapiro-Wilk test showed a normal distribution of EC data in the three soil strata (df = 20; p-values > 0.056). An Anova test suggested the existence of significant differences for EC between the soil strata under study (df = 20; p-value < 0.001). In this regard, a Tukey test allowed to display the greatest difference of EC between the strata 1 and 3 (df = 20; p-value < 0.001). However, the pairs of strata 1-2 and 2-3 showed no significant differences in EC (df = 20; p-values > 0.061).

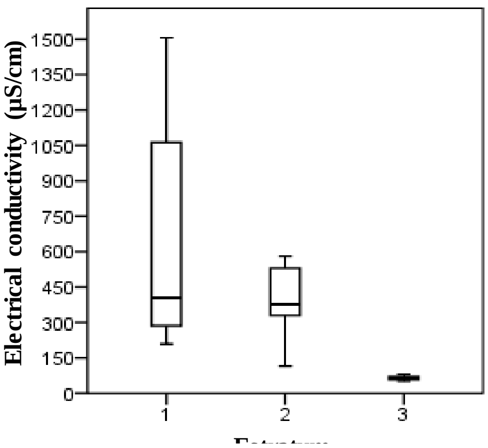

Figure-3. EC variation for the three soil strata. Stratum 1 = Erosion gullies, Stratum 2 = Lichens, and Stratum 3 = Benches.

In this study, the results suggested comparatively the existence of a relationship between EC and soil erosion degree. The implementation of bioengineering works (benches) probably generated a reduction of EC in the soil. In other words, as the soil was recovered through the implementation of bioengineering works, its EC tended to decrease (Figure 3). This trend was probably associated with the increase of organic matter and stabilization of the aggregates by microorganisms existing in the soil. [2] reported similar results during the implementation of bioengineering works for two series of abandoned fields in Southeast Spain.

Microbiological abundance (MA)

Bacterial colonies: Stratum 1 (erosion gullies) showed the lowest amount of CFU-bacteria/g of soil in relation to the other study strata. Thus, in the strata 2 and 3 were evidenced greater CFU-bacteria/g of soil in relation to Stratum 1 (Table I). The results suggested the existence of a relationship between bacterial MA and degree of soil erosion. In other words, the implementation of bioengineering works possibly tended to increase the soil bacterial communities (MA increase). [5] reported similar results in relation to the increase of bacterial communities for implementation of bioengineering works on eroded soils.

Fungal colonies: Once again Stratum 1 (erosion gullies) showed a lesser amount of CFU-fungal/g of soil in relation to the strata 2 and 3. Stratum 1 also showed the least diversity of fungal colonies (Table I). Thus, the results suggested the existence of a relationship between CFU-fungal/g of soil and erosion degree. The implementation of bioengineering works tended to increase the soil fungal communities (MA increase). Differences between the strata 2 (lichens) and 3 (benches) in relation to CFU-fungal/g of soil were also evident. Lichens in Stratum 2 probably generated a high microbiological content, mainly fungal, possibly due to the association that existed between fungi and algae to form lichens. This trend was also previously reported by [17].

Stratum 1 (erosion gullies) showed the greatest homogeneity in distribution of colony groups, as well as the smaller number of microorganism's groups with different macroscopic characteristics. In contrast, Stratum 3 (benches) showed more colony groups in relation to Stratum 1 (Table I). The results suggested that MA tended to be greater with the implementation of bioengineering works or with the reduction in the soil erosion degree. Studies on this matter also reported a direct relationship between the present carbon (organic matter) and composition of the soil bacterial communities [5]. In this study, it was confirmed as reported by [11], in relation to the possible existence of an inverse correlation between the soil erosion degree and microbiological abundance.

Table-1. Microbiological Abundance and Distribution for Each Soil Stratum under Study.

Stratum	Bacterial colonies		Fungal colonies			
	UFC/g	Colonies number*	UFC/g Fungus-Mold	UFC/g Yeast	Colonies number*	
		Bacteria			Fungus-Mold	Yeast
1	$83.0x10^2$	6	$12.0x10^2$	$11.1x10^2$	4	2
2	$1.32x10^5$	10	$8.8x10^3$	$5.72x10^4$	8	8
3	$1.15x10^5$	8	$4.7x10^3$	$1.80x10^5$	7	4

Note. *Total groups of different colonies macroscopically.

Relationship between pH, EC, and MA

The possible relationship between pH and EC was studied with Pearson correlation coefficient (r) in each of the soil strata: r-Stratum 1 = 0.067 (p-value = 0.109), r-Stratum 2 = 0.051 (p-value = 0.091), and r-Stratum 3 = 0.162 (p-value = 0.059). The results suggested the non-existence of relationship between these two variables. Therefore, the findings insinuated that the non-relationship of these two variables was probably a characteristic of the soil erosion phenomenon. [18] reported similar results in relation to pH and EC in eroded soils.

Comparatively, the results showed that pH and EC tended to take higher values in the soil stratum with greater erosion degree (Stratum 1: erosion gullies; see figures 2 and 3). Probably, this trend was associated with the presence of metal salts (ions of iron or sulphates) that had the capacity to act as electric conductors. For example, it was also reported that the presence of iron ions in eroded soils was directly related to high pH and EC values [6].

The results suggested comparatively the existence of a relationship between pH and MA. In this regard, Stratum 3 (benches) tended to show lower pH (average = 5.2) and higher MA values in relation to Stratum 1 (erosion gullies). [11] reported that MA (bacteria) was influenced by the pH range. In other words, MA tended to decrease significantly for pH < 2.7 and tended to increase significantly for pH > 5.7.

CONCLUSIONS

The results show the existence of significant differences between the three tropical soil strata under study (erosion gullies, lichens, and benches) in relation to the three indicator variables of soil quality and health: pH, EC, and MA. In other words, these indicator variables change significantly when implementing bioengineering works to control soil erosion. In this study, there is evidence of a decrease in pH to a range of beneficial magnitude for the increase of soil microorganisms (pH = 5.2). There is also a decrease of EC possibly by the increase of organic matter and stability of soil aggregates generated by the implementation of these bioengineering works (EC = 64.3 µS/cm). Finally, the abundance microbiological (bacteria, fungi, and yeasts) is incremented between 3.91 and 162 times through these bioengineering works (benches).

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