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Original article

Characterization of glomalin fractions in Red Ferrallitic soils with different use

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ABSTRACT

Arbuscular mycorrhizal fungi (AMF) establish symbiosis with most land plants; producing and releasing to soil a glycoprotein named glomalin, which promote the formation of water stable aggregates and improve soil structure. The objective of the present work was to characterize various Red Ferrallitic soils of the Red Prairie of Havana, with different uses, by means of several biological and chemical properties (organic matter, pH, P, Ca, C, N); as well as to establish correlations between both variable types. The biological variables were the AMF spore number and the contents of glomalin-related soil proteins (total and easily extractable). To this, different extraction methods were used following by the estimation of protein concentration or the total spore counting. Results revealed differences in the determined variables related to crop presents and soil management. In general, the forests showed superior values in the glomalin fractions, followed by sugar cane (*Saccharum officinarum*) and pastures. The inferior values corresponded to potato (*Solanum tuberosum*) cultivated soils. These variables constitutes better indicators of soil quality than the spore number, due to its correlation with several chemical variables of soil such as organic matter, C, N, pH and Ca.

Future researches are suggested to elucidate obtained results, mainly towards the use of glomalin as biological indicator of soil degradation/rehabilitation according to the ecosystem to study.

Key words: agricultural management, soil improvement, arbuscular mycorrhizae

INTRODUCTION

AMF are obligate biotrophs that are grouped in the *Glomeromycotina* class of the *Mucoromycota* phylum [1,2], which are widely known for their importance in plant nutrition [3] and in soil aggregates formation and stability [4,5]. These fungi are also important regulators of the carbon (C) flow from plants to soil [6], since they consume between 4 and 20 % of the C from plant photosynthesis, depending on the fungal species involved, and contribute significantly to soil microbial biomass in most ecosystems [7,8].

Glomalin is a recalcitrant glycoprotein produced by AMF, with high stability, a half-life between 6 and 42 years, a slow degradation rate that depends on the soil of origin, and it has been indicated that it constitutes the largest component of soil organic matter. This protein can influence soil fertility by complexing with iron (Fe), as well as in the remediation of contaminated soils by complexing it with potentially toxic elements [4,5,9,10].

Various studies show that the concentration of glomalin is highly correlated with the percentage of stable aggregates in water in a wide range of soils, be they acidic or calcareous, and under various crops such as pastures, cereals, forest species, among others [4,5,8]. Therefore, it is considered that AMF significantly improve the soil structure stability and quality and, contribute to the agroecosystem sustainability, while reducing soil erosion and water losses [11,12].

Two possible ways are proposed for the soil glomalin deposition, which have very different implications for its functionality. The first one that was considered is the secretion from the AMF mycelium in its immediate environment (mycorrhizosphere), but the main it seems to be the release produced by the decomposition of hyphae or spores as they are a structural part of their walls [12,13].

On the other hand, studies involving AMF have the disadvantage of the relatively limited range of response variables suitable for measuring their abundance and activity, among which are spore identification and counting and root colonization, which have practical limitations as they involve a hard laboratory work and long years of visual experience. Therefore, the glomalin determinations have been included in this type of study because protein quantification is a fast, objective, cheap and relatively easy technique to perform [14].

Glomalin is operationally quantified as glomalin-related soil protein (GRSP) and two fractions can be evaluated: total glomalin (TG) and easily extractable glomalin (EEG). The first represents the maximum quantity that can be extracted and it is strongly bound to soil particles, thus requiring more time (multiple cycles) of exposure to high temperatures for extraction. While EEG is the pool with the most recent deposition and it has even been suggested that it comes from a partial decomposition of the more stable glomalin (TG) [(4)]. In addition, some authors have found that conditions of soil water stress enhance the glomalin deposition [(11)].

On the other hand, the Cuban Red Ferrallitic soils were considered the most fertile with average organic matter values of 5-7 %, according to data reported by Bennet and Allison at the beginning of the 20th century. This indicates that, in the second half of the 20th century, these soils had an acceleration in the degradation processes, related to inefficient management. At present, the productivity of these soils is low and the structure degradation is high, one of the causes being the organic matter losses. In addition, there is evidence that exudates and biomass from roots and microorganisms can form a layer around the particles that modify their properties, increasing their hydrophobic character. Hence, a relationship has been established between these processes and the soil biological activity, where AMF could play a fundamental role.

The present study was carried out as part of the activities framed in a project aimed at contributing to elucidate the degradation processes of the Red Ferrallitic soils of the Red Prairie of Havana, by comparing soils with different exploitation characteristics. To later, and based on the results, propose appropriate measures to stop their deterioration and help their rehabilitation. In which the definition of biological variables indicating the soil quality could be of interest.

Therefore, the objective of the work was to characterize several Red Ferrallitic soils of the Red Prairie of Havana, with different uses, through some chemical and biological properties. These last variables related to AMF presence and functioning. In addition, it was established correlations between the both type of studied variables.

MATERIALS AND METHODS

To carry out the study, eleven Red Ferrallitic soils [(15)] were selected, corresponding to Ferrallic Nitisol [(16)], with different uses (forest or forest vegetation and cultivated with sugar cane (*S. officinarum* L.), pastures and potato (*S. tuberosum* L.). Those are from different Municipalities and localities (Aguacate, San José de las Lajas, Managua, Güira de Melena, San Nicolás de Bari, Güines and Batabanó), belonging to the Havana, Mayabeque and Artemisa Provinces, Cuba (Table 1).

Table 1. Information corresponding to the different Red Ferrallitic soils used in the study

Area	Use	Locality	Coordinates (North/West)	Abbreviation
1	Forest or forest vegetation	Aguacate	414514.09/ 414514.09	Bos_A
2	Forest or forest vegetation	San José de las Lajas (Nazareno)	373436.46/ 349211.14	Bos_N
3	Forest or forest vegetation	Managua	369759.67/ 346762.83	Bos_M
4	Sugar cane	Aguacate	413135.72/ 350216.08	C_A
5	Sugar cane	San Nicolás de Bari	405687.85/ 327668.51	C_SN
6	Sugar cane	Güira de Melena	351429.44/ 335236.60	C_GM
7	Pastures	San José de las Lajas (Guayabal)	380688.14/ 352725.93	P_SJ
8	Pastures	San José de las Lajas (ICA)	393737.58/ 341265.54	P_ICA
9	Potato	Güira de Melena	347033.77/ 326533.58	Pa_GM
10	Potato	Güines	392994.03/ 329935.10	Pa_Gui
11	Potato	Batabanó	371394.72/ 328216.67	Pa_B

Some soil chemical properties were evaluated in the A horizon, at a depth of 0 to 20 cm, for which a random sampling was carried out in the selected localities for 30 samples per site. The chemical properties evaluated and the methodologies used were the following: soil organic matter (SOM, %) Walkley and Black, pH (H_2O), potentiometry. Besides that assimilable phosphorus (P_2O_5, mg kg^{-1}), Oniani, exchangeable calcium (Ca^{2+}, $cmol_c$ kg^{-1}) Maslova, cationic exchange capacity CEC, ($cmol_c$ kg^{-1}) 1N ammonium acetate (pH 7.0), the percentages of carbon (C) and nitrogen (N) were calculated from the MOS and the C/N ratio was calculated.

Soil samples were taken at two depths (0-10 and 10-20 cm) in a nested scheme for 10 samples per location for the study of biological variables: number of AMF spores, total glomalin-related soil proteins (TG) and easily extractable glomalin-related soil proteins (EEG). The depth for taking these samples was established since the fungi studied are mainly found in the first 20 cm of the soil. Both glomalin fractions were extracted according to previously described protocols (4) and they were quantified in the extracts by evaluating the protein concentration by the Bradford method (17), where the absorbance reading was performed at 595 nm in a spectrophotometer (Genesys 10 UV Thermo Fisher). For this, a standard curve of bovine serum albumin was prepared from a solution of 1 g L^{-1}, using 6 concentrations of this solution between 0.05-0.5 g L^{-1}. Glomalin concentrations were expressed in mg g^{-1} of soil.

To extract the spores from the soils, we proceeded according to a modification made [(18)] of the wet sieving and decanting protocol [(19)]. Once the spores were separated, they were washed with distilled water and poured into a nematode count plate for quantification stereo microscope (Stemi 2000-C/50X).

With the data obtained from the biological variables evaluated, the confidence intervals were calculated for each soil analyzed, with a confidence of 95 %, to make the comparison and establish the statistical differences. In addition, Pearson correlations were performed with a significance (α) of 0.05, between the soil chemical variables and the determined biological ones. For this, in the case of the biological variables, a single mean value (depth 0-20 cm) was taken, calculated from the evaluations made at the two depths. Likewise, correlations were made between the biological variables evaluated at the two depths and the total mean values calculated for the depth 0-20 cm. These analyzes were performed using the statistical package IBM SPSS Statistics, Version 22 for Windows.

RESULTS AND DISCUSSION

Table 2 shows the results of the chemical properties of the soils studied. The highest percentages of soil organic matter (SOM) were found in two forest areas (~5), followed by the two pasture areas (~4), and the lower values were observed in two of the areas cultivated with sugar cane (2, 6 and 2.9), as well as in two areas destined to potato cultivation (~3). C and N showed a similar trend to SOM. The pH ranged between 5.6 and 8.1, corresponding to a forest area and a potato area, respectively. An area of pasture and one of sugar cane also showed acid pH. Another forest zone presented basic pH, while the rest showed values around neutrality.

Phosphorus showed differences associated with land use (Table 2), with lower values in sugar cane areas (<90 mg kg^{-1}), followed by pasture (~105) and then those cultivated with potatoes (~250). While the 3 forest areas presented high levels with differences between them, being the acid pH and high SOM (Managua) the one with the lowest content of this element (125 mg kg^{-1}). The highest P content was in Nazarene (384 mg kg^{-1}) found, where the SOM was also high and the pH was close to neutrality (4.7). On the other hand, the Avocado forest presented similar values of P and SOM to that of the mumps areas, and the pH was basic, similar to the potato area of Batabanó.

The Ca content showed a trend in correspondence with the use of the land and the pH (Table 2). Thus, in the two forests with a pH greater than 7, the values of this cation were also the highest (20-30 $cmol_c$ kg^{-1}), while the forest with acid pH showed a low value compared to the rest of the soils analyzed. In sugar cane areas, Ca ranged between 9 and 15-$cmol_c$ kg^{-1}, the lowest value corresponding to acidic soil and the highest value to pH 7.1. For their part, the pastures presented average values and agreed to the pHs, being the lowest in acidic soil. The areas cultivated with potatoes showed high values (14-16 $cmol_c$ kg^{-1}), only below the two forests, and whose pHs ranged from neutral to basic. The capacity to change bases showed a behavior similar to that of the Ca content and fundamentally at the pH of the soils. Furthermore, the C/N ratio showed similar values between 11.2 and 11.71 (Table 2).

It is noteworthy that the low SOM and P values presented by the areas dedicated to the cultivation of sugar cane is a consequence of the many years of exploitation that these lands have suffered, which commonly date from the mid-18th century for this cultivation in our country. On the other hand, the high values of P, Ca and CCB in the potato areas, even of pH in one of them, are due to the chemical fertilization. It takes place in this crop, which high input is considered, which contrasts with the low percentage of SOM that these soils presented due to their intensive cultivation and management, leading to their degradation.

Table 2. Results of the chemical properties of the Red Ferrallitic soils studied according to their use and location

Use/locality	**SOM**	**pH (H_2O)**	**P_2O_5**	**Ca^{2+}**	**CEC**	**C**	**N**	**C/N**
	(%)		**(mg kg^{-1})**	**$cmol_c$ kg^{-1}**			**%**	
Forest_Aguacate	3.30	7.7	261.0	30.20	38.22	1.91	0.17	11.24
Forest _Nazareno	5.40	7.4	384.0	20.00	25.19	3.13	0.27	11.59
Forest _ Managua	5.00	5.6	125.0	11.20	12.61	2.9	0.25	11.60
Sugar cane_Aguacate	3.80	6.0	18.0	9.50	15.86	2.20	0.19	11.58
Sugar cane_San Nicolás	2.60	7.1	36.0	15.00	22.84	1.51	0.13	11.62
Sugar cane_Güira de Melena	2.93	6.8	87.5	10.10	12.72	1.70	0.15	11.33
Pastures_Guayabal	4.00	6.9	104.0	13.70	17.58	2.32	0.2	11.60
Pastures_ICA	4.30	5.7	107.0	12.50	15.10	2.49	0.22	11.32
Potato_Güira de Melena	3.43	7.3	245.5	14.95	17.69	1.83	0.16	11.44
Potato_Güines	3.15	6.9	267.0	14.35	16.92	1.99	0.17	11.71
Potato_Batabanó	3.00	8.1	265.5	15.70	27.23	1.74	0.15	11.60

SOM- soil organic matter, P- assimilable phosphorus, Ca^{2+} - exchangeable calcium, CEC-base exchange capacity, C- carbon, N- nitrogen, C/N- C/N ratio

The results of the EEG content are observed in Figure 1. In general, a behavior related to land use was detected at a depth of 0-10 cm (Figure 1A), where the forests presented high

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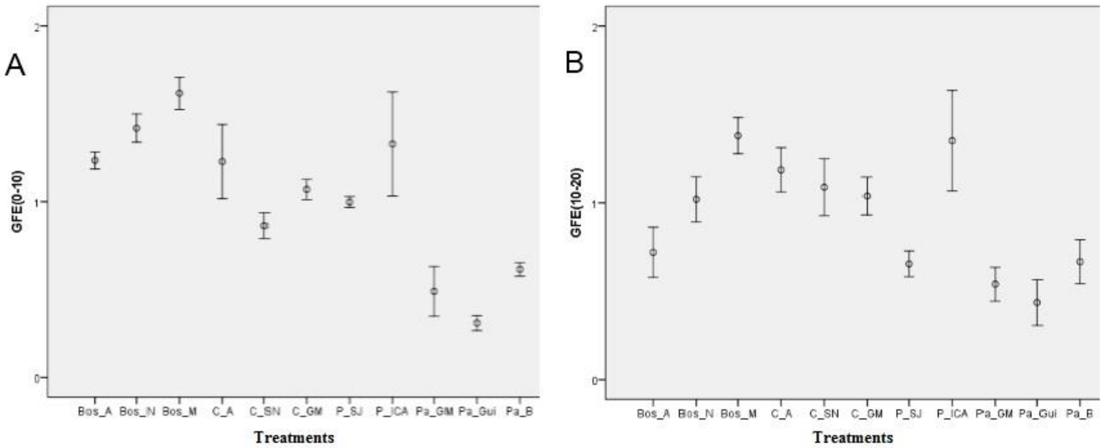
values with significant differences between them, highlighting that of Managua (Bos_M). It was followed by areas cultivated with pastures and sugar cane with intermediate values, although the ICA pasture did not show differences with the three forests, nor did Aguacate sugar cane from the two low value forests. The lower values of this variable corresponded to the potato crop with differences between some areas. At a depth of 10-20 cm (Figure 1B), the areas cultivated with potatoes also showed the lower values, as did a pasture area (P_SJ) and the Aguacate forest (Bos_A). The rest of the studied soils showed higher and similar values, except for the two forests that presented significant differences between them.

Comparing the EEG at the two depths evaluated, no significant differences were in this variable observed in most of studied soils (Figure 1). However, the three forests and one pasture area (Guayabal) presented values higher than the shallow depth (0-10 cm). It should be noted that this variable evaluated at both depths showed a positive and highly significant correlation ($p=0.002$; $\alpha=0.05$). In addition, the EEG (0-20 cm) showed a positive correlation with the SOM ($p=0.044$; $\alpha=0.05$), the C ($p=0.05$; $\alpha=0.05$) and the N ($p=0.042$; $\alpha=0.05$) and negative with pH ($p=0.036$; $\alpha=0.05$).



Bos_A- forest Aguacate, Bos_N- forest Nazareno, Bos_M- forest Managua, C_A- sugar cane Aguacate, C_SN- sugar cane San Nicolás de Bari, C_GM- sugar cane Güira de Melena, P_SJ- pastures Guayabal, P_ICA- pastures ICA, Pa_GM- potato Güira de Melena, Pa_Gui- potato Guines, Pa_B- potato Batabanó

Figure 1. Results of the content of soil proteins related to easily extractable glomalin (EEG) at depths 0-10 (A) and 10-20 (B) cm, expressed in mg g^{-1} of soil, in Red Ferrallitic soils with different use of diverse localities. Confidence intervals (95 %) are shown

The contents of TG (Figure 2) were higher than those of EEG (Figure 1), as expected given what each of these fractions represents in the soil and the extractive methods used due to their stability and lability, rates of degradation and half-life time [4,8,20,21]. Similar to the EEG, in the TG content between the studied depths (Figure 2), no differences were detected in the areas cultivated with potatoes, in the ICA pasture and in two sugar cane areas (C_SN and C_GM). In addition, the rest of the soils showed higher values at the shallowest depth. Another common aspect between the two-glomalin fractions analyzed was that the significant differences according to land use were better evidenced at depths of 0-10 cm according to land use (Figures 1 and 2). In this sense, a positive correlation was found between TG and EEG evaluated at this depth ($p=0.049$; $\alpha=0.05$), which was not observed at a depth of 10-20 cm.

The results of the TG content are observed in Figure 2, where at 0-10 cm depth a behavior related to land use was detected (Figure 2A). The highest values corresponded to the three forests, highlighting that of Aguacate (Bos_A). Then, with intermediate values, the sugar cane areas and Guayabal pasture (P_SJ) were found; although the sugar cane cultivated in Aguacate (C_A) did not differ from two of the areas cultivated with potatoes. The potato soils and the ICA pasture showed the lowest values of TG content. While at the 10-20 cm depth (Figure 2B), the highest value was observed in the Aguacate forest, followed by the Nazareno forest (Bos_N) and two sugar cane areas. The Managua forest (Bos_M) and the potato area of Batabanó (Pa_B) presented similar and low values. The lower values corresponded to the other two potato cultivated areas, the two pastures and the sugar cane area of Aguacate (C_A). This variable evaluated at both depths showed a positive and highly significant correlation ($p=0.006$; $\alpha= 0.05$). Furthermore, TG (0-20 cm) showed a positive correlation with Ca ($p = 0.012$; $\alpha= 0.05$) and CEC ($p = 0.032$; $\alpha= 0.05$).

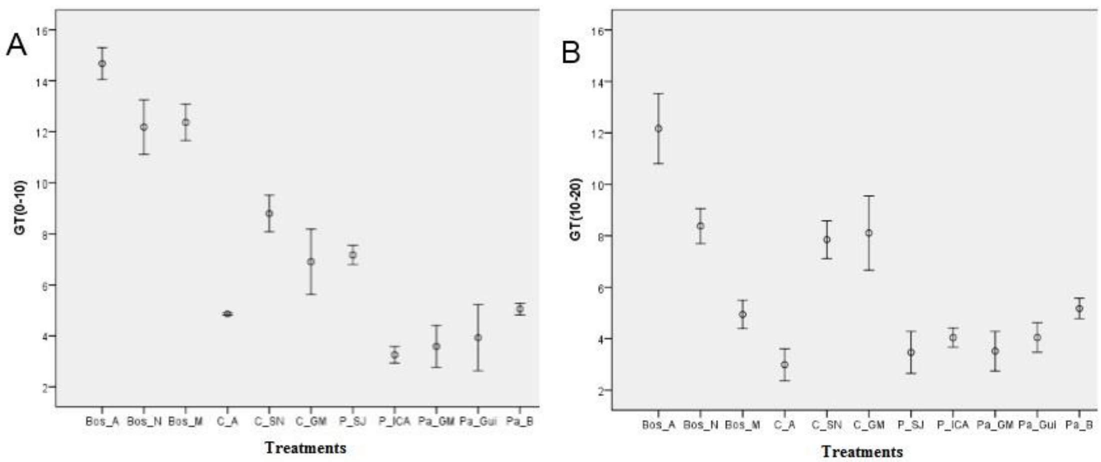


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Figure 2. Results of the content of soil proteins related to total glomalin (TG) at depths 0-10 (A) and 10-20 (B) cm, expressed in mg g^{-1} of soil, in Red Ferrallitic soils with different use of diverse locations. Confidence intervals (95 %) are shown

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The differences found in both fractions of glomalin, between the depths, and in the different soils studied can be attributed to the different uses and exploitation of the land according to the locality. This has had a fundamental weight the types of cultivation and the time of establishment, as well as the cultivars/varieties of these species, given the characteristics of their root systems, and the agricultural management practices applied in each case. In summary, the degree of disturbance of the ecosystem is related to the response of these biological variables closely. Likewise, it is necessary to take into account the various arboreal plant species present in the forests and the time they were established, and which are mostly associated with ectomycorrhizal fungi [(18)], although in some cases herbaceous species were also observed.

In agreement with this study, the results found in three leached Red Ferrallitic soils with different management showed differences in these three variables, the values where the anthropic action was more intense being lower than the soil under intensive cultivation. Therefore, the authors concluded that the losses in the structure of these soils were greater according to determined physical-chemical and biological indicators, to a point that leads to their degradation, as well as the loss of their content of organic matter, plant nutrients and microbial population in general [(20)].

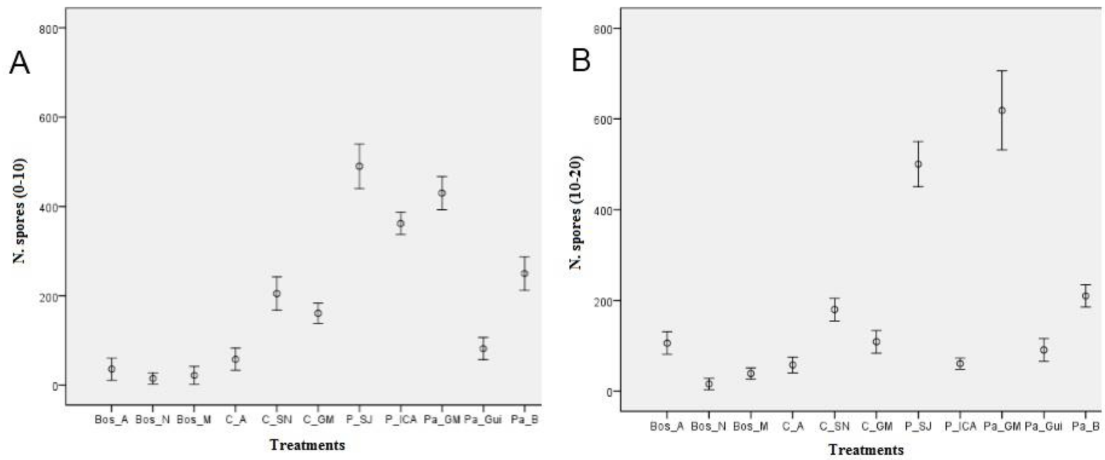
Another experiment carried out on Red Ferrallitic soil cultivated with tomato and inoculated with *Glomus cubense* (Y. Rodr. & Dalpé) in liquid formulation [(21)], reported EEG values of 0.8 mg g^{-1} being higher than the non-inoculated treatment. These values are low compared to those of sugar cane and grass in this study, but it is higher than those detected in soils cultivated with potatoes; which confirms the relationship between the observed differences to cultivation.

In addition, fieldwork with corn (*Zea mays* L.) reported EEG and TG values of 0.745 and 5.8 g kg^{-1}, respectively [(22)], in black soils (Chernozem, Phaeozem and Cambisols according to the classification - 16). Similarly, these values are between those obtained here for sugar cane and pastures and those presented by the soils cultivated with potatoes at a depth of 0-10 cm. This shows the differences in the behavior of these biological variables related to crop and edaphic conditions.

Although there is practically no evidence of comparisons between glomalin fractions at different depths, it is worth highlighting a study of 360 soil samples from 72 farms where a vertical profile was made up to 1 m deep. The result of it showed a linear decrease in glycoprotein from top to bottom associated with the physicochemical characteristics and the nutrients of the soil [(22)]. Establishing a comparison between this and the present work is not appropriate since the first depth ranged from 0-20 cm; however, the differences detected here followed this trend (Figures 1 and 2) between the depths evaluated (0-10 and 10-20 cm).

The number of AMF spores in 50 g of soil at the evaluated depths ranged between 15 and 620 (Figure 3). The forests presented low values of this variable in both depths, in the sampling period, which could be due to the aforementioned regarding the preferential association of tree species with ectomycorrhizal fungi [(18)]. However, it has been pointed out that the absence of sporulation by these fungi does not necessarily indicate their absence at the site, since other fungal structures such as mycelium may be present, which are rich in glomalin, and that sporulation depends on spatial and seasonal factors, among others [(23)].

In general, in the cultivated areas (Figure 3), a potato zone (Pa_GM) and those of pastures showed higher values of the number of AMF spores; while the Aguacate sugar cane (C_A) and the Güines potato (Pa_Gui) showed low values. The rest of the sugarcane soils and the potato of Batabanó (Pa_B) presented intermediate values. This variable evaluated at both depths showed a positive correlation (p=0.015; α=0.05). However, it did not show correlation with the other biological variables determined or with the soil chemical properties. These results are influenced, in part, by factors such as management in each of these areas (tillage, crop rotation, irrigation, fertilization), the time the different crops have been established and the varieties used; and mainly due to the conditions of the sporulation process mentioned above that characterize these fungi.



Bos_A- Aguacate forest, Bos_N- Nazareno forest, Bos_M- Managua forest, C_A- Aguacate sugar cane, C_SN- San Nicolás de Bari sugar cane, C_GM- Güira de Melena sugar cane, P_SJ- Guayabal pastures, P_ICA- ICA pastures, Pa_GM- potato Güira de Melena, Pa_Gui- potato Güines, Pa_B- potato Batabanó

Figure 3. Results of the number of AMF spores in 50 g, at depths 0-10 (A) and 10-20 (B) cm, of Red Ferrallitic soils with different use in diverse locations.

Confidence intervals (95 %) are shown

In particular, numerous works carried out in pastures have shown different results in the yield and number of AMF spores depending on the species and cultivar used and, fundamentally, its management (cuts, irrigation, applied fertilizers and doses and others) [24–27]. Similar results have been obtained in other crops such as cassava (*Manihot esculenta* Crantz), banana (*Musa* spp) and *Canavalia ensiformis* [28–30]. In addition, some authors suggest that adecuate agricultural practices for soil management tend to increase the contents of TG and EEG [11,31–33], among which they pointed out the use of organic or green fertilizers and bioproducts based on efficient microorganisms, plant growth promoting bacteria, rhizobia or beneficial fungi.

Coincidentally, a study carried out in 83 plots that underwent 10 to 20 years cultivating corn, wheat (*Triticum vulgare* L.) or barley (*Hordeum vulgare* L.) with or without occasional rotation of beans (*Phaseolus vulgare* L.) or broad bean (*Vicia faba* L.); perennials: agapando (*Agapanthus* spp.), nopales (*Opuntia* spp.) and agave (*Agave* spp.). Also, ornamentals: rose (*Rosa* spp.), (*Chrysanthemum* spp.), carnation (*Dianthus* spp.), fruit trees: blackberry (*Rubus* fructicosus L.), raspberry (*R. idaeus* L.), fig tree (*Picus carica* L.), capulín (*Prunus serotina* Cav.), peach (*P. persica* L.). Ten classes of agronomic management (incorporation / removal of harvest residues, conventional tillage or no tillage, with or without incorporation of organic fertilizers, irrigation) were evaluated, it was found that the management conditions had a significant influence on the accumulation of stable organic carbon (COS), glomalin and glomalin carbon (CG). A correlation of COS with glomaline and CG was also observed [34].

Likewise, it has been shown that the inoculation of AMF (*Rhizophagus intraradices* and *Funneliformis mosseae*) and PGPR (*Pseudomonas mendocina*), in degraded soils and under drought conditions, promote the formation and stability of soil aggregates by microbial populations indigenous to these soils by stimulating their proliferation and increasing the concentrations of carbohydrates and proteins in the soil related to glomalin [7]. Works like this confirm the importance of making an accurate diagnosis in degraded agricultural soils, through physical-chemical and biological properties as it was in this study done, in order to propose ecological alternatives that contribute to their rehabilitation and sustained productivity. In fact, the results corroborated that the glomalin fractions determined here could be considered biological indicators of soils quality and their degree of disturbance/degradation. In this sense, glomalin has been reported by some authors as a useful parameter to monitor desertification and the improvement/rehabilitation of degraded soils [22,35] and its estimation has been suggested as a biological indicator of soils [32].

Regarding the correlation that was found between some of the variables evaluated, it was statistically demonstrated that low pH and high soil organic C content were associated with high levels of EEG and TG in several agroecosystems cultivated with corn [22]. Another work carried out under controlled conditions also detected a high positive correlation between the C content of the soil and that of GRSP [32]. Both results agree with those of the EEG in this investigation. However, it is worth clarifying that the discrepancy regarding the behavior of the TG must be influenced by the inclusion of natural ecosystems such as forests in the analysis carried out here. In fact, a recent study reported that glomalin's contribution to organic C differed according to land use and seasonality in the tropics and that the ratio of glomalin C to organic C was lower in forests compared with soils dedicated to agriculture [36].

CONCLUSIONS

- The biological variables evaluated can be determined at depths 0-10 or 0-20 cm, keeping the results given the correlation found and among them, those that determine glomalin are better indicators of soil quality than the number of AMF spores, due to their correlation with some soil chemical variables.
- The forests showed higher values in TG and EEG, followed by sugar cane and pasture crops, while the lower values corresponded to soils cultivated with potatoes. Both these results and those of the chemical variables revealed differences regarding the properties of the soils analyzed, being indicators of the degree of disturbance/degradation of the same. This was by various factors conditioned such as the crops present or the use of the land and the agricultural practices used or the management of the soil, among others.
- However, it is valid to emphasize the particularities that each analysis entails depending on the type of ecosystem, confirming that the relationships between the types of variables evaluated may be different in agroecosystems and in undisturbed ecosystems such as forests. Therefore, future research is suggested to elucidate the results obtained, mainly regarding the use of glomalin as a biological indicator of the degradation / rehabilitation of soils according to the ecosystem under study.

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