Enzymatic activities of potato crop soils subjected to conventional management and grassland soils

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Abstract

The effect of soil management on the activities of urease, phosphodiesterase, arylsulphatase, and β -glucosidase in soil samples from three municipalities in the Cundinamarca department of Colombia, Tausa (T), Villapinzón (V), and Zipaquirá (Z), was evaluated in this study. Two types of samples were taken in each municipality: 1) soils with a history of potato (*Solanum tuberosum*) farming using conventional soil management and agrochemical application (P) and 2) grassland soils that had not been treated with agrochemicals (G). The urease activity for T, V, and Z was higher in the G samples. The phosphodiesterase and arylsulphatase activities for T and V were greater in the G samples, while the β -glucosidase activity for T and Z was greater in the P samples. The phosphodiesterase and β -glucosidase activities for T were lower than for the other two municipalities, indicating a possible effect of the site on these enzymatic activities. The differences in the enzymatic activities among the samples indicate an important effect of soil use and management on the soil's biochemical properties.

Keywords: Soil enzyme, soil quality, urease, phosphodiesterase, arylsulphatase, β -glucosidase.

1. Introduction

Soil has not received the attention it deserves from society in spite of its life-sustaining importance. Soil degradation is a serious threat for the future of humanity. Scientists, therefore, face a double challenge in preserving and increasing soil quality to safeguard human survival (Bautista-Cruz *et al.*, 2004; Das and Varma, 2011). Soil quality is defined as the specific ability of soil to function in a natural or man-made ecosystem according to three main roles: 1) to promote system productivity without losing physical, chemical, and/or biological properties (sustainable

biological productivity), 2) to mitigate environmental contamination and pathogens (environmental quality), and 3) to promote plant, animal, and human health (Doran and Parkin, 1994). A set of parameters called quality indicators (physical, chemical, and biological) are used to establish land use quality and soil health. For a number of quality indicators, enzymatic activity is considered to be sensitive to changes in the soil as a result of land use (Cerón and Melgarejo, 2005).

Soil enzymes have been suggested as potential quality indicators because of their relationship with the soil biology. The presence of enzymes in soil depends on their continuous release by organisms inhabiting the soil ecosystem (Burns, 1982; Han *et al.*, 2010). Soil enzymes are related to ecological functions, such as biomass production, contaminant treatment, and ecosystem conservation (Dick and Tabatabai, 1992). Crop species and the use of chemicals have a significant influence on the enzymatic activity in soil (Acosta-Martínez and Tabatabai, 2000). Several studies have shown that chemical products used in farming (e.g., fertilisers, pesticides, herbicides) have a marked influence on the soil enzyme activity (Alvear *et al.*, 2006). In this context, the potato crop is particularly important, as it is one of the top ten major crops worldwide. In Colombia, the potato production system has the highest demand for fungicides and insecticides and the second highest demand for chemical fertilisers (Devaux, 2010; Ochoa, 2005).

To our knowledge, no research regarding the effect of soil use and soil location on enzymatic activity has been performed using Colombian soil. Therefore, in the present study, we analysed the activity of a number of enzymes in two types of soil samples: 1) soils that had a history of potato farming (*Solanum tuberosum*) using conventional soil management (chemical fertiliser, pesticide, and herbicide use) and 2) grassland soils that had not been treated with agrochemicals. The urease, phosphodiesterase, arylsulphatase, and β -glucosidase activities (which are related to the nitrogen, phosphorus, sulphur, and carbon cycles, respectively) of these samples were analysed as potential soil quality indicators. This study also assessed whether the enzyme activities in soil is related to its physicochemical parameters.

2. Materials and Methods

2.1 Soil sampling and experimental design

Soils were sampled from three farms in the Cundinamarca department of Colombia in the municipalities of Tausa (T), Zipaquirá (Z), and

Villapinzón (V). The soils from T were from a pathway on the Páramo Bajo farm: Páramo Bajo N 03°40'14.9"; W 073°39'51.1" and N 03°35'50.4"; W 073°28'56.0". The soils from Z were from a pathway on the Páramo Guerrero Oriental farm: Puente de Tierra N 04°05'59.7"; W 072°54'34.6" and N 03°37'32.9"; W 073°37'39.8". The soils from V were from a pathway on the Salitre Alto farm: Santa Ana N 03°43'43.5"; W 073°42'18.6" and N 03°43'43.5"; W 073°42'18.6". The soils from T belonged to the Andisol order (Hapludands great group), the soils from V belonged to the Alfisol order (Hapludalfs great group), and the soils from Z belonged to the Inceptisol order (Dystrudepts great group).

Two types of soil samples were collected from each farm. The first sample type included soils used for potato monoculture (*S. tuberosum* variety "parda pastusa") that had at least 10 years of agricultural use in a conventional management scheme and had been treated with agrochemicals, including the insecticides Agricon®, Carbotox®, Nudrin®, Roxion®, Larvin®, Lorsban®, Lannate®, Eltra®, Methox®, Carbofed®, Furalimor SC®, Alodrin®, Fursem®, and/or Furadan®, among others; fungicides, such as Magricen 80%, copper oxychloride, Mancozeb®, Acrobat®, Forum®, Antracol®, Fitoraz®, Previcur®, Rhodax®, Curzate®, Manzate®, and/or Kasumin®; herbicides, such as Glifosato®, Sencor®, Gramafin®, Afalon®, Fusilade®, Gramoxone®, and/or Reglone®; and other chemically synthesised fertilisers with varying nitrogen, phosphorus, and potassium contents in amounts that corresponded to the crop requirements. These soil samples from Tausa, Zipaquirá, and Villapinzón were called TP, ZP, and VP, respectively. The second sample type included grassland soils (*Calamagrostis* sp.) that had not been treated with agrochemicals (pesticides or fertilisers) for at least 10 years. These soil samples from Tausa, Zipaquirá, and Villapinzón were named TG, ZG, and VG, respectively.

For each sample type from each location (TP, TG, ZP, ZG, VP, and VG), three samples of soil were collected along a zigzag track in an area of one hectare. Each sample contained ten pooled subsamples that were

collected every 15 steps. Each 50 g subsample was taken from the first 20 cm of soil. The samples were stored at -20°C over a period not exceeding two weeks.

2.2. Physicochemical parameters

The following physicochemical parameters were determined by the IGAC (Instituto Geográfico Agustín Codazzi, Colombia); texture (Bouyoucos method); pH (pH meter); exchangeable acidity (extraction with KCl); organic carbon percentage (Walkley-Black method), total nitrogen percentage (Kjeldahl method); cationic exchange capacity (CEC) and calcium, magnesium, potassium, and sodium levels (extraction with ammonium acetate); the neutral proportions of minor elements, such as manganese, iron, zinc, and copper (extraction with DTPA); available boron (extraction with hot water); and available phosphorus (Bray II method).

2.3. Enzymatic activities

The urease activity (EC 3.5.1.5) was determined using urea as a substrate, based on the method described by Alefand Nannipieri (1995). The phosphodiesterase activity (EC 3.1.4.1) was determined using bis-p-sodium nitrophenyl phosphate as a substrate (Browman and Tabatabai, 1978). The arylsulphatase activity (EC 3.1.6.1) was determined with p-nitrophenyl potassium sulphate as a substrate (Tabatabai and Bremner, 1970). The β -glucosidase activity (EC 3.2.1.21) was determined using p-nitrophenyl- β -D-glucoside as a substrate (Eivazi and Tabatabai, 1988). The above methods used different amounts of sample; 0.1g of soil was used for the urease activity analysis, and 0.2 g of soil was used for the other enzymatic analyses. The amounts of the other reagents and substrates were modified according to amount of sample used. The urease activity is expressed in $\mu\text{g N g}^{-1}\text{dw } 2 \text{ h}^{-1}$. The phosphodiesterase, β -glucosidase, and arylsulphatase activities are expressed in $\mu\text{g pNP g}^{-1}\text{dw h}^{-1}$.

2.4. Statistical analysis

Data were analysed using the free statistical software R version 2.10.0. Bartlett and Shapiro-Wilk's tests were used for analysis of variance and normality homogeneity assumptions. Duncan's multiple comparison tests were used for the determination of statistically significant differences or clusters. Pearson's correlation was used to search for correlation among parameters.

3. Results and Discussion

3.1. Physicochemical parameters

Table 1 summarises the physicochemical properties of the soils analysed in this study. According to the granulometric analysis all soil samples had similar contents of sand, silt, and clay. The pH of all of the samples was less than 5.5, which classifies these soils between strongly and extremely acidic. The pH was not significantly affected by the soil use or location ($p < 0.05$). The samples from V and Z (both G and P) exceeded 3 meq 100 g^{-1} of exchangeable acidity, indicating that those soils were acidic enough to affect e.g. microbiotic and plant growth.

Because of their high organic carbon content (greater than 5%), all of the samples were placed in the high organic carbon category (IGAC, 2007). Furthermore, the P samples showed greater organic carbon content than the G samples. All of the soil samples had a nitrogen content that was greater than 0.30% and were thus considered to be rich in nitrogen (IGAC, 2007). The nitrogen content for TP was slightly higher than TG, but no significant effect was observed ($p < 0.05$). A similar trend in the nitrogen content was observed for ZP and ZG ($p < 0.05$). The T samples (TP and TG) showed almost double the percentage of nitrogen compared with the V and Z samples.

Table 1. Physicochemical parameters of the analysed soils. Granulometric analysis (sand, lime, and clay), percentage of organic carbon (CO), total nitrogen (TN), pH, exchangeable acidity (EA), carbon: nitrogen ratio (C:N), cationic exchange capacity (CEC), and minor elements. Sand, lime, clay, CO, and TN are expressed in percentages. EA, CEC, Ca, Mg, K, Na, Mn, Fe, Zn, Cu, and B are in meq 100 ml⁻¹. P is in mg kg⁻¹. TG, VG, and ZG: grassland soil without agrochemical treatment from Tausa, Villapinzón, and Zipaquirá, respectively. TP, VP, and ZP: potato crop soil with conventional soil management from Tausa, Villapinzón, and Zipaquirá, respectively.

Soil properties	Soil samples					
	TG	TP	VG	VP	ZG	ZP
sand	60.5	44.2	41.8	40.9	54.6	33.2
lime	22.0	33.5	24.9	31.7	26.8	33.4
clay	17.6	22.3	33.3	27.4	18.6	33.4
CO	9.5	18.6	8.1	9.3	5.6	7.4
TN	1.10	1.20	0.57	0.56	0.42	0.50
pH	5.1	4.7	3.9	3.9	4.1	4.0
EA	1.4	3.1	7.6	9.2	5.4	6.1
C:N	11.4	20.5	18.8	22.0	17.6	19.5
CEC	65.1	76.4	42.1	46.4	30.4	41.0
Ca	3.6	5.1	2.2	1.1	1.2	3.1
Mg	2.5	1.1	0.7	0.4	0.3	0.6
K	4.8	1.2	1.0	1.2	0.3	0.6
Na	0.18	0.13	0.10	0.04	0.07	0.07
P	18.8	67.3	70.1	198.0	18.8	76.4
Mn	0.64	0.88	3.4	1.8	1.7	2.7
Fe	116	81.2	368	233	314	305
Zn	3.2	1.3	2.0	0.5	1.1	0.5
Cu	0.08	0.18	0.16	0.22	0.40	0.26
B	0.52	1.50	0.86	0.66	0.51	0.82

The carbon: nitrogen (C:N) ratio was particularly low for sample TG (Table 1). A low C:N ratio indicates low carbon content and suggests high humic content. The degree of soil humification is likely important when carrying out enzymatic assays, as humic substances are very stable molecules and are therefore more resistant to enzymatic and microbial action.

All of the samples were found to be in the high cationic CEC category (Table 1); in all cases, the CEC values

exceeded 20 meq 100 g⁻¹. High CEC values indicate a high capacity for supplying Ca²⁺, Mg²⁺, K⁺, and other ions to plants. Moreover, the fact that the CEC was higher in the P samples (TP, VP, and ZP) than in the G samples (TG, VG, and ZG) indicates a soil use effect. The TG and TP samples had higher CEC values than those from the other two locations, which is in accordance with their higher pH and lower acidity values. This pattern in the T samples might be related

to a high level of humic substances (such as in TG), which is caused by soil pH-cushioning properties and an increased CEC or possibly by the soil location.

3.2. Enzymatic activities and agricultural management

Figure 1 shows the enzymatic activities of the soils under study. Urease catalyses the hydrolysis of urea or urea-type substrate and produces CO_2 and NH_3 as reaction products. The urease activity was greater in the G samples than in the P samples. These results suggest that the use of chemical fertilisers, pesticides, and conventional management practices (used in the P samples) inhibited the activity of urease. The higher urease activity found in Z suggests that the nitrogen cycle operates at a higher level in these samples. Our results are consistent with the results obtained by Anacona (2008), who studied protease activity in the same sample types. In that work, the protease activity was greater in the G samples ($\text{VG} = 3010$ and $\text{ZG} = 1379$ $\text{mg tyrosine.g}^{-1}.\text{dw}^{-1}.\text{h}^{-1}$) than in the P samples ($\text{VP} = 1885$ and $\text{ZP} = 1148$ $\mu\text{g tyrosine.g}^{-1}.\text{dw}^{-1}.\text{h}^{-1}$), and the same trend has been observed for amidase activity (J Sanchez *et al.*, 2012). Interestingly, as described above, the use of fertiliser seems to inhibit several enzymes involved in the nitrogen cycle, including urease, amidase, and protease. Furthermore, Dick *et al.* (1988) showed a decrease in the urease and amidase activities when the levels of ammonia-based fertiliser increased, which is due to the presence of the final product of these enzymatic reactions (NH_4^+) (Bandick and Dick, 1999).

As observed for urease the activity of phosphodiesterase (Figure 1) in the TG and VG samples was higher than in the TP and VP samples, respectively. In contrast, the urease and phosphodiesterase activities in ZG were lower than those in ZP. The phosphodiesterase activity was lower in TG and TP than in the other samples ($p < 0.05$). Anacona (2008) analysed the phosphate-solubilising bacteria levels in samples from T and V. The author reported a higher bacteria count (expressed as colony forming units (cfu)/g soil) in TG and VG than in TP and VP. Therefore, the inhibition of phosphodiesterase upon

fertiliser use and conventional soil management that was found in TP and VP is likely related to low levels of phosphate-solubilising bacteria.

The arylsulphatase activity (Figure 1) showed a similar trend to that observed for phosphodiesterase: the V and Z samples had higher arylsulphatase activity than the T samples. The arylsulphatase activity in T and V was greater in the G samples than in the P samples. In contrast, the arylsulphatase activity in Z was greater in the P samples than in the G samples. Arylsulphatase catalyses the break down of the sulphate ester (S-O) link. The role of arylsulphatase in the sulphur cycle is important because 50% of the sulphur present in soil appears as a sulphate ester and can be converted to inorganic sulphates through hot alkali treatment (Freney, 1961; Das and Varma 2011).

When evaluating the effect of location on the activity of β -glucosidase, the following order was obtained for both the G and P samples: $\text{V} > \text{Z} > \text{T}$. When comparing the effect of soil use, TP and ZP had higher β -glucosidase activity than the homologous samples TG and ZG. In contrast, VP had lower β -glucosidase activity than VG, which agrees with previous reports in which the β -glucosidase activity was evaluated in soils under pasture and farmland (Acosta-Martínez *et al.*, 2007). β -Glucosidase is a hydrolase involved in the carbon cycle; specifically, it hydrolyses β -glycoside links in large carbohydrate chains, a mechanism used by soil microorganisms to acquire energy (Alef and Nannipieri, 1995; Acosta-Martínez *et al.*, 2011).

3.3. Enzymatic activity and soil location

It has been shown that humic substances have a strong effect on enzymatic activity. Data reported by Dong *et al.* (2008) are consistent with our results for the T samples, which had lower enzyme activity than the V and Z samples. His behaviour might be due to the higher humic content of the soil from T, which is dependent on the C:N ratio and the parental origin of the sample; the T samples are Andisols, which are characterised by high humic content.

Figure 1. Enzymatic activity of the analysed soils. The urease activity is expressed in $\mu\text{g N g}^{-1} \text{ dw } 2 \text{ h}^{-1}$. The phosphodiesterase, β -glucosidase, and arylsulphatase activities are expressed in $\mu\text{g pNP g}^{-1} \text{ dm h}^{-1}$. TG, VG, and ZG: grassland soil without agrochemical treatment from Tausa, Villapinzón, and Zipaquirá, respectively. TP, VP, and ZP: potato crop soil with conventional soil management from Tausa, Villapinzón, and Zipaquirá, respectively. $n = 4$ replicates. Different letters within each enzyme indicate significant differences; the same letters within each enzyme indicate that there were no statistically significant differences.

It has been reported that humic acid fractions with different molecular masses have different effects on the activity of urease and protease, which could be related to molecular rigidity, the presence of aromatic rings, and the level of condensation of these molecules (Dong *et al.*, 2008). However, theories around this effect vary. For example, Nayak *et al.* (2007) showed that the carbon fractions of humic and fulvic acids have a positive, statistically significant relationship with the activity of dehydrogenase enzymes, cellulase, β -glucosidase, urease, and amidase.

With respect to the phosphodiesterase activity, site variation resulted in statistically significant differences for the three localities (T, V, and Z), with Z showing the highest activity. This pattern is likely linked to the type of soil in the samples from T (i.e., Andisol). The Andisols are characterised by high allophane content, which explains their increased ability to fix humic compounds protecting them from decomposing bacteria and, therefore, from enzymatic activity. In contrast, the soils from Z are derived from Inceptisols, which have lower humic content, allowing enzymes

more mobility and activity. A similar situation is observed for the soils from V (Alfisols), which have common characteristics with Inceptisols, according to the French classification. The samples from Z and V registered higher phosphodiesterase activity, which is likely linked to their respective taxonomic soil classifications. The differences in phosphodiesterase activity reflect variations in the quality of these soils due to their history, use, and sampling location, indicating changes in phosphorus cycle function of the analysed soils. Most likely, phosphodiesterase regulates the labile organic phosphorus activity in many biochemical processes in soil (Turner and Haygarth, 2005).

Figure 1 shows that the β -glucosidase activity in the Z and V samples was significantly higher than in the T samples. This is consistent with the taxonomic classification of the soils from T, as these soils are Andisol sand may have a higher content of humic substances, which decrease the soil β -glucosidase activity. García (2001) has shown that the β -glucosidase enzyme is inactivated through stabilisation with humic acids. The author reported that the β -glucosidase activity declines in soils because the organic material is mineralised from the most labile forms containing more humified fractions, thereby hampering degradation by microbial biomass. Other authors found that β -glucosidase and arylsulphatase are affected as much by soil use as by parental origin. For example, statistically significant differences exist between Oxisol β -glucosidase activity and that of Inceptisols (Acosta-Martínez *et al.*, 2007). Our study supports this conclusion because the enzyme activity was affected by the parental origin of the soil; it was lower in Andisols than in Inceptisols and Alfisols. The soil samples under pasture from V showed higher β -glucosidase activity than those under grass from V, which is consistent with studies that showed that grass coverage can retain more organic carbon (Neill *et al.*, 1997; Yakimenko, 1997). The differences in β -glucosidase activity reflect variations in the quality of these soils due to

agricultural use and location, indicating changes in the carbon cycle function of the studied soils.

In our study, the enzymatic activities varied according to the parental origin of the soil, with less activity in the Andisols (T) than in the Inceptisols (Z) and Alfisols (V). Hypotheses for this trend vary; negative correlations between humic content and enzyme activity have been documented. Furthermore, some authors have reported positive correlations between enzyme activity and humic content, mainly due to the role of these enzymes and immobilisers in the formation of humus-clay colloids, which act as anti-denaturant enzyme agents.

Enzymatic activity is also affected by the soil use; lower values are obtained in soils used for crops than in unaltered or less disturbed soils (Pascual *et al.*, 1999). Furthermore, grassland soils have increased enzymatic activity compared to farm soils because of the positive effects of surface coverage, vegetation, and the lack of tillage, which influence soil properties, including microbial populations and enzymatic activity (Acosta-Martínez *et al.*, 2007). Microbial biomass in the soil generally increases according to the following order: farm soils < forest cover < grassland (Acosta-Martínez *et al.*, 2007). This hierarchy has been verified in our study for the samples from V and T, as the enzyme activity was higher in the soils under pasture (G) than in soils used for agriculture (P). However, the same relationship was not observed for the Z samples, which may suggest high variability in the enzymatic response to different agricultural practices that arise for the same land use.

3.4. Correlations between enzymatic activities and physicochemical properties

Table 2 shows that the urease, phosphodiesterase, and arylsulphatase activities were positively correlated. This finding indicates a trend, in the sense that the samples from V and T (non-agricultural use) and the G samples (no agrochemicals) showed higher enzymatic activity than the P samples (agricultural use).

with agrochemicals). In the samples from Z the opposite was observed (the G samples showed lower enzymatic activity than the P samples). However, these correlations were not statistically significant. The urease activity did not show a statistically significant correlation with any physicochemical parameter, but the urease activity negatively correlated with organic carbon, total nitrogen, and cation exchange capacity, while it positively correlated with zinc, iron, and copper.

The phosphodiesterase activity positively correlated with the arylsulphatase activity. This indicated a trend in which the samples not used for farming (G) showed a higher enzyme activity than the samples from Z, which whose activity was inversely correlated. However, these correlations were not statistically significant. The β -glucosidase activity also showed a positive correlation with the phosphodiesterase activity, although this correlation was not statistically significant.

Other authors have reported results that contradict our investigation. For example, Ross *et al.* (1995) found statistically positive correlations between urease, acid phosphatase, alkaline phosphatase, phosphodiesterase, arylsulphatase, and β -glucosidase. Gil-Sotres *et al.* (2005) and Izquierdo *et al.* (2005) found that all of their studied enzymatic activities were significantly correlated (β -glucosidase, cellulase, protease, casein, and acid phosphatase) ($p < 0.001$ in most cases). Our results suggest a strong correlation between the enzymatic processes involved in the carbon, nitrogen, and phosphorus cycles. Gil-Sotres *et al.* (2005) suggested that the arylsulphatase activity is not correlated with other enzymatic activities, which would indicate that the sulphur cycle is not coupled to the other major nutrient cycles. However, this contradicts the results of other authors (Frankenberger and Dick, 1983; Speir *et al.*, 1980)

The phosphodiesterase activity had a positive correlation with manganese, iron, clay, exchangeable acidity, and copper (Table 2). However, these correlations were not statistically significant. The β -glucosidase activity showed a positive correlation with clay, magnesium, exchangeable

acidity, and iron, but these correlations were also not statistically significant. The arylsulphatase activity did not show a statistically significant correlation with any physicochemical parameter; even its positive correlation with magnesium and iron was not statistically significant (Table 2). Some studies have shown a positive correlation between the activity of the hydrolases involved in the N, P, C, and S cycles (urease, protease, β -glucosidase, and arylsulphatase) and the organic matter content (García and Hernández, 1997). However, our results did not show this positive correlation with organic carbon.

In agreement with other reports, positive correlations were found between the organic material content and the activities of β -glucosidase, acid phosphatase, alkaline phosphatase, and urease (Dick *et al.*, 1988; Eivazi and Tabatabai, 1988; Santrucková *et al.*, 2004; Turner *et al.*, 2002). However, only phosphatase and invertase significantly correlated with the agricultural soil organic carbon content in the research of Gianfreda *et al.* (2005). Our results indicate that a high organic carbon content does not necessarily reflect a corresponding increase in enzymatic activity.

Gianfreda *et al.* (2005) found inconsistent correlations between soil enzyme activities and the most important biological nutrients (C, N, P, and S) in their study of cultivated and uncultivated soils in Europe. The literature seems to confirm that cause-effect relationships can not be directly derived from changes in the soil in response to a given factor and present contradictory variations in the soil enzyme activity and behaviour. Enzyme activities provide a definitive measure of the final effects of a given process in the soil, which can not be understood independently (Epelde *et al.*, 2008).

In summary, enzyme activities may be used as soil quality indicators. However, they are involved in complex processes, making their exact function difficult to ascertain. Thus, quality indicators must be analysed as part of a set, including physical, chemical, biological, and microbiological parameters, to ensure correct interpretation.

Table 2. Correlations between the physicochemical parameters of the soils. Ure: urease; Pd: phosphodiesterase; β -Glu: β -glucosidase; Aryl: arylsulphatase; Snd: sand; Lim: lime; Cly: clay; EA: exchangeable acidity; OC: organic carbon; TN: total nitrogen; CEC: cation exchange capacity. Asterisks (*) indicate statistical significance ($p < 0.05$).

	Pd	β -Glu	Aryl	Snd	Lim	Cly	pH	EA	%OC	%TN	CEC	Ca	Mg	K	Na	P	Mn	Fe	Zn	Cu	B
Ure	0.6	-0.1	-0.7	-0.1	0.1	0.0	-0.3	0.0	-0.6	-0.6	-0.7	-0.3	-0.4	-0.5	0.4	-0.4	0.3	0.5	-0.4	0.8	-0.4
Pd		0.7	0.7	-0.5	-0.0	0.7	-0.8*	0.7	-0.8	-0.9*	-0.9*	-0.7	-0.6	-0.6	-0.7	0.1	0.9*	0.98*	-0.4	0.5	-0.5
β -Glu			0.3	-0.6	0.0	0.8*	-0.8	0.8	-0.3	-0.5	-0.5	-0.4	-0.5	-0.5	-0.5	0.4	0.9*	0.7	-0.2	-0.0	0.1
Aryl				-0.2	-0.2	0.4	-0.2	-0.1	-0.5	-0.4	-0.5	-0.0	-0.0	-0.1	0.1	-0.6	0.6	0.6	0.1	0.2	-0.2
Snd					-0.8	-0.9*	0.7	-0.6	-0.1	0.4	0.2	0.0	0.6	0.7	0.6	-0.6	-0.7	-0.4	0.7	-0.1	-0.4
Lim						0.4	-0.3	0.3	0.4	-0.1	0.1	0.2	-0.6	-0.6	-0.5	0.5	0.1	-0.1	-0.9*	0.3	0.6
Cly							-0.7	0.7	-0.2	-0.5	-0.4	-0.2	-0.5	-0.5	-0.5	0.5	0.9*	0.6	-0.4	-0.0	0.2
pH								-0.9*	0.5	0.9*	0.8	0.7	0.9*	0.8*	0.9*	-0.5	-0.8*	-0.9	0.7	-0.6	0.2
EA									-0.4	-0.8	-0.7	-0.7	-0.8	-0.7	-0.9*	0.7	0.7	0.7	-0.7	0.4	-0.2
OC										0.8*	0.9*	0.8	0.3	0.1	0.4	0.1	-0.5	-0.8	0.1	-0.4	0.9*
TN											0.98*	0.9*	0.8	0.66	0.8*	-0.3	-0.7	-0.9*	0.6	-0.7	0.5
CEC												0.8*	0.7	0.6	0.7	-0.1	-0.7	-0.9*	0.4	-0.7	0.6
Ca													0.6	0.4	0.7	-0.4	-0.4	-0.7	0.3	-0.5	0.7
Mg														0.96*	0.9*	-0.5	-0.6	-0.7	0.9*	-0.8	-0.1
K															0.8	-0.3	-0.6	-0.6	0.8*	-0.8	-0.3
Na																-0.6	-0.5	-0.6	0.9*	-0.7	0.2
P																	0.2		-0.0	0.1	
Mn																		0.9*	-0.3	0.2	-0.1
Fe																			-0.4	0.5	-0.4
Zn																				-0.7	-0.1
Cu																					-0.2

4. Conclusions

In this study, we determined the effect of use and location on the physicochemical properties and enzymatic activities of soils. The physicochemical parameters and enzymatic activities of our soil samples varied in agricultural management and location but did not result in dramatic changes. Various correlations between the physicochemical parameters and enzymatic activities were found but were sometimes contradictory. Our results reflect the complexity of the biochemical processes that take place in soil and enhance our understanding of the activities of various enzymes as indicators of soil quality.

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