Correlations between enzymatic activities and microbiological parameters in lacustrine and alluvial soils of Venezuela under different uses

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ABSTRACT
The objective of this work was to evaluate the possible correlations between some microbiological parameters of the soil (basal respiration, carbon of the microbial biomass) and the activity of some enzymes involved in the C, N and P cycles, in order to know if the latter could be considered as indicators of microbial activity in alluvial and lacustrine soils of the Lake Valencia Basin (Venezuela) under different uses. The activities of β glucosidase, urease, protease, acid and alkaline phosphomonoesterase, dehydrogenase and arginine ammonification were determined in soils under natural vegetation, sugarcane and banana cultivation. Positive and significant correlations were found between enzymatic activities and microbial biomass carbon and basal respiration, as well as with total organic carbon content, water-soluble carbon, and soil physical and chemical properties. Protease activity showed the highest correlation coefficient with the carbon of the microbial biomass. Acid phosphomonoesterase activity had the highest coefficient with respect to basal respiration, and alkaline phosphomonoesterase with dehydrogenase activity and arginine ammonification. The correlation coefficient between β glucosidase activity and the percentage of total organic C was found to be the highest for all hydrolases. Positive and significant correlations between enzyme activity and biological activity with total organic carbon suggest the existence of an important relationship between microbiological activity and soil organic matter content.

Keywords: Soil organic carbon, Microbial biomass, Metabolic quotient, Metabolic efficiency quotient, Water-soluble carbon.

1 INTRODUCTION

In soil, which can be thought of as a biological entity, with complex biochemical reactions, enzymes play an important role from an ecological point of view, by catalyzing countless reactions. Soil enzymes can originate from plants, animals, fungi, actinomycetes, and bacteria, although it is generally accepted that the microbial component is the main source of enzymes in soil.

Dick (1997) highlights that soil enzymes act as mediators and catalysts for important functions including: the decomposition of organic waste, the transformation of native soil organic matter, the release of inorganic nutrients for plant growth, nutrient cycling, N2 fixation, xenobiotic detoxification, and nitrification and denitrification processes.

It has been suggested that enzyme activities have the ability to reflect differences with respect to agricultural management practices (Dick, 1997; Gianfreda & Bollag, 1996), probably because they are related to microbial biomass, which is sensitive to these treatments (Nannipieri, 1994; Beyer *et al*, 1999; Borie *et al*, 1999). In addition, the determination of soil enzymatic activity has been used to study the anthropogenic effects of heavy metals and other organic and inorganic pollutants (Nannipieri, 1994). On the other hand, as the physical and chemical properties of the soil have an important influence on the activity and quantity of microorganisms and the concentrations of substrates, they also play a significant role in the activity of enzymes.

For all the above reasons, enzymatic activities have been used as indicators of changes in soil quality and fertility, taking into account that soil quality is related to soil functionality, its ability to provide essential ecosystem services, and soil health. Healthy soils are important for growing crops, raising healthy animals, and supporting a healthy human population through nutritionally balanced diets and environmentally healthy habitats (Lal, 2020).

The study of the relationships between different enzymatic activities and microbiological parameters facilitates the determination of soil quality indices that have proven to be useful in monitoring soil degradation or contamination (Trasar-Cepeda *et al*., 1998; Ruiz-Dager & Paolini, 2022).

In this work, the relationships between enzyme activities, microbiological parameters and physical and chemical properties have been studied in lacustrine and alluvial soils of Venezuela, under different uses.

2 MATERIALS AND METHODS

The area in which this research was carried out is located in the north-central region of Venezuela, in the plain of the Lake Valencia Basin, which is approximately delimited by the meridians of west longitude 67° 10' – 68° 10', and by the parallels of north latitude 10°00' – 10° 20'. The climate of the basin is humid tropical. In this area there is a marked climatic biseasonality, characterized by a period of low rainfall (January, February and March), and another of high rainfall (June, July, and August), which vary between 900 mm and 1150 mm, with an annual average of 1000 mm. The average annual temperature is 24.6 $^{\circ}$C.

Ten soils were chosen, five of them of lacustrine origin and five of alluvial origin (Table 1). Two soils under natural or native vegetation were included, one lacustrine (LVN) and the other alluvial (AVN), which have not been cultivated or irrigated, so they were considered as control soils in each case. The remaining soils are under sugarcane or banana cultivation and are irrigated with water of different origin or composition. The lacustrine soils are all classified as *MOLLIC USTIFLUVENTS, loamy, carbonate, mixed, isohyperthermal,* and the alluvial soils as FLUVENTIC *USTROPEPTS, coarse loam mixed isohyperthermal,* with the exception of AB2 soil, which is classified as *FLUVENTIC HAPLUSTOLLS* (Elizalde *et al.*, 2007).

Table 1. Characteristics of the soils studied

Origin of the Soil	Land use	Acronyms	Type of irrigation water
Lacustrine	Native vegetation	LVN	No
	Sugarcane	LC1	Lake Valencia (untreated)
		LC2	Deep Well
		LC3	Residual untreated
	Banana	LB1	Embalse Taigüaigüay (tratada)
Alluvial	Native vegetation	AVN	No
	Sugarcane	AC1	Aragua River (Untreated Waste)
		AC2	Embalse Zuata (treated)
	Banana	AB1	Embalse Zuata (treated)
		AB2	Turmero River (Untreated Residual)

In the control soils, the natural or native vegetation is made up of tall trees and abundant shrubs. As for the cultivated sites, it should be noted that of the soils of lacustrine origin, three of them were planted with sugar cane for thirteen years, while the other had been under bananas for twenty years. Among the cultivated soils of alluvial origin, two of them had been planted with sugar cane for forty-three years, and the other two had been cultivated with bananas for six years (previously corn was grown in these soils for more than ten years). All cultivated soils had been subjected to conventional management, with the use of chemical fertilizers and pesticides. In addition, the soils under bananas received poultry manure as organic fertilizer. In the management of sugarcane, pre-harvest burning has always been practiced.

Soil samples were taken at a depth of 0-5 cm. For each type of land use, subsamples of equal volume were collected at 20 different points in the area to be considered in a zig-zag pattern and mixed to obtain three composite samples. The composite samples were divided into two portions. One of the portions was air-dried, crumbled and sifted to 2 mm to be used in the determinations of pH, organic carbon (Corg), water-soluble carbon (CHS), available N, P and extractable cations. The other portion was preserved with field moisture, sifted to 2 mm and stored in polyethylene bags under refrigeration at 4 °C for subsequent analysis of basal respiration or microbial activity, microbial biomass carbon and enzyme activities over a period of no more than two weeks (Ruiz and Paolini, 2004).

pH was determined in a soil:water suspension 1:2.5; electrical conductivity in a soil:water suspension 1:1. Total nitrogen (N) was determined by Kjeldhal's method, and available phosphorus was determined by Olsen and Sommers (1982). The determination of Ca, K, Na and Mg was carried out by Atomic Absorption Spectrophotometry from soil extract obtained with North Carolina extractor solution (Page, 1982). Total organic carbon (Corg) was determined by wet oxidation of organic carbon by a mixture of potassium dichromate and sulfuric acid and subsequent spectrophotometric determination of the Cr+3 ions produced,

according to the method described by Heanes (1984) and Paolini (2018). Water-soluble carbon (CHS) was extracted by agitating soil samples with water in centrifuge tubes, with a soil/water ratio of 1:10 for 1 hour. After centrifuging them for 15 minutes, at 3,500 revolutions per minute, the supernatant was passed through a 0.45 mμ Millipore filter. Organic carbon was measured by combustion with catalytic oxidation in a Shimadzu 5000A carbon analyzer.

For the quantification of basal respiration (RB), the procedure described by Paolini (2018) was followed. The carbon of the microbial biomass (Cmic) was determined according to the substrate-induced respiration method (Ruiz & Paolini, 2004). Once the 2 parameters mentioned above were determined, the following ecophysiological coefficients were calculated: metabolic quotient (qCO 2 = RB/Cmic) and metabolic efficiency coefficient (qCO2/Corg).

Determinations of enzymatic activities were carried out according to the standard methods described by García *et al.* (2002), Alef and Nannipieri (1995) and Tabatabai (1994). Dehydrogenase (DH) activity was determined by the reduction of triphenyltetrazolium chloride to triphenylformazan after incubating the soil for 24 h at 37 °C. Arginine deamination or ammonification (ARG) was determined by measuring the ammonium released after incubating the soil with arginine as a substrate for 3 h at 25 ºC. The determination of the activity of acid phosphomonoesterase (FAC), alkaline phosphomonoesterase (FAL) and β-glucosidase (GLU) was based on the determination of the released p-nitrophenol (p-NF) after incubating the soil for 1 h at 37 ºC with the substrates buffered to the respective pHs: p-nitrophenofolfolphate and p-nitrophenyl-β-D-glucopyranoside. Urease activity (UR) was estimated by ammonium released after incubating soil with urea as substrate for 2 hours at 37 °C. Protease activity (PROT) was determined by measuring tyrosine released with the Folin-Ciocalteau reagent after soil incubation for 2 h at 50 °C with casein as substrate at pH 8.1. The results were expressed based on the dry weight of the soil. The moisture content was estimated from the difference in weight that the samples experienced after being heated to 105 °C for 24 hours.

The statistical analysis of the data was carried out with the STATISTIX program for Windows version 8.0, 2003. All assumptions and tests were validated with a significance level of 95%.

3 RESULTS AND DISCUSSION

The results corresponding to the content of total organic carbon, water-soluble carbon, pH, microbiological parameters (basal respiration and carbon of microbial biomass), ecophysiological coefficients: qMic (Cmic/Corg), metabolic quotient (qCO2) and metabolic efficiency coefficient (qCO2/Corg), and enzymatic activities (dehydrogenase, β-glucosidase, arginine ammonification, urease, protease, acid phosphomonoesterase and alkaline phosphomonoesterase) have been reported in previous publications (Ruiz-Dager & Paolini, 2021 and 2022).

Table 2 shows the contents of some elements in the soils studied, the cation exchange capacity (CEC), the C/N ratio as well as phosphorus and extractable cations.

Table 2. Available nitrogen, phosphorus and extractable cations with North Carolina solution from the soils studied.

Soil	N	C/N	CIC	Phosphorus	Potassium	Calcium	Magnesium	Sodium
	(g kg^{-1})		(cmol kg-1)	(mg $^{kg-1}$)				
LVN	6,6	12,4	29,58	332	1040	10016	992	1368
LC1	2,0	8,7	13,40	114	155	4968	264	384
LC2	1,9	9,2	12,70	113	189	6240	282	144
LC3	2,4	13,7	29,40	64	234	2722	203	472
LB1	4,7	11,4	28,88	658	85	6024	840	136
AVN	3,2	14,7	36,54	367	263	2904	496	53
AC1	1,6	12,3	17,05	137	140	2336	185	94
AC2	1,9	10,8	18,44	129	26	2857	206	143
AB1	1,8	5,1	16,88	33	24	2328	117	214
AB2	1,4	9,0	19,31	125	27	2599	172	163

N = Total Nitrogen; C/N = C/N ratio; CIC = cation exchange capacity.

From the results obtained in the different determinations carried out in the soils studied, simple linear correlations were established between the parameters evaluated.

3.1 CORRELATIONS BETWEEN ENZYMATIC ACTIVITIES AND MICROBIOLOGICAL PARAMETERS.

Table 3 presents the matrix of correlations of the biological parameters and the enzymatic activities studied (only the statistically significant ones are shown). Regarding microbiological properties, a significant and positive correlation was observed between RB and Cmic, ARG, and DH. The use of each of these variables has been suggested individually as an indicator of biological activity (Frankenberger & Dick, 1983; Alef and Kleiner, 1986; 1987; Lin and Brookes, 1999).

Table 3. Correlation coefficients between enzymatic activities and biological properties.

	GLU	DH	I do	WAVES	PROT	BORN	Cmic	RB
ARG	0,85**	0,75*	0,82**	0,86**	0,85**	0,69*	0,95***	0,92***
GLU		0,90***	0,91***	0,94***	0,88***	0,79**	0,77*	0,88***
DH			0,83*	0,96***	0,83**	0,79**	0,73*	0,71*
FAC				0,93***	0,92***	0,79**	0,83**	0,94***
FAL					0,90***	0,80**	0,84**	0,85**
PROT						0,93***	0,89***	0,92***
UR							0,76*	0,76*
Cmic								0,90***

*, **, ***, Significant at probability levels of 0.05; 0.01 and 0.0001, respectively. Cmic = carbon of microbial biomass. RB = basal respiration. DH, ARG, FAC, FAL, GLU, UR and PROT correspond to the enzymatic activities of dehydrogenase, arginine deamination, acid phosphomonoesterase, alkaline phosphomonoesterase, β-glucosidase, urease and protease respectively.

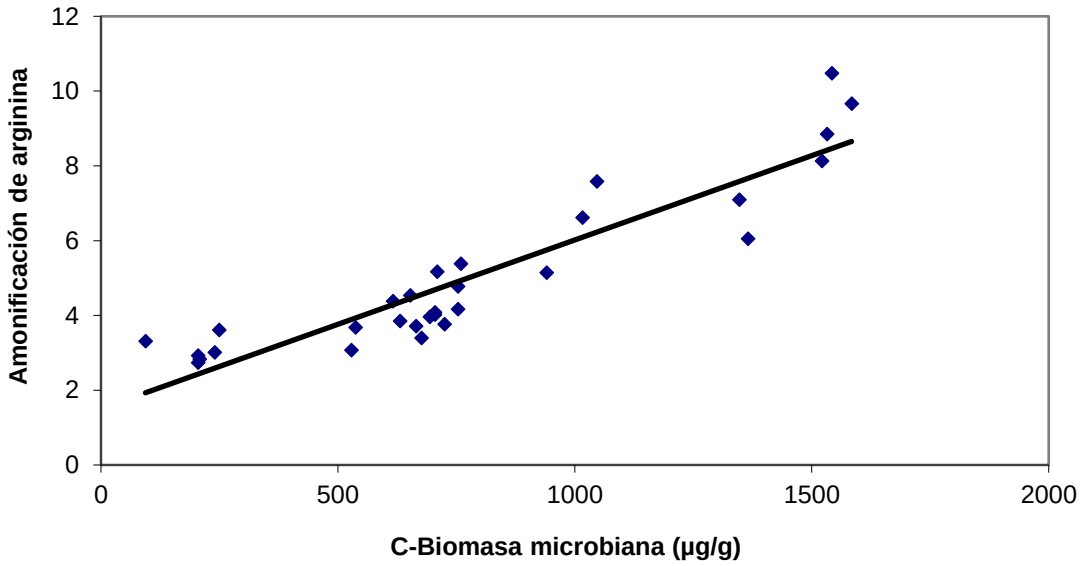
The results of these correlations could confirm this fact for the soils studied and correspond with the findings of Franzluebbers *et al.* (1995), who found that microbiological parameters (RB, Cmic) and ARG correlated significantly with each other, and therefore appear to adequately reflect biomass and potential microbiological activity under laboratory conditions.

A statistically significant correlation between basal respiration and CMIC (r = 0.80) was also found in soils cultivated with sugarcane in Brazil (Duarte et al., 2008), as well as in subtropical climate regions of China, where conversion of native vegetation forests to plantations of tree species of commercial interest has occurred (Wang et al., 2013), as well as in soils under wheat or maize located in the north of that country (Hu and Cao. 2007). Similarly, in the semi-arid central Pampas region of Argentina, it was observed that 73% ($p<0.0001$) of RBI was associated with Cmic, resulting in a positive linear regression between both variables (Fernández *et al*., 2018). A similar result was found in semi-arid soils in Spain (Bastida et al., 2006b).

The Cmic/Corg relationship, which has also been proposed as an indicator of biological activity, did not correlate significantly with RB or Cmic; nor did it do so with the DH or the ARG.

The correlation coefficients of the regression equations relating the ARG to the RB and the CMIC are quite high (Table 3, Figure 1). This trend is similar to that found by Alef and Kleiner (1986; 1987), and Suttner and Alef (1988) in different soils in Germany; and by Lin and Brookes (1999) in UK soils. As Suttner and Alef (1988) point out, these highly significant correlations demonstrate that ARG can be used as an indicator or as a useful measure of biomass and microbial activity in different soils.

Figure 1. *Correlation Between Arginine Ammonition and Biomass Carbon*



microbial in the soils studied.

The correlation coefficients between DH and RB, or Cmic, are lower and of a lower level of significance than those found for the correlation between ARG and the aforementioned microbiological parameters. Other studies have shown a high correlation between DH and CMIC (Goyal *et al.*, 1993; Chander *et al.*, 1998; Zamora *et al.*, 2005).

The parameters of microbiological activity (RB, Cmic), ARG and DH are positively and significantly correlated with the activities of hydrolasesβ (-glucosidase, urease, protease, acid and alkaline phosphomonoesterase) determined in this study (Table 3), which highlights the close relationship of these enzymatic activities with soil microbial activity. However, only a negative and significant correlation was found between Cmic/Corg and GLU ($r = -0.45$; $p < 0.05$), with the rest of the hydrolases there was no correlation. The PROT showed the highest correlation coefficient with the Cmic, while the FAC had the highest coefficient with respect to the UBI, and the FAL with the DH and the ARG. Regarding phosphomonoesterase, the results are consistent with those of Chander *et al.* (1998), who also found a high correlation between Cmic and FAL ($r = 0.99$; $n = 4$) in an Indian Inceptisol, as did Hu and Cao (2007) in cereal-grown soils in northern China. With respect to UR, there is similarity with the relationship found between Cmic and the activity of this enzyme by Wang *et al.* (2013) and Hu and Cao (2007) in Chinese soils.

The high correlation found between FAC activity and UBI supports the approaches of other studies (Frankenberger & Dick, 1983; Jordan *et al.*, 1995), according to which FAC activity has been suggested as an appropriate indicator of relative soil microbial activity. The results are also in agreement with those found in Argentine soils, where the activities of the FAC, GLU, PROT and UR correlated positively and

significantly with RB and DH (Jiménez *et al*, 2002); in Chilean forest soils that showed positive and significant correlations between the CMIC and the activities of FAC and the GLU (Alvear et al., *2008) and in semi-arid soils in Spain in which the CMIC correlated positively and significantly with the activities of the UR, PROT, FAL, DH and GLU (Bastida* et al., 2006b).

The positive and significant correlation between ARG and PROT reflects the close relationship between protein hydrolysis and amino acid ammonification in soil, suggesting the possibility of using ARG as a measure of the intensity of microbial nitrogen mineralization in the soil environment (Alef *et al*., 1988, Franzluebbers, *et al*., 1995).

Table 3 shows a significant and positive correlation between the activities of the different hydrolases, even though each enzyme acts on a specific substrate and in a different reaction. Possibly the close relationship between enzyme activities and soil microbiological activity, already indicated, leads to this correlation between enzymatic activities. Similar results have been found by Frankenberger and Dick (1983), Suttner and Alef (1988), Jimenez *et al.* (2002), Hinojosa *et al.* (2004), Aponte *et al*. (2011) and Pajares *et al*. (2011). In this latest study, carried out in soils of an altitudinal transect in the Mexican neovolcanic axis, high positive correlations were found between the total activities of the enzymes UR, PROT, GLU and FAC, suggesting a balance between the main nutrient cycles, according to the authors.

As part of the present research, in a previous publication (Ruiz-Dager & Paolini, 2022) it was reported that, based on the determinations of the activities of dehydrogenase, arginine ammonification, acid phosphomonoesterase, alkaline phosphomonoesterase, β-glucosidase, urease and protease, it was possible to calculate three soil quality indices: alteration index 3, enzymatic geometric mean and radar diagram area, which showed that agricultural use causes a disturbance of the natural balance, the order being: natural vegetation > sugarcane > banana. The alteration index (IA3) and the enzymatic geometric mean (MGe) correlated significantly with the metabolic efficiency ratio. Radar plots for each soil type (lacustrine and alluvial) under the two types of land use (sugarcane and banana) confirmed the findings of the other indices. Soils planted with both crops showed lower quality compared to reference soils under native vegetation.

3.2 CORRELATIONS OF MICROBIOLOGICAL PARAMETERS AND ENZYMATIC ACTIVITIES WITH THE PHYSICAL AND CHEMICAL PROPERTIES OF THE SOIL

The physical and chemical properties of the soil have an appreciable influence on the amount of microorganisms, the concentrations of substrates, enzymes, metabolites and inorganic nutrients in the soil, and consequently on microbiological activities (Stotzky and Burns, 1982). For this reason, the effects of some physical and chemical properties of the soil on the parameters of microbiological activity and enzymatic activity in the chosen area were investigated. Table 4 shows the correlation coefficients between microbial activity parameters and physical and chemical properties.

Table 4. Correlation coefficients between microbiological properties and physical and chemical properties of soil

	Corg	HIGH	DH	Cmic	RB	CHS	qMic	qCO2	qCO2/Corg
pH	- 0,59***	-0,75****	- 0,66***	- 0,68****	- 0,56**	-0,65****	ns	ns	0,44*
CE	0,75****	0,74****	0,72****	0,64***	0,79****	0,58***	ns	ns	ns
N	0,97****	0,76****	0,81****	0,68****	0,87****	0,88****	ns	0,45*	-0,50**
C_{org}	1	0,86****	0,86****	0,79***	0,92****	0,93****	- 0,45*	ns	-0,62*
CHS	0,93****	0,74****	0,86***	0,65***	0,75***	1	-0,55**	ns	-0,55**
C/N	0,61***	0,71****	0,59***	0,77****	0,57***	0,59***	ns	ns	-0,82***
CIC	0,76****	0,72***	0,52**	0,67***	0,67****	0,82****	- 0,41*	ns	-0,47***
K	0,82****	0,84****	0,82****	0,76****	0,86****	0,70****	ns	ns	-0,44*
Ca	0,72****	0,52**	0,75****	0,51**	0,71****	0,61***	ns	ns	-0,39*
Mg	0,94****	0,66***	0,83****	0,59***	0,79****	0,89****	- 0,59***	0,45*	-0,52**
Na	0,69****	0,75****	0,59***	0,68****	0,82****	0,48**	- 0,53**	ns	ns
Pdisp	0,70****	0,33 ns	0,56**	0,28 ns	0,44*	0,74****	- 0,66****	0,39*	-0,45*

*,**,***,**** Significant at probability levels of 0.05, 0.01, 0.001, 0.0001 respectively; ns = not significant.

As can be seen, these correlations were significant with almost all parameters. Only in the case of available phosphorus was no significant correlation with ARG or Cmic. All correlations are also positive, except for those established with pH, which coincides with the data found by Frankenberger and Dick (1983) and by Suttner and Alef (1988), who found significant correlations between ARG and total N ($r = 0.881$; $p < 0.01$), and ARG with CIC ($r = 0.848$; $p < 0.01$); but not with pH. They also confirm the results observed in soils of the Brazilian Cerrado, in which DH activity correlated significantly and positively with available phosphorus content (Pdisp) and exchangeable Ca and Mg contents (Baligar *et al.*, 1999).

Positive and significant correlations between the parameters of biological activity and the Corg or CHS (Table 4) confirm the existence of a close relationship between microbiological activity and soil organic matter content. These results are consistent with those observed for German soils by Alef and Kleiner (1986, 1987), who found a positive and significant correlation between ARG and Corg ($r = 0.78$), and by Suttner and Alef (1988), for the same relationship ($r = 0.81$; $p < 0.01$); as did Lin and Brookes (1999) in UK soils ($r = 0.85$; $n = 12$).

In research carried out in Spain, Trasar-Cepeda *et al*. (1998) observed significant correlations ($p < 0.001$) of the Cmic with the Corg ($r = 0.88$) and the total N ($r = 0.87$) in areas under natural vegetation in Galicia, while in soils with a semi-arid climate, the Corg and the CHS correlated positively and significantly with the RB and the Cmic (Bastida *et al*. (2006b). These same correlations have been found in banana agroecosystems located in tropical areas of China (Zhong *et al.*, 2015) and in Australian soils cultivated with sugarcane and grass ($r = 0.83$; $p < 0.05$) (Stirling et al., 2010).

Dominy *et al*. (2002) showed a linear correlation between Corg content and CMIC ($r = 0.75$; $p<0.01$) in sugarcane-planted areas of South Africa. In Venezuela, positive and significant correlations have also been found between Cmic and Corg in soils of the state of Falcón under tomato monoculture, in tomato and onion crop rotation (Zamora et al., 2005*), in areas of secondary forest and soils planted with melon or aloe vera* (Mogollón et al., 2010).

In relation to DH activity, high correlation coefficients were observed with Corg, CHS and N (Table 4), a result that coincides with that obtained by Navas *et al*. (2009) in soils in Spain subjected to different uses. With respect to these findings, it should be noted that dehydrogenase activity plays a fundamental role in the initial stages of organic matter oxidation (Ross, 1971), which is why it has been considered as an indicator of soil microbiological activity (Casida *et al*., 1964).

Table 4 also shows that qMic correlated significantly and negatively with Corg, CHS, CIC, Pdisp, Mg, and N.

In this study, no relationship was found between qCO2 and Corg, CHS or Cmic, but a negative and significant correlation was obtained ($r = -0.69$; $p < 0.0001$) between qCO2 and qMic. The same relationship was found by Saviozzi *et al.* (1999) in Italian agricultural soils, by Martín-Lammerding *et al.* (2015) in semi-arid areas of Spain and by Paolini (2018) in Venezuelan coffee soils and indicates that the smaller the microbial biomass in the soil, the more active the population of microorganisms. In addition, a positive and significant correlation was observed between qCO2 and RB ($r = 0.40$; $p < 0.05$), which did not occur with the other parameters of microbiological activity and coincides with the findings of Paolini (2018). On the other hand, qCO2 did not correlate with hydrolase activities, only with PROT ($r = 0.4126$; $p < 0.05$). Regarding physicochemical parameters, a correlation ($p < 0.05$) was found between qCO2 and Pdisp, Mg and N (Table 4).

In contrast to qCO2, the qCO2/Corg ratio showed a negative and significant correlation with the Corg ($r = -0.62$; $p < 0.001$), with the CHS ($r = -0.55$; $p < 0.01$) and with the Cmic ($r = -0.76$; $p = 0.0000$), but did not correlate with qMic. These results are in full agreement with those observed by Paolini (2018) in soils of the Venezuelan Andes, but contrast with the findings of Martín-Lammerding *et al*. (2015), in which study, higher values of qMic correlated with lower values of qCO2/Corg.

Significant correlations of the activities of all enzymes with the physical and chemical properties of the soils studied were observed (Table 5). The highest correlation coefficients were presented with the content of Corg, CHS and N. Several studies converge in the same direction: to this end, Frankenberger and Dick (1983) show the existence of significant correlations between the activities of the FAL, FAC and UR with the C_{org}, total N and CIC in California soils (USA).

Table 5. Correlation coefficients between enzymatic activities and soil physical and chemical properties.

	GLU	I do	WAVES	PROT	BORN
pH	- 0,61***	- 0,49**	- 0,67****	- 0,57***	- 0,47**
CE	0,82****	0,83****	0,82****	0,65****	0,40*
N	0,97****	0,90****	0,90****	0,88****	0,86****
C_{org}	0,89****	0,78****	0,84****	0,85****	0,89****
CHS	0,95****	0,90****	0,86****	0,85****	0,79****
C/N	0,57**	0,47**	0,61***	0,69****	0,70****
CIC	0,66****	0,53**	0,56**	0,74****	0,81****
K	0,89****	0,88****	0,90****	0,77****	0,54**
Ca	0,77****	0,89****	0,80****	0,67****	0,54**
Mg	0,92****	0,87****	0,84****	0,82****	0,82****
Na	0,74****	0,81****	0,74****	0,65****	0,35 ns
Pdisp	0,63***	0,52**	0,50**	0,59***	0,78****

*, **, ***, **** Significant at probability levels of 0.05, 0.01, 0.001, 0.0001 respectively,
ns = no significant

Other research indicates that the activity of acid phosphomonoesterase, alkaline phosphomonoesteraseβ, glucosidase, protease and urease have been positively and significantly correlated with Corg, CHS and total N in Spanish soils (Trasar-Cepeda *et al*., 1998; Bastida *et al*., 2006b; Navas *et al*., 2009); Argentina (Jiménez *et al*, 2002); Mexico (Pajares *et al*., 2011); China (Zhong et al., 2015; Zhang et al., 2016); Turkey (Kizilkaya and Dengiz, 2010) and Venezuela (Mogollon et al., 2010). A high correlation between enzymatic activities and soil organic matter levels has been found in Venezuelan semi-arid ecosystems, demonstrating the importance of organic carbon in these ecosystems (Aponte et al., 2011).

Table 5 also shows that the correlation coefficient between the activity of GLU and Corg is the highest of all hydrolases, evidencing the relationship of this enzyme with the carbon cycle. According to Turner *et al*., (2002), the positive correlation between βglucosidase activity and organic carbon is logical because this enzyme is synthesized by soil microorganisms in response to the presence of available substrates. The positive and significant correlation shown by the activity of this enzyme with the contents of Ca and Mg was also observed in Costa Rican soils under different crops, including sugarcane and banana (Henríquez *et al*., 2014).

4 CONCLUSIONS

The relationship between the enzymatic activities studied and other edaphic parameters related to activity, microbial biomass and organic matter was verified through the positive and significant correlations found between enzymatic activities and total organic carbon, basal respiration, microbial biomass carbon and soil physical and chemical properties. The correlation coefficient between βglucosidase activity and total organic C content was found to be the highest of all hydrolases. Positive and significant correlations between biological activity parameters and enzyme activity with total organic carbon suggest the existence of an important relationship between microbiological activity and soil organic matter content

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