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Effect of ecological and conventional managements on soil enzymatic activities in coffee agroecosystems[1]

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ABSTRACT

Understanding the impacts of agricultural practices on soil quality indicators, such as enzymatic activities, is of great importance, in order to advance in their diagnosis and sustainable management. This study aimed to evaluate the effect of ecological and conventional agricultural managements on enzymatic activities of a soil under coffee agroecosystems. The enzymatic activities were associated with the biogeochemical cycles of nitrogen (urease and protease), phosphorus (acid and alkaline phosphatase) and carbon (β-glucosidase), during the rainy and dry seasons. Physical-chemical soil proprieties were also assessed and related to resilience scores linked to the climatic variability reported for the areas under study. The activities of urease, alkaline and acid phosphatase and ß-glucosidase were statistically higher in ecological agroecosystems than in conventional ones. This may be attributed to the greater application of organic waste in the ecological environment, as well as to the absence of pesticides and synthetic fertilizers, which allow better conditions for the microbial activity. The resilience scores to the climate variability that showed the highest correlations with the assessed enzymatic activities were: the farmers' knowledge on soil microorganisms, non-use of pesticides and synthetic fertilizers and non-dependence on external supplies. It was concluded that the enzymatic activities are modified by the management systems, being specifically favored by the ecological management. This agroecosystem, in the long term, ensures an efficient use of the soil resources, with a lower degradation and contamination.

KEYWORDS: Urease; protease; β-glucosidase; acid and alkaline phosphatase.

RESUMO

Efeito de manejos ecológico e convencional sobre atividades enzimáticas do solo em agroecossistemas cafeeiros

Compreender os impactos de práticas agrícolas sobre os indicadores de qualidade do solo, como atividades enzimáticas, é de grande importância para avançar no diagnóstico e no manejo sustentável. Objetivou-se avaliar o efeito dos manejos agrícolas ecológico e convencional sobre as atividades enzimáticas de um solo em agroecossistemas sob cultivo de cafeeiro. As atividades enzimáticas foram associadas aos ciclos biogeoquímicos do nitrogênio (urease e protease), fósforo (fosfatase ácida e alcalina) e carbono (β-glicosidase), durante as estações chuvosa e seca. Propriedades físico-químicas do solo também foram avaliadas e relacionadas a escores de resiliência vinculados à variabilidade climática reportada para as áreas em estudo. As atividades de urease, fosfatase alcalina e ácida e ß-glicosidase foram estatisticamente maiores nos agroecossistemas ecológicos do que nos convencionais. Isto pode ser atribuído à maior aplicação de resíduos orgânicos no manejo ecológico, bem como à ausência de pesticidas e fertilizantes sintéticos, o que possibilita melhores condições para a atividade microbiana. Os escores de resiliência à variabilidade climática que mostraram as maiores correlações com as atividades enzimáticas avaliadas foram: conhecimento dos agricultores sobre micro-organismos do solo, não uso de agrotóxicos e fertilizantes sintéticos e não dependência de insumos externos. Concluiu-se que as atividades enzimáticas são modificadas pelos sistemas de manejo, sendo especificamente favorecidas pelo manejo ecológico. Este agroecossistema, a longo prazo, assegura o uso eficiente dos recursos do solo, com menor degradação e contaminação.

PALAVRAS-CHAVE: Urease; protease; β-glucosidase; fosfatase ácida e alcalina.

INTRODUCTION

Soil is the basis for agriculture and terrestrial ecosystems, and life on the planet depends on it. It is a living, dynamic and non-renewable natural resource, and its functioning is key for the production of food and for the maintenance of environmental quality (Ochoa et al. 2007).

Conventional agriculture has demonstrated a capacity for production and profitability in the short term; however, resources such as soil, water and genetic diversity have been overused. As a result,

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soils have been salinized due to excessive irrigation with low quality water containing salts, compacted by excessive tillage, leading to a loss of permeability and increase in runoff, contamination by pesticides and heavy metals, reduction of structural quality due to loss of organic matter, loss of fertility and increase of erosion (Gliessman 2002). In addition, the release of greenhouse gases and the eutrophication of rivers, streams, lakes and coastal and marine ecosystems are also consequences of a bad soil management.

As a response to the degradation of natural resources associated with conventional agriculture, ecological agriculture has emerged, which belongs to the so-called alternative agricultures. It rejects the use of pesticides for the management of insects and diseases, seeks to increase the soil fertility and to prevent the degradation of its structure, avoids any type of contamination, prioritizes policrops on crops and seeks the integrated management of the agroecosystem (Peris et al. 2000). As their components are integrated, the general biological efficiency is increased, and the productive and self-sufficient capacity of the agroecosystem is maintained (Altieri 2001).

The indicators of soil quality can be physical, biological or chemical, and, considering the enzymatic activity, they can also be biochemical (Avellaneda-Torres 2008). Soil enzymatic activities have been suggested as a potential within the set of indicators, due to their relationship with the soil biology, since their presence depends directly on the continuous release carried out by the organisms that inhabit the ecosystem (Albiach et al. 2006). Likewise, the enzymatic activity in cultivated soils is also related to cultivation practices and may be directly associated with the availability of nutrients, since nutrients play important roles in each biogeochemical cycle of elements required for plant growth (Torres & Lizarazo 2006). In some scenarios, it has been suggested that organic amendments increase the activity of enzymes in the soil (Martens et al. 1992) in the same way that the use of organic amendments (slurry, composting, bokashi) stimulate the microbial life in the soil and the nutrition of the plants. On the other hand, Pascual et al. (2002) observed that at 360 days after making an organic amendment in orchard soils, the increase in the urease activity persisted. In this same line, the ecological succession, both the natural and the one that causes the fallow in the rotations, is positively correlated with the urease activity (García et al. 2010).

This investigation aimed at evaluating the impacts of ecological and conventional agricultural managements on the enzymatic activities of soils under coffee cultivation, and their relationship with the resilience scores, in relation to the climatic variability reported for these agroecosystems.

MATERIAL AND METHODS

The study was carried out in 2015 and the selected study sites were composed of six coffee agroecosystems, being three ecological and three conventional, in Anolaima (Cundinamarca, Colombia), located at 1,650 m above the sea level. The study area has slopes with an inclination that ranges between 75 % and 100 %. Its soils are of the Inceptisol type, whose central feature is the susceptibility to mass removal. These soils also present high contents of expansive clays that generate the cracking of the ground in dry periods (Córdoba & León 2013). The coffee plantations of both agroecosystems were ten years old.

The ecological agroecosystem sites were Don José, El Laurel and Los Pantanos (Table 1). These sites are characterized by being self-sufficient,

Table 1. Basic information of the study sites with ecological or conventional coffe agroecosystems.

Agroecosystem management	Farms	Code	Altitude (m a.s.l.)	Coordinates	
				W	N
Ecological	Don Jose	E1	1,488	74º29´11.1”	04º49´21.4”
	El Laurel[1]	E2	1,590	74º28´53.5”	04º49´25.4”
	Los Pantanos	E3	1,525	74º29´46.7”	04º49´15.7”
Conventional	El Turista	C1	1,583	74º28’36.2”	04º48’37.8”
	La Cajita	C2	1,583	74º29´10.8”	04º49´21.3”
	Don Arturo	C3	1,521	74º29´45.7”	04º49´19.0”

[1] Also named locally as “Los Ocobos”.

carrying out soil conservation practices such as not using herbicides, insecticides, fungicides or mineral synthetic fertilizers. In these sites, biodiversity is employed as a strategy to manage insects and disease-causing agents. They also use organic fertilizers, drainage ditches and permanent coverage (Córdoba & León 2013).

The conventional agroecosystem sites were El Turista, La Cajita and Don Arturo (Table 1). The agricultural practices in these areas are based on the use of synthetic insecticides, fungicides and herbicides, such as aldrines, calbaryl (sevin), manzate and glyphosate (Córdoba & León 2013). According to these authors, some fungi-based formulations (*Beauveria bassiana* and *Metarhizium anisopliae*) are also employed. The farmers of these conventionally managed farms do not keep track of quantity, frequency or corrective actions, regarding the doses of agrochemicals applied. In this way, the application of fertilizers and pesticides is made based on suggestions given by agrochemical marketers and using trial and error. In this sense, these applications are not preceded by technical recommendations and/or soil fertility studies, hence the difficulty of specifying quantities and corrective measures applied in each area.

The sampling was carried out in the first 20 cm of the soil depth. Quadrants of 10 m x 10 m were established in each agroecosystem, collecting samples in zigzag in five different points. At each point, five subsamples were taken and mixed to obtain a homogeneous composite sample. In total, thirty composite samples were collected, five for each of the agroecosystems.

Samples were taken in two seasons: in the months of highest (May) and lowest (August) rainfall rate, reported by the Institute of Hydrology, Meteorology and Environmental Studies of Colombia (IDEAM by its abbreviation in Spanish). The samples were transported under refrigeration and stored at -20 ºC.

The following physical proprieties were determined as it follows (IGAC 2006, Avellaneda-Torres et al. 2018): soil moisture; plasticity index, according to the Atterberg limits (minimum moisture, in which the soil can be rolled forming non-fragmented rods of 3 mm in diameter, and the liquid limit, with the "casuela de Casagrande"); and bulk density by the wax immersion method. The chemical assessed proprieties were: pH; electrical conductivity by saturated soil paste extract; organic carbon by the Walkley-Black method; total nitrogen; interchangeable bases (Ca, K, Mg, Na) by extraction with ammonium acetate; effective cation exchange capacity by displacement of NH_4; interchangeable acidity by KCl extraction; available P (Bray II); micronutrients (Cu, Fe, Mn, Zn) by extraction with DTPA; and boron by extraction with mono calcium phosphate (IGAC 2006, Avellaneda-Torres 2018).

The urease activity was according to Alef & Nannipieri (1995), modified by Avellaneda-Torres (2008), which is based on the colorimetric determination at 690 nm of the released ammonia, after incubation with a solution of urea for 2 h, at 37 ºC (Alef & Nannipieri 1995).

The protease activity was determined by using casein as substrate, after incubation for 2 h at 50 ºC and pH 8.1. In this method, the released amino acids react with the Folin-Ciocalteu reagent in alkaline solution to form a blue complex that is colorimetrically determined (700 nm) (Ladd & Butler 1972).

The acid and alkaline phosphatase activities were quantified by determining the p-nitrophenol that was released after the incubation with p-nitrophenyl phosphate solution for 1 h at 37 ºC (Alef & Nannipieri 1995). The p-nitrophenol was photometrically determined at 400 nm (Tabatabai & Bremner 1969 and Eivazi & Tabatabai 1988, modified by Avellaneda-Torres 2008).

The β-glucosidase activity was determined by quantifying the p-nitrophenol released after the incubation with p-nitrophenyl glucoside solution for 1 h, at 37 ºC. The p-nitrophenol was photometrically determined at 400 nm (Alef & Nannipieri 1995, modified by Avellaneda-Torres 2008). The soil samples collected in order to determine their enzymatic activity were transported in the shortest time possible at 4 ºC, until storage at -20 ºC in the laboratory. The determination of the enzymatic activities was carried out from the previously stored wet soil. Enzymatic activities were expressed by g of dry soil, determined from the gravimetric humidity of the soils at the time of analysis.

The enzymatic activities were related to the resilience scores of the climate variability of the agroecosystems under study. These scores were obtained from previous reports generated by Córdoba & León (2013), which indicated the biophysical and cultural characteristics that determine the resilience to the climate variability of the aforementioned agroecosystems. These authors carried out evaluations in a scale from 1 to 5, drawn from 62 guidelines: 4 of the physical type, 5 related to soils, 4 to soil management, 8 to water management, 9 of biological diversity, 13 of social aspects, 7 related to economic aspects, 6 to institutional aspects, 3 of political aspects and 3 of technological level.

The relationships among data of soil enzymatic activities and resilience scores of climatic variability associated to the assessed agroecosystems were determined by multivariate analysis tools.

Normality and homoscedasticity tests were applied by using the Shapiro Wilk and Barttlet tests, respectively. Additionally, an average-to-average comparison was performed, by using the Wilcoxon and t-Student tests. To establish the relationships among physicochemical proprieties, enzymatic activities and biophysical and cultural characteristics that determine resilience to the climatic variability, canonical ordinations based on principal coordinates analysis were used (Anderson & Willis 2003). For the analyses, the package Permanova for Primer v6 software was used (Clarke & Warwick 2001, Anderson et al. 2008).

RESULTS AND DISCUSSION

There were statistically significant differences ($p < 0.05$) associated to the soil managements for the following physicochemical proprieties: percentage of organic carbon, content of nitrogen in the soil and available boron. The means for this variables were higher in the ecological management, if compared with the conventional one (Table 2).

All agroecosystems showed percentages of organic carbon above 5 %, which can be considered very high organic carbon soils. The higher organic carbon content in the ecological farms may be related to the adopted soil conservation practices, such as weed management, use of slurry, composting, soil cover and zero tillage. These practices bring benefits such as a lower carbon expenditure by respiration and a greater immobilization in biomass, as well as the superficial accumulation of organic matter, among others (Sánchez de Prager et al. 2012). In this regard, it has been reported that the no-tillage increases the soil organic carbon values. Different types of management, such as fertilization and the use of pesticides, may affect the carbon storage (Roldán et al. 2005). This could explain the lower organic carbon content for the conventional sites (Ernani et al. 2001).

The soil organic carbon content did not change with the sampling periods (Table 2), probably because the biodiversity in these agroecosystems becomes important facing adverse effects of climate variations, making them more resilient to this changes (Varela 2010).

Table 2. Soil physicochemical proprieties assessed in ecological and conventional coffee agroecosystems, with sampling in two growing seasons.

Soil propriety	Unit	Management		Season	
		Ecological	Conventional	Rainy	Dry
Moisture	%	37.25 a[1]	45.11 a	41.74 a	40.61 a
Bulk density	kg m^{-3}	1.031 a	1.037 a	1.035 a	1.033 a
Plasticity index	-	11.23 a	13.10 a	14.01 a	10.32 a
pH (water 1:1)	-	5.95 a	5.70 a	5.80 a	5.85 a
Organic carbon	%	7.99 a	5.09 b	6.37 a	6.72 a
N	%	0.69 a	0.44 b	0.55 a	0.58 a
Al	cmol kg^{-1}	0.05 a	0.19 a	0.05 a	0.19 a
P	mg kg^{-1}	51.81 a	51.36 a	52.46 a	51.77 a
ECEC[2]	cmol kg^{-1}	26.28 a	25.08 a	24.67 a	26.70 a
Ca		19.357 a	18.233 a	17.657 a	19.933 a
K		0.927 a	1.027 a	0.963 a	0.990 a
Mg		5.875 a	5.537 a	5.905 a	5.507 a
Na		0.070 a	0.093 a	0.085 a	0.078 b
Cu	mg kg^{-1}	2.38 a	2.10 a	2.50 a	1.98 a
Fe		106.17 a	129.05 a	130.63 a	104.58 a
Mn		11.71 a	12.70 a	12.55 a	11.85 a
Zn		16.52 a	9.60 a	12.74 a	13.38 a
B		0.80 a	0.55 b	0.68 a	0.67 a

[1] Means followed by the same letter do not have a significant statistical difference by the t-Student test at 5 % of probability (the comparisons are only between cropping managements and between growing seasons). [2] ECEC: effective cation exchange capacity.

The content of nitrogen (N) differed statistically between the management systems, being also higher in the ecologically managed sites (Table 2). It was found that, in general, the means of this variable for the six sites were greater than 0.3 % of N, what places them as having a very high N content. The greater N content in the soil of the ecological agrosystem is consistent with the organic carbon content for the same agroecosystem. Furthermore, the lower N content in conventional sites may be related to practices such as the application of agrochemicals, which exerts a selective pressure on microorganisms, which, over time, can modify the physicochemical and biological characteristics of the soil (Manna & Singh 2001). Environmental factors such as the content of organic matter and the availability of energy sources and other nutrients, as well as the presence of growth factors such as moisture, temperature, pH, redox potential and soil structure, may affect the ecology, activity and dynamics of the soil microbial community (Nannipieri et al. 2003).

The urease activity was statistically higher in the soil under ecological management, if compared with the conventional one (Table 3). This would indicate that the conventional management practices are decreasing the activity of urease, corroborating Dick et al. (1988), who showed that the urease and amidase activities decreased with the increasing application of ammonia-based fertilizers in a conventional soil management. The addition of the final product of the enzymatic reaction (NH_4^+) decreased the activity of the enzymes (Bandick & Dick 1999).

The increased activity of urease under ecological management may be due to soil conservation practices, such as the use of organic fertilizers and permanent coverage, that result in a better functioning of the nitrogen cycle in the soil. These results have been observed when conservation tillage and conventional tillage are compared, confirming that tillage practices allow for a greater activity of urease throughout the crop cycle, due to the content of organic matter that favors the maintenance of this activity in the soil (Contreras et al. 2005).

Statistically significant differences were also found in the urease activity between sampling seasons (Table 3), being higher in the dry season, when compared with the rainy season. This may be related to the influence of water content, temperature, pH and buffer capacity, cation exchange capacity and nitrogen compounds (Salamanca 2008).

The protease activity did not show statistically significant differences between the management systems (Table 3). The same result can be observed regarding the effect of the climate condition at the sampling seasons on the protease activity.

The acid and alkaline phosphatase activities showed statistically significant differences between the management systems, being greater under the ecological management, if compared with the conventional one (Table 3). These results coincide with those reported by Oberson et al. (1996), who found that the activity of the acid phosphatases was higher in soils under ecological and biodynamic cultivation than in the conventionally managed ones. They argued that the incorporation of organic matter into the soil increases the mineralization of organic phosphorus, thus promoting the P biogeochemical cycle. They also observed that the activity of acid phosphatase was higher in soils covered in prairie with high organic matter contents, both in the rainy and dry seasons. In addition, the acid phosphatase activity is stimulated by the soil microbial activity, amount of substrates that are available, soil moisture (Gálviz et al. 2007), crops, management practices and production systems. The positive impact of the organic production on alkaline phosphatase

Table 3. Enzymatic activities of soils under ecological and conventional coffee agroecosystems with sampling in two growing seasons.

Enzymatic activity	Unit	Management		Season	
		Ecological	Conventional	Rainy	Dry
Urease	μg N g^{-1} $(2\ h)^{-1}$	21,798 a	16,379 b	13,725 a	24,452 b
Protease	μg tyr g^{-1} $(2\ h)^{-1}$	72 a	61 a	71 a	62 a
Acid phosphatase	μg pNP g^{-1} h^{-1}	1,049 a	783 b	694 a	1,139 b
Alkaline phosphatase	μg pNP g^{-1} h^{-1}	795 a	370 b	237 a	928 b
ß-glucosidase	μg pNP g^{-1} h^{-1}	785 a	492 b	554 a	723 a

[1] Means followed by the same letter do not have a significant statistical difference by the t-Student test at 5 % of probability (the comparisons are only between cropping managements and between growing seasons).

(compared to the conventional production), or the application of organic products in the fertilization of crops, has also been demonstrated by Quenum (2010).

The lower activity of phosphatases under conventional systems could be related to the higher availability of phosphorous. Considering that enzymatic activities, especially phosphatases, are inhibited when exposed to a high availability of labile P, the fertilization practices, especially with P fertilizers, could suppress the secretion of enzymes involved in the mineralization of organic P in the long term (Zamora et al. 2005).

Acid and alkaline phosphatases also showed statistically significant differences between seasons (Table 3), generating a greater activity of this enzyme in the dry season, if compared with the rainy one. This indicates that, with a decrease in the rainfall, the ecological management favors the biogeochemical cycle of phosphorus. A similar study by Yoshioka et al. (2006) differs from the results obtained, reporting a greater activity of the alkaline phosphatase in the conventional management, and a lower one for the traditional and organic managements. This was associated with the greater activity of microorganisms as an energy expenditure, since the behavior of this enzyme is related to the activity of soil bacteria and fungi (Criquet et al. 2004, Dick 1997), what leads to an accelerated metabolism that is reflected in the enzymatic activity (Sánchez de Prager 2003). A higher rate of residues input brings with it a greater development of microorganisms and, therefore, a higher production of enzymes (Bandick & Dick 1999).

Similarly to the urease and phosphatases, the ß-glucosidase activity was statistically higher in the soils under ecological management, when compared with the conventional one (Table 3). This may be due to the fact that the enzymatic activities and microorganisms that secrete them are sensitive to the application of herbicides (Alvear et al. 2006), and that the microorganisms reduce the enzyme production rate under excess of inorganic fertilizers (González-Prieto & Carballas 1995). These results are similar to those reported by Ochoa et al. (2007), who found a greater activity of dehydrogenase, β-glucosidase and arylsulfatase in the soil where there was a minimal tillage, if compared with the conventional tillage.

The activity of ß-glucosidase, however, was not statistically influenced by the growing seasons. This may be due to the fact that, in these agroecosystems, in general, peasant practices are used, such as polycrop and cover; therefore, the mulching of the soil surface reduces temperature oscillations, keeping it cool, maintaining the soil moisture during hot and dry seasons and promoting a microbial activity and crop development (Albiach et al. 2006).

Figure 1 shows an important grouping, in relation to the management systems, confirming the results from the univariate analysis (Table 3). Thus, the use of organic inputs and permanent coverage are benefiting the activity of the hydrolytic enzymes and favoring the recycling of carbon and nutrients in these soils.

The agricultural management influences the soil microorganisms and microbial processes due to changes in the quantity and quality of plant residues that enter the soil, their spatial distribution, changes in the supply of nutrients and physical changes (Christensen 1996). On the other hand, conventional agroecosystems, in general, tend to contrast with ecological agroecosystems. Conventional management practices, such as the use of pesticides, herbicides and synthetic fertilizers, are inhibiting the enzymatic activities in the aforementioned agroecosystems; and such indicators of soil quality may help to predict early changes caused by

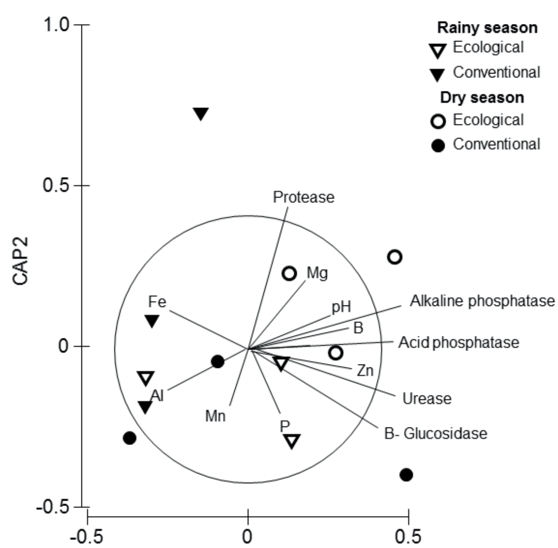

Figure 1. Canonical analysis of the principal coordinates, based on enzymatic activities and physicochemical proprieties of soils, under ecological (organic) or conventional management, in two growing seasons of the coffee agroecosystems.

agricultural practices. As some researchers indicate, agrochemicals can produce negative environmental impacts on ecosystems (Norgaard & Sikor 1995). Conventional agriculture causes the reduction of soil fertility and compaction and a decrease of the organic matter and the biodiversity associated with it, such as microorganisms responsible for the production of soil enzymes (Rosset 1997).

Enzymatic activities of the ecological agroecosystems are related to higher levels of magnesium, pH, boron, zinc and phosphorus, indicating that these soil characteristics favor enzymatic activities in those sites; while the conventional agroecosystems are correlated with iron, interchangeable acidity and manganese (Figure 1).

The sampling period was another important grouping criterion, since there was a trend for clustering in the dry season, in agreement with the univariate analysis (Table 3), which showed statistically significantly higher enzymatic activities in the drought. Thus, the biochemical indicators are sensitive to climate variability, and are favored by low rainfall and high temperatures.

The enzymatic activities of ecological management are correlated with the variables that refer to the non-purchase of inputs, what means that the fact of not acquiring or relying on these external inputs gave them a high score, in terms of resilience (Figure 2). Likewise, variables such as the non-use of pesticides and herbicides, non-dependence on pesticides and use of external fertilizers, which are also correlated with the enzymatic activities of the ecological management, suggest that the non-use of chemical synthesis products improves the resilience scores of the agroecosystems and favors their soil enzymatic activities.

The enzymatic activities of the ecological agroecosystems were related to the fact that the respective farmers belong to some type of organization, what may be positively influencing other variables that increase its resilience scores, such as the use of soil conservation practices, weed management, farmers' knowledge about pollination, microorganisms in general and nitrogen-fixing microorganisms, which are closely related to the high content of nitrogenous substrates and the origin of organic material. Similarly, the low presence of pests in these agroecosystems is due to the fact that farmers use the biodiversity as a management strategy for insects and disease agents, which favors high enzymatic activities and resilience scores of the ecosystem.

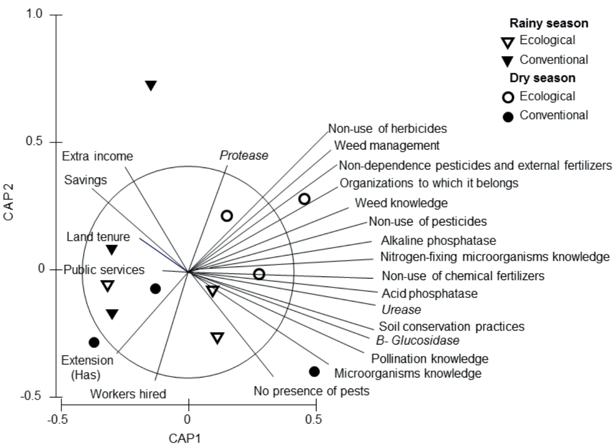

Figure 2. Canonical analysis of the principal coordinates based on soil enzymatic activities and resilience scores of agroecosystems, under ecological and conventional management, in two growing seasons of coffee plantations.

The enzymatic activities of the conventional agroecosystems showed a relation with the variables savings and extra income, since the respective peasants may have higher incomes from their crops, if compared to those normally obtained from the ecological ones. The relation of the ecological agroecosystems with a higher percentage of workers that have been hired in these sites may be linked to the need for fertilization and soil tillage.

CONCLUSIONS

1. The enzymatic activities are modified by the management systems, and these are specifically favored by the ecological management. Hence, in the long term, this agroecosystem ensures an efficient use of the soil resources with a lower degradation and contamination;
2. Urease, acid and alkaline phosphatase activities are sensitive to climate variability, and are favored by low rainfall and high temperatures;
3. The resilience scores to climate variability that showed the highest correlations with the enzymatic activities and with the ecological agroecosystems were the farmers' knowledge of soil microorganisms, non-use of pesticides and synthetic fertilizers, non-dependence on external inputs, use of soil conservation practices and belonging to some peasant organization.

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