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Edaphic indicators after the conversion of a grassland area into agroecological systems

Guillermina Hernández-Vigoa†, Grisel de la Caridad Cabrera-Dávila, Irma Izquierdo-Brito, Ana América Socarrás-Rivero, Luis Hernández-Martínez and Jorge Alberto Sánchez-Rendón

Instituto de Ecología y Sistemática; Ministerio de Ciencia, Tecnología y Medio Ambiente
Carretera de Varona 11835, Calabazar, Boyeros, La Habana 19, CP 11900, Cuba
Corresponding author: grisel17@ecologia.cu

Abstract

The objective of the study was to evaluate the conversion of a grassland area into a forage and a polycrop area with the application of agroecological methods, through different soil biological, physical and chemical variables, in a farm with animal husbandry-agriculture integration in the Cangrejeras locality –Artemisa province, Cuba–. The total macrofauna and mesofauna; functional groups of epigeal, anecic and endogeal species of the macrofauna; oribatids, uropodines and gamasines of the mesofauna; underground phytomass; hydrosoluble carbon content; microbial biomass; activity of the dehydrogenase and acid phosphatase enzymes; total organic carbon; percentage of stable aggregates and apparent soil density, were studied. The relation among the variables and their contribution to the grassland conversion were explored by the principal component analysis. From the 16 evaluated variables, only nine (epigeal and endogeal macrofauna, oribatid and uropodine mesofauna, total organic carbon and hydrosoluble carbon, acid phosphatase enzyme, percentage of aggregates and apparent soil density) were recommended for the integral analysis of soil quality and of the impact of the land use change. The integrated analysis of all the variables, according to their correlations and the system arrangement, showed that the conversion from grassland to forage was a favorable agroecological practice for the conservation of soil quality and sustainable soil use; while crop sowing and rotation (polycropping) affected quality.

Keywords: exploitation systems, soil conservation, soil fauna.

Introduction

In order to evaluate the soil health status and productive capacity biological, physical and chemical variables are used, acknowledged as indicators of soil quality (Bastida *et al*., 2008). Among the biological variables, edaphic biodiversity plays a significant role in the regulation of the important services of ecosystems and in the complexity of the food chain in the soil, for which the use of organisms is essential to monitor its functions and conditions (De Vries *et al*., 2013).

In Cuba, the use of edaphic indicators has been aimed mainly at learning the effect of the disturbances caused by different soil uses and managements, which include organic agriculture and rehabilitation of degraded or contaminated soils (Alguacil *et al*., 2012; Socarrás-Rivero and Izquierdo-Brito, 2014). However, it is known that the selection of these indicators and their application is difficult, due to the natural diversity and high spatial-temporary heterogeneity of the soil properties; as well as to the number and complexity of edaphic processes, especially the biological ones (Bastida *et al*., 2008). In Cuba, most of the results have shown high variability, caused by seasonality, soil type, and land use.

Based on these results, the need of an integral analysis of the studied variables to search for generalizations (or patterns) with the use of edaphic indicators, was identified. For such analysis, some results of the project «Evaluation of agroecological methods through the use of bioindicators of the soil conservation status», which was carried out to determine the impact produced by the conversion of a grassland area into agroecological systems (Izquierdo-Brito *et al*., 2004), were used. The objective of this study was to evaluate the transformation of grassland into an area of forage and another one of polycrop applying agroecological methods, through different biological, physical and chemical variables of the soil; as well as to suggest the most relevant variables for indicating soil quality and impact of land management.

Materials and Methods

Study location. The study was conducted in an agroecological farm in the Cangrejeras locality (23º 02' W, 82º 31' N), Artemisa province, Cuba. The climate of the region is humid subtropical, with mean annual temperature of 24,6 ºC and total annual rainfall of 1 300 mm, mainly distributed from May to October. The soil in these areas corresponds to the genetic type Ferralitic Red, according to the criteria exposed in the classification of Cuban soils (Hernández-Jiménez *et al*., 2015).

Evaluated areas. The experimental sites started from a grassland area cultivated for more than 20 years, in which one part was turned into a forage production field and the other one to polycrop, of 1 000 and 500 m^2, respectively. A remnant site of 1 000 m^2 was preserved as grassland (control). The more detailed analysis of the experimental design was described by Izquierdo-Brito *et al*. (2003).

To the grassland (G), referred as control, no organic amendments were applied, and its stocking rate was low (below 2,0 LAU ha^{-1}). In the plant community *Megathyrsus maximus* Jacq., *Cynodon nlemfuensis* Vanderhyst and *Teramnus uncinatus* (L.) Sw. prevailed, and the yield in this area was 11 t ha^{-1} of dry matter (DM).

The forage area (F) was sown with *Saccharum officinarum* L., *Pennisetum* sp. and *Leucaena leucocephala* (Lam.) de Wit. This system was aimed at the practice of silvopastoralism with a stocking rate similar to that of the grassland, and cutting was also applied in order to supply forage for cattle. The agricultural yield obtained was 16,5 t ha^{-1} DM. Thus, for the grassland as well as the forage area, the yields reached responded to the feeding plans for cattle in the farm.

In the polycrop (C), short-cycle crops were combined with long-cycle crops in a 30:70 ratio. The short-cycle crops included: cassava (*Manihot esculenta* Crantz.), beans (*Phaseolus vulgaris* L.), squash (*Cucurbita pepo* L.), tomato (*Solanum lycopersicum* L.), papaya (*Carica papaya* L.) and spinach (*Spinacia oleracea* L.); and among the long-cycle ones: plantains (*Musa paradisiaca* L.), grapefruit (*Citrus paradisi* Macf.), bitter orange (*Citrus aurantium* L.) and cherimoya (*Annona reticulata* L.). The short-cycle crops were subject to a rotation system in which tomato-beans, papaya-cassava, beans-cassava, spinach-tomato and squash-beans were associated. The yields of the main crops were (t ha^{-1} of fruits): *P. vulgaris*: 1,2; *C. pepo*: 16,9; *S. lycopersicum*: 11,4; *M. paradisiaca*: 141,7; *C. paradisi*: 24,5; *C. aurantium*: 4,3; *A. reticulata*: 1,8; which were within the conceived food production plans.

In the forage and polycrop areas organic fertilizer (compost, earthworm humus and harvest waste) was applied, before sowing, at a rate of 4,0-5,6 t ha^{-1}, respectively. Eight years after the establishment of the systems, the physical, chemical and biological indicators were evaluated during a year, in the rainy and dry seasons.

Biological variables. The soil macrofauna (invertebrates larger than 2 mm of diameter) was sampled according to the methodology of the international program *«Tropical Soil Biology and Fertility»* or TSBF (Anderson and Ingram, 1993), which consisted in the *in situ* revision of four soil monoliths of 25 x 25 x 3 cm for each evaluated system. To sample the mesofauna (invertebrates between 0,2 and 2,0 mm diameter) five soil samples were taken in each area, using a cylinder of 5 cm diameter and 10 cm depth. In the laboratory the edaphic mesofauna was extracted with Tullgren funnels, without heat source during seven days. The macrofauna and mesofauna were identified to the family level, with the aid of different specialists, the review of taxonomic works and the consultation of the entomological collection located in the Institute of Ecology and Systematics –Havana, Cuba.

From a functional point of view, the macrofauna was separated into: epigeal organisms, including those invertebrates that live on the surface and the soil litter with mainly detritivorous trophic habit, such as millipedes, snails, woodlice, among others; anecic organisms, which live partly in the soil and are essentially constituted by termites and ants; and endogeal organisms, which permanently reside in the soil and include earthworms and some beetles (Lavelle, 1997). For the mesofauna, only oribatids and uropodines, as detritivorous groups, and gamasines, as predator organisms, were taken into consideration, all susceptible to the organic matter quality and to moisture and, thus, indicators of the fertility and stability of the edaphic medium (Socarrás-Rivero, 1999).

In the case of the macrofauna biomass values based on humid weight in the preserving solution (formaldehyde 4 % + alcohol 80 %) were estimated. The biomass was chosen because it shows directly the function of macrofauna in the transformation of the soil physical properties (Barbault, 1992). For the mesofauna the density values (ind.m^{-2}) were calculated, from the number of individuals. The biomass as well as density was calculated for the total fauna and for the different functional groups.

The estimation of the underground phytomass in the pastureland was done by randomly extracting three soil samples of 0-10 cm of depth in each area, with a cylinder of 5 cm diameter. Afterwards, the material was dried in stove at 105 ºC, for determining total underground phytomass by gravimetric analysis.

The other biological variables and the physical-chemical ones were randomly evaluated in five soil samples, composed by six subsamples of 0-10 cm depth in each area, with a 150-cm^3 cylinder; the full procedure was described by Izquierdo-Brito *et al*. (2003; 2004). Likewise, the activity of the dehydrogenase and phosphatase enzymes, hydrosoluble carbon and carbon from the microbial biomass were determined, through the methodologies described by Izquierdo-Brito *et al*. (2003).

Physical-chemical variables. The total organic carbon, percentage of aggregate stability and apparent density were determined by the methodologies described in the TSBF (Anderson and Ingram, 1993).

Data analysis. The relations that were established among the biological, physical and chemical properties of the soil and their contribution to the essay, as a result of the transformation of the grassland into agroecological systems (forage and polycrop), were explored through a principal component analysis (PCA) performed by the program PAST version 3.11 (Hammer, 2015). The variables used were: total edaphic macrofauna (MAC); epigeal (EPI), endogeal (END) and anecic organisms (ANEC) of the macrofauna; total edaphic mesofauna (MES); oribatids (ORIB), uropodines (URO) and gamasines (GAM) belonging to the mesofauna; underground phytomass (UP); total organic carbon (TOC); water soluble carbon (SC); microbial biomass carbon (CBIO); activities of the enzymes phosphatase (PA) and dehydrogenase (DA); apparent density (AD) and aggregate stability (AS). The PCA was made from a correlation matrix, and the significance of the variables was specified through the internal correlation circle proposed by Fariñas (1996). This was defined by the values of r (correlation coefficient) for the sample size [(combination of plots x seasons) (n = 24) minus 2 (n – 2) (degrees of freedom)]. Thus, every vector that was outside the internal circle showed significant correlation (p < 0,05). The PCA also served to determine how the studied sites were interrelated and grouped depending on the response of the edaphic variables. For such purpose, the dual graph or biplot was constructed.

Results and Discussion

Biological, physical and chemical variables. Most of the studied edaphic variables (10) showed higher values in the grassland and forage areas, in the dry as well as the rainy seasons (table 1). The total and endogeal macrofauna followed this pattern, although the total one did not keep it in the rainy season, because its highest values were manifested in the forage and the polycrop and not in the grassland. The endogeal macrofauna was represented by earthworms, which commonly showed high biomass in the grassland ecosystems, which coincides with the findings by Lavelle (1997), Bartz *et al*. (2013) and Chávez-Suárez *et al*. (2016). Within the macrofauna, the epigeal and anecic organisms were favored with the forage and polycrop management, especially during the rainy season. Both functional groups mainly have detritivorous function and, thus, could have been benefitted by the input and quality of the litter from leucaena and the different crops in these systems (Cabrera-Dávila *et al*., 2007).

In the case of the mesofauna, it was proven that the agricultural practices that characterized the grassland and forage areas positively contributed in total abundance and in the abundance of the different edaphic microarthropods that compose it, during the two seasons (table 1). Such result shows the influence of the higher stability in management, of root density and of the direct contribution of cattle dejections on these areas, which served as stimulation in the establishment of the mesofauna (Sánchez-de-Prager *et al*., 2015; Socarrás-Rivero and Izquierdo-Brito, 2016).

Regarding the underground phytomass, it was higher during the dry season in the three studied sites, mainly in the grassland; while the lowest values were obtained during the rainy season (table 1). The distribution pattern of the underground phytomass, inverse with regards to the aerial one depending on seasonality, has been frequently found in grassland ecosystems, and explains the strategies of resource allocation of the plant, which concentrates or transfers its reserves to the underground organs (roots and rhizomes) during the senescence period until spring or the onset of rains, when the regrowth of aerial components occurs (Hernández and Sánchez, 2012).

This behavior of root biomass distribution has been observed in many studies which involve plants from temperate and tropical regions (Tomlinson *et al*., 2012), and it is stated that the distribution of more biomass to the roots is mainly due to mechanisms of morphological adjustments that increase the water and nutrient absorption capacity, probably in association with the mycorrhizae (Sánchez *et al*., 2011; Herrera-Peraza *et al*., 2016). Hernández and Sánchez (2012), in a study about the dynamics of soil moisture and the phytomass of fine roots

Table 1. Mean values (± SD) for the edaphic variables in the grassland (G), forage (F) and polycrop (C) areas.

Edaphic variable	Dry season			Rainy season		
	G	F	C	G	F	C
Total macrofauna (gm^{-2})	23,9 (23,0)	36,2 (21,6)	6,8 (5,1)	33,2 (11,0)	66,9 (16,5)	62,8 (53,6)
Epigeal macrofauna (gm^{-2})	2,5 (2,1)	26,3 (22,9)	3,1 (4,3)	4,5 (6,8)	49,8 (21,5)	54,4 (45,6)
Anecic macrofauna (gm^{-2})	0,58 (0,7)	0,49 (0,3)	0,49 (0,2)	0,83 (0,5)	0,49 (0,2)	1,77 (1,0)
Endogeal macrofauna (gm^{-2})	20,8 (20,9)	9,4 (1,7)	3,2 (3,5)	27,9 (17,3)	16,6 (5,0)	6,6 (7,8)
Total mesofauna ($ind.m^{-2}$)	82 449 (4 293,7)	100 563 (3 576,6)	59 322 (1 295,9)	111 980 (8 272,2)	140 993 (10 314,5)	52 427 (2 338,6)
Mesofauna-oribatids ($ind.m^{-2}$)	22 896 (798,4)	31 896 (1 648,7)	7 747 (361,7)	41 229 (4 850,2)	49 882 (3 073,9)	8 144 (906,4)
Mesofauna-uropodines ($ind.m^{-2}$)	2 545,4 (401,9)	5 090,1 (269,9)	1 527,0 (33,85)	12 725 (551,3)	15 270 (759,5)	5 090,1 (358,2)
Mesofauna-gamasines ($ind.m^{-2}$)	18 833 (1 812,9)	23 991 (917,2)	15 042 (628,8)	29 522 (3 053,0)	37 666 (1 982,1)	14 252 (768,4)
Underground phytomass (gm^{-2})	1 962,2 (52,7)	1 078,1 (9,9)	277,3 (3,8)	1 298,2 (12,3)	749,3 (13,8)	156,0 (4,6)
Total organic carbon ($g\ kg^{-1}$)	26,1 (0,02)	21,1 (0,02)	20,1 (0,03)	27,6 (0,01)	20,1 (0,01)	21,2 (0,02)
Water soluble carbon ($\mu g\ g^{-1}$)	246 (3,6)	164 (2,4)	135 (2,3)	284 (3,2)	206 (5,6)	151 (2,5)
Microbial biomass ($\mu g\ g^{-1}$)	546 (12,0)	466 (13,9)	438 (22,5)	690 (17,2)	488 (9,6)	464 (6,2)
Dehydrogenase enzyme (μg INTF g^{-1})	79 (0,1)	26 (0,7)	22 (1,7)	45 (0,8)	32 (1,0)	16 (1,2)
Acid phosphatase enzyme (μmol PNP $g^{-1}h^{-1}$)	3,0 (0,01)	2,70 (0,01)	1,75 (0,02)	2,00 (0,01)	1,57 (0,02)	1,33 (0,03)
Aggregate stability (%)	86,1 (1,9)	80,5 (1,3)	82,3 (1,8)	87,6 (1,6)	86,6 (0,8)	67,6 (2,4)
Apparent density ($mg\ m^{-3}$)	1,26 (0,01)	1,33 (0,04)	1,37 (0,02)	1,28 (0,01)	1,3 (0,01)	1,36 (0,05)

G-grassland, F- forage, C- polycrop

(< 1,0 mm), in seven ecosystems with different soil conditions and vegetation types in the Sierra del Rosario Biosphere Reserve –Cuba–, found that the underground phytomass changed with the seasons and that the highest values were found in the microphyllus forest, where the soil moisture was lower.

The concentrations of total organic carbon and water soluble carbon were higher in the grassland area with regards to the forage and the polycrop areas, in both seasons (table 1). This result was associated with a higher input of root exudates and a lower organic matter mineralization rate, compared with the forage and the polycrop, which were not compensated by the permanence of organic remains from the agroecological management or by the addition of compost (Izquierdo-Brito *et al*., 2003).

The microbial biomass and the activity of the enzyme acid phosphatase were also higher in the grassland compared with the forage and polycrop areas, in both seasons; nevertheless, the phosphatase activity in the latter in the rainy season did not vary considerably with regards to the forage area. Likewise, the activity of the enzyme dehydrogenase, an oxidoreductase which is present only in living cells (Dick, 2011), was higher in the grassland in both seasons and in the forage area in the rainy season (table 1). According to Bardgett (2005), the biological and biochemical activity can be affected by the physical properties of the soil, particularly by the structural stability.

In fact, the best structural stability was found in the grassland and forage areas in the rainy season, with regards to the polycrop area, which can be related to the increase of the fraction of water soluble carbon (Izquierdo-Brito *et al.*, 2003). The roots and the decomposition of crop waste are an important part for the formation of macroaggregates, a dynamic process that can be modified by any change in the source of labile organic matter (Gupta-Vadakattu *et al.*, 2006).

Lastly, the apparent density was another variable that influenced the biological activity (Izquierdo-Brito *et al.*, 2003), because the lowest and optimum values, which show higher soil quality, were obtained in the grassland and forage areas in the rainy and the dry season, compared with the polycrop where the higher values were found, compaction indicators (table 1).

Integrated analysis of the variables. The principal component analysis of the biological, physical and chemical variables allowed to know the correlations that were established between them and their contribution, according to the impact produced by the conversion of the area from grassland to forage and polycrop and the seasonality. In general, all the variables, except the mesofauna gamasines (GAM), played a significant role ($p < 0,05$) in the study, according to the internal correlation circle proposed by Fariñas (1996), which in the first bidimensional plane explained between the first two components more than 55 % of the total variation of the data (fig. 1).

A set of vectors that were correlated among themselves and negatively with axis 1 was observed, represented by the variables MAC, EPI, END, MES, ORI and URO, TOC, SC, CBIO, AS, UF, PA and DA. To this group of vectors the variables AD and ANE were opposed, which were positively correlated with the first axis; while MAC and EPI were positively correlated with axis 2. The performance of the last two variables was independent from that of variables URO, SC, TOC, AS, MES and END (fig. 1).

The macrofauna groups functionally defined by EPI and ANE are organisms that feed from litter, for which they are related to the possibility of

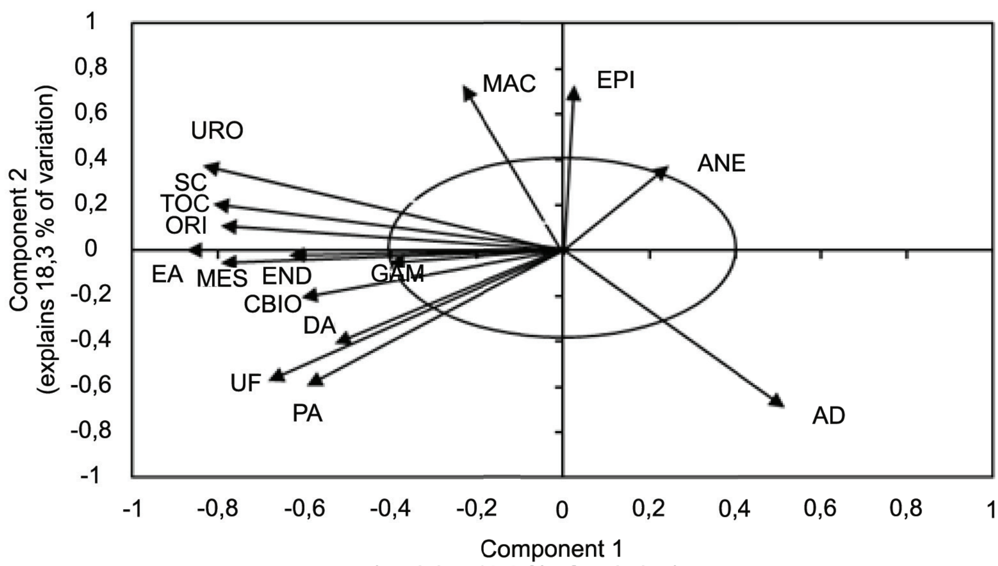

Figure 1. Arrangement of the variables in the first bidimensional plane. Symbology: MAC (edaphic macrofauna), EPI (epigeal organisms), ANE (anecic), END (endogeal species), MES (soil mesofauna), ORI (oribatids), URO (uropodines), GAM (gamasines), TOC (total organic carbon), SC (water soluble carbon), CBIO (carbon of the microbial biomass) AS (aggregate stability), AD (apparent density), UF (total underground phytomass), PA (phosphatase activity), DA (dehydrogenase activity). The vector corresponding to each variable indicates the direction in which they increase, and the correlation circle indicates the value from which they are significant.

exploitation of surface food sources and act in the processing or initial transformation of organic matter (Lavelle, 1997). On the other hand, END, constituted by earthworms, are more involved with the physical conditions of the soil, aspect that has been corroborated by their positive correlation with most of the studied variables (fig. 1). Hence the vectorial opposition of the apparent density and the total macrofauna found in this study was more related with the presence of END organisms that with EPI and ANE, because of the changes produced fundamentally by the in the physical structure of the soil. Different authors, such as Vasconcellos *et al.* (2013), Gutiérrez and Cardona (2014) and Souza *et al.* (2016), enumerater the effects of earthworm communities on soil porosity, water infiltration and aggregation; at the same time they are known to stimulate considerably the microbial biomass and biological activity, especially the phosphatase activity of the soil.

On the other hand, the influence exerted by the UF on the development and activity of the edaphic biota is known, as in the case of some groups that compose the soil mesofauna, which find in root exudates a source of food and energy, as well as shelter against disturbance conditions (Siddiky *et al*., 2012; Genoy *et al*., 2013). The presence of certain mesofauna groups, such as ORI and URO associated to the higher contents of organic matter in the soil, mainly to total organic carbon and water soluble carbon, shows the importance of their function in decomposition and nutrient recycling (Bedano, 2012; Peredo *et al*., 2012). In addition, pH, organic carbon, total nitrogen and other nutrients can influence the mesofauna and macrofauna communities of the soil (Moreira *et al*, 2012; Schon *et al*. 2012).

The organic carbon of the soil, released by the roots, promotes the activity and establishment of a thicker microbial community near the roots (Picone, 2002). Besides, it can produce increases of this biomass and of the enzymatic activity in the rhizosphere, as occurred in this study with the microbial biomass and the activity of the analyzed enzymes, especially of dehydrogenase in the grassland (table 1).

The biological properties are acknowledged as very sensitive indicators. Especially the enzymatic activity has been used as potential indicator of the soil quality in a broad context, due to the relation with its biological activity, easiness of measurement and fast response to management change (Dick, 2011).

The formation of stable aggregates requires the action of diverse physical, chemical and biological factors. As it was mentioned above, the activity and excrements of macrofauna organisms, especially earthworms and millipedes, can be an important factor in the formation of these organic-mineral complexes. Also the fine roots and microorganisms, which produce a wide range of agglutinating polysaccharides, can bind the soil particles with the fungal hyphae and, literally, sustain the mineral fractions to the organic matter of the soil (Bardgett, 2005). All this explains the correlations among the variables URO, SC, TOC, ORI, AS, MES, END, CBIO, DA, PA and UF (fig. 1).

The variable apparent density, which significantly favored the second component, was negatively correlated with the above-mentioned variables. The AD increases are generally related to the increase of soil compaction, causing pore decrease and gaseous exchange, which in turn hinder water retention and availability and root growth (Kulli-Honauer, 2002). From this its relation with the soil structure is derived and, thus, it constitutes a significant physical indicator to know the impact of a use or use change on its quality.

Within the analyzed indicators, total organic carbon, as main attribute of the soil, is strongly influenced by management. It is a very important indicator in the sustainability of agricultural systems, because it affects the soil properties or quality indicators which have more influence on its sustained yield (Martínez *et al*., 2008).

For the dual analysis with the individuals or surveys per sites and in order to know the influence of the soil use and seasonality, the variables EPI, ANE, END, ORI, URO, UF, SC, PA, AS and AD were selected. Such selection was based on the correlation established among the variables, the axes and agroecological methods used.

The combinations or treatments referred to the soil management type and season defined four groupings determined by the analysis from 1 to 24 (fig. 2). In the first group (polycrop area), with two subgroups: dry season (C-D) and rainy season (C-R), the first subgroup was relatively close to the position where the maximum values of apparent density were obtained (fig. 2), as mentioned above.

The AD increases are associated to the increase of soil compaction, which affects its fundamental properties and its functions. In tropical soils, the transformation processes of their properties, due to the land use change and its subsequent exploitation,

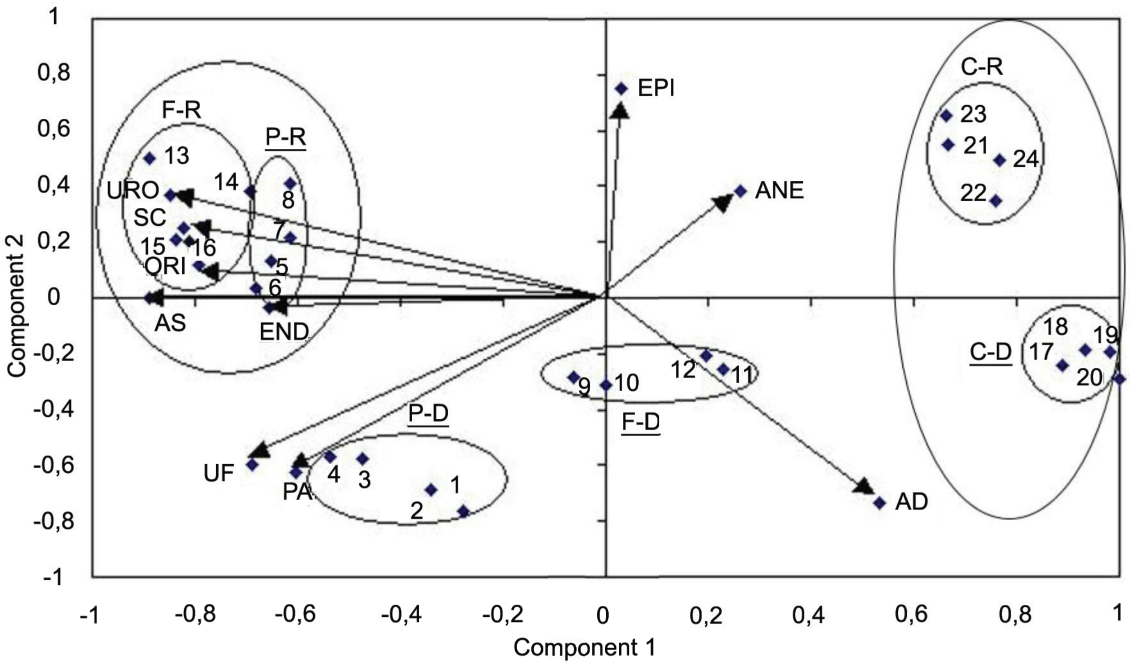

Figure 2. Dual graph of the sites and variables in the first arrangement plane. The vector corresponding to each variable indicates the direction in which they increase. The numbers correspond to the replicas of the treatments (1-4: pasture dry season (P-D), 5-8: pasture rainy season (P-R), 9-12: forage dry season (F-D), 13-16: forage rainy season (F-R), 17-20: polycrop dry season (C-D), 21-24: polycrop rainy season C-R). The groups called C-D and C-R, P-D, F-R and P-R, and F-D represented the groupings, according to the geometric distance of the treatments in the bidimensional space. The meaning of the variables is shown in figure 1.

lead to their degradation, aggregate rupture and loss of their structure (Hernández *et al*., 2009).

In the second subgroup the treatments tended to occupy regions of the space close to where the anecic population increased (fig. 2), defined by some species of ants, which are considered invasive and highly adaptable to conditions of stress and disturbance in the edaphic medium (Cabrera-Dávila, 2012; Cabrera-Dávila *et al*., 2017). These individuals which are congregated in disturbed areas, where disturbances have occurred in the rhizospheric soil linked to the management with crop alternation, are separated or overlapped in the sense in which the maximum values of underground phytomass and activity of the phosphatase enzyme, zone where the second group of individuals from the grassland area in the dry season was placed (fig. 2).

In the grassland area during the dry season a higher development of UF and PA was reached, as well as higher microbial biomass and enzyme activity. The increase of root density and microbial activity benefit the presence of endogeal organisms, particularly of earthworms, which were also more in this system (table 1). In agreement, the highest contribution of earthworm casts was found in the grassland area, with values of 379 g m^{-2}, compared with those recorded in the forage and the polycrop (249,6 and 176,4 g m^{-2}, respectively), and coincides with the report by Izquierdo-Brito *et al*. (2004).

The third group was oriented in the sense in which the variables END, ORI, URO, SC and AS increased, constituted by the combinations of the forage (FR) and grassland areas (GR) in the rainy season (fig. 2). This proved that these uses are favored by the higher and more homogeneous plant cover, for the conditions of higher moisture and accumulation of animal excreta and due to the mean annual contribution of litter in the grassland and forage areas (84,3 and 112,3 g m^{-2}), higher compared with 76,5 g m^{-2} in the polycrop (Izquierdo-Brito *et al*., 2004). As has been stated, especially in the rainy season these systems have the best physical and chemical conditions; for example, the organic and labile carbon sources (table 1) for microbial development, which also constitute the main food source for the edaphic biota, contributing to diversify and increase the edaphic fauna communities and, thus, to improve and preserve soil fertility.

The fourth group stood out because it gathered the variables from the forage area in the dry season (F-D), which are placed near the centroid, with regards to the arrangement of all the variables in the bidimensional space (fig. 2). The position of this group might respond to the moderate values reached by the studied variables, which was determined by the seasonality and subsequent lower soil moisture, as well as by the buffering cover conditions in this system. Such result also shows the influence of seasonality on some variables, described above, in which different responses could be observed for the same use (table 1, fig. 2).

In general, the studied variables allowed an integrated interpretation of soil quality, from its values, correlations and interrelations, as well as from the grouping they generated for the compared systems. Depending on the agroecological methods and the seasonality, higher contributions of organic matter (roots and litter), content of total organic carbon and fractions of hydrosoluble carbon, microbial biomass and enzymatic activity were obtained; as well as an increase of the edaphic fauna communities in the grassland and forage areas, which allowed to maintain the soil structure (better in the forage area than in the grassland). However, the plant cover (more scarce and irregular in the polycrop area), the differences in the characteristics of the root systems of the crops, as well as the disturbance caused by their sowing and rotation propitiated soil compaction and lower structural stability, reduced the microbial biomass and enzymatic activity, and favored the presence of invasive, opportunistic and infertility indicator fauna groups.

Conclusions

It was proven that the utilization of agroecological methods in an integrated agriculture-animal husbandry system, such as planting of forage species, crop rotation and association and addition of organic residues, causes changes in the physical, chemical and biological properties of the soil. The sowing of perennial plants was favorable, because in general they maintain soil quality due to the stability in plant cover and to the association of grasses and legumes; while the intense tillage generated by polycrop planting and rotation reduces it.

Although all the evaluated variables can function as bioindicators of soil quality, the biological variables of the epigeal and endogeal macrofauna, the oribatid and uropodine groups of the mesofauna, hydrosoluble carbon and phosphatase enzyme activity, as well as the physical variables of aggregate stability and apparent density and chemical variable of total organic carbon, are particularly suggested for this analysis, taking into consideration that they are highly susceptible indicators and the ones with faster response, in a very short term, to the effects produced on the soil due to the change and intensity of land use.

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