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Papers

Soil Quality Indicators in Agroecological Systems in the Cerrado of Minas Gerais, Brazil

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Abstract
Soil quality is its ability to function within the limits of the ecosystem and land use to ensure biological productivity, preserve environmental quality, and promote plant and animal health. Thus, the objective of this study was to select soil quality indicators sensitive to different agricultural practices adopted in areas of agroecological systems in the Cerrado of Minas Gerais, Brazil. Soil samples were collected in the 0-20 cm layer, at the end of the dry season, in three different rural properties dedicated to an agroecological system (AS) located in the municipalities of Romaria and Uberlândia, Minas Gerais, Brazil. Ten soil samples were evaluated, five from areas with agroecological management and five from pasture areas as reference. Chemical attributes, microbiota population, microbial biomass carbon (MBC), soil basal respiration (SBR), and activity of beta-glucosidase, phosphatase, and arylsulfatase enzymes were evaluated. The variables basal respiration, beta-glucosidase, pH, and bacterial and actinobacterial colonies were sensitive to different agroecological (AS) and pasture managements, so these variables can be used as indicators of soil quality. The mean values between the ratio of AS and pasture of these indicators were 1.69, 1.20, 3.57 and 2.44, respectively. Agroecological system areas showed a soil with better quality and, possibly, greater activity of its basic functions.

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INTRODUCTION

Agroecology refers to principles of agricultural production practices that improve ecological systems. This includes nutrient recycling, soil improvement and increased interactions between different components. As an example, there may be the integration of animals and crops, planting of other crops, and also increased biodiversity (WACH, 2021). It provides the principles to manage productive agroecosystems and ensure the conservation of natural resources (ALTIERI; KOOHAFKAN, 2008). This practice aims to redesign the food system, encompassing the ecological, economic and social dimensions of sustainability (CIACCIA et al., 2019; WOOD et al., 2015).

Alternative and sustainable agricultural models, such as agroecology, tend to reduce the adverse environmental or social effects of conventional agriculture that negatively affect rural areas (SKRZYPCZYŃSKI et al., 2021). The agroecological movement developed as opposed to the use of agrochemical inputs such as pesticides and inorganic fertilizers, mechanization and monocultures, since these practices deplete soils, reduce biodiversity, pollute watercourses and cause other types of environmental damage (WACH, 2021). The adoption of agroecological systems has been driven mainly by society's demand for healthier foods and for production to result in lower negative environmental impacts (FERREIRA et al., 2017; LIMA et al., 2020). An agroecological perspective links the nutritional value of food to the environmental impacts of food production. This reconnection between ecology and nutrition, which underlies the reconnection between agriculture, environment and food, raises fundamental ethical and ontological questions about our place as humans in the broader system, which, according to ecological theory, emphasizes the interconnection of different species and places humans as just one part of an ecosystem (LAMINE; DAWSON, 2018).

According to Bünemann et al. (2018), soil quality is measured by the soil's ability to function within the boundaries of the ecosystem and land use to ensure biological productivity, preserve environmental quality and promote plant and animal health. The concept of soil quality was developed to enable the evaluation of the condition of a soil under a specific management (SARMIENTO et al., 2018). The relevance of using indicators is linked to the expression of soil functionality, which highlights the deficiencies of the evaluated areas and guides for soil recovery (CAVALCANTE et al., 2020).

Some examples of soil quality indicators are microbial biomass carbon, basal respiration and enzymatic activities, which are important for evaluating the effects of cultivation and land-use changes. In particular, soil microbial biomass and enzymes generally respond more rapidly to the disturbance caused by agricultural practices or changes in environmental conditions compared to other soil variables (RAIESI; BEHESHTI, 2014). In addition to biological and physical indicators, chemical indicators are also used to measure soil quality (ARAÚJO et al., 2012).

This study highlights the most appropriate soil quality indicators to be used in soil quality analyses in the Cerrado biome in the state of Minas Gerais, since there is a wide amount of variables that can be used to this end, but some of them do not generate significant results. Thus, the objective of this study was to select soil quality indicators for agroecological systems of family farming in the Brazilian Cerrado, in the municipalities of Uberlândia and Romaria.

MATERIAL AND METHODS

Characterization of the study area

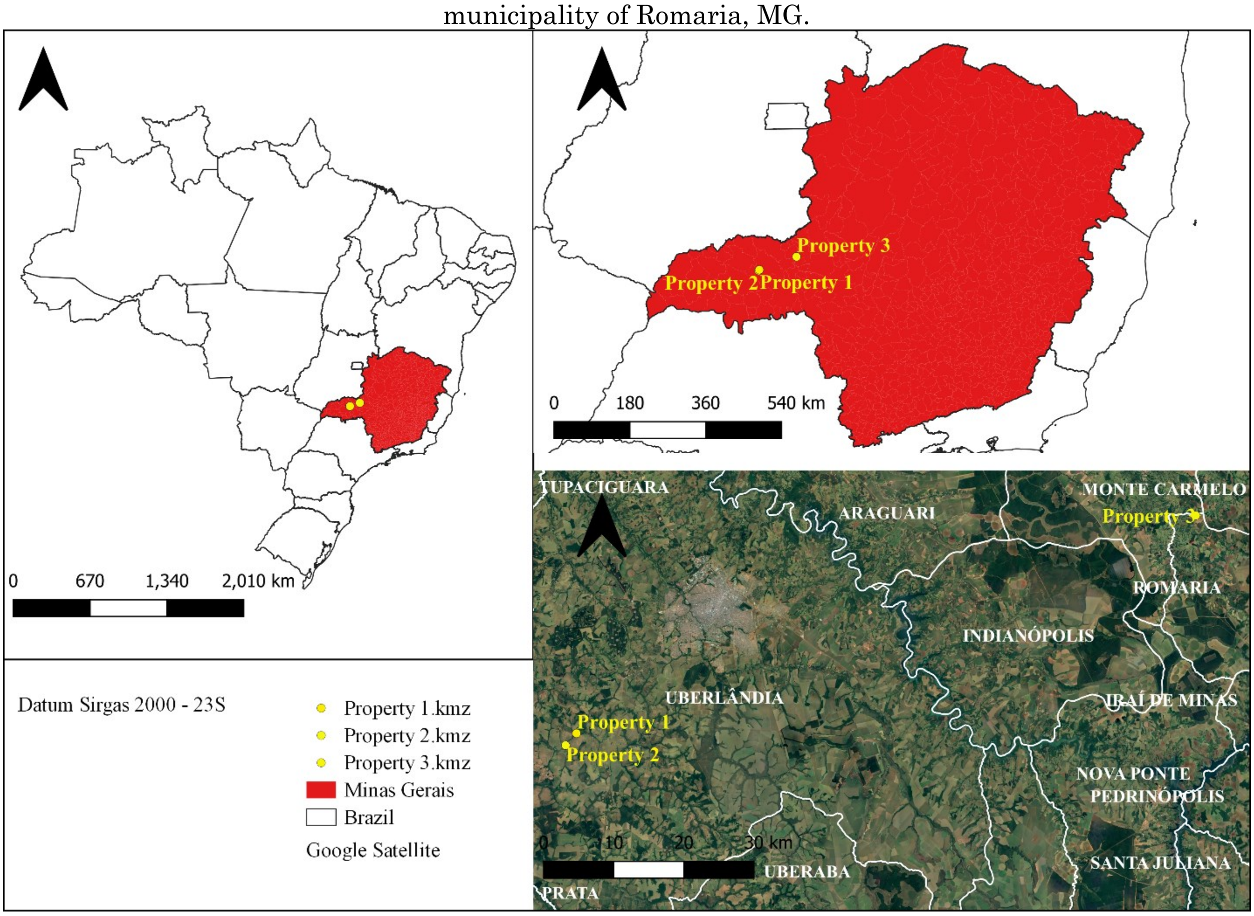
In this study, three agroecological properties of family farming were analyzed, and properties 1 and 2 conduct agroecological systems within the same rural settlement in the city of Uberlândia-MG, which were implemented in 2015, and the transition to agroecological production was completed in 2017. The other agroecological rural property is located in the city of Romaria-MG. Properties 1 and 3 participate in Social Control Organizations (SCO), and their producers are certified as organic by the Ministério da Agricultura, Pecuária e Abastecimento (MAPA), which is the ministry responsible for agriculture in Brazil. Organic foods and agroecological foods do not use pesticides in their cultivation. One of the points that differentiate them is that agroecological food has an expanded ideology, which encompasses relationships with nature, trade and fair labor relations, review of consumption patterns and are based on family farming (WARMLING, 2014). In addition, the certification of organic food is carried out by "audit" and the certification of agroecological food is "participatory" (ABREU et al., 2012).

Family farming property 1, located in Uberlândia-MG, with geographic coordinates

19º04'05.0"S and 48º27'51.6"W (Figure 1), has a total area of 12.5 ha, being 2,493 m² occupied by an agroecological and agroforestry system (AS1) and a side area used for agroecological production (AS2). The agricultural and forest species found in the AS1 area were: papaya, mango, red angico, cecropia, jatobá, pink ipe, West Indian elm, pacara ear pod, guariroba, eucalyptus, castor bean, pigeon pea, elephant grass, Mexican sunflower, gliricidia, jack bean, velvet bean and signalgrass. In the AS2 area, the species found were: garlic, lemongrass, chives, coriander, lemon balm, mint, pepper, parsley, onion, acerola, banana, lemon, passion fruit, guava, blackberry, cashew, cowpea, corn, zucchini, eggplant, scarlet eggplant, cherry tomato, maroon cucumber, strawberry, lettuce, leek, chicory, purslane, broccoli, kale, spinach, mustard, cabbage, arugula, sweet potato, beetroot, arrowroot, carrot, radish, yam, cassava, yacon potato, and sunflower (SILVA, 2019).

The main aspect that differentiates the AS1 and AS2 areas of this property is that in AS2 there is a predominance of vegetables, while AS1 is mostly constituted by tree species. The rural producer of this property, for environmental reasons, left an area for agroforestry recomposition (AS1 area), with exploitation of crops that had already been planted before 2015, but without the reintroduction of vegetables, which would constantly depend on fertilization. In addition, AS2 has a greater diversity and quantity of plant species. The AS1 and AS2 areas of this property are irrigated with tilapia aquaculture effluent, which is rich in nutrients (SILVA, 2019). In addition, these two areas receive inputs of Yoorin, which also contains phosphorus, calcium, magnesium, silicon, dicalcium phosphate and other nutrients. The addition of these agricultural inputs is allowed by the regulations for agroecological/organic crops. Organic compounds, which are sources of macro and micronutrients, were also incorporated into the soil of these areas.

Figure 1 - Location of the family farms. Properties 1 and 2: managed with agroecological system located in the municipality of Uberlândia, MG; Property 3: agroecological system, located in the municipality of Romaria, MG.



Data Source: NEREUS (2021); Elaborated by the author (2021).

In property 1, two samples were collected as it had areas with distinct agricultural practices: AS1 corresponds to agroecological and agroforestry management implemented in 2015, and AS2 corresponds to agroecological management with the predominance of vegetables, implemented in 2017, in addition to the two pasture samples used as reference.

Table 1 shows the characteristics of the soils collected in the 3 rural properties for the 10 different samples. Soil classification was performed according to the methodology described by Teixeira (2017).

Table 1 - Taxonomic classification of soils at the sampling sites.

Property	Sample	Soil[1]	Municipality
1	AS1	*Neossolo Quartzarênico hidromórfico* (Quartzipsamment)	Uberlândia
	AS 2	*Latossolo Vermelho Distrófico* (Oxisol), medium texture, lower landscape stratum	
2	AS 3	*Latossolo Vermelho Distrófico* (Oxisol), medium texture, upper landscape stratum	Uberlândia
3	AS 4 AS 5	*Latossolo Vermelho Distrófico* (Oxisol), clay texture, lower landscape stratum	Romaria

Source: the author (2021).

Before the agroecological intervention, the main activity carried out in the lot of properties 1 and 2, by the former owner of the farm, was beef cattle farming, so most of the landscape is currently characterized by degraded pasture. Currently, there is rearing of some pigs in pigsty, cow, bull and chickens in the pasture area in the properties of the Celso Lúcio Settlement. The areas of Pasture 1 and Pasture 2 correspond to these pasture areas that have not suffered interference for a while.

Family farming property 2, with coordinates 19°04'59.5"S and 48°28'46.0"W, located in the municipality of Uberlândia, MG (Figure 1), has a total area of 13.2 ha, with 1,018 m^2 intended for agroecological and agroforestry cultivation since 2015. In this area, vegetables and tree species are found. The plant species found on this property are coriander, lemon balm, ginger, mint, basil, pepper, parsley, common rue, saffron, boldo, fennel, onion, avocado, acerola, banana, lemon, papaya, mango, guava, cashew, orange, tangerine, cowpea, corn, zucchini, scarlet eggplant, bell pepper, okra, maroon cucumber, strawberry, watercress, lettuce, chicory, purslane, common chicory, kale, mustard, arugula, malanga, sweet potato, arrowroot, yam, cassava, guariroba, cambuí, eucalyptus, castor bean, pigeon pea, elephant grass, Mexican sunflower, gliricidia, jack bean, velvet bean and signalgrass (SILVA, 2019). In addition, the agricultural producer of this area incorporates organic matter in the soil of the beds.

Finally, there is the family agricultural property with coordinates 18°48'3.02"S 47°37'13.10" (Figure 1), located in the municipality of Romaria, MG. This producer has an agroecological system in the two areas of his property (AS4 and AS5), maintaining agroecological practices of recycling biomass from tree pruning, weeding and crop residues, use of mulch formed by straw and litter of native forest (Cerrado), crop rotation, green manure and other practices that promote nutrient recycling. In this property, in both areas, various plants are cultivated in full sun such as papaya, lemongrass, chives, coriander, lemon balm, mint, pepper, parsley, onion, acerola, banana, lemon, eggplant, scarlet eggplant, tomato, lettuce, leek, chicory, broccoli, kale, spinach, mustard, cabbage, arugula, sweet potato, beetroot, carrot, cassava and yacon potato.

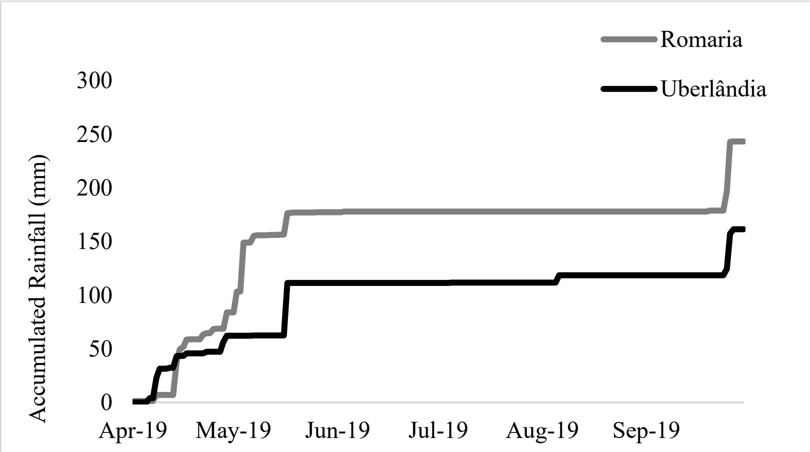
Sampling

Soil samples were collected at a depth of 20 to 25 cm, with a hoe. Samples were collected randomly within the farmers' cultivation systems. In addition, the samples were composed of five points per area and were collected after removing the litter and avoiding places near the trees.

The samples were collected between September and October 2019 (end of the dry season), in georeferenced points. Soil samples were also collected from areas used for pasture very close to the collection points to serve as a reference for the absence of agroecological management, representing neighboring areas, under the same climate and in similar soils, with another cultivation system and that did undergo intervention by farmers. The pasture samples of this study constitute a comparative treatment to the agroecological and agroforestry system.

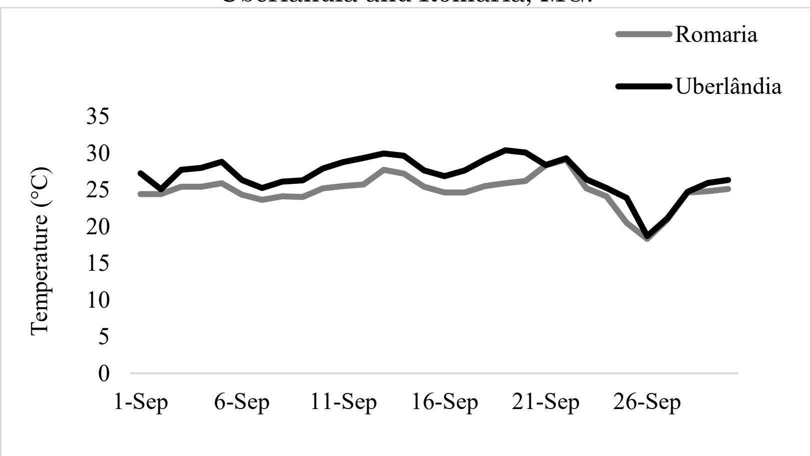
Figure 2 shows the accumulated rainfall of the six months prior to the day of collection of soil samples in the municipalities of Uberlândia and Romaria, and Figure 3 shows the temperature in the month in which the samples were collected in these municipalities.

Figure 2 - Accumulated daily rainfall (mm) in the six months prior to the collection of soil samples in the municipalities of Uberlândia and Romaria, MG.



Data Source: INMET (2020) e Sismet Cooxupé (2020). Elaborated by the author (2021).

Figure 3 - Temperature (°C) in the month of collection of soil samples in the municipalities of Uberlândia and Romaria, MG.



Data Source: INMET (2020) e Sismet Cooxupé (2020). Elaborated by the author (2021).

The 10 samples evaluated in this study (Table 1) were sieved through a 2-mm mesh and used for chemical, microbial (colony forming units) and biochemical (enzymatic activity, biomass carbon and basal respiration) analyses.

Soil chemical, biochemical and microbial analyses

The fertility parameters pH (in water), phosphorus (P) - P meh^{-1} - Mehlich^{-1} Extractant, potassium (K) in which K = [0.05 mol L^{-1} HCl + 0.0125 mol L^{-1} H_2SO_4], calcium (Ca), magnesium

(Mg), organic matter (OM) - Colorimetric method, effective cation exchange capacity (CEC) and base saturation (V %) were analyzed according to Teixeira (2017).

The number of colony-forming units (CFU) was determined in triplicate in selective culture media for bacteria and actinobacteria, using the method of serial dilution and spreading on a plate with a solid culture medium. For the cultivation of actinobacteria, SCN medium (TAVARES, 2019) supplemented with antifungal agent nystatin and antibiotic agent streptomycin was used. For the cultivation of bacteria, nutrient agar medium (CARDOSO, 2012) supplemented with nystatin was used. The plates were kept at a temperature of 25±2°C, under a photoperiod of 12 hours, for three days for actinobacteria and bacteria. The results were expressed in number of colony-forming units per 1g gram of soil.

The soils destined for the evaluation of microbial biomass carbon and basal respiration had their moisture content adjusted to 60% of the water retention capacity by the gravimetric method according to the methodology of Silva et al. (2007). Microbial biomass carbon (MBC) was analyzed using the fumigation-extraction method (FE), which followed the methodology described by Souza et al. (2015). The quantification of carbon in extracts from the soil sample was performed according to the methodology of Mendonça and Da Matos (2005). Basal respiration (SBR) was evaluated according to the procedure of Silva et al. (2007).

Activity of ß-glucosidase (GLU) was determined according to the methodology of Eivazi and Tabatai (1988), phosphatase (PHOS) was determined according to Tabatabai and Bremner (1969) with modifications, and the arylsulfatase enzyme (ARYL) was determined according to Tabatabai and Bremner (1970). The results of this analysis were expressed in µg product released g dry soil^{-1} h^{-1}.

The data of soil fertility, MBC, SBR, activity of enzymes and population of bacteria and actinobacteria were subjected to analysis of variance (ANOVA) and the means were compared by the Skott-Knott test at 5% significance level using the program SISVAR 5.7 (FERREIRA, 2019). In addition, principal component analysis (PCA), which is a linear ordering technique, was performed using CANOCO software version 4.5 (ter BRAAK; SMILAUER, 2002).

The results of the bioindicators of this study were interpreted using the Fertbio model created by Mendes et al. (2018), because this method incorporates microbial and fertility indicators in soil analyses in Brazil. Through this model, it is possible to interpret ß-Glucosidase and Arylsulfatase indicators for clayey *Latossolos* (Oxisol) of the Cerrado, under annual crops for air-dried soil samples. Although not all properties have this type of soil, this interpretation model was used for all properties of the present study. The indicators were compared by the ratio of their values for each system. The higher the result, the greater the sensitivity of the bioindicator to changes in the management systems (MENDES et al., 2018).

RESULTS AND DISCUSSION

According to the analysis of soil chemical attributes (Table 2), the variables pH, Ca, Mg, OM, effective CEC and V% are found in greater proportion in agroecological management systems than in pasture areas.

Table 2 - Chemical attributes in soil samples collected in agroecological system (AS) and pasture areas.

Chemical attributes	AS	Pasture
pH H_2O	6,99*	5,84*
P meh-1 (mg dm^{-3})	99,49	10,52
K (mg dm^{-3})	726,60	70,58
Ca (cmolc dm^{-3})	6,14*	1,62*
Mg (cmolc dm^{-3})	3*	0,64*
OM (dag Kg^{-1})	3,09	1,53
effective CEC	11,02*	2,47*
V%	87,59*	54,03*

Source: The author (2021). Numbers followed by asterisk (*) represent a significant difference between the two treatments by the Scott-Knott test at 5% significance level.

The higher proportions of the attributes pH, Ca, Mg, OM, effective CEC and V% in the areas of AS are possibly due to the incorporation of organic matter and the diversity of species in these cultivation areas. OM was not significant probably because the litter was removed before sample collection. It is important to note that the chemical attributes may have changed due to the addition of agricultural inputs in properties 1 and 3.

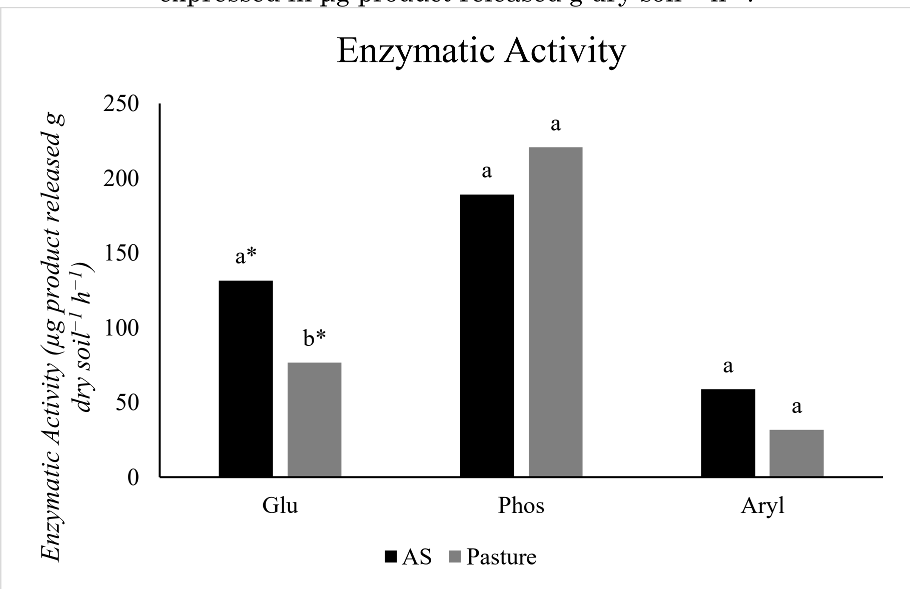
Similar results were reported by Santiago et al. (2018), who observed that the pH in the 0 to 20 cm layer of soils in transition to agroecological systems showed positive correlations over the time of use, proving that the pH values tend to increase in these soils in transition. The present study also obtained results agreeing with those reported by Obeng and Aguilar (2015), who found that the soils of cocoa agroforests had higher concentrations of Ca and Mg than those of native forest areas in the region.

In a study conducted by Samani et al. (2020), higher proportions of Mg were obtained in the soil of agroforestry systems than in soil samples from other cultivation systems. According to the authors, this may have occurred due to the treetops, which created adequate conditions for mineral weathering with ideal temperature and humidity, so greater amounts of Mg are released. This explains the lower concentrations of Mg in pasture areas.

According to Kassa (2018), higher pH and CEC values in agroforestry systems compared to monoculture areas are probably related to high levels of organic matter, linked to the fall of tree leaves and the protection against soil erosion provided by them. According to the author, higher soil CEC is related to high clay contents and organic matter. This is consistent with the results found in the present study, since the AS areas obtained a higher CEC than the pasture areas, probably due to the greater amount of plant residues present in the former. According to Teixeira (2013), V% is indicative of the general conditions of soil fertility, since it is a result of the sum of bases and effective CEC. Thus, it is possible to notice that the areas under agroecological management have higher fertility compared to pasture areas.

Regarding enzymatic analyses, it was found that the concentration of the enzyme ß-glucosidase was significantly higher in the agroecological system samples than in the pasture soil samples (Figure 4). The higher concentration of this enzyme in AS areas is possibly due to the greater amount of plant residues in the soil, which come from the great diversity of perennial vegetation of this system and also due to the biomass recycling practices carried out used by rural producers.

Figure 4 - Concentration of the enzymes ß-glucosidase, phosphatase and Arylsulfatase in the management of Agroecological Systems and Pasture. The values of the enzymatic activities were expressed in µg product released g dry soil^{-1} h^{-1}.



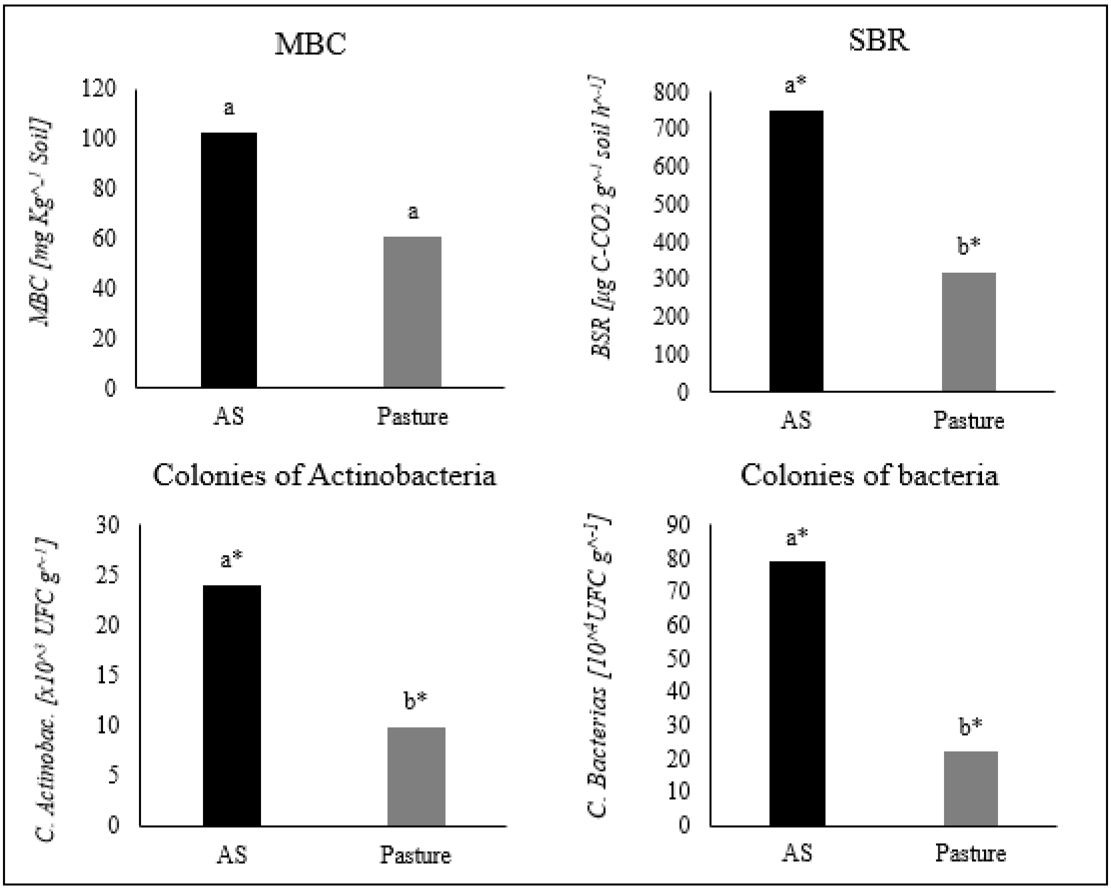
Source: The author (2021).

According to Paudel et al. (2011), the greater activity of certain soil enzymes is improved by conservation practices, such as agroecological system, which can raise other soil quality parameters, such as organic matter content, aggregation and water infiltration into the soil, as well as its sustainability and productivity.

Vallejo et al. (2010) analyzed the enzymatic activity of ß-Glucosidase and found a higher concentration of these enzymes in the 12-year-old agroforestry system compared to the conventional pasture area. According to Paudel et al. (2011), the higher activity of the enzyme ß-glucosidase in perennial vegetation treatments can be explained by the biomass accumulation of perennial vegetation in the soil.

In relation to the analysis of microorganisms, there was a significant increase in the amount of actinobacteria of the AS samples compared to the respective pasture areas (Figure 5). In addition, the colonies of actinobacteria found in the pasture were very small and white in color, while those found in the AS areas showed with yellow color. Actinobacteria population data are in accordance with those reported by Beule et al. (2020), who found that in general, these microorganisms were in greater abundance in AS soil samples than in monoculture soil samples. This was due to the increase in above-ground plant biomass and diversity, which increased litter input, and the increase in the amount and diversity of root exudates.

Figure 5 - Biological indicators of soil quality (SBR, MBC, actinobacteria and bacteria) in soil samples collected at properties with agroecological system (AS) and pasture.



Source: The author (2021). Means followed by similar letters do not differ significantly by the Scott-Knott test at 5% significance level.

For the SBR values, the areas of agroecological system had significantly higher values than the pasture areas taken as a reference for each property (Figure 5). This result represents a higher activity of microorganisms in AS areas, which may have occurred due to the greater amount of colony-forming units of bacteria and actinobacteria in this soil, in addition to the greater amount of organic residues deposited.

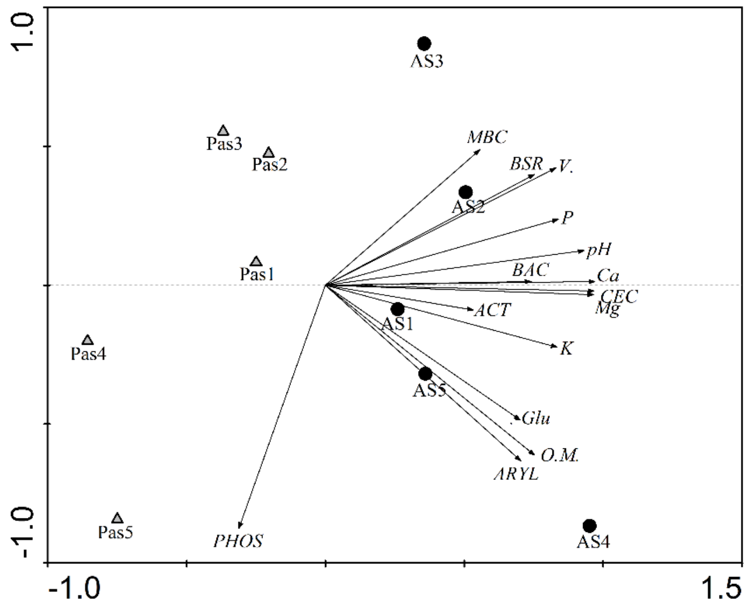
Tian et al. (2013) found that basal respiration was significantly higher in agroforestry systems than in monoculture systems. A higher rate of basal respiration in agroforests may be due to the existence of large availability of labile carbon substrates.

In the present study, bacteria were found in greater amount in AS areas than in the respective pasture areas. The samples with bacterial colony-forming units from the pasture areas showed a white color. On the other, the bacterial colonies found in the AS areas predominantly showed a yellow/orange color.

The results presented here are in accordance with those reported by Henneron et al. (2015), who stated that the amount of bacteria present in soil under organic system is significantly higher than in soils under conventional management. In addition, the abundance of certain bacterial genes was positively correlated with soil organic C, total N, available P in the plant and exchangeable K and Mg (BEULE et al., 2019).

The biplot resulting from the principal component analysis (PCA), based on soil quality indicators and sampling subareas, clearly expresses the relationship between some enzymatic activities and the two types of management: agroecological system (AS) and pasture. According to the analysis, axis 1 explained 60.8% of the bioindicator-environment relationship and, together with axis 2, explained 16.5% of the data variation (Figure 6).

Figure 6 - Biplot of the different management areas and soil quality indicators - ACT: actinobacteria, ARYL: Arylsulfatase; BAC: Bacteria; Ca: Calcium; MBC: Microbial Biomass Carbon; PHOS: Phosphatase, GLU: ß-glucosidase; K: Potassium; Mg: Magnesium; OM: Organic Matter; P: Phosphorus; SBR: Soil Basal Respiration; V%: Base Saturation in potential CEC



Source: The author (2021).

It was possible to observe that the AS areas are more related to the higher values of soil quality variables, except for PHOS, which is an indication that these areas have higher quality. On the other hand, pasture areas are inversely related to soil quality indicators. Axis 1 is the one that most separates the types of management. Thus, the variables that most differentiate the AS from the pastures are Mg, Ca, bacteria, pH, CEC and actinobacteria. Possibly, the greater relationship of soil quality variables with AS was found because this management increases the amount of residues from several agricultural species and increases vegetation cover, avoiding nutrient leaching.

Soil samples from AS4 and AS5 showed a higher relationship with OM concentration and the activities of arylsulfatase and ß-glucosidase. The enzymatic activity of these enzymes is positively related to the O.M concentration in the soil (WALMSLEY; SKLENIČKA, 2017; PAUDEL et al., 2011). The greater relationship of these samples with organic matter can be explained by the practices that promote the recycling of nutrients carried out by the rural producer of property 3.

The soils evaluated in the present study have different typologies of *Latossolos Vermelhos* (Oxisols) (Table 1). Although there is this distinction between the classification of the soils, by comparing the obtained values of ß-Glucosidase and Arylsulfatase with the data from the bioindicator interpretation table of Mendes et al. (2018) (Table 3), it was possible to demonstrate that the samples collected in the areas of agroecological system showed a better class of interpretation than the pasture soil samples (Table 4).

Table 3 - Interpretation of bioindicators for the activity of ß-Glucosidase and Arylsulfatase enzymes in soil samples collected in properties with agroecological system (AS).

Samples	ß-Glucosidase	Arylsulfatase
AS	Adequate	Moderate
Pasture	Moderate	Moderate

Source: [a] The author (2021). According to Mendes et al. (2018), ß-Glucosidase activity ≤ 66 is considered low; between 67 and 115 is considered moderate; and >116 is considered adequate. For the arylsulfatase enzyme, values ≤ 30 are considered low; between 31 and 70 are considered moderate; and >71 are considered high.

According to Mendes et al. (2018), it is possible to interpret ß-Glucosidase and Arylsulfatase indicators for clayey *Latossolos Vermelhos* (Oxisols) of the Cerrado, under annual crops for air-dried soil samples. According to these authors, low values of the indicators can demonstrate that inadequate management practices are being adopted in the area. On the other, higher values of these bioindicators can be understood as desirable values that must be maintained for the proper functioning of the soil. According to the bioindicator ß-Glucosidase, soil quality in agroecological system areas is better than in pasture areas, while for Arylsulfatase there was no difference.

Table 4 shows the comparisons of the various soil quality indicators between the different areas of study (agroecological system and pasture).

Table 4. Ratio between soil variables collected in agroecological system (AS) areas and in adjacent pasture areas.

Treatment / Samples	AS1 / Pas1	AS2 / Pas2	AS3 / Pas3	AS4 / Pas4	AS5 / Pas5	Average AS / Average Pas
MBC	3,00	1,22	4,75	1,33	1,13	1,68
SBR	1,75	1,34	12,27	2,82	3,17	2,35
ß-Glucosidade	2,22	2,03	1,35	2,58	0,86	1,69
Arylsulfatase	1,89	1,42	1,56	3,96	1,09	1,85
Phosphatase	0,98	0,85	0,45	1,68	0,71	0,86
Actinobacterial colonies	2,04	7,55	1,00	12,38	6,58	2,44
Bacterial colonies	5,81	4,36	17,50	2,24	1,94	3,57
pH	1,16	1,08	1,35	1,22	1,20	1,20
OM	1,12	1,60	1,64	5,45	1,51	2,03
P	0,72	38,50	14,62	10,25	16,10	9,46
K^+	0,82	2,50	4,25	17,36	44,95	10,30
Ca^{2+}	1,58	1,79	5,90	6,20	9,97	3,78
Mg^{2+}	1,40	2,73	6,67	7,98	113,50	4,67
CEC	1,50	2,12	5,58	7,85	15,51	4,46
V%	1,19	1,25	2,28	1,34	3,78	1,62

Source: The author (2021).

All variables, except for acid phosphatase enzyme activity, were higher in the AS areas compared to the pasture area, since values greater than 1 were obtained. The variables that obtained the most marked differences were K, P, Mg^{2+}, Ca^{2+}, CEC and bacterial colonies, which shows that these variables are more sensitive to changes according to the management system. The variables K, P, Mg^{2+}, Ca^{2+}, CEC of the AS had higher values possibly due to the addition of external inputs, which are allowed by the body that certifies organic products, during the management. The indicators SBR, actinobacterial colonies, MBC, Arylsulfatase, pH, OM and V% also stood out and were sensitive to the change in management.

Thus, the variables bacterial colonies, actinobacterial colonies, ß-Glucosidase and pH present themselves as possible indicators of soil quality, because were sensitive (Table 4). In addition, these indicators mentioned above show a significant difference between the AS and Pasture samples in the means comparison test (Table 2, Figure 4 and Figure 5) and also there is greater relationship of these indicators with the AS areas, as shown in the PCA (Figure 6).

FINAL CONSIDERATIONS

The following soil quality variables proved to be sensitive to the difference in management between agroecological system and pasture areas: basal respiration, ß-glucosidase, bacterial and actinobacterial colonies and pH, and it is possible to use these variables as indicators of soil quality. Other variables such as K, P, Mg^{2+}, Ca^{2+} and CEC were not considered as good indicators in the present study because, possibly, they had undergone changes in their values due to the addition of external inputs by farmers, inputs that are allowed by the body that certifies organic products during management.

The indicators basal respiration, ß-glucosidase, pH, and colonies of bacteria and actinobacteria proved to be able to identify changes in soil functioning in the areas of family farming. The higher soil quality in the agroecological system areas resulted in higher values of these variables. Possibly these managements have greater activities of their basic functions, such as movement and supply of water to soil and plants, nutrient cycling, resistance to organic and inorganic pollutants and high productivity.

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AUTHORS' CONTRIBUTION

Ana Flávia Brandão Rocha conceived the study, collected, analyzed the data, wrote the text, carried out fieldwork and laboratory experiments. Ana Carolina Silva Siquieroli supervised the study, collected the data, wrote and revised the text and carried out fieldwork and laboratory experiments. Adriane de Andrade Silva carried out fieldwork, collected data and revised the work. Amanda Mendes De Lima Carneiro collected the data and performed experiments in the laboratory. Bruno Nery Fernandes Vasconcelos carried out fieldwork, collected data and revised the text. Danielle Davi Rodrigues Gondim collected the data and carried out experiments in the laboratory.