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Crop tillage, soil depth, and their influence on extracellular enzyme activities

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Abstract

Agricultural practices can alter both physicochemical properties and soil microbial parameters, modifying the dynamics of soil biochemical functioning and, consequently, nutrient cycling. This study evaluated the effect of land use on chemical and biochemical attributes, and relationships between environmental variables. We used a sampling design to collect soil samples at different depths in different agroecosystems. Soil samples from natural ecosystems (native Cerrado) and agroecosystems (cotton and sugarcane cultivation) were collected at 0–0.1 m, 0.1–0.2 m, 0.2–0.5 m, and 0.5–1.0 m from 12 areas in the State of Goiás, Brazil. Twelve chemical properties and two biochemical attributes (enzyme activity and microbial biomass carbon) were evaluated using a generalized linear model of variance and Tukey's test with three factors: correlation between all soil attributes, multiple regression between soil attributes, and biochemical variables. Soil chemical and biochemical attributes were significantly affected by variable depth ($p<0.05$). Most of the metabolic activity in the soil occurred at 0 to 0.2 m, independent of land use class. Seasonality also affected enzyme activity in the soil, with higher activity during the rainy season. In contrast, microbial biomass carbon, an attribute generally related to organic matter and carbon mineralization, did not vary significantly with different soil depths and seasons. Thus, enzyme activity is an important indicator of soil fertility variations and is more sensitive than chemical and microbial parameters.

Keywords: Brazilian Cerrado; soil quality; no-till.

Abbreviations: B_coefficient of multiple regression; CEC_cation exchange capacity; M%_aluminum saturation; MBC_microbial biomass carbon; N_total nitrogen; NPK_nitrogen-phosphorus-potassium fertilizer; OM_organic matter; SE_standard error; TOC_ total organic carbon; V%_base saturation.

Introduction

Soil is an important component of agricultural activities. Proper use and management of soil are essential for sustainable practices (Cunha et al., 2008; Somasundaram et al., 2019). Soil is an important resource for the survival of species and as the growth medium for plants, providing them with support and nutrition. In addition, soil acts as a medium for nutrient cycling and organic waste decomposition and provides habitats for different species of microorganisms (Coelho et al., 2013; Zhang et al., 2021).

In Brazil, agricultural growth causes approximately 40% of soil conversion in areas of original vegetation of the Cerrado biome. Agribusiness projections indicate a 17.6% increase in grain production by 2030 (MAPA, 2021). Agribusiness is the main recipient of government investments because of its relevance to the Brazilian economy. These investments encourage the expansion of the market for new monoculture technologies that can generate socioeconomic benefits such as the supply of agricultural products, mainly for export (Scarpare et al., 2016).

Notable crops in Brazil include soybean, corn, cotton, and sugarcane (Sano et al., 2010) and as biofuels supply energy to domestic and foreign markets. Intensive land use has led to increased crop productivity, thereby meeting the needs of production scales and leading to investment in intensive mechanization (MAPA, 2021). Many factors explain the increased exploration and conversion of soil for agricultural use, especially the increasing world population and the consequently increasing demand for food. Brazil is the biggest exporter of soybean. Currently, 90% (15.6 million hectares) of agriculture in the Brazilian Cerrado is devoted to soy. In 2013–2014 it represented around 52% of soy cultivated in this biome (Nepstead et al., 2019; MAPA, 2021), an increasing of 38%.

Furthermore, constant variations in the price of oil and the exchange rate are driving the search for alternative fuel sources, such as ethanol. Sugarcane has thus become an important source of ethanol, with the planted area in Brazil (2020–21) estimated at 9 million hectares (MAPA, 2021; CONAB, 2021).

Cotton, by contrast, is mainly used in the textile industry, and approximately 2.44 million tons of cotton lint was harvested in Brazil during 2020–21. Cotton production in Brazil is concentrated to Bahia and Mato Grosso states. However, plantations are located in the Cerrado biome (MAPA, 2021). Projections indicate that Brazil will produce 12.5% of the global cotton crop by 2030 (OECD-FAO, 2021).

Despite the economic advantages, these activities have detrimental environmental impacts. The use of fertilizers and

Table 1. Generalized linear model of variances (GLM) to compare the chemical attributes of the land use, different depths, and seasonality*.

Atribute	Effect	df	SS	MS	F	p
aminopeptidase	Depth	3	14249.80	4749.94	14.79	0.000
	Season	1	19144.90	19144.87	59.60	0.000
	Depth*Season	3	11514.70	3838.23	11.95	0.000
β-glucosidase	Depth	3	30002.80	10000.92	22.05	0.000
phosphatase	Depth	3	129246.00	43082.00	7.89	0.000
	Season	1	111168.00	111168.00	20.35	0.000
protease	Depth	3	0.04	0.01	3.83	0.011
	Season	1	0.02	0.02	4.12	0.044
MBC	Crop*Season	2	7736.10	3868.10	5.62	0.004
urease	Depth	3	413870.00	137957.00	8.80	0.000
	Season	1	736972.00	736972.00	47.03	0.000
	Depth*Season	3	132965.00	44322.00	2.83	0.040
pH	Crop	2	1.79	0.90	3.34	0.038
	Depth	3	4.01	1.34	4.99	0.002
Ca	Depth	3	311.99	104.00	13.18	0.000
Mg	Depth	3	42.53	14.18	17.46	0.000
Al	Season	1	0.73	0.73	7.15	0.008
CEC	Depth	3	841.80	280.60	20.32	0.000
P	Depth	3	331.42	110.47	3.89	0.010
	Crop*Season	2	223.82	111.91	3.94	0.021
K	Crop	2	0.61	0.30	13.16	0.000
	Depth	3	0.45	0.15	6.51	0.000
OM	Depth	3	196.27	65.43	47.25	0.000
M%	Depth	3	2519.70	839.90	3.96	0.009
V%	Crop	2	3903.20	1951.60	3.96	0.021
	Depth	3	12733.60	4244.50	8.61	0.000
N	Depth	3	0.49	0.16	46.33	0.000
TOC	Depth	3	65.73	21.91	47.18	0.000

*Only significant parameters are presented.

pesticides causes loss of organic matter and soil, contaminates water, and lowers the quality of soil by altering chemical, physical, or biological properties (Carneiro et al., 2009; Ogura et al., 2021). Once altered, the soil cannot perform its functions optimally, leading to variability in agricultural production (Araújo and Monteiro, 2007).

In the Brazilian Cerrado, in particular, there is little information about soil biology (Carneiro et al., 2009). Studies that demonstrate the properties of soils cultivated with agricultural crops in comparison to areas of native vegetation can help understand the dynamics of these soils, as changes related to the removal of native vegetation cover for agricultural expansion result in changes in soil organic matter (Matsuoka et al., 2003; Lopes et al., 2018). In recent decades, enzyme activity has been recognized as an early indicator of soil change. Enzymes participate mainly in the decomposition process and nutrient availability (Bowles et al., 2014; Lopes et al., 2018).

Investigations of enzyme activity can be more efficient than the analysis of physicochemical attributes. Thus, studies focusing on the activities of native Cerrado soil enzymes are required. The purpose of this study is to evaluate the response of biochemical indicators, such as enzymes and physicochemical attributes, of soils cultivated with annual and perennial crops, more specifically cotton and sugarcane, and to evaluate the effects of soil depth and seasonality. Soils were collected at various depths in agricultural areas and Cerrado to compare and analyze the impact of agricultural practices in which native vegetation is removed. We hypothesized that the crop rotation system combined with no-tillage contributes positively to soil quality. The hypothesis was tested by monitoring specific biochemical parameters.

Results

We obtained different results after observing each soil attribute in relation to culture, depth, and season variables. Culture only influenced fertility attributes such as pH, potassium (K), and base saturation (V%) (p=0.000, Table 1). Depth influenced all variables except microbial biomass

carbon (MBC) and aluminum saturation (M%) (p=0.000, Table 1). M% was the most affected soil behavior.

If analyzed separately, the difference between cultures and the Cerrado influenced only the enzymatic variables of aminopeptidase, acid phosphatase, protease, and urease (p=0.000, Table 1), without a response to any of the soil fertility variables. In an integrated way, the relationship between culture and depth did not affect any of the variables, whereas culture seasonality only affected MBC (p=0.000, Table 1). Other relationships among land use, seasonality, and depth are summarized in Tables 1 and 2.

We observed variations in protease, urease, and total organic carbon (TOC) with increasing depth. However, only TOC showed a relevant relationship, with values reduced considerably with increasing soil depth (coefficient [coef]=-21.5; p=0.00; r^2= 0.362). TOC was significantly affected by several soil fertility variables (Table 3).

TOC increased with increasing calcium (Ca) (coef=2.3018; p=5.48E-21; r^2=0.45), magnesium (Mg) (coef=0.69578; p=1.33E-16; r^2=0.40), and CEC (coef=3.1718; p=0.00; r^2= 0.498). For nitrogen (N), an effect was evident, with little variation (coefficient=0.080; p=0.00; r^2=0.929). This relationship was also observed for V% (coef=13.02; p=0.023; r^2=0.248), and (OM) (coef=1.713; p=0.00; r^2=0.999) (Table 3).

Depth influenced soil fertility and enzyme activities (F=5.662; p=0.000), seasonality (F=16.521; p=0.000), and the interactions between culture and seasonality (F=1.692; p=0.010) and depth and seasonality (F=2.489; p=0.000).

The enzymatic difference between depth and seasonality was evident. For aminopeptidase, in the rainy season the value was 58.19 µmol g^{-1} h^{-1} at depths of 0 to 10 cm. The value declined in the autumn to 2.03 µmol g^{-1} h^{-1} at depths of 50 to 100 cm. In the dry season, values ranged from 2.03 to 0.04 µmol µmol g^{-1} h^{-1}. Similar patterns were found for β-glucosidase, acid phosphatase, protease, and urease. MBC measurement did not vary even though it is an indicator of microbial metabolism in the soil. Table 2 presents the values for all enzymes assayed.

Discussion

Soil biochemical analysis indicated that enzyme activity is sensitive to depth and disturbances caused by seasonality. The activities of glycine aminopeptidase, β-glucosidase, acid phosphatase, and protease were significantly lower at depths exceeding 0.2 m and differed in their activities in dry and rainy seasons (Table 2).

The diversity of plant cover constitutes a varied source of nutrients in the soil. The litter that forms provide greater humidity, reduces temperature variation, and provides more organic matter. These conditions trigger the secretion of microbial extracellular enzymes (Zago et al., 2018). In addition to the greater availability of nutrients in the surface layer of the soil, there is also more oxygen, which, along the soil profiles, has its supply reduced and is due to the extensive compaction of deeper soil profiles (Sun et al., 2021). Consequently, the microbial biomass is reduced as the soil sampling depth increases.

In the three land use types, the enzyme activities related to nitrogen cycling (protease and urease) varied significantly between sampling depths and seasonality. Urease catalyzes the hydrolysis of urea into carbon dioxide and ammonia. Urease activity is related to mineralizable nitrogen in the soil. However, the rate of hydrolysis depends on the type of vegetation (Lanna et al., 2010; Almagro et al., 2021). In the present study, analysis of the urease activity data together with the nitrogen available in the soil revealed that the nitrogen contents also did not differ between cultures but were sensitive to TOC and urease (Table 2 and 3).

Protease activity can be influenced simultaneously by biotic and abiotic factors (Geisseler and Horwath, 2008). These factors need to be studied separately for apt identification and understanding. Therefore, further studies are needed to understand the mechanisms that regulate soil protease activity and its effect on nitrogen availability in the soil.

According to Ivashchenko et al. (2021), phosphatase activity is influenced by the plant cover and soil temperature. In our study, we also observed a simultaneous effect of depth and variation in seasonality (Table 1). The relationship between phosphatase activity and availability should also be highlighted. This is because, in the chemical analysis, this element varied depending on both soil depth and interactions between crops and seasons (Table 1). This result is attributed to the availability of inorganic phosphate in the soil, which is generally higher in cultivable areas owing to the use of phosphate-containing fertilizers (Esposito and Azevedo, 2004).

Conservation agriculture practices, such as no-till and crop rotation, contribute to the maintenance of plant residues from the harvest, and these factors help increase enzyme activity (Araújo and Monteiro, 2007).

Unlike most attributes, MBC did not show significant variation by soil depth. However, it was sensitive to changes between seasons and between land use classes when analyzed in an integrated manner (Table 1). These findings show the importance of maintaining plant cover to provide an environment rich in organic matter that can stimulate soil microorganisms to act as decomposers. Cerrado soils showed the highest MBC values during the rainy season. In soils with cotton crops, MBC was higher in the dry season, probably due to pivot irrigation. These situations present a natural ecosystem and a crop with rotational management, which allows the renewal of nutrients in the soil and a lower degree of compaction, thus providing good conditions for microorganisms (Carneiro et al., 2009).

When vegetation is replaced in agricultural areas, changes occur in the diversity of flora. These changes interfere with the soil microbiota and, consequently, with the functioning of the ecosystem. Analysis of aminopeptidase, phosphatase, urease, and protease activities in the different types of soil management in this study revealed differences in activity when comparing the crop*Cerrado categories (Table 1).

Areas intended for cotton cultivation undergo a no-tillage process to take advantage of plant residues that contribute to the maintenance of organic matter in the soil and make nutrients available for microorganisms (Matsuoka et al., 2003). The areas also undergo crop rotation, with the off-season periods being cultivated with soybean and corn. This crop rotation process also provides better soil quality maintenance and is an important mechanism for sustainable soil use, allowing for better productivity and conservation of natural resources (Lanna et al., 2010).

Sugarcane is a perennial monoculture crop. Planting renewal occurs after approximately two or three consecutive parings. However, the soil management process is less extensive than that observed for the cotton crop. Fertilization is performed at the time of planting and only after the cuts, which occur once a year. This protocol has the greatest impact on the soil, causing loss of plant and animal biodiversity (Almagro et al., 2021).

Studies that aim to describe the behavior of enzyme activity in different crops should be considered. The information

Table 2. Mean attributes of different soil biochemical variables in relation to land use, seasonality and depth.

Land use	season	Depth (m)	Aminopeptidase* (µmol g^{-1} h^{-1})	β-Glucosidase* (µmol g^{-1} h^{-1})	Phosphatase* (µmol g^{-1} h^{-1})	Protease* (U g^{-1} h^{-1})	Urease* (µmol g^{-1} h^{-1})	MBC (µg C g^{-1})
Cotton	Dry	0-0.1	58.19	50.63	195.03	0.11	283.89	35.65
		0.1-0.2	33.68	13.97	156.61	0.02	196.94	35.60
		0.2-0.5	14.28	11.99	119.80	0.04	145.82	42.51
		0.5-1.0	4.93	7.31	95.83	0.05	73.05	24.27
	Rainy	0-0.1	2.03	34.70	102.52	0.01	56.50	15.45
		0.1-0.2	1.17	9.02	98.64	0.01	24.85	19.58
		0.2-0.5	0.27	0.32	81.62	0.02	13.85	22.08
		0.5-1.0	0.04	2.69	78.68	0.03	2.49	8.82
Sugarcane	Dry	0-0.1	37.49	33.71	210.45	0.03	263.91	28.30
		0.1-0.2	20.31	14.52	193.64	0.01	130.98	22.86
		0.2-0.5	7.88	13.27	156.30	0.01	91.18	14.84
		0.5-1.0	0.01	9.55	120.82	0.06	51.60	39.54
	Rainy	0-0.1	2.96	39.15	162.07	0.02	60.25	21.86
		0.1-0.2	1.26	13.66	130.15	0.00	39.46	20.32
		0.2-0.5	0.62	11.12	105.18	0.03	9.75	30.50
		0.5-1.0	0.00	6.57	80.14	0.07	0.00	14.68
Cerrado	Dry	0-0.1	49.57	43.58	201.45	0.08	275.56	29.23
		0.1-0.2	28.11	14.20	172.04	0.02	190.45	23.67
		0.2-0.5	11.61	12.52	135.01	0.03	128.97	11.22
		0.5-1.0	2.88	8.24	106.24	0.06	65.31	12.07
	Rainy	0-0.1	2.36	36.94	127.31	0.01	57.40	31.93
		0.1-0.2	1.22	10.96	111.77	0.00	28.92	25.46
		0.2-0.5	0.41	4.82	91.44	0.03	12.06	33.46
		0.5-1.0	0.02	4.30	79.29	0.05	1.45	32.78

*No significant difference were evident between mean values of enzymes for culture. **Differences between dry and rainy seasons; for depth, multiple regression values were used.

Table 3. Multiple regression between soil attributes and biochemical variables*.

Atribute	Constant	B	SE	t	p	R^2
	Protease	82.13	30.21	2.72	0.007	0.012
	Urease	-0.05	0.01	-3.19	0.002	0.093
Depth	TOC	-21.50	2.69	-8.01	0.000	0.362
	phosphatase	0.00	0.00	-4.55	0.000	0.022
pH	TOC	0.28	0.04	6.21	0.000	0.189
	Phosphatase	-0.01	0.00	-4.04	0.000	0.000
Ca	TOC	2.30	0.22	10.67	0.000	0.451
	Phosphatase	0.00	0.00	-3.24	0.001	0.012
	Aminopeptidase	0.01	0.00	1.49	0.137	0.061
Mg	TOC	0.70	0.08	9.12	0.000	0.408
	Phosphatase	0.00	0.00	3.37	0.001	0.017
Al	TOC	-0.08	0.03	-2.58	0.011	0.042
	Phosphatase	-0.01	0.00	-3.02	0.003	0.012
CEC	TOC	3.17	0.30	10.65	0.000	0.499
P	TOC	1.30	0.54	2.39	0.018	0.023
K	TOC	0.08	0.02	5.21	0.000	0.175
OM	TOC	1.71	0.00	513.13	0.000	1.000
	Phosphatase	0.09	0.02	5.32	0.000	0.017
	Aminopeptidase	-0.16	0.06	-2.67	0.008	0.033
M%	TOC	-4.60	1.29	-3.58	0.000	0.108
N	TOC	0.08	0.00	39.18	0.000	0.930
	Phosphatase	-0.13	0.02	-5.41	0.000	0.011
V%	TOC	13.02	1.89	6.88	0.000	0.248

*Only variables that showed statistical significance are presented.

obtained may be useful for soil sustainability. The adoption of sustainable practices makes the process more productive and less environmentally destructive.

The evaluation of the total enzymatic activity related to the nitrogen cycle (glycine aminopeptidase and urease), carbon cycle (β-glucosidase), and phosphorus cycle (acid phosphatase) showed that areas of native vegetation have higher activity values in soil layers (Table 4). This reflects the impact of replacing native vegetation with agriculture, which corroborates the hypothesis that native vegetation areas provide different substrates because of the complexity of the organic matter, despite cropped soils. This can be justified by the observation that native areas have greater floristic diversity, which influences microbial variability and activity (Ribeiro and Walter, 2008).

Materials and Methods

Sampling area

The study was performed in sugar and alcohol plantation areas, in the State of Goiás. Twelve natural ecosystems and 12 agroecosystems were selected. Sugarcane (perennial crop) and cotton (annual crop) were cultivated in six each. For each agroecosystem collection, the soil was sampled from a natural ecosystem (Supplementary Material).

All the natural ecosystems sampled had vegetation typical of the Brazilian Cerrado, featuring a mosaic of vegetation and species typical of the biome, with a predominance of trees with forest formation, classified as Cerradão (Ribeiro and Walter, 2008).

In all agroecosystems, the planting of the annual cotton crop occurred between February and March. Harvesting occurred between June and July of 2019. The areas were managed using no-tillage techniques and intercropping soybean and corn crops in the off-season periods of the crop. Central pivot irrigation was used in the dry season.

The soil was fertilized with chemicals containing nitrate, inorganic phosphate, potassium, (nitrogen, phosphorus, and potassium - NPK), with the components in a 10-10-10 ratio (60 kg ha^{-1}), urea, herbicides (Engeo®, Sanson 40S®), and fungicides (Mancozeb®, Nativo®).

Perennial sugarcane cultivation in the sampling areas was performed using conventional planting techniques with revolving soil. Paring was carried out annually in the dry season using agricultural machinery, preceded by the burning of sugarcane. After four consecutive cuts, planting was renewed. NPK fertilizer was also used (19-04-19, 80 kg ha^{-1}) before and after planting. To control and eliminate pests, herbicides (Provence ®, Combine ®, Advance ®, Ancosar 720 ®, and DMA 806 ®), fungicides (Glifosato ®), and insecticides (Orthenia ®, Regent ® 800WG, Aureo ®, Bazuka 216SL ®) were used.

According to the Köppen classification, the climate of the region is type Aw. This corresponds to a rainy tropical climate,

with 1,500 ± 500 mm of precipitation, with a dry season in the winter from May to September, and predominantly hot and rainy in summer from October to April.

Soil sampling

Soil samples were collected from January to March 2019 (rainy season) and resampled in June and July 2019 (dry season). At each collection point, three subsamples were obtained for each type of land use (cotton, sugarcane, and native Cerrado) and depth (0-0.1, 0.1-0.2, 0.2-0.5, and 0.5-1.0 m). The samples were combined to form a composite sample that was homogenized, sieved (2 mm), and placed in polyethylene bags at 4 °C. The moisture content of each sample was measured by oven-drying 5 g of soil at 105 °C for 24 h.

Determination of soil chemical attributes

The following chemical properties were measured: pH, Ca^{2+}, Mg^{2+}, Al^{3+}, K^{+}, P, cation exchange capacity (CEC), M%, V%, organic matter (OM), TOC, and total nitrogen (N) (Embrapa, 1997).

Biochemical attributes

Enzyme assays

The α-glucosidase, β-glucosidase, and acid phosphatase activities were determined as described by Baldrian et al. (2005) and modified by Zago et al. (2018) at 400 nm at 40 °C for 1 h. Glycine aminopeptidase activity was measured as described by Allisson and Vitousek (2005) with the following modifications. Samples (0.1 g of soil (dry mass) and 0.9 mL of substrate (5 mmol L-1) were incubated at 37 °C. After 1 h, enzyme activity was measured at 405 nm.

Urease enzyme activity was determined at 690 nm after incubation for 1h at 37 ºC (Kandeler and Gerber, 1988). Protease activity in the soil was determined as described by Ladeira et al. (2010) at 420 nm at 37 °C after 10 min. For assay controls, the substrate was added after the addition of trichloroacetic acid to stop the enzyme reaction. Except for protease, controls with soil were performed by replacing the substrate with acetate buffer. All assays were performed in triplicate and enzyme activity was expressed in µmol *p*-nitrophenol g^{-1} h^{-1} (α-glucosidase, β-glucosidase, acid phosphatase), µmol *p*-nitroaniline g^{-1} h^{-1} (glycine aminopeptidase), µmol N g^{-1} h^{-1} (urease), and U g^{-1} h^{-1} (protease). The assay temperature was chosen based on the average seasons in the area (CLIMATE-DATA, 2021). Data on β-glucosidase, acid phosphatase, and glycine aminopeptidase activities for each land use type were pooled to estimate the total enzymatic activity.

MBC

MBC was estimated using the irradiation-incubation method (Ferreira et al., 1999). The amount of CO_2 released by the microbiota after 10 d of incubation in hermetically sealed pots was measured by titration with HCl (1 mol L^{-1}). The results are expressed in micrograms of carbon per gram of soil (µg C g^{-1}) using a conversion factor (kc) of 0.45.

Statistical analyses

In this study, we used a sampling design in previously installed agroecosystems with three types of land use (cotton plantation, sugarcane, and native Cerrado). Data were analyzed using treatments in a 3 × 4 × 2 factorial scheme, with three types of land use (cotton, sugarcane, and native Cerrado), four depths (0-0.1, 0.1-0.2, 0.2-0.5, and 0.5-1.0 m), and seasonality (dry and rainy seasons). The variables evaluated were 13 soil chemical attributes (pH, Ca^{2+}, Mg^{2+}, K^{+}, Al^{3+}, CEC, P, M%, V%, OM, TOC, N, MBC) and enzymes (α- and β-glucosidase, acid phosphatase, urease, protease, and aminopeptidase). The Tukey mean comparison test was applied to evaluate the differences between the variables that affected the generalized linear model ($p < 0.05$). To relate soil fertility and enzymatic variables, correlation analysis was performed to verify the coefficient, significance, and multiple regression between soil attributes to verify the effect on the biochemical variables. Statistica software (version 7.0) was used to analyze and transform data results and to apply statistical tests.

Conclusion

Soil depth was the most important variable for determining the differences between soil attributes. The availability of nutrients, oxygen, and physical parameters such as porosity should determine the biological activity in the soil and, consequently, the rate of decomposition of organic matter. Considering the climatic conditions of the Cerrado biome, seasonality also influenced the microbial and enzyme activities analyzed in this study. Conservation agriculture techniques that prioritize soil quality can assist in biological activity, decomposition of organic matter, and consequently, nutrient cycling. Therefore, it was possible to verify that enzyme activity was higher in areas with native vegetation and was more sensitive than the chemical parameters, which are capable of indicating changes in soil cover. This fact was observed in different types of land use up to the 20 cm layer, which demonstrates that the management system applied to the surface layers interfered with enzyme activity. It is also important to note that the management system used by no-tillage with crop rotation contributes to soil conservation. We assumed that the enzyme activity, more precisely hydrolases, is a potential way of monitoring the quality of these ecosystems evaluated and can be used as an indicator of soil quality, as these enzymes showed more precise changes in soils than chemical attributes. The present study showed that biological parameters were more efficient in detecting soil changes due to the conversion of native vegetation areas into agricultural cultivation areas, demonstrating the importance of these parameters in the analysis of soil quality in agricultural systems. In this way, the use of biological parameters can also be an alternative in the search for sustainability in agroecosystems, as they demonstrate the effects of changes in the soil more quickly, which allows for more careful use of agricultural areas.

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