

Effects of cover crop species on soil quality and maize yield

Efeitos de espécies de cobertura na qualidade do solo e produtividade do milho

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ABSTRACT - The environmental impacts of agriculture have attracted considerable attention in recent years. Management practices such as the no-tillage system (NTS) can mitigate these impacts by enhancing soil biological activity, resulting in greater yield and resilience. This study evaluated the agronomic performance of summer-sown maize and soil quality indices under NTS with different cover crops in a crop rotation system. The experiment was conducted on a *Latosolo Vermelho Distroférico típico* in Dourados, Mato Grosso do Sul, Brazil, under NTS during the 2021 fall–winter through the 2022/2023 summer seasons, totaling two summer and two fall–winter crop cycles. The experimental design was a randomized block with five treatments conducted during the second season: an intercropping system composed of *Crotalaria ochroleuca* + pearl millet (*Pennisetum glaucum* L.) + buckwheat (*Fagopyrum esculentum* Moench) + signal grass (*Urochloa brizantha*), and the sole cropping of niger (*Guizotia abyssinica*), *Crotalaria spectabilis*, common vetch (*Vicia sativa* L.), and forage radish (*Raphanus sativus* L.), with four replications. Plant height, first cob insertion height, stem diameter, cob diameter and length, number of grains per cob, 1000-grain weight, and grain yield were evaluated at maize harvest. The treatments did not influence maize yield components. However, the activities of the arylsulfatase and β -glucosidase enzymes were affected by the crop rotation model, indicating that the adopted management contributed to improving soil biological quality. It is concluded that, based on crop rotation, NTS enhances soil biological quality and promotes the long-term sustainability of maize production.

RESUMO - Os impactos da agricultura no ambiente têm despertado grande interesse nos últimos anos. Práticas de manejo, como o sistema plantio direto (SPD), podem atenuar esses impactos por meio do incremento da atividade biológica do solo, resultando em maior produtividade e resiliência. O objetivo deste estudo foi avaliar o desempenho agrônômico do milho semeado no verão e os índices de qualidade do solo manejado em SPD, com diferentes espécies em modo de rotação de culturas. O experimento foi conduzido em Latossolo Vermelho Distroférico típico, em Dourados, Mato Grosso do Sul, Brasil, sob SPD ao longo das safras de outono-inverno de 2021 até o verão de 2022/2023, totalizando duas safras de verão e duas de outono-inverno. O delineamento foi em blocos casualizado, com cinco tratamentos durante a segunda safra: consórcio de *C. Ochroleuca* + Milheto + Trigo Mourisco + Braquiária, Níger, *C. spectabilis*, Ervilhaca e Nabo Forrageiro, com quatro repetições. Na colheita do milho, foram avaliados a altura de plantas, altura de inserção da espiga, diâmetro do colmo, diâmetro e comprimento da espiga, número de grãos por espiga, massa de mil grãos e rendimento de grãos. Os tratamentos não influenciaram os componentes de produção do milho. Entretanto, a atividade das enzimas arilsulfatase e β -glicosidase foi afetada pelo modelo de rotação de culturas, evidenciando que o manejo adotado contribuiu para a melhoria da qualidade biológica do solo. Conclui-se que o SPD, fundamentado na rotação de culturas, favorece a qualidade biológica do solo e promove a sustentabilidade da produção do milho ao longo do tempo.

Keywords: No-tillage system. Soil bioanalysis. Arylsulfatase. β -glucosidase.

Palavras-chave: Plantio direto. Bioanálise do solo. Arilsulfatase. β -glicosidase

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INTRODUCTION

The sustainable intensification of agriculture is one of the main challenges for crop production, requiring management systems that balance yield with the conservation of natural resources. Among these practices, the no-tillage system (NTS), crop rotation, and the use of cover crops stand out, as they promote improvements in soil quality and help mitigate environmental impacts (MORAES SÁ et al., 2025; MENDES et al., 2021).

In the no-tillage system (NTS), the continuous maintenance of soil cover with plant residues or living plants promotes an increase in organic matter, reduces erosion, and enhances the soil thermal and moisture stability conditions that stimulate root development and soil biological activity (SILVA et al., 2021). In this system, crop rotation plays a central role by promoting species diversity, improving soil structure, and reducing the incidence of pests and diseases. Its implementation in tropical environments, such as the Brazilian Cerrado, is even more strategic, given that these soils are typically acidic, with low natural fertility and reduced organic matter content (SANZONOWICZ, 2021; SILVA et al., 2022).

Legume, grass, and crucifer cover crops, grown either alone or in intercropping systems, can further enhance the effectiveness of the no-tillage



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system (NTS). These species differ in nutrient content and the amount of residue they produce, directly influencing nutrient cycling, soil structuring, and organic matter dynamics (SILVA et al., 2021). Intercropping promotes synergy among these plant groups, positively affecting the soil's physical, chemical, and biological properties (SILVA et al., 2021).

The no-tillage system (NTS), by maintaining soil thermal and moisture stability and supplying organic matter, enhances soil biological activity, which can be assessed through the activity of extracellular enzymes that serve as indicators of soil quality. Among these enzymes, arylsulfatase and β -glucosidase are effective indicators because they respond rapidly to management-induced changes (MENDES et al., 2020; MENDES et al., 2021). β -glucosidase participates in cellulose decomposition, whereas arylsulfatase participates in mineralizing sulfur-containing compounds. Quantifying the activity of these enzymes provides insights into soil functioning and the sustainability of the agroecosystem, making them particularly useful for assessing the impact of different cover crop systems (FARMAHA; SEKARAN; FRANZLUEBBERS, 2022).

Despite advances in understanding soil quality in areas under no-tillage systems (NTS), there are still gaps regarding the impact of different preceding crops on enzyme activity and the agronomic performance of commercial crops such as

maize. Assessing these effects is crucial to guide more efficient management practices, especially in regions like the Cerrado, where NTS adoption is well established, yet the long-term effects of cover crop systems on biological soil attributes remain poorly understood.

In light of this, the present study aimed to evaluate the effect of different cover crop species grown during the off-season on the growth, development, and yield of summer-grown maize, as well as on the activity of arylsulfatase and β -glucosidase enzymes in a Latossolo under long-term no-tillage management in the Cerrado.

MATERIALS AND METHODS

Characterization of the experiment site

The experiment was carried out at the Experimental Farm of the Federal University of Grande Dourados (UFGD), located in Dourados, Mato Grosso do Sul, Brazil (22°14' S, 54°49' W; altitude 458 m) (Figure 1). The soil at the site is classified as a Latossolo Vermelho Distroférico típico with a clayey texture, containing 638 g kg⁻¹ of clay, 211 g kg⁻¹ of silt, and 150 g kg⁻¹ of sand in the 0–30 cm layer (PIATI, 2022).

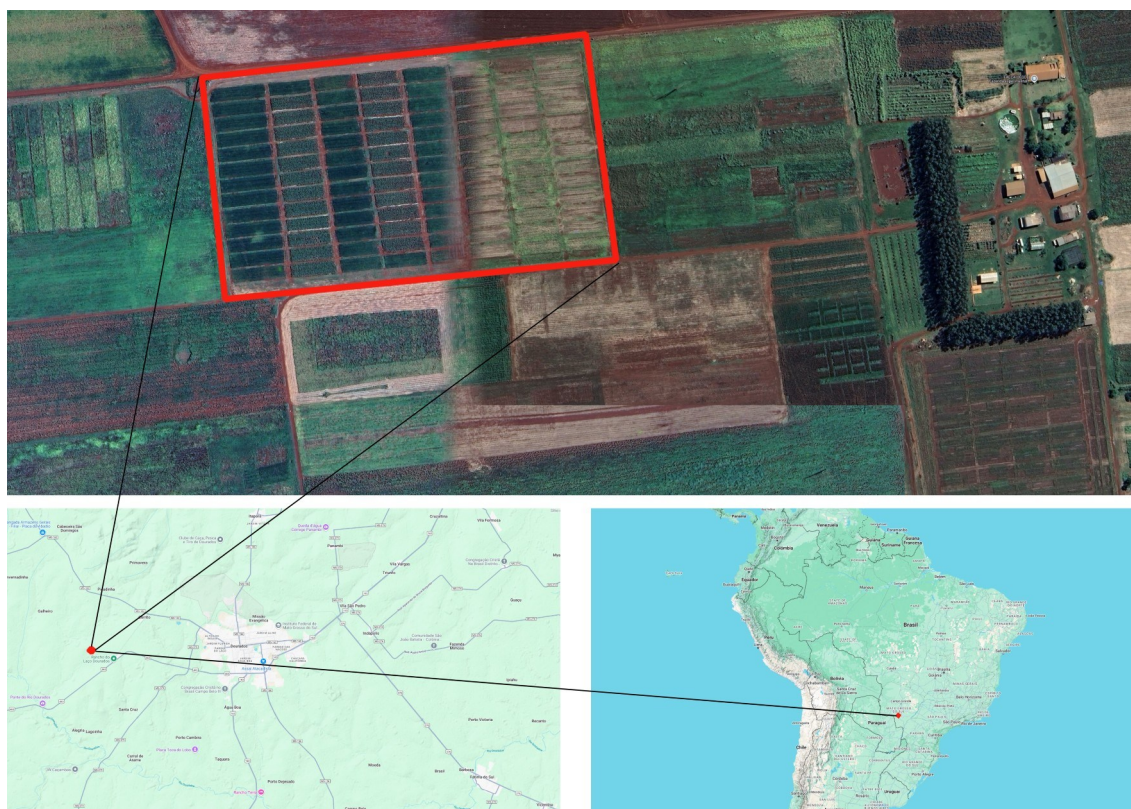


Figure 1. Location map of the experimental site. Source: Google Maps (2025).

According to the Köppen–Geiger classification, the local climate is Cwa, characterized as humid subtropical with hot summers and dry winters. The region's annual rainfall ranges from 1,400 to 1,500 mm, and the mean annual temperature is approximately 24 °C (FIETZ; FISCH, 2008). Climatic data for the 2021–2023 maize growing seasons are

presented in Figure 2.

The experimental area has been managed under a no-tillage system (NTS) since 2009, when the necessary adjustments for its implementation were made. The results of the soil analysis for the experimental area are shown in Table 1.

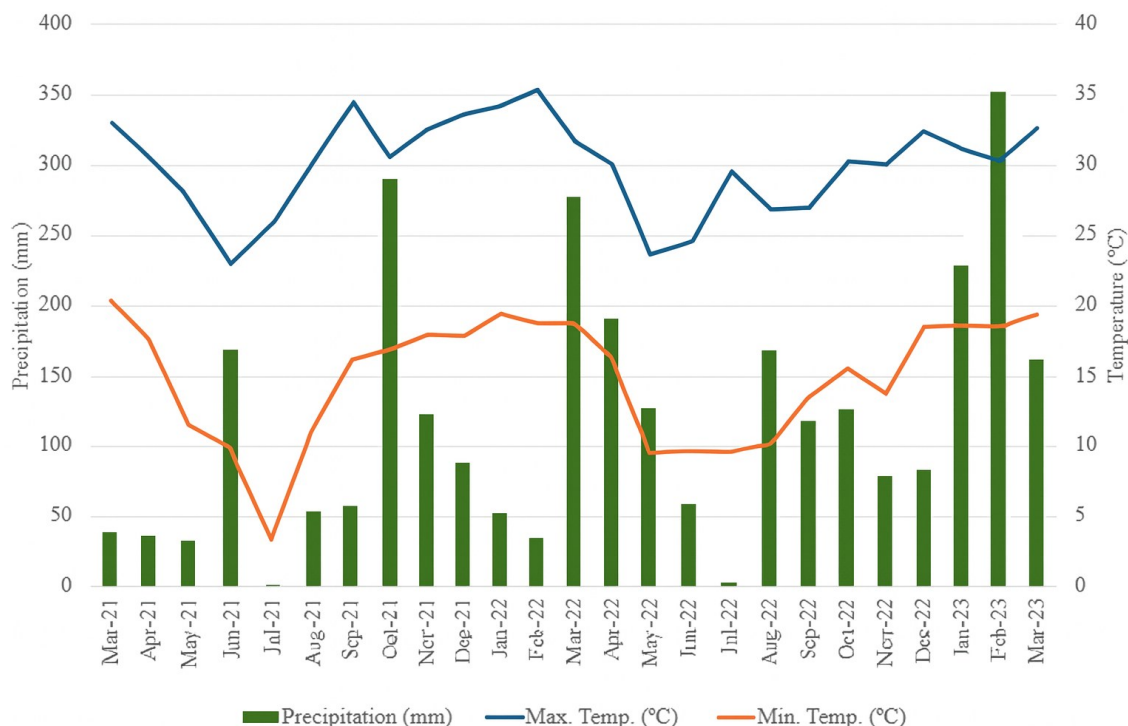


Figure 2. Rainfall, and maximum and minimum air temperatures from October 2021 to March 2023 in Dourados, MS, Brazil. Source: EMBRAPA (2024).

Table 1. Soil chemical properties in the 0–10 cm layer in Dourados, MS, Brazil (2024).

Treatments	pH	K ⁺	Ca ²⁺	Mg ²⁺	H ⁺ + Al ³⁺
	CaCl ₂	cmol _c dm ⁻³			
<i>Crotalaria ochroleuca</i> + Pearl millet + Buckwheat + Brachiaria	5.27	0.8	4.49	1.97	5.81
Niger	5.42	0.69	4.93	1.8	5.01
<i>Crotalaria spectabilis</i>	5.48	0.42	6.79	2.76	5.43
Common vetch	5.42	0.78	4.85	1.97	4.82
Forage radish	5.63	1.13	5.29	2.12	4.83
Treatments	P	SB	CEC	V	O. M.
	mg dm ⁻³	cmol _c dm ⁻³		%	g dm ⁻³
<i>Crotalaria ochroleuca</i> + Pearl millet + Buckwheat + Brachiaria	31.26	7.23	13.04	55.39	33.88
Niger	31.61	7.43	12.44	59.67	32.04
<i>Crotalaria spectabilis</i>	20.75	10.17	15.6	65.13	38.93
Common vetch	31.61	7.61	12.43	61.05	33.03
Forage radish	31.83	8.54	13.38	63.77	36.82

For the research conducted in this study, the fall–winter seasons of 2021 and 2022 and the summer seasons of 2021/2022 and 2022/2023 were evaluated, totaling two summer and two fall–winter crop cycles.

The randomized block design was adopted with five treatments (Table 2) and four replications. Each experimental unit measured 35 m in length by 13 m in width, totaling an area of 455 m².

The sowing of the intercropping of *Crotalaria ochroleuca* + pearl millet + Buckwheat + *Brachiaria*, and the

sole cultivation of *Crotalaria spectabilis*, Niger (*Guizotia abyssinica*), Common vetch (*Vicia sativa* L.), and Forage radish (*Raphanus sativus* L.) took place on March 18, 2021, and March 15, 2022. A fertilizer-seeder with eight rows spaced at 0.17 m was used to sow the autumn–winter crops. A seeding density of 20 seeds per meter was applied for all autumn–winter crops, which were flattened with a roller-blade. Afterwards, the biomass of the cover crops was assessed by cutting plants at soil level in two 1.0 m² samples per plot before the maize sowing.

Table 2. Sequence of experimental treatments for each crop year.

Fall/Winter 2021	Summer 2021/2022	Fall/Winter 2022	Summer 2022/2023
<i>Crotalaria ochroleuca</i> + Pearl millet + Buckwheat + Brachiaria	maize	<i>Crotalaria ochroleuca</i> + Pearl millet + Buckwheat + Brachiaria	maize
Niger	maize	Niger	maize
<i>Crotalaria spectabilis</i>	maize	<i>Crotalaria spectabilis</i>	maize
Common vetch	maize	Common vetch	maize
Forage radish	maize	Forage radish	maize

Fall–Winter Crops: Pearl millet (*Pennisetum glaucum* L.), *Crotalaria ochroleuca*, Buckwheat (*Fagopyrum esculentum* Moench), Brachiaria (*Urochloa brizantha*), Forage radish (*Raphanus sativus* L.), Niger (*Guizotia abyssinica*), *Crotalaria spectabilis*, Common vetch (*Vicia sativa* L.). Summer Crop: Maize (*Zea mays*).

The summer crops were sown on October 6, 2021, and October 20, 2022. The single-cross maize hybrid K9606 VIP3 was used, with a population density of 66,000 plants ha⁻¹ and a row spacing of 0.90 m. A maintenance fertilization was applied at sowing, consisting of 200 kg ha⁻¹ of an NPK 08–20–20 formulation enriched with 0.15% B and 0.50% Zn.

Weed control was carried out 30 days before maize sowing by applying glyphosate at a 3 L ha⁻¹ rate. During the week before sowing, 2 L ha⁻¹ of S-Metolachlor (960 g L⁻¹) and 200 mL ha⁻¹ of a non-ionic surfactant were applied. In the post-emergence stage, two applications of glyphosate were performed at 15 and 35 days after crop emergence. Pest control was conducted as required by the crop-specific needs.

Harvest and agronomic performance of maize

The maize harvest was carried out manually on February 21, 2022, and March 7, 2023, corresponding to the first and second years of the experiment, respectively. Harvesting was performed from the two central rows of each plot, each five meters long, which were threshed and weighed to determine grain yield per plot. Grain weight was adjusted to a moisture content of 13%, and a grain sample was used to determine the 1000-grain weight according to the *Rules for Seed Testing* (BRASIL, 2009).

To evaluate the agronomic performance of maize in the two growing seasons under crop rotation, plant height, first cob insertion height, and stem diameter were measured using a caliper. For the cobs, measurements included cob diameter, cob length, number of grain rows per cob, and grains per cob. In addition, the 1000-grain weight and grain yield were also assessed.

Evaluation of soil enzymatic activity

Soil samples were collected from the 0–10 cm layer in July 2022. Sampling was performed on and between the crop rows of the most recent cultivation, forming a composite sample that was subsequently air-dried and sieved through a 2 mm mesh. The samples were then sent to the Soil Microbiology Laboratory at Embrapa Cerrados to determine enzymatic activity.

The activities of the enzymes β -glucosidase and arylsulfatase were determined colorimetrically by quantifying the p-nitrophenol released by each enzyme after soil

incubation with a buffered solution containing specific substrates for each enzyme, following the method described by Tabatabai (1994). Enzymatic activity was expressed as p-nitrophenol micrograms per hour ($\mu\text{g PNP g}^{-1} \text{ soil h}^{-1}$). For each sample, two analytical replicates and one control were performed.

Data for all variables were subjected to analysis of variance to assess the effects of the crops. When significant, means were grouped using the Scott-Knott test at a 5% probability level, and the adjusted means were obtained with the aid of the emmeans function from the emmeans package in R software version 4.3.2.

RESULTS AND DISCUSSION

The treatments did not affect the agronomic traits or grain yield of maize; only the enzymes arylsulfatase and β -glucosidase activities were significantly influenced ($P < 0.05$) by the crop rotation treatments.

The mean values of maize plant height and stem diameter are presented in Table 3, averaging 2.04 m and 24.2 mm, respectively.

All plots were sown with the same hybrid at the same seeding density, resulting in a similar final plant stand across all treatments. This uniformity may have contributed to the lack of statistically significant differences in these traits, as maize plant height is a quantitative characteristic related to lodging tolerance due to its association with the plant center of gravity and is influenced by the final plant stand (CUI et al., 2022; STUBBS et al., 2023). However, the average plant height observed was lower than the range recommended by the hybrid developer, 2.25–2.40 m.

The types of crop rotation did not influence the first cob insertion height or cob length (Table 4), nor did they affect cob diameter and the number of grains per cob (Table 5). These results may be related to the stabilization of the agricultural system provided by the established rotation system, as in the study site, where only the sowing row is disturbed. At the same time, the soil remains permanently covered and receives continuous inputs of organic matter, contributing to nutrient cycling.

The evaluated treatments affected the 1000-grain weight and grain yield, with the means showing no statistically significant differences, as shown in Table 6.

Table 3. Mean values and 95% confidence intervals for plant height and stem diameter of maize plants during the 2022 and 2023 growing seasons under different preceding crops.

Treatments	Plant height (m)		Stem diameter (mm)	
	2022	2023	2022	2023
<i>Crotalaria ochroleuca</i> + Pearl millet + Buckwheat + Brachiaria	2.07 (1.99; 2.14)	1.99 (1.91; 2.06)	23.16 (21.75; 24.57)	26.57 (25.16; 27.98)
Niger	2.09 (2.03; 2.15)	1.97 (1.91; 2.03)	22.68 (21.60; 23.77)	24.97 (23.89; 26.06)
<i>Crotalaria spectabilis</i>	2.18 (2.12; 2.25)	1.97 (1.91; 2.04)	23.57 (22.37; 24.78)	26.23 (25.02; 27.44)
Common vetch	2.11 (2.05; 2.17)	2.02 (1.96; 2.09)	23.58 (22.38; 24.79)	24.23 (23.03; 25.44)
Forage radish	2.08 (2.02; 2.15)	1.99 (1.93; 2.06)	23.48 (22.27; 24.68)	25.22 (24.02; 26.43)

Table 4. Mean values and 95% confidence intervals for first cob insertion height and cob length of maize plants during the 2022 and 2023 growing seasons under different preceding crops.

Treatments	First cob insertion height (m)		Cob length (cm)	
	2022	2023	2022	2023
<i>Crotalaria ochroleuca</i> + Pearl millet + Buckwheat + Brachiaria	1.14 (1.05; 1.23)	1.05 (0.96; 1.14)	16.40 (15.48; 17.33)	15.84 (14.91; 16.77)
Niger	1.14 (1.07; 1.20)	0.98 (0.92; 1.05)	15.31 (14.59; 16.02)	17.02 (16.3; 17.73)
<i>Crotalaria spectabilis</i>	1.21 (1.14; 1.29)	0.99 (0.91; 1.06)	16.22 (15.43; 17.01)	17.50 (16.71; 18.29)
Common vetch	1.14 (1.07; 1.21)	1.09 (1.02; 1.17)	16.07 (15.28; 16.86)	16.23 (15.44; 17.02)
Forage radish	1.13 (1.06; 1.20)	1.03 (0.96; 1.10)	15.99 (15.20; 16.78)	16.40 (15.61; 17.19)

Table 5. Mean values and 95% confidence intervals for cob diameter and number of grains per cob of maize plants during the 2022 and 2023 growing seasons under different preceding crops.

Treatments	Cob diameter (cm)		Number of grains per cob	
	2022	2023	2022	2023
<i>Crotalaria ochroleuca</i> + Pearl millet + Buckwheat + Brachiaria	4.84 (4.67; 5.01)	4.91 (4.74; 5.08)	29.24 (26.89; 31.60)	32.09 (29.74; 34.45)
Niger	4.62 (4.49; 4.75)	4.88 (4.75; 5.01)	26.47 (24.66; 28.29)	33.64 (31.82; 35.45)
<i>Crotalaria spectabilis</i>	4.72 (4.57; 4.86)	4.99 (4.85; 5.14)	28.42 (26.41; 30.44)	35.80 (33.79; 37.81)
Common vetch	4.81 (4.66; 4.95)	4.86 (4.71; 5.00)	27.60 (25.59; 29.62)	31.00 (28.99; 33.01)
Forage radish	4.76 (4.61; 4.91)	4.84 (4.69; 4.99)	28.94 (26.93; 30.95)	33.11 (31.10; 35.12)

Table 6. Mean values and 95% confidence intervals for 1000-grain weight and maize grain yield during the 2022 and 2023 growing seasons under different preceding crops.

Treatments	Thousand grain weight (g)		Yield (Kg ha ⁻¹)	
	2022	2023	2022	2023
<i>Crotalaria ochroleuca</i> + Pearl millet + Buckwheat + Brachiaria	291.15 (267.69; 314.62)	292.17 (268.70; 315.63)	7378.62 (6204.32; 8552.93)	9130.47 (7956.17; 10304.78)
Niger	269.76 (251.69; 287.84)	306.53 (288.45; 324.61)	6083.94 (5179.15; 6988.72)	9428.38 (8523.6; 10333.17)
<i>Crotalaria spectabilis</i>	279.15 (259.10; 299.20)	320.35 (300.30; 340.41)	6833.33 (5829.9; 7836.77)	9556.94 (8553.51; 10560.38)
Common vetch	303.87 (283.82; 323.93)	308.00 (287.95; 328.05)	7315.28 (6311.85; 8318.71)	9370.83 (8367.4; 10374.27)
Forage radish	273.07 (253.02; 293.13)	291.62 (271.57; 311.68)	7038.89 (6035.45; 8042.32)	9173.61 (8170.18; 10177.05)

The difference in grain yield between the two evaluated years may be related to the low rainfall during the first year of cultivation, as shown in Figure 1. The stabilization of the agricultural system, as in this long-term experiment, combined with maintaining crop residues on the soil surface, can support high crop yield even in years of low rainfall. The vegetative cover provides multiple benefits, such as mitigating the impact of rainfall on the crops, reducing water evaporation, and consequently maintaining soil moisture, thereby improving the soil water-holding capacity

(SALOMÃO et al., 2020).

Regarding residue production, no statistically significant differences were observed among the evaluated treatments (Table 7). All treatments produced adequate amounts of residue, exceeding 6,000 kg ha⁻¹, a threshold that, according to Alvarenga et al. (2001), is sufficient to ensure good soil cover. Such coverage protects the soil from erosion, reduces water loss through evaporation, limits the presence of invasive plants, maintains soil thermal stability, and enhances soil microbial activity.

Table 7. Mean values of crop residue (kg ha⁻¹) and mean activities of arylsulfatase and β -glucosidase enzymes (μ g PNP g⁻¹ soil h⁻¹) under different preceding crops.

Treatments	Crop residue	Arylsulfatase	β -glucosidase
<i>Crotalaria ochroleuca</i> + Pearl millet + Buckwheat + Brachiaria	8256.65 ^{ns}	68.57 a	209.24 a
Niger	7266.50	49.26 b	174.46 b
<i>Crotalaria spectabilis</i>	8222.50	75.75 a	223.25 a
Common vetch	8520.00	71.00 a	218.75 a
Forage radish	7063.25	75.25 a	191.50 b

Means followed by the same letter belong to the same group according to the Scott-Knott test at a 5% probability level. NS indicates not significant.

The data obtained for arylsulfatase activity were classified as ranging from moderate to adequate, according to the scale proposed by Mendes et al. (2018) for Latossolos Vermelhos (Oxisols) of clayey texture in the Cerrado under annual cropping systems at the 0–10 cm soil layer, where activity is considered low ($\leq 30 \mu$ g PNP g⁻¹ soil h⁻¹), moderate (31–70 μ g PNP g⁻¹ soil h⁻¹), and adequate ($> 71 \mu$ g PNP g⁻¹ soil h⁻¹).

There were differences among the results, with the Niger treatment differing from the others. This outcome may be related to sulfur accumulation in the crop tissues, as the highest arylsulfatase enzyme activity values were observed in treatments containing cruciferous and leguminous species.

These species have a higher sulfur demand, which may explain the increased enzyme activity in these treatments.

According to Mauad et al. (2015), Niger has a lower sulfur requirement compared to other macronutrients, accumulating 47.23 mg of sulfur per plant, of which only 14% is exported in the achenes. Thus, since most sulfur remains in the soil, lower arylsulfatase activity is observed, in agreement with the results of Matsuoka, Mendes, and Loureiro (2003).

Furthermore, it is expected that the cultivated species directly influence arylsulfatase activity. The higher the sulfur demand of the crops, the greater the arylsulfatase activity in the soil (SHERENE, 2017). In this context, the highest arylsulfatase activity values were associated with crops

containing legumes and cruciferous species, which require approximately 40–50 kg ha⁻¹ and 40–45 kg ha⁻¹ of sulfur, respectively. This higher demand can reduce the available sulfur content in the soil, increasing arylsulfatase activity (MATSUOKA; MENDES; LOUREIRO, 2003).

Arylsulfatase is an important enzyme in the soil sulfur cycle, as it participates in the hydrolysis of organic sulfate esters, releasing sulfate ions that are essential for plants (RODRIGUES et al., 2022). Additionally, its activity has been used to indicate soil degradation, as it reflects variations in soil organic matter content (CHAVES et al., 2024).

Another important factor is the presence of crop residue, which positively influences arylsulfatase activity. Residues help maintain soil moisture and serve as a substrate for the enzyme, enhancing its activity. Miguel et al. (2020) report that arylsulfatase activity can be reduced by water deficit and decreases in organic matter content, the primary source of sulfate esters.

Despite the significant difference observed in the Niger treatment, the values of arylsulfatase enzyme activity remained within the range considered moderate to adequate. This is likely due to the benefits provided by the crop rotation system that has been in place at the site for over 15 years.

The β -glucosidase enzyme activity in the rotation systems that included Niger and forage radish did not differ from each other but was lower compared to the other treatments (Table 5). This reduced β -glucosidase activity can be attributed to the absence of legumes in these systems, in contrast to the other treatments.

Legumes enhance the soil microbial community by providing increased nitrogen through biological nitrogen fixation (BNF) and root exudates rich in carbon (KANTÉ et al., 2021). This greater availability of nutrients and energy can lead to increased microbial biomass and metabolic activity, and consequently, higher production of extracellular enzymes such as β -glucosidase. Thus, it is likely that the treatments containing legumes outperformed the Niger and forage radish treatments due to the probable increase in soil microbial biomass induced by BNF, which may have stimulated β -glucosidase production and activity, supporting the findings of Kanté et al. (2021) and Bicalho et al. (2024).

Despite the lower β -glucosidase activity observed in the Niger and forage radish treatments, all treatments exhibited values considered adequate, according to the scale proposed by Mendes et al. (2018), where low activity is $\leq 66 \mu\text{g PNP g}^{-1} \text{ soil h}^{-1}$, moderate activity ranges from 67–115 $\mu\text{g PNP g}^{-1} \text{ soil h}^{-1}$, and adequate activity is $>116 \mu\text{g PNP g}^{-1} \text{ soil h}^{-1}$.

β -Glucosidase activity is sensitive to management practices that alter the amount of organic matter on the soil surface (ACAR et al., 2018). These authors highlight that maintaining crop residues on the soil surface can increase β -glucosidase activity up to threefold due to the greater availability of substrate. This factor, combined with the management applied in the rotation systems, may explain the high values observed for the activity of this enzyme.

The presence of crop residues helps maintain soil moisture, a factor that favors β -glucosidase activity. Zhang et al. (2011) report that this enzyme is affected by soil moisture levels, with higher water availability increasing the enzyme's affinity for its substrate. Moreover, enzymatic activity can decrease by 10 to 80% with only a 10% reduction in soil moisture (SARDANS; PEÑUELAS, 2005). The high

β -glucosidase activity observed in the treatments reflects its role in cellulose decomposition in the soil, a process that releases β -D-glucose through the hydrolysis of cellobiose (TABATABAI, 1994).

Under the conditions assessed, the rotation systems did not significantly influence the yield components of maize. However, the systems with the mix of *Crotalaria ochroleuca* + pearl millet + buckwheat + brachiaria, as well as the sole-crop treatments of *Crotalaria spectabilis*, common vetch, and forage radish, showed high arylsulfatase activity. Regarding β -glucosidase activity, the mix of *Crotalaria ochroleuca* + pearl millet + buckwheat + brachiaria, along with the sole-crop treatments of *Crotalaria spectabilis* and common vetch, exhibited the highest enzyme activity, which is an indicator of soil biological quality.

These results reinforce the importance of crop rotation in no-tillage systems (NTS). The inclusion of legumes proved to be crucial for improving soil quality, an essential component of soil health, and for sustaining maize grain yield in the Cerrado.

CONCLUSION

The agronomic traits and grain yield of maize were not affected by intercropping with *Crotalaria ochroleuca*, pearl millet, buckwheat, and Brachiaria, nor by the sole cropping of niger, *Crotalaria spectabilis*, common vetch, or forage radish.

Crop rotation models influenced soil enzymatic activity under no-tillage conditions in the Cerrado. In the maize–niger rotation, arylsulfatase activity was reduced, and β -glucosidase activity was lower in soils following niger and forage radish.

REFERENCES

- ACAR, M. et al. Tillage effects on soil organic carbon, microbial biomass carbon and beta-glucosidase enzyme activity in a typic haploxerert soil. **Scientific Papers-Series Agronomy**, 61: 13-20, 2018.
- ALVARENGA, R. C. et al. Plantas de cobertura de solo para sistema de plantio direto. **Informe Agropecuário**, 22: 25-36, 2001.
- BICALHO, T. F. et al. Biological activity of soil cultivated with pigeon pea under different fertilization managements. **Ciência Rural**, 54: e20220635, 2024.
- BRASIL. Ministério da Agricultura, Pecuária e Abastecimento. **Regras para análise de sementes**. Brasília, DF: MAPA/ACS, 2009. 399 p.
- CHAVES, V. B. S. et al. Enzymatic Activity in Different Crop Succession Systems in the Cerrado Region. **Agronomy**, 14: 810, 2024.
- CUI, J. et al. Maize grain yield enhancement in modern hybrids associated with greater stalk lodging resistance at a high planting density: a case study in northeast China. **Scientific Reports**, 12: 14647, 2022.

- EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária. **Guia Clima: dados meteorológicos**. Dourados, MS: Embrapa Agropecuária Oeste, 2024. Available at: <<https://clima.cpao.embrapa.br/>>. Access on: Mar. 03, 2024.
- FARMAHA, B. S.; SEKARAN, U.; FRANZLUEBBERS, A. J. Cover cropping and conservation tillage improve soil health in the southeastern United States. **Agronomy Journal**, 114: 296-316, 2022.
- FIETZ, C. R.; FISCH, G. F. **O clima da região de Dourados, MS**. 2. ed. Dourados, MS: Embrapa Agropecuária Oeste; Embrapa, 2008. 92 p. (Documentos 92).
- GOOGLE. Google Maps. **Location map of the experimental site**. 2025. Available at: <<https://maps.app.goo.gl/P94i61YMwcGxeGt19>>. Access on: Nov.14, 2025.
- KANTÉ, M. et al. Soil Enzyme Activity and Stoichiometry: Linking Soil Microorganism Resource Requirement and Legume Carbon Rhizodeposition. **Agronomy**, 11: 2131, 2021.
- MATSUOKA, M.; MENDES, I. C.; LOUREIRO, M. F. Biomassa microbiana e atividade enzimática em solos sob vegetação nativa e sistemas agrícolas anuais e perenes na região de Primavera do Leste (MT). **Revista Brasileira de Ciência do Solo**, 27: 425-433, 2003.
- MAUAD, M. et al. Produção de matéria seca e acúmulo de macronutrientes na parte aérea das plantas de niger. **Revista Brasileira de Ciência do Solo**, 39: 533-540, 2015.
- MENDES, I. C. et al. **Bioanálise de solo: como acessar e interpretar a saúde do solo**. Planaltina, DF: Embrapa Cerrados, 2018. 24 p. (Circular Técnica, 38).
- MENDES, I. C. et al. Bioanálise de solo: a mais nova aliada para a sustentabilidade agrícola. **Informações Agronômicas NPCT**, 8: 1-11, 2020.
- MENDES, I. C. et al. **Tecnologia BioAS: uma maneira simples e eficiente de avaliar a saúde do solo**. 1. ed. Planaltina, DF: Embrapa Cerrados, 2021. 50 p. (Documentos, 369).
- MIGUEL, D. L. et al. Soil microbiological properties and enzyme activity in agroforestry systems compared with monoculture, natural regeneration, and native Caatinga. **Bioscience Journal**, 36: 1-16, 2020.
- MORAES SÁ, J. C. et al. No-till systems restore soil organic carbon stock in Brazilian biomes and contribute to the climate solution. **Science of The Total Environment**, 977: 179370, 2025.
- PIATI, G. L. **Atributos físicos do solo e características agronômicas da soja em sistemas de sucessão e rotação de culturas**. 2022. 61 f. Tese (Doutorado em Agronomia: Área de Concentração em Produção Vegetal) – Universidade Federal da Grande Dourados, Dourados, 2022.
- RODRIGUES, R. N. et al. Soil enzymatic activity under coffee cultivation with different water regimes associated to liming and intercropped brachiaria. **Ciência Rural**, 52: e20200532, 2022.
- SALOMÃO, P. E. A. et al. The Importance of Straw No-Tillage System for Soil Restructuring and Organic Matter Restoration. **Research, Society and Development**, 9: e154911870, 2020.
- SANZONOWICZ, C. **Solos do Cerrado**. 2021. Available at <<https://www.embrapa.br/agencia-de-informacao-tecnologica/tematicas/bioma-cerrado/solo>>. Access on: Apr. 20, 2024.
- SARDANS, J.; PEÑUELAS, J. Drought decreases soil enzyme activity in a Mediterranean Quercus ilex L. forest. **Soil Biology and Biochemistry**, 37: 455-461, 2005.
- SILVA, M. A. et al. Plantas de cobertura isoladas e em mix para a melhoria da qualidade do solo e das culturas comerciais no Cerrado. **Research, Society and Development**, 10: e11101220008, 2021.
- SILVA, M. A. et al. Sistema de plantio direto e rotação de culturas no Cerrado. **Research, Society and Development**, 11: e376111335568, 2022.
- SHERENE, T. **Role of soil enzymes in nutrient transformation-A review**. [s.l: s.n.], 2017. Available at: <https://www.biobulletin.com/articles/role-of-soil-enzymes-in-nutrient-transformation-a-review.pdf>. Access on: Apr. 10, 2024.
- STUBBS, C. J. et al. Moving toward short stature maize: The effect of plant height on maize stalk lodging resistance. **Field Crops Research**, 300: 109008, 2023.
- TABATABAI, M. A. Soil enzymes. In: WEAVER, R. W.; ANGLE, J. S.; BOTTOMLEY, P. S. (Eds.). **Methods of soil analysis. Part 2: microbiological and biochemical properties**. Madison: Soil Science Society of America, 1994. v. 5, p. 778-835.
- ZHANG, Y. et al. Kinetic parameters of soil β -glucosidase response to environmental temperature and moisture regimes. **Revista Brasileira de Ciência do Solo**, 35: 1285–1291, 2011.