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Soil chemical and physical attributes in an area with single maize and intercropped with *Panicum maximum*

Atributos químicos e físicos do solo em área com cultivo de milho solteiro e consorciado com Panicum maximum

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ABSTRACT: In the Cerrado Biom, a commonly used intercropping is between corn species and *Urochloa*, however, there are alternative grasses able to improve the corn intercropping, such as those of genus *Panicum*. Studies show that diversified crop rotation improves the efficiency of the agricultural system. Thus, it was aimed to evaluate the effect of the corn (*Zea mays*) and Zuri grass (*Panicum maximum* BRS Zuri) grown in the monoculture or intercropped under conditions with and without soil scarification in chemical and physical soil attributes. For this, an area under Red Oxisoil was used, in which part was scarified up to 30 cm deep and the other was not. In February 2020, corn and Zuri grass were planted in cultivar sole system or intercropped between the two species in compacted and scarified area, creating six evaluation areas. After the crop cycle, with corn harvest and Zuri grass crushing, soil sampling was carried out for evaluations at five points in each area. Corn in monoculture had lower soil moisture and greater resistance to penetration. And the soil without scarification had a higher C stock. The results showed that the Zuri grass using after soil revolving can be applied as a management strategy, looking to dry mass accumulation, bigger carbon stock and soil porosity, improving soil conditions for the summer crop. Besides that, the intercropped used improves the chemical soil conditions.

Keywords: Compaction; Scarification; Brazilian Cerrado; Physicochemical properties.

RESUMO: No bioma cerrado um consórcio comumente utilizado é entre as espécies de milho e *Urochloa*, porém, há gramíneas alternativas capazes de aprimorar o consórcio com milho, como as do gênero *Panicum*. Estudos mostram que a rotação diversificada de culturas melhora a eficiência do sistema agrícola. Assim, objetivou-se avaliar o efeito do cultivo consorciado de milho (*Zea mays*) e capim Zuri (*Panicum maximum* BRS Zuri) nos atributos físicos e químicos do solo em condição de manejo com e sem escarificação. Para isso, foi utilizada uma área sob Latossolo Vermelho, em que uma parte foi escarificada até 30 cm de profundidade e outra não. Em fevereiro de 2020 foi plantado milho e capim Zuri em sistema de cultivo solteiro ou consórcio agrícola entre as duas gramíneas em área compactada e escarificada, gerando seis áreas de avaliação. Após o ciclo das culturas, com colheita do milho e trituração do capim Zuri, foi efetuada a amostragem de solo para as avaliações em cinco pontos de cada área. O milho em monocultivo teve menor umidade do solo e maior resistência a penetração. E o solo sem escarificação teve maior estoque de C. Os resultados mostraram que o uso de capim Zuri após um revolvimento do solo pode ser utilizado como estratégia de manejo, visando acúmulo de massa seca, maior estoque de carbono e porosidade do solo, melhorando as condições de solo para a cultura de safra. E o uso de consórcio agrícola melhora as condições químicas do solo.

Palavras-chave: Compactação; Escarificação; Cerrado brasileiro; Propriedades físico-químicas.

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INTRODUCTION

No-tillage system (NT) is the main grain production system in the Brazilian Cerrado, which advocates minimal soil disturbance, preservation of straw on the soil surface and crop rotation, aiming to improve soil health and sustainability (Thapa *et al.,* 2023). The permanence of some species of cover plant, whether in the dry-season and summer crop, has been a strategy with good results for soil quality, that is, the cover crop promoted by these species protects the soil from erosion and adds organic matter to the soil (Almeida *et al.,* 2017; Salomão *et al.,* 2020) in addition to the creation of aeration biopores, which reduces the physical impediment for the subsequent crop (Guelfi *et al.,* 2013).

One of the obstacles to agriculture is soil compaction due to the traffic of large machines during the soil preparation and harvesting phases. In the Brazilian Central-West region, this situation is worrying, due to the regular distribution of rain only from October to April. This restricts the successive cultivation of soybeans and corn in short windows for planting and harvesting, which means that operations are carried out almost simultaneously and with the use of large machines for greater operational yield, increasing pressure on the soil, resulting in its compaction (Ferreira et al., 2023).

Grasses have shown potential to the soil, including that of biological soil decompaction. According to Lima *et al.* (2015), species of *Urochloa* are able to develop even in compacted soils with a bulk density level of 1.65 Mg m^{-3}, considered high. In addition to *Urochloa*, another forager species with potential for use in intercropping is *Panicum Maximus cv*. BRS Zuri, which has fast growth, good shading tolerance without changing its root system, keeping its roots vigorous even when cultivated with another crop (Januscklewicz *et al.,* 2021).

According to Shah *et al.* (2021), diversified crop rotation improves the efficiency of the agricultural system, as it reduces the incidence of insects, diseases and weeds, in addition to improving the physical and chemical structure of the soil. Therefore, it is necessary to explore new rotation combinations. Crop rotation increases microbial diversity in the soil, which improves soil fertility and production, due to changes in physical-chemical properties, in addition to acting in the biological control of phytopathogenic microorganisms, production of phytohormones, biological N fixation, among others benefits (Zhang *et al.,* 2023). Diversified crop rotation also increases the absorption and storage of water in the soil (Shah *et al.,* 2021).

Zuri grass fits into the category of an advanced species in tiller population restoration (Barbosa *et al.,* 2021), strongly influenced by nitrogen (N) content, linearly increasing its root mass, SPAD chlorophyll content and forage mass as the doses of N is increased (Gomide *et al.,* 2018). Testing the combination of plant species for the edaphoclimatic conditions of the Brazilian Cerrado becomes extremely relevant seen the need to improve crop rotation in the current production system, especially in the Brazilian Cerrado, which in most areas uses soybean/corn cycle per year.

It is believed that the combination of *Panicum maximum* with corn promotes better physical and chemical conditions for the soil, even in a compacted environment, when compared with the corn monoculture. And although plants grow better in scarified soils, scarification harms the carbon content of the soil. Thus, the objective was to evaluate the effect of intercropping maize (*Zea mays*) and Zuri grass (*Panicum maximum* BRS Zuri) on physical and chemical soil attributes under management conditions with and without soil scarification.

2 MATERIAL AND METHODS

2.1 EXPERIMENTAL AREA

The experiment was carried out in the areas of Fazenda São Benedito, in the city of Montividiu-GO, with a geographical location corresponding to -17.3456090 south latitude and 51.5217380 west longitude. The climate is classified as tropical savannah (Aw) by the Koppen classification (Lopes Sobrinho *et al*., 2020). The area under study has a flat topography with a slope of (3 %), and the soil is classified as a dystroferric Red Oxisol (Santos *et al.,* 2018), with its chemical characterization described in Table 1.

Table 1. Chemical characterization in the experimental area, before the implementation of dry season management.

Prof (m)	pH[1]	P[2]	K	S	Ca	Mg	sand	lime	clay
	-	----- mg dm^{-3} -----			cmol$_c$ dm^{-3}		----- g kg^{-1} -----		
0.00-0.20	5.7	23.7	68	4.6	4.89	1.44	675	50	275

[1] pH in CaCl$_2$; [2] P Mehlich

The study areas were cultivated in a no-tillage system in sequence of soy (summer) and corn (autumn-winter) for 10 years. Part of the area was scarified to a depth of 40 cm, 2 months before the treatment's implementation (area with scarification - With-SCA) and part of the area was preserved, characterizing the stationary area (area without scarification - Without-SCA).

After 15 days of the scarified area tilling, the soil penetration resistance (PR) was characterized in order to identify the compaction level. It is worth mentioning that the characterization was carried out 2 days after precipitation that wet the soil and left it in ideal conditions (friable soil) for PR evaluation (Table 2).

Table 2. Values of soil resistance to penetration (MPa) evaluated between the planting line and interline before installing the dry season management.

Soil depht (m)	Soil with scarification (With-ESC)	Soil without scarification (Without-ESC)
00.0-0.10	0.00	1.94
0.10-0.20	0.00	4.01
0.20-0.30	0.66	4.18
0.30-0.40	3.32	4.52
0.40-0.50	5.38	4.86
0.50-0.60	4.52	5.03

One year before the experiment, soil acidity correction was managed using 1.05 t ha^{-1} of calcitic limestone. The fertilizing management was annual and in 2020 (year of experiment collection) 215 kg ha^{-1} of N-P-K (05-37-00) and 165 kg ha^{-1} of KCl were used in the top-dressing fertilizing.

2.2 TREATMENTS

The experiment area consisted of 6 areas (treatments) with corn or Zuri grass in the monoculture or intercropping in soil with scarification (With-ESC) and without scarification (Without-ESC), installed in strips, with each measuring 5 m wide x 50 m long.

Seed distribution was carried out using an MS60-CR seeder coupled to a self-propelled sprayer, with an average range of 10 meters. The description of the treatments is in table 3.

Table 3. Description of treatments used in the study.

Treatments	Description
T1	Monoculture corn in soil with scarification
T2	Monoculture corn in soil without chiseling
T3	Monoculture Zuri grass in soil with scarification
T4	Monoculture Zuri grass in soil without scarification
T5	Corn and Zuri consortium in soil with scarification
T6	Corn and Zuri consortium in soil without scarification

2.3 SOIL ANALYSIS

In each area, five deformed (chemical analyzes) and undisturbed (soil density and porosity) soil samples were collected in layers of 0.00-0.10 and 0.10-0.20 m depth. Soil organic carbon was determined according to the method of Sims and Haby (1971), whose principle is the oxidation of organic matter in a wet process with potassium dichromate with H_2SO_4. The carbon stock was calculated based on the carbon content, density and equivalent mass layer of soil using equation by Veldkamp's (1994).

The soil penetration resistance (PR) was performed using a digital pentrometer (Penetrolog FALKER) which has two ultrasonic sensors that calculate the PR through a constant speed, and the distance between the sensor and a metal plate in its base. The evaluation of porosity bulk density was carried out according to the methodologies of Embrapa (2017), and the bulk density consisted of obtaining the dry mass value of the soil after being subjected to 105 °C for 24 hours. And the soil porosity corresponded to the pore volume of the soil, obtained by the difference in the weight of the saturated and oven-dried samples.

The Ca, Mg, P and K percentages were obtained following the methodology of Embrapa (2017), and for Ca and Mg the 1 M KCl extractor was used and determined by titration with EDTA 0.0125 M. Phosphorus and Potassium were obtained with the Mehlich extractor solution (HCl 0.05 M + H_2SO_4 0.0125 M) and analyzed by spectrophotometer and flame photometry, respectively. And for the extraction of sulfur (Sulfate), the method proposed by Vitti (1989) was used, consisting of the extraction of sulfate by phosphate ions (500mg of P/L) dissolved in 2 M acetic acid and quantification by means of a spectrophotometer (Embrapa, 2017).

In addition to soil analysis, dry mass was collected and evaluated after the cultivation of the dry season managements. For this, a 1 m^2 template was randomly thrown at four points per area, where the dry mass of the soil surface contained within the template was collected, whose material was dried in an oven and weighed. The amount of mass equivalent to 1 m^2 was transformed into Mg ha^{-1}.

2.4 STATISTICAL ANALYSIS

The statistical model used was that of subdivided plots for each soil depth, with soil management as the first factor (with and without scarification) and agricultural management as the second factor (monoculture cultivation or intercropping between corn and Zuri). Analysis of variance was performed between the factors, and when significant, an average comparison test (Tukey) was applied at 5% probability. The SISVAR program was used (Ferreira *et al.,* 2019).

Finally, a correlation network between of soil physical and chemical attributes in an area with different dry season managements was constructed, based on *Pearson's* correlation (threshold set at 0.60), in which the proximity between the nodes is proportional to the values of absolute correlation between the variables. These analyses were performed in the Rbio software (Bhering, 2017).

3 RESULTS AND DISCUSSION

Soil moisture was always higher in areas with a history of Zuri grass use, either in monocropping or intercropped cultivation when compared to monoculture corn use (Table 4), that is, in the area after Zuri grass cultivation, whether in monoculture or intercropping, the humidity was 27 % higher in these areas when compared to the soil under monoculture corn cultivation. This effect highlights the coverage potential of Zuri grass, generating greater preservation of soil moisture (Januscklewicz *et al.,* 2021).

Table 4. Average soil physical attributes under different dry season managements in Rio Verde/GO.

Crop Managment	**0.00-0.10 m**					
	Sm (kg kg^{-1})			RP (MPa)		
	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M
Corn in monoculture	0.07 bA	0.08 bA	0.08	2.25^{ns}	1.28^{ns}	1.76 a
Zuri in monoculture	0.27 aA	0.19 aB	0.23	0.80^{ns}	0. 87^{ns}	0.83 b
Corn and Zuri in intercropped	0.27 aA	0.20 aB	0.23	1.19^{ns}	0.85^{ns}	1.02 ab
M	0.21	0.16	-	1.42^{ns}	1.00^{ns}	-
	Bd (Mg m^{-3})			TP (m^{3} m^{-3})		
	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M
Corn in monoculture	1.27^{ns}	1.18^{ns}	1.23^{ns}	0.52^{ns}	0.55^{ns}	0.54^{ns}
Zuri in monoculture	1.30^{ns}	1.25^{ns}	1.28^{ns}	0.51^{ns}	0.53^{ns}	0.52^{ns}
Corn and Zuri in intercropped	1.41^{ns}	1.25^{ns}	1.33^{ns}	0.46^{ns}	0.53^{ns}	0.50^{ns}
M	1.33 A	1.22 B	-	0.50 B	0.54 A	-
	0.10-0.20 m					
	Sm (kg kg^{-1})			RP (MPa)		
	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M
Corn in monoculture	0.07 bA	0.04 bB	0.06	2.75^{ns}	2.80^{ns}	2.77 a
Zuri in monoculture	0.25 aA	0.17 aB	0.21	0.45^{ns}	0.77^{ns}	0.62 b
Corn and Zuri in intercropped	0.25 aA	0.18 aB	0.22	1.03^{ns}	1.03^{ns}	1.03 b
M	0.19	0.13	-	1.42^{ns}	1.53^{ns}	-
	Bd (Mg m^{-3})			TP (m^{3} m^{-3})		
	Without-ESC	With-ESC	M	Without-ESC	With-ESC	M
Corn in monoculture	1.27^{ns}	1.38^{ns}	1.32 a	0.52 abA	0.48 bA	0.50
Zuri in monoculture	1.17^{ns}	1.20^{ns}	1.18 b	0.56 aA	0.55 aA	0.56
Corn and Zuri in intercropped	1.37^{ns}	1.26^{ns}	1.31 a	0.48 bB	0.55 aA	0.52
M	1.27^{ns}	1.28^{ns}	-	0.52	0.53	-

Sm: soil moisture; RP: resistance to penetration; Bd: bulk density. With-SC: soil with scarification; Without-SCA: soil without scarification; TP: total porosity; M: medium value. Average followed by the same letter (lower case in the column and upper case in the line) do not differ from each other by Tukey's test at 5% probability; ^{ns}: not significant.

When comparing the effect of soil management, in general, moisture was higher in the compacted management than in the scarified one, because, in the scarified area, the aeration was higher, which facilitated the movement and loss of water in the soil between soil layers. It is expected that the permeability of the pore space is affected by soil management, mainly affecting the surface layers of the soil (Notaris *et al.,* 2021).

Higher soil moisture in areas with Zuri grass influenced lower soil penetration resistance (PR), confirmed by the correlation between both attributes of -0.49 and -0.71 in the layers of 0.00-0.10 (Fig. 1A) and 0.10-0.20 m (Fig. 1B), respectively. In the 0.00-0.10 m layer, PR values can be considered moderate (Arshad *et al.,* 1996), even for the area after monocropping corn culture, which presented a significantly higher PR of 1.76 MPa. However, in the 0.10-0.20 m layer, for this same area, the PR was 2.77 MPa, configuring a higher physical impediment to the successor crop when compared to the areas that used Zuri grass either in monoculture cultivation with 0.62 MPa or in consortium with 1.02 MPa. This result reinforces the potential use of forage species before planting the crop, as the root system of forage plants favors soil structure through the creation of aeration channels, smoothing the path for root growth of the succeeding crop, in addition to improve soil aeration.

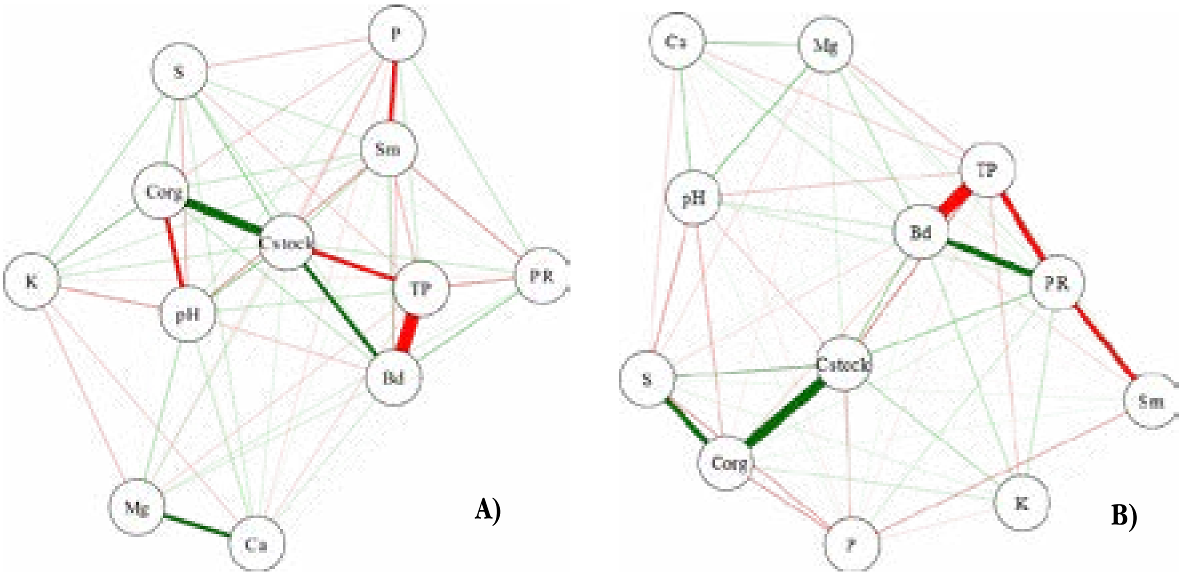

Figure 1. Correlation network illustrating *Pearson's* correlations between of soil physical and chemical attributes in an area with different dry season managements. A: 0.00-0.10 m; B: 0.10-0.20 m. Thicker and red lines represent the highest negative correlations (threshold set at 0.6 and p-values < 0.05). Thicker and green lines represent the highest positive correlations (threshold set at 0.6 and p-values < 0.05). Abbreviations – SM: soil moisture; Bd: bulk density; TP: total porosity; Corg: soil organic carbon; Csotck: soil organic stock; P: phosphorus; Ca: calcium; pH: hydrogenion potential; Mg: magnesium; K: potassium; S: sulfur.

Soil bulk density and porosity data in the 0.00-0.10 m layer showed a negative correlation of 0.98 (Fig. 1A) and differed between soil managements, with the area that was scarified having lower density and higher porosity total (Table 4). While in the 0.01-0.20 m layer, the effect of crop management was significant, with Monoculture Zuri cultivation providing lower soil density when compared to corn monocropping, reinforcing the same trend already reported for PR.

However, soil porosity in the 0.10-0.20 m layer showed a significant effect of the interaction between crop and soil management, and, in general, the planted area with monocropping Zuri left greater total porosity when compared to the other managements (Table 4). The growth of plant species with an aggressive root system shows a high turnover of tillers throughout the year, due to this stability in the appearance rate of tillers there is a correspondence of larger aeration channels, indicating whether this is a good strategy for dry season management, regardless of soil conditions, whether compacted or scarified (Duchini *et al.,* 2018).

In the assessment of carbon stock (Cstock), there was no significant effect of the interaction between crop management and soil factors, but they were significant in isolation (Fig. 2). Thus, it was possible to observe in the 0.00-0.10 m layer a higher Cstock in the area that had intercropped corn and Zuri with 6.43 kg m^{-2} and a lower Cstock in the area with monoculture corn with 5.14 kg m- two. Likewise, in the 0.10-0.20 m layer, the use of Zuri, whether in monocropping or intercropped cultivation, showed a higher Cstock.

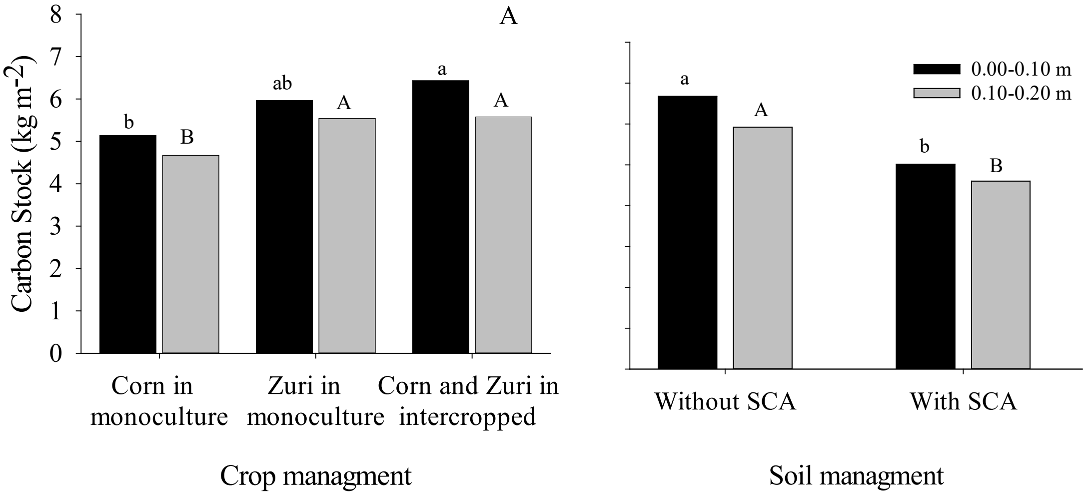

Figure 2. Soil Carbon Stock in an area with different crop and soil management at depths of 0.00-0.10 and 0.10-0.20 m. Average followed by the same letters (lower case for 0.00-0.10 m and upper case for 0.10-0.20 m) do not differ from each other by Tukey's test at 5% probability.

This result reinforces the strategy of Zuri grass using in the dry season, as in addition to benefiting the soil structure, it promoted higher accumulation of carbon in the soil, configuring an important action for soil conservation and mitigation of soil carbon by agriculture. Possibly the Zuri had its development stimulated by the well-drained soils of the Cerrado, thus producing a high content of plant mass, which, according to Sá *et al.* (2019), increased productivity of leaves and stems of forage plants, results in greater productivity of dry mass from the shoot and, consequently, greater amounts of carbon are kidnapped to increase productivity and storage in the soil via roots.

When evaluating the soil management, this one with scarification presented lower Cstock of the soil, being 24 and 22% lower when compared to the non-scarified soil in the layers of 0.0-0.10 and 0.10-0.20 m respectively (Fig. 2B). This is because soil turning actions promote the breakdown of aggregates and exposure of soil organic matter that is readily available to soil microorganisms, increasing mineralization and reducing its concentration in the soil profile (Kunde *et al.,* 2018; Salomão *et al.,* 2020).

The dry mass data showed that the use of Zuri grass left a higher amount of dry mass on the soil with 7.80 and 16.90 Mg ha^{-1} in the soil management without and with scarification, respectively. While smaller amounts were found in the area with monoculture corn with less than 3 Mg ha^{-1} (Fig. 3).

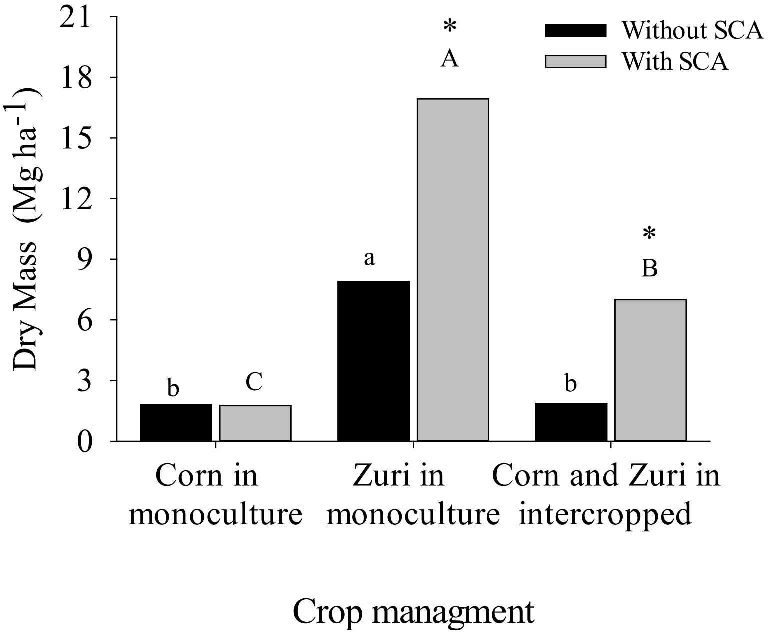

Figure 3. Dry mass production in areas with different crop and soil management. Average followed by the same letters (lower case compare management in compacted soil and upper case in scarified soil) do not differ from each other by Tukey's test at 5% probability. * Indicates when significant difference in soil management within each crop management.

If, on the one hand, soil scarification can result in losses of soil organic matter, on the other hand, it can improve soil aeration conditions and reduce physical impediments to plants. Based on this, it was possible to observe that the largest amounts of dry mass left by the Zuri grass, whether in monoculture cultivation or intercropping, were in the area with scarification (Fig. 3), whose result can be used as a management strategy, that is, when there is the scarification management, it is recommended to plant Zuri grass in the area in order to increase dry mass accumulation, as it is a culture with high dry mass production (Pedreira *et al.,* 2017). This was also highlighted in a study by Salomão *et al.* (2020), where they stated that the use of grasses in intercropped with other species such as legumes in the first years of implementation of the agricultural system is ideal, as it provides a higher increase in organic matter in the soil.

In the evaluation of soil chemical attributes, it was possible to observe, in the 0.00-0.10 m layer, a higher pH value of the soil after corn cultivation with 6.36 and lower in the area with Zuri and corn intercropping with 5.5 (Table 5). It is possible that this effect is explained by the higher number of organic acids excreted by forage species. In a study by Santos *et al.* (2011), evaluating soil quality in crop-livestock integration systems, the authors observed an increase in the pH value in this system. According to Ramos *et al.* (2010), the release of organic acids by grass straw is a positive effect on the soil, as it helps in the solubilization of less soluble fertilizer.

At the same depth, pH values were higher in the scarified area. There was a significant and negative correlation between pH and soil moisture (-0.48) indicating that increased humidity favors nutrients to be in the soil solution, being easily absorbed by plants. As a consequence of this, there is acidification of the medium.

Similarly, when the 0.10-0.20 m layer was evaluated, it was possible to observe lower pH values in the soil with a history of Zuri grass use, whether in single or intercropping when compared to single corn, but these differences were observed in the area that had scarification. This is because in this environment, the development of Zuri grass may have been favored, as evidenced by data on physical attributes, the increase in plant metabolism and the excretion of acids in the soil. The presence of organic acids in these areas can be verified by the negative correlation between carbon and pH, that is, as higher the number of organic compounds in the soil, as lower the pH values (Fig. 1B).

The P content in the soil in the 0.00-0.10 m layer differed with the different crop and soil managements, and in the soil without scarification, cultivation with Zuri grass may have consumed a higher amount of P, leaving 3.58 mg dm^{-3}, a very low amount when compared to single corn cultivation, with a soil amount of 15.17 mg dm^{-3} (Table 5), an amount considered adequate for the amount of clay in the soil according to Sousa and Lobato (2004). The K content was higher in the soil without scarification (Table 5). Scarification increases soil porosity, which facilitates the leaching of nutrients.

Table 5. Average chemical soil attributes under different dry season managements in Rio Verde/GO.

Manejo agrícola	0.00-0.10 m								
	pH (CaCl$_2$)			P (mg dm^{-3})			K (mg dm^{-3})		
	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M
Corn in monoculture	5.89^{ns}	6.83^{ns}	6.36 a	15.17 aA	16.11 abA	15.64	266.00^{ns}	1050.0^{ns}	185.00^{ns}
Zuri in monoculture	5.80^{ns}	6.14^{ns}	5.97 ab	3.58 bB	19.20 aA	11.39	192.00^{ns}	175.67^{ns}	183.43^{ns}
Corn and Zuri in intercropped	5.52^{ns}	5.58^{ns}	5.55 b	6.46 abA	7.62 bA	7.04	310.00^{ns}	175.75^{ns}	242.88^{ns}
M	5.74 B	6.19 A	-	8.41	14.31		256.00 A	152.14 B	-
	S (mg dm^{-3})			Ca (cmolc dm^{-3})			Mg (cmolc dm^{-3})		
	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M
Corn in monoculture	10.66^{ns}	6.33^{ns}	8.50^{ns}	3.65^{ns}	3.73^{ns}	3.69 ab	0.42^{ns}	0.47^{ns}	0.45^{ns}
Zuri in monoculture	10.87^{ns}	5.32^{ns}	8.10^{ns}	4.01^{ns}	3.86^{ns}	3.93 a	0.52^{ns}	0.47^{ns}	0.49^{ns}
Corn and Zuri in intercropped	10.98^{ns}	5.24^{ns}	8.11^{ns}	3.80^{ns}	2.88^{ns}	3.34 b	0.42^{ns}	0.34^{ns}	0.38^{ns}
M	10.84 A	5.63 B	-	3.82^{ns}	3.49^{ns}	-	0.45^{ns}	0.42^{ns}	-
	0.10-0.20 m								
	pH (CaCl$_2$)			P (mg dm^{-3})			K (mg dm^{-3})		
	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M
Corn in monoculture	4.34 bB	6.52 aA	5.43	4.91^{ns}	10.40^{ns}	7.66^{ns}	170.00^{ns}	153.80^{ns}	161.90^{ns}
Zuri in monoculture	5.67 aA	5.45 bA	5.56	1.83^{ns}	7.85^{ns}	4.84^{ns}	117.60^{ns}	88.20^{ns}	102.90^{ns}
Corn and Zuri in intercropped	5.36 aA	5.33 bA	5.35	4.38^{ns}	6.83^{ns}	5.60^{ns}	161.00^{ns}	148.40^{ns}	154.70^{ns}
M	5.12	5.77	-	3.71 B	8.36 A	-	149.53^{ns}	130.13^{ns}	-
	S (mg dm^{-3})			Ca (cmol$_c$ dm^{-3})			Mg (cmol$_c$ dm^{-3})		
	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M	Without-SCA	With-SCA	M
Corn in monoculture	19.95^{ns}	6.08^{ns}	13.02^{ns}	2.36 aB	3.15 aA	2.75	0.24 aB	0.42 aA	0.33
Zuri in monoculture	12.03^{ns}	6.53^{ns}	9.28^{ns}	2.94 aA	2.20 bA	2.57	0.34 aA	0.29 abA	0.31
Corn and Zuri in intercropped	15.13^{ns}	7.73^{ns}	11.43^{ns}	2.46 aA	2.49 bA	2.47	0.29 aA	0.27 bA	0.28
M	15.70 A	6.78 B	-	2.59	2.61	-	0.29	0.33	-

With-SC: soil with scarification; Without-SCA: soil without scarification. M: medium value. Average followed by the same letter (lower case in the column and upper case in the line) do not differ from each other by Tukey's test at 5% probability; ^{ns}: not significant

However, in conditions of scarified soil in the same layer, the use of Zuri grass monocropping promoted significantly higher P percentage in the soil with 19.20 mg dm^{-3} when compared to the use of corn and Zuri intercropping with 7.62 mg dm^{-3} (Table 5). It is possible that the combination of two species increased the soil P requirement (Mota *et al.,* 2021), as agricultural crops in a CL system tend to extract more nutrients from the soil (Costa *et al.,* 2015).

In the 0.10-0.20 m layer, the area with chiseling showed a higher P content in the soil with 8.35 mg dm^{-3}, being 44 % higher when compared to the area without chiseling (Table 5). The correlation analysis in this layer showed a negative correlation between the P content and the Corg and Cstock, which may indicate that the lower carbon contents in the scarified area led to the breakdown of aggregates and exposure of organic matter and release of P into the soil (Garland *et al.,* 2018; Salomão *et al.,* 2020).

For sulfur, there was an opposite trend in relation to soil management, that is, the area with scarification had lower S percentages in the two evaluated layers when compared to the area without scarification.

Thus, in the area with scarification, S values in the soil can be considered average values (5-9 mg dm^{-3}), while in the soil without scarification, they are high (>10 mg dm^{-3}) for the Brazilian Cerrado soil (Sousa and Lobato 2004). One hypothesis to explain this effect is that S has high mobility in the soil, therefore, scarification favors the element linked to soil loads to return to the soil solution, supporting its descent to deeper layers of the profile.

The S percentage showed a positive correlation with C, Cstock and a negative correlation with pH in the two soil layers evaluated, that is, as higher the S binding in the soil organic matter (SOM), as higher its accumulation. On the other hand, the more acidic pH keeps the oxides with a net positive charge, where the P will be bound and the S left over. Furthermore, very acidic soils favor the protonation of SOM functional groups leaving only fulvic acids soluble and this further increase sulfur mobility. P and S compete for soil loads, and P always wins the loads (Pias *et al.,* 2019).

The Ca content in the 0.00-0.10 m layer showed higher levels in the soil after monocropping Zuri grass cultivation with 3.93 cmolc.dm^{-3} and lower in intercropping management 3.34 cmolc.dm^{-3} (Table 5). Despite the difference between the environments, the amounts can be considered satisfactory (1.5-7.0 cmolc.dm^{-3} for a layer of 0-20 cm) according to Sousa and Lobato (2004) and therefore without chemical restrictions on plant development. In the 0.10-0.20 m layer, it was possible to observe a greater amount of Ca in the soil after growing single maize with 3.14 cmolc.dm^{-3}, the result of which was due to the higher pH in this area, verified by the significant correlation between Ca and pH of 0.44 (Fig. 1B).

The Mg content in the 0.10-0.20 m layer showed a similar tendency to that of Ca, with higher values in the soil after single maize cultivation (0.42 cmolc.dm^{-3}) and lower in intercropping (0.27 cmolc.dm^{-3}), however, the amounts can be considered low (<0.5 cmolc.dm^{-3}), indicating the need for liming management with dolomitic lime.

In general, soil chemical attributes showed favorable concentrations in areas with a history of agricultural intercropping, emphasizing the importance of this management for soil fertility, aiming at better nutrient utilization for the successor crop and lower production costs. Li et al. (2021) also concludes in their study that the wider adoption of intercropped crops can increase agricultural production and its long-term sustainability.

4 CONCLUSIONS

Corn in monoculture had lower soil moisture and greater resistance to penetration. And the soil without scarification had a higher C stock. The use of Zuri grass after soil revolving can be used as a management strategy, aiming at accumulating dry mass, higher carbon stock and soil porosity, improving soil conditions for the summer crop culture.

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