PRODUCTION OF CORN AND SOYBEAN CULTIVATED IN SUCCESSION AND ROTATION WITH DIFFERENT COVERAGES IN THE CERRADO

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ABSTRACT

Objective: To evaluate the dry mass production of coverings and the productivity of corn and soybeans grown in succession.

Method/design/approach: In a randomized block design, with subdivided plots, four covers were evaluated: Sunn hemp, Pearl millet, Signal grass and fallow; at two times of the year: spring and autumn/winter, with 4 repetitions. After cover management, the plots were subdivided, then corn and soybeans were sown on the residues of these plants. The dry mass production of the coverings and the productivity of corn and soybeans in each harvest were evaluated.

Result and conclusion: Pearl millet and Sunn hemp were the covers with the highest dry mass production, with Sunn hemp residues positively influencing the production of corn grown in succession and none of the plants used affected soybean production. Corn and soybean production increased as the system stages evolved until reaching the consolidation stage.

Research implications: the study proves that residues from different coverings that are used in rotation with corn can affect its productivity, especially when the covering comes from a Fabacea, as there is more nitrogen available in the soil in these areas, which come from of biological fixation carried out by these plants, while the same does not happen with soybeans.

Originality/value: The search for maintaining or increasing crop production using a more conservationist management system in the cerrado is a constant, a condition that is achieved when the appropriate cover plant is chosen.

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Keywords: Poaceae, Fabaceae, Plant Residues, Nutrient Cycling, Grain Production.

PRODUÇÃO DE MILHO E SOJA CULTIVADOS EM SUCESSÃO E ROTAÇÃO COM DIFERENTES COBERTURAS NO CERRADO

RESUMO

Objetivo: Avaliar a produção de massa seca das coberturas e a produtividade do milho e da soja cultivados em sucessão.

Método: No delineamento de blocos ao acaso, com parcelas subdivididas, foram avaliadas quatro coberturas: crotalária, milheto, braquiária e pousio; em duas épocas do ano: primavera e outono/inverno, com 4 repetições. Após o manejo das coberturas, as parcelas foram subdivididas, depois semeados milho e soja sobre os resíduos destas plantas. Foram avaliadas a produção de massa seca das coberturas e a produtividade de milho e soja em cada safra.

Resultado e conclusão: milheto e crotalária foram às coberturas com maior produção de massa seca, sendo que os resíduos da crotalária influenciaram positivamente a produção do milho cultivado em sucessão e que nenhuma das plantas utilizadas afetou a produção da soja. A produção de milho e soja aumentou à medida que os estádios do sistema foram evoluindo até atingir o estádio de consolidação.

Implicações da pesquisa: o estudo comprova que os resíduos das diferentes coberturas que são utilizadas na rotação com o milho podem afetar a sua produtividade, principalmente quando a cobertura for proveniente de uma Fabacea, pois há mais nitrogênio disponibilizado no solo nestas áreas, que são provenientes da fixação biológica realizadas por estas plantas, enquanto que o mesmo não acontece com a soja.

Originalidade/valor: A busca pela manutenção ou aumento da produção das culturas utilizando um sistema de manejo mais conservacionista no cerrado é uma constante, condição esta que vem obtida quando se escolhe a planta de cobertura adequada.


1 INTRODUCTION

In recent decades, the soybean (Glycine max (L.) Merrill) and maize (Zea mays L.) have become the most cultivated crops in the world, with Brazil occupying the first and third positions as the world's largest producer of these crops, with production of 135 and 113 million tons of grains in the crop2021/22, respectively, (Conab, 2022; Inacio and Cortez, 2023).

Soybeans and corn are also more produced crops in the Brazilian cerrado, which is still one of the main agricultural frontiers of the country, due to its high extent, since it occupies a total area of 204 million hectares, covering 13 Brazilian states, presenting high potential for expansion of the areas in production (Reatto et al., 2008).

Amongst the technological innovations adopted to produce soybeans and corn in a more sustainable way in the Cerrado, the direct sowing system (SSD) has stood out and contributed to the increase in the production of these crops in this biome (Kluthcouski and Stone, 2003). The mobilization of soil only in the planting line, the maintenance of residues on the surface and crop rotation, will protect the soil against erosion, provide nutrient cycling, increase diversity of organisms, which will improve soil quality (Ferreira et al., 2019; Zanatta et al., 2022).
According to Torres et al. (2022) the quantity and quality of this cultural waste deposited on the soil surface is one of the main components for the success of SSD in the Cerrado, however, producing straw in the region in the dry period and keeping the soil covered by the waste has been one of the main challenges for the success of SSD in this region (Torres and Pereira, 2013), since the decomposition of this waste is accelerated when compared to those observed in cold climate regions (Lal and Logan, 1995). One of the solutions to alleviate this problem is the cultivation of cover plants that are adapted to the climatic conditions of the region, as has been proven to occur with brachiaria, crotalaria, millet and the maintenance of spontaneous vegetation (fallow), which produce high residues in the dry or rainy period in the region (Andrade et al., 2009).

The corn and soybeans grown on these vegetable residues behave differently, because while the corn can decrease, maintain or increase its production (Carvalho et al., 2011; Assis et al., 2013; Torres e Pereira, 2014; Torres et al., 2015), the soybean seems to be indifferent to the type of cover or residues left by the majority of the crops that preceded it in the area, however, this information needs to be better evaluated (Chioderoli et al., 2012; Torres and Pereira, 2012).

Given this context, this study aimed to evaluate the production of dry mass of the different soil covers and the productivity of corn and soybeans grown in succession, after ten harvests in the Cerrado region of Minas Gerais.

2 THEORETICAL FRAME

Soybeans have become one of the main products that drives the country's economy, which is the world's largest producer, which produced 135 million tons of grains, in a cultivated area of 41,492 million hectares, where average productivity was 3.0 t ha$^{-1}$ in the 2021/22 crop. While corn for dry grain production reached the level of the most cultivated agricultural crop in the world, surpassing the one billion tons mark of grain produced, Brazil holds third place as the world's largest producer, with production of 113 million tons in the 2021/22 crop, in a total area of 21,581 million hectares, with an average productivity of 5.2 t ha$^{-1}$ (Conab, 2022; Inacio and Cortez, 2023).

Maize and soybeans have their productivity defined through the interaction of environment, plant and management, and in order to obtain high productivity the ideal is that the soil and climatic conditions for their cultivation are favorable in all their phenological stages, with this the management of the soil becomes an important factor to define the yield of the crop (Anjos et al., 2009).

In Brazil, corn and soybeans were cultivated in a conventional way for several years, where the turning of the surface layers of the soil by successive gradation was carried out to control the invading plants of the area, incorporate organic matter, correctives and fertilizers, increase the porous spaces and, with this, increase the permeability and the storage of air and water (Santiago and Rossetto, 2022). This type of management still occurs to the present day, however, it has been losing space among farmers, mainly after the system of direct sowing (SSD) has been transformed into a production system, which has evolved technologically in the last 50 years and has consolidated itself as one of the most modern systems of sustainable agricultural production for the Brazilian cerrado (Torres et al., 2018; Mazetto Junior et al., 2019, Febrapt, 2022), a region that accounts for more than 50% of the national corn and soybean production area in the country (Anjos et al., 22 005).

The rotation of commercial crops (corn and soybeans) with the cover plants should be planned in SSD, because the residues of these plants and the remnants of the root systems of these crops, mainly Poaceae, will provide greater aggregation and stability of the structure of this soil, diversify and increase the microbiota, increase the intake of organic matter, with this will provide maintenance or improvement of soil fertility (Pacheco et al., 2011; Torres et al., 2015).
With the introduction of the Fabaceae in rotation, the biological fixation of nitrogen (N) and greater availability of the element in the soil, besides other nutrients, however, the decomposition of the residues is accelerated in the Cerrado, due to the precipitation and temperature conditions that occur in the region and the lower carbon/N (C/N) ratio of the plants used for the production of straw (Pacheco et al., 2017, Silveira et al., 2021; Torres et al., 2021, 2022).

In the Brazilian regions that produce grain, and especially in the Brazilian cerrado, millet and brachiaria, crotalaria are the main cover plants used in the rotation system, whether in monocultures or in mixtures, which, added to the use of spontaneous vegetation (fallow) as a cover for the soil, are characterized by high mass production in the dry and rainy period, and their residues persist over the soil for longer after they have been handled. These are crops that protect the soil against erosive processes, have a high capacity for extracting nutrients from the soil, favoring nutrient cycling, mainly N and K, reducing leaching losses (Crusciol and Soratto, 2009).

The search for the sustainability of agricultural production is associated with the evolution of production systems, which should bring economic advantages to rural producers, maintaining or increasing production, without causing harm to the environment, based on these perspectives, the SSD has been shown to be the most suitable for the soil and climatic conditions of the cerrado (Torres et al., 2018). However, soybeans and maize when grown on the residues of different coatings may present different responses in relation to their development and their production (Torres and Pereira, 2014).

For soybeans, the results reported in the literature are controversial, since some studies have proven that soybeans when grown after crop rotation (commercial or cover plants) show a grain yield always higher when compared to soybeans in monoculture (Ciotta et al., 2002; Pedersen and Lauer, 2003; Chioderoli et al., 2012).

Assessing the yield of soybeans grown on different soil coverings, Torres et al. (2015) observed that no significant differences occurred when the crop was grown on any evaluated cover. Similar results were obtained by Pacheco et al. (2011), where they observed that the productivity of soybeans was not influenced when cultivated on the residues of brachiaria ruziziensis, brachiaria brizantha, millet, consortium brachiaria + guandu and fallow.

However, other studies highlight that depending on the predecessor plant and the rotation system used, there is no significant difference in the yield of soybeans (Yusuf et al., 1999; Fontaneli et al., 2000; Santos and Roman, 2001; Carvalho et al., 2004; Torres et al., 2008; Torres and Pereira, 2013; Santos et al., 2013).

With regard to corn the same does not occur, the crop almost always responds positively when cultivated on the residues of other plants, mainly Fabaceae, due to the greater availability of N in the soil.

Evaluating the productivity of the corn crop on different soil coverings in the Cerrado, Carvalho et al. (2004) quantified productivity values higher than 18%, when the crop was cultivated on crotalaria residues. Similar results were obtained by Torres et al. (2014), when evaluating the productivity of corn grown in succession to different coverings under direct sowing in the cerrado, where they observed that this productivity was superior when the crop was cultivated on the residues of millet ENA2 and pork beans.

3 METHOD

The study was developed in an experimental area at the Federal Institute of the Minas Gerais Triangle (IFTM), Campus Uberaba, located between the coordinates 19° 39’ 19” latitude South and 47° 57’ 27” longitude West, with 795 m altitude, in the period between 2000 and
2014, where were conducted were always maintained the same covers in the parcels throughout the period, rotating corn and soybeans after each harvest.

The climate of the region is classified as Aw, hot tropical, according to the updated Köppen classification (Beck et al., 2018), having hot and rainy summer and cold and dry winter. The region has a historical average annual precipitation and temperature of 1600 mm and 22.6 °C, respectively (Inmet, 2021). In the years 2001/02, 2004/5, 2005/06, 2006/07 and 2011/12 the accumulated precipitation in the year was 1230, 2315, 1675, 2138, 2180 and 1680 mm, while in 2000/01, 2008/09, 2009/10 and 2013/14 were 1970.7, 1853, 1759 and 1619 mm, respectively, according to data obtained at the IFTM Campus and Uberaba meteorological station.

The soil has been classified as dystrophic Red Latosol (Santos et al., 2018), sandy-loam texture, with arable layer (0 - 20 cm), 210 g kg⁻¹ of clay, 710 g kg⁻¹ of sand and 80 g kg⁻¹ of silt, which generally as chemical characteristics presents pH (H₂O) 5.9; 15.2 mg dm⁻³ of P (Mehlic mol)-1; 2 mm mm c dm⁻³ of K; 12 mmolc dm⁻³ of Ca²⁺; 4.0 mmolc dm⁻³ of Mg²⁺; 21 mmolc dm⁻³ of H⁺Al and 10 g dm⁻³ of organic matter (MO).

The design used was random blocks, with subdivided parcels, with four soil covers: crotalaria (Crotalaria spectabilis); millet (Pennisetum glaucum L.), brachiaria (Urochloa brizanthacv marandu) and fallow (spontaneous vegetation with a predominance of Poáceas) in parcels of 126 m² (7.0 x 18.0 m), with 4 repetitions. After desiccation of the roofs, the parcels were subdivided into areas of 63 m² (7.0 x 9.0 m) and sown maize and soybeans on the vegetable residues of these roofs, and commercial crops were rotated after each crop.

In all the years of cultivation carried out in this study, the same cover was always maintained in the experimental plots, only commercial crops were rotated.

The sowing of the cover plants has always been carried out mechanically, with Semina 2 sower, with 5 rows spaced 0.20 m, 25, 50 and 50 seeds per meter of crotalaria, brachiaria, millet, respectively (Figure 1).

Figure 1. Fertilizer sower used in planting millet, brachiaria, crotalaria (photo by the author) and other cover plants in the area, preceding the cultivation of soybeans and corn.

Source: Elaborated by the authors.
While spontaneous vegetation developed naturally from existing seed banks in the area, without any kind of mechanical or chemical control.

The cover plants were sown and cultivated at two times in these areas, in the autumn/winter period (April/June) in the 2001/02, 2004/5, 2005/06, 2006/07, 2008/09 and 2011/12 crops and in the spring (September/October) in the 2000/01, 2007/08, 2009/10 and 20013/14, always in the same place and time of planting, without application of any type of complementary chemical or organic fertilizer.

With the exception of brachiaria, which had a slower initial development, the other plants of roofing plants reached an average of 50% of full bloom, with about 100 days, and all the plants were sampled at the same time for evaluation of the dry mass in an area of 2 m² in each parcel. The fresh plant material was tested at 65 °C for 72 hours or until constant weight for determination of dry mass, then weighed and results expressed in kg ha⁻¹.

After the sampling of the cover plants for evaluation of fresh (MF) and dry mass (MS), crop management was performed, consisting of desiccation of the total area using the active ingredient N-(Phosphonomethyl) glycine 792.5 g kg⁻¹ (Roundup WGR) salt at a dose of 2 kg ha⁻¹ of the commercial product. The products were applied with traced bar sprayer, with flow of 250 L ha⁻¹ of syrup.

Corn and soya were always sown until the 30th of November of each year evaluated, on the residues of the toppings.

The corn seed recommended for the region was used, always with a semi-early cycle in all crops, sown with 3 seeds per meter, in the spacing of 0.45 m between rows, with 60,000 plants ha⁻¹. 380 kg ha⁻¹ of the formula 08-28-16 + 0.5% Zn was applied to sowing. In cover applied 100 kg ha⁻¹ of N and 80 kg ha-14 K, parcel at 20 and 40 days after sowing. For soybeans, the seed used was also recommended for the region of semi-precocious cycle, sown with 13 seeds per meter and spacing of 0.45 m between rows, with 300,000 plants ha⁻¹. Applied 200 kg ha⁻¹ of the formula 0-20-15 + 2.5% Zn in sowing.

Corn and soybeans had their productivity assessed along the four central lines, in an area of two m² per parcel. The mass values of the grains of the crops were corrected to 13% humidity and expressed in t ha⁻¹.

The assumptions of residue normality and homogeneity of residual variances were checked by the Shapiro-Wilk and Bartlett tests, respectively. The values of the characteristics assessed were analyzed for variance using the Agroestat statistical program. The F-test was applied for significance and, where significant, the averages of the cover plants were compared by the Scott-Knott (α=0,05) averaging pooling test.

4 RESULTS AND DISCUSSION

Analyzing the production of dry mass of brachiaria, millet, crotalaria and fallow cultivated in spring (rainy period) (September/October) in agricultural years 2000/01, 2007/08, 2009/10 and 2013/14, it was observed that for brachiaria there was variation between 2.0 and 10.6 t ha⁻¹, for millet between 3.9 to 12.2 t ha⁻¹, crotalaria between 2.1 and 10.5 t ha-1e for fallow between 2.1 and 7.2 t ha⁻¹. These values are similar to the values found in the literature in some other studies carried out in the cerrado, and in the majority of the results presented the high production of MS of these plants in this period is related to the rainfall that occurs in these regions.

Under natural conditions in the rainy season, brachiaria, millet and crotalaria have produced 7 to 12 t ha⁻¹, 6 and 13 t ha⁻¹ and 4 and 9 t ha⁻¹ of dry mass, respectively, which has provided high nutrient cycling when compared to other plants used in the region (Assis et al., 2013, Pacheco et al., 2013; Torres et al., 2014; Collier et al., 2018; Mazetto Junior et al., 2019), values similar to those found in this study, with a few exceptions.
Other studies also carried out in the same region highlight the high performance of the Poaceae when sown in the period that precedes the planting of summer crops. In Viçosa, MG, Perin et al. (2004) quantified values of 7.1 t ha\(^{-1}\) for millet and 9.3 t ha\(^{-1}\) for crotalaria, while Kliemann et al. (2006), in Santo Antônio de Goiás-GO, quantified MS production of 6.41 t ha\(^{-1}\) for brachiaria.

In the autumn/winter period (April/June) (dry period), when the roofs were sown soon after the harvest of the commercial summer crops, the plants had slower development and with MS production much lower, when compared to those obtained in the spring period (rainy period), with this in the crops 2001/02, 2004/05, 2005/06, 2006/07, 2008/09 and 2011/1, for brachiaria, heto, crotalaria and fallow, it was observed that MS production values ranged between 1.4 and 5.5; 1.5; 5.2 2.0 to 3.7 and 2.2 to 3.8 t ha\(^{-1}\), while in spring in years 2000/01, 2007/08, 2009/10 and 2013/14 ranged between 2.0 and 10.6; 2.1 to 10.5; 3.9 to 12.2 and 2 1 to 7.2 t ha-1, respectively (Figure 3).
Figure 3. Production of dry mass of cover and fallow plants, produced in the autumn/winter period (April/June), after the commercial crop harvest, in Uberaba, MG.

Source: Elaborated by the authors.

In Uberaba, MG in the Cerrado of Minas Gerais, Ceballos et al. (2018) highlight the difficulties in obtaining adequate amounts of plant residues from soil covers, grown after the harvest of commercial summer crops (March/April). It also points out that it is not always possible to cultivate them in the winter/spring period (May-October), due to the scarcity (May/July) and the irregularity of the rains (August/October) that occur in this period.

In Santo Antonio de Goias-GO, sowing the roofs at the end of March and evaluating 90 days after sowing, Pacheco et al. (2011), quantified MS production of 6.4, 3.9 and 1.6 t ha\(^{-1}\) for brachiaria (*Urochloa brizantha*), millet and fallow, respectively. In Planaltina-DF, Sodré Filho et al. (2004) recorded the production of 1.9 t ha\(^{-1}\) with millet, 2.4 t ha\(^{-1}\) with crotalaria and 0.7 t ha\(^{-1}\) in fallow in winter. Carvalho et al. (2004), in Selvíria-MS, observed values of 7.3 to 9.4 t ha\(^{-1}\) for millet, 3.5 to 5.3 t ha\(^{-1}\) for crotalaria and of 4.1 to 5.1 t for fallow. Nunes et al. (2006), in Diamantina - MG quantified production values of 4.0 t ha\(^{-1}\) for brachiaria and 3.6 t ha\(^{-1}\) with fallow, values close to those found in this study.

Evaluating the productivity of the cultivated maize on the residues of the roofs grown in spring (September/October) and autumn/winter (May/June), it was generally observed that the values were higher when the crop was sown on the crotalaria residues, which ranged from 6.7 to 11.0 t ha\(^{-1}\) and from 9.0 to 8.4 t ha\(^{-1}\), while the lower values occurred on the fallow residues, which ranged from 5.9 to 9.2 t ha\(^{-1}\) and from 6.1 to 9.2 t ha\(^{-1}\), respectively (Table 1), values higher than the national average productivity of 5.2 t ha\(^{-1}\).

Table 1. Production of corn grains in 10 consecutive harvests, cultivated on the residues of the cover plants (brachiaria, crotalaria and millet) and fallow, in the period between the 2000/01 and 2013/14 harvests, in Uberaba-MG.

<table>
<thead>
<tr>
<th>Coverage</th>
<th>Evaluated period</th>
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<tbody>
<tr>
<td>Brachiaria</td>
<td>6.5 a*</td>
</tr>
<tr>
<td>Crotalaria</td>
<td>6.7a</td>
</tr>
<tr>
<td>Millet</td>
<td>6.3 a</td>
</tr>
<tr>
<td>Fallow land</td>
<td>5.9 b</td>
</tr>
<tr>
<td>CV (%)</td>
<td>6.2</td>
</tr>
</tbody>
</table>

*Averages followed by the same letter in the column do not differ by 5% (Scott-Knott)

Source: Elaborated by the authors.
This productivity of the high corn is directly related to the high rainfall and its good distribution that occurred in the period, with the exception of the one observed in the 2001/02 crop, which associated with the high production of dry mass of the assessed covers, provided greater cycling of nutrients. The highlight of the production of corn occurred when the crop was cultivated on the residues of crotalaria, which is a plant with high biological nitrogen fixation, which after being managed, makes available a greater amount of N in the soil, with this, the corn that is a demanding crop in this nutrient, with high productive potential, responds well to this greater quantity of N available (Silveira et al., 2021).

Crotalaria can fix 150 to 165 kg ha\(^{-1}\) of N per cycle, cycling around 41 kg ha\(^{-1}\) of phosphorus (P) and 217 kg ha\(^{-1}\) of potassium (K) or higher (Mazetto Junior et al., 2019, Silveira et al., 2021, Torres et al., 2021, Torres et al., 2022).

Studies conducted in Uberaba-MG under the same soil and climate conditions, by Torres et al. (2008) and Torres e Pereira (2008) quantified the production of dry mass of brachiaria, millet and crotalaria of 6.0, 10.3 and 3.9 t ha\(^{-1}\), which accumulated high values of N (130.80; 165.55 and 118.11 kg ha\(^{-1}\)), P (13.30; 2222.60 and 10.80 kg ha\(^{-1}\)) and K (214.70; 218.90 and 59.20 kg ha\(^{-1}\)) in the rainy season, while in the dry season the production of dry mass for these same plants was 2.1, 3.6 and 3.7 Mg ha\(^{-1}\), which accumulated quantities of N (41.65; 55.75 and 76.385 kg ha\(^{-1}\)), P (2.33; 4.71 and 4.0 45.79; 56.47 and 39.11 kg ha\(^{-1}\)), respectively.

In Lavras-MG, Teixeira et al. (2009), quantified the dry mass of millet and the mixture millet + crotalaria at 6.9 and 12.45 t ha\(^{-1}\), which accumulated N (131.10 and 252.11 kg ha\(^{-1}\)), P (18.23 and 30.67 ha\(^{-1}\)) and K (161.25 and 210.45 kg ha\(^{-1}\)). ria-MS, Leal et al. (2013), evaluating the millet and crotalaria MS, observed production of 4.2 and 4.2 t ha\(^{-1}\), respectively, with accumulation of N (50.5 and 107.3 kg ha\(^{-1}\)), P (9.6 and 12.1 kg ha\(^{-1}\)) and K (49.2 and 72.5 kg ha\(^{-1}\)) in their residues, while Silva et al. (2017), in the same region, observed MS production of talaria of 19.7 and 11.4 t ha\(^{-1}\) in the years 2015 and 2016, which accumulated N (387.5 and 394.2 kg ha\(^{-1}\)), P (66.3 and 45.9 kg ha\(^{-1}\)) and K (396.0 and 192.7 kg ha\(^{-1}\)), respectively.

With regard to soybean production, different behavior from corn was observed, since the crop was not influenced by the residues of the predecessor crop from the second year onwards, for seven consecutive crops, with the exception of the first crop (2000/01), which occurred in the soon after the implantation of the no-till system in the area (Table 2).

**Table 2.** Production of soybeans in 08 consecutive crops, cultivated on the plant residues of brachiaria, crotalaria, millet and fallow, in the period between the 2000/01 and 2011/14 crops, in Uberaba-MG.

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Brachiaria</td>
<td>3.3 b*</td>
<td>0.6 a</td>
<td>3.6a</td>
<td>3.1a</td>
<td>4.9a</td>
<td>3.6a</td>
<td>3.7a</td>
<td>—</td>
<td>5.7a</td>
<td>—</td>
</tr>
<tr>
<td>Crotalaria</td>
<td>3.4 b</td>
<td>0.9a</td>
<td>4.0 a</td>
<td>3.3a</td>
<td>4.8 a</td>
<td>4.0 a</td>
<td>5.3 a</td>
<td>—</td>
<td>5.2 a</td>
<td>—</td>
</tr>
<tr>
<td>Millet</td>
<td>3.5a</td>
<td>1.2a</td>
<td>3.3a</td>
<td>3.0 a</td>
<td>4.0 a</td>
<td>3.3a</td>
<td>4.3 a</td>
<td>—</td>
<td>5.5 a</td>
<td>—</td>
</tr>
<tr>
<td>Fallow</td>
<td>3.5a</td>
<td>1.0 a</td>
<td>3.2a</td>
<td>2.8a</td>
<td>4.8 a</td>
<td>3.2a</td>
<td>3.7a</td>
<td>—</td>
<td>5.2 a</td>
<td>—</td>
</tr>
<tr>
<td>CV (%)</td>
<td>4.5</td>
<td>6.0</td>
<td>19.6</td>
<td>10.1</td>
<td>9.9</td>
<td>20.4</td>
<td>24.5</td>
<td>—</td>
<td>15.0</td>
<td>—</td>
</tr>
</tbody>
</table>

* Averages followed by the same letter in the column do not differ by 5% (Scott-Knott)

**Source:** Elaborated by the authors.

In the seven consecutive harvests, the productivity of soybeans grown on brachiaria residues ranged from 3.1 to 5.7 t ha\(^{-1}\), for millet from 3.0 to 5.5 t ha\(^{-1}\), for crotalaria from 3.3 to 5.3 t ha\(^{-1}\), and from 2.8 to 4.8 t ha\(^{-1}\), for fallow, values close to or higher than the national average of 3.0 t ha\(^{-1}\) for crop 2022/23, as highlighted by Conab (see 22). While in the 2001/02 crop, the production of
soybeans varied between 0.6 and 1.2 t ha\(^{-1}\) of the 2022/23 crop, which is due to the weak distribution of rainfall that occurred in the region in this period.

Similar results were observed in studies conducted in the southern region of Brazil, rotating soybeans with other winter or summer species, where no significant differences were observed in the yield of soybeans or in the components of the yield of this crop (Fontaneli et al., 2000; Santos and Roman, 2001) and others in the Brazilian cerrado (Carvalho et al., 2004; Torres et al., 2008; Chioderoli et al., 2012).

Assessing the yield of soybeans grown on different soil coverings, Torres et al. (2015) observed that no significant differences occurred when the crop was grown on any evaluated cover. Santos et al. (2013), in their studies of production systems with crop-livestock integration over five years, also found no difference in grain yield, mass of a thousand grains, height of plants and height of insertion of the first pods of soybeans.

However, some other studies have already proven that soybeans, when grown after crop rotation, have an always higher grain yield when compared to soybeans in monoculture (Ciotta et al., 2002; Pedersen and Lauer, 2003; Chioderoli et al., 2012). In another study, when soybeans were grown under no-till system, the yields of grains were higher in the wheat/soybean and vetch/corn rotation (2.9 t ha\(^{-1}\)) in the first crop or two consecutive summers of crop rotation (wheat/soybean, flax/soybean and vetch/corn (2.8 t ha\(^{-1}\)) (Santos et al., 1998).

This area has been cultivated in direct sowing system with corn and soybeans for 10 consecutive crops, being rotated with cover plants for 14 years, in this time the SSD has already passed the initial stage, transition and entered the consolidation stage, as described by Sá et al. (2004), with this it can be said that there was an increase in organic carbon content and the improvement of chemical quality (Pereira et al., 2013) and soil structural (Betiolí Júnior et al., 2012; Torres et al., 2022).

At this stage of consolidation of the SSD, with the improvement of the quality of the soil, there were constant increases in crop production, with corn maintaining a production above 8.0 t ha\(^{-1}\) (Table 1) and soybeans of 5.0 t ha\(^{-1}\), (Table 2) which are considerable productions of these crops for the Brazilian cerrado.

Similar results have already been observed in other studies, where the greater time of the area being cultivated under SSD has brought about the improvement of the physical, chemical and biological quality of the soil, with greater production of the crops cultivated in it (Pittelkow et al., 2015; Costa et al., 2016; Mazetto Júnior et al., 2019; Zanatta et al., 2022; Pinto et al., 2023; Torres et al., 2023).

5 CONCLUSION

Millet and crotalaria were the crops with the highest dry mass production in most of the evaluations carried out;

Corn, when grown on crotalaria residues, had the largest production of maize, while soybean production was not affected by residues from the predecessor crops;

The production of maize and soybeans increased as the direct sowing system stages were overtaken.

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