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Technical efficiency of forage production from residues of green corn (*Zea mays* L.) in Sergipe, Brazil

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ABSTRACT: There has been an investigation using the association between three soil tillage systems (conventional, minimum, and no-tillage) with different previous crops (Pearl millet, Sun hemp, pigeon pea, and cowpea) and combination of nitrogen fertilization with *Azospirillum brasilense* in order to assess the technical efficiency of growing green corn under different soil tillage systems associated with crops before the planting of green corn under the combined presence of nitrogen fertilization and *A. brasilense*. The experiment was carried out on the Experimental Farm of the Universidade Federal de Sergipe, municipality of São Cristóvão, state of Sergipe, Northeast region, Brazil, from February to October, 2020. The chosen design was conducted in experimental strips with divided subplots, where the strips were made of by the systems. The subplots where the crops were randomized within each strip in three replications. This experiment evaluated green corn regarding: a) plant height; b) total leaf chlorophyll content; c) dry biomass yield; d) dry matter; e) mineral matter; f) crude protein; g) neutral and acid detergent fiber; h) total digestible nutrients. The CT/Guandu/N treatment promoted a greater increase in corn plant height and chlorophyll content; MT/Pearl millet/I obtained higher dry biomass yield; GO NT/Cowpea/N had the highest dry matter content; MT/Guandu/I promoted higher crude protein. Neutral and acid detergent fiber, total digestible nutrients were better in NT/Guandu/I, NT/Cowpea, and MT/Cowpea, respectively. The objective of the study was to evaluate the technical efficiency of forage production from green corn residues.

Key words: *Azospirillum brasilense*; bromatological composition; green manures; no-tillage; soil management; *Zea mays* L.

Eficiência técnica da produção de forragem de resíduos do milho verde (*Zea mays* L.) em Sergipe, Brasil

RESUMO: Com o objetivo de avaliar a eficiência técnica do cultivo do milho verde da produção de forragem de resíduos de milho verde sob diferentes sistemas de cultivo do solo associados a culturas antecedentes ao plantio do milho verde sob presença combinada de adubação nitrogenada e *Azospirillum brasilense*, foram estudados a associação entre três sistemas de preparo do solo (cultivo convencional, mínimo e plantio direto) com diferentes culturas antecedentes (Pearl millet, crotalaria, guandu e cowpea) e combinação da adubação nitrogenada com *A. brasilense*. O experimento foi realizado na Fazenda experimental da Universidade Federal de Sergipe, na localidade de São Cristóvão entre fevereiro e outubro de 2020. Adotou-se o delineamento em faixas experimentais com subparcelas divididas, sendo as faixas compostas pelos sistemas e as subparcelas com as culturas aleatorizadas dentro de cada faixa em 3 repetições. Avaliou-se as alturas das plantas de milho verde, teor de clorofila foliar total, produtividade de biomassa seca, matéria seca, matéria mineral, proteína bruta, fibra em detergente neutro e ácido, nutrientes digestíveis totais. O CC/Guandu/N promoveu maior aumento na altura do milho e no teor de clorofila; CM/Pearl millet/I obteve maior produtividade de biomassa seca; GO PD/Cowpea/N teve maior teor de matéria seca; O CM/Guandu/I promoveu maior proteína bruta; A fibra em detergente neutro, ácido e os nutrientes digesíveis totais foram melhores no PD/Guandu/I, PD/Cowpea e CM/Cowpea, respectivamente.

Palavras-chave: *Azospirillum brasilense*; composição bromatológica; adubos verdes; plantio direto; manejo do solo; *Zea mays* L.

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Introduction

Corn (*Zea mays* L.) is a Poaceae family grass, originally from Mexico, with great adaptation to different soil and climatic conditions, due to its genetic variability (Cardoso et al., 2021). In recent decades, it has become the largest agricultural crop in the world, producing more than 1 billion tons and surpassing rice and wheat, its main competitors (Contini et al., 2019). In Brazil, it is estimated that in the 2022/2023 crop year corn will be grown on 21,972.9 hectares, corresponding to a production of 124,879.7 million tons with an average yield of 5,683 tons ha^{-1} (Conab, 2023), establishing itself as the third largest corn producer in the world and the second largest exporter with about 47 million tons (Seapa, 2023).

While the country ranked 3rd in the world, the Northeast produced in the 2nd harvest of 2023, 3,028.677 million tons of corn ha^{-1} presenting an average yield of 3,366 thousand tons, while Sergipe produced 749,153 thousand tons and obtained an average yield of 4,663 tons in the same period (IBGE, 2023). Both occupy the 4th position among Brazil regions (Conab, 2022a) and the most productive Northeastern states, respectively (Conab, 2022b). It is highly important for world agriculture, as it is one of the main cereal grains to be included in the basic diet of a large part of the population in Latin America, Asia, and Africa. Grains are consumed in their fresh form and processed foods, such as flaked flour, corn starch, and canned corn, but also in animal feed (Giordano et al., 2018), in the production of forage, energy, and industrial materials (Guo et al., 2018). However, there is no official record of green corn in Brazil, however, it is known that in 2018 world production was 9.1 million tons with an average yield of 8.1 Mg ha^{-1} (Nunes et al., 2022).

Green corn refers to the harvested corn containing 70 to 80% moisture (Cândido et al., 2020), 72% starch, 7 to 14% protein, 9% neutral detergent fiber, 0.06 to 0.45% of minerals, and 2.5 to 5% of ethereal extract (Santos, 2018). It is consumed and traded in Brazil throughout the year in the main consumer centers and, due to its good acceptance, it has received greater added value, surpassing that of corn in grain (Souza, 2017). It has also become an important source of forage for animal diet, so to guarantee the roughage fraction of the feed in sufficient quantity and quality for the adequate nutritional supply for animals during periods of food shortage, especially in regions with water deficit or low temperature (Santos et al., 2022).

In Sergipe, green corn is predominantly grown in areas that adopt the conventional cultivation system, using traditional technologies of soil tillage with mechanized agricultural implements. This system has made the environmental sector unsound through soil compaction (Assunção, 2019). According to Ayangbenro & Babalola (2021), the intensive use of land and the reduction of vegetation cover has resulted in the degradation of natural resources, especially in the reduction of soil fertility through the adoption of continuous monoculture and the use of inadequate equipment. In this context, there is an ever-growing concern with the environmental sector and the demand for renewable materials that can be used or replaced in the production chain to reduce the dependence on fossil energy resources, especially the agricultural residues from various crops (Scatolino et al., 2017).

It is estimated that, for each ton of processed corn, 700 kg of straw and 180 kg of cob are the by-products from production (Souza et al., 2019). These residues are provided from the industrial processing of green corn, consisting of straws, cobs, discarded whole ears, and ends of ears. All of which could be discarded in the environment or used as low-cost alternative food in animal diets, becoming an economically viable option for the producer (Cavalcante, 2018). In any case, the destination given to residues from the production of green corn has been a source of concern and experiments due to the impact they can cause on the environment (Mühl & Oliveira, 2022).

Thus, the introduction of different technologies whose aim is to maintain and/or raise the nutritional and productive level of corn, transcending the production residues in different agricultural regions in Brazil, has been a source of experiments, particularly when resulting from the association of different previous crops with corn inoculation and tillage systems, as observed in the study of Portugal et al. (2017) and Grunewald (2021).

These residues are usually part of the basis of the ruminant diets, where the dry matter intake is influenced by the digestibility of the feed, being responsible for maintaining the ruminal function in optimal range (Raffrenato et al., 2017) and nutritive value is determined by its chemical and physical composition, which may change according to the chemical, physical and structural factors added in the plant, the influence of the environment, and the edaphoclimatic conditions of the place (Lopes et al., 2017).

In this sense, studies that show different technological systems to enable the technical efficiency of agriculture sustainably with prevention and reduction of environmental, economic, and social impacts have been carried out and have shown favorable responses for the cultivation of corn, mainly in relation to partial or total substitution in the use of nitrogen inputs in the production, which is the main responsible for the high cost of production (Mortate et al., 2020).

Along these lines, the objective of this study was to evaluate the technical efficiency of green corn residues, to forage cultivation under different soil tillage systems associated with crops before the planting of green corn under the combined presence of nitrogen fertilization and *Azospirillum brasilense*.

Materials and Methods

The study was conducted on the Experimental Farm of the Universidade Federal de Sergipe - Campus Rural (10° 55' 24" S; 37° 11' 57" W), municipality of São Cristóvão, state of Sergipe, Brazil, from February to October 2020, in an experiment that has been conducted since 2001 using three cropping systems: conventional (CT), minimum (MT) and no-tillage (NT) associated with the planting of four crops before green corn and inoculation with *A. brasilense*, totaling 24 treatments. The results shown in this study refer to the 20th year of cultivation.

According to the Köppen and Geiger classification, the climate is As, characterized as rainy tropical with a dry summer season. The average annual rainfall is 1145 mm and the average annual temperature is 25.3 °C (Climate-Data, 2022). The meteorological indices of monthly average temperature and rainfall (mm) during the experiment are illustrated in Figure 1. The soil in the experimental area is a typical dystrophic Red-Yellow Argisol with sediments from the Barreiras group (Santos et al., 2018).

The chosen design was conducted in experimental strips with split-subplots (Gomes, 1987) in a 3 × 4 × 2 factorial scheme with 24 treatments, with soil tillage systems implanted in each strip (conventional tillage - CT; minimum tillage - MT; and no-tillage - NT) and in the subplots, four crops were planted before corn: Sun hemp (*Crotalaria juncea* L.); pigeon pea (*Cajanus cajan* (L.) Mill sp.); cowpea (*Vigna unguiculata* (L.) Walp.), and Pearl millet (*Pennisetum americanum* L.). The combination of 120 kg ha^{-1} of N without green corn inoculation and 60 kg ha^{-1} with green corn inoculation was used. Each strip had 830 m², split into 12 subplots with 60 m² (6 × 10 m) each.

The previous crops were manually sown in the subplots with three randomized repetitions, with a spacing of 0.5 m between rows and 0.2 m between plants. At 90 days after emergence, the previous crops were layered and incorporated into the soil according to the characteristics of each tillage system.

Green corn was mechanically sown in June 2020, using the Jumil pneumatic planter, model POP EX 2670, adopting the average spacing of 0.8 m between rows and 0.2 m between plants. The experiment used conventional BM 3066 from Biomatrix hybrid corn variety of dual purpose (green corn cob production and forage for silage), early cycle, with an average population of 55-70 thousand plants ha^{-1} (summer) and 50-55 thousand plants ha^{-1} (winter).

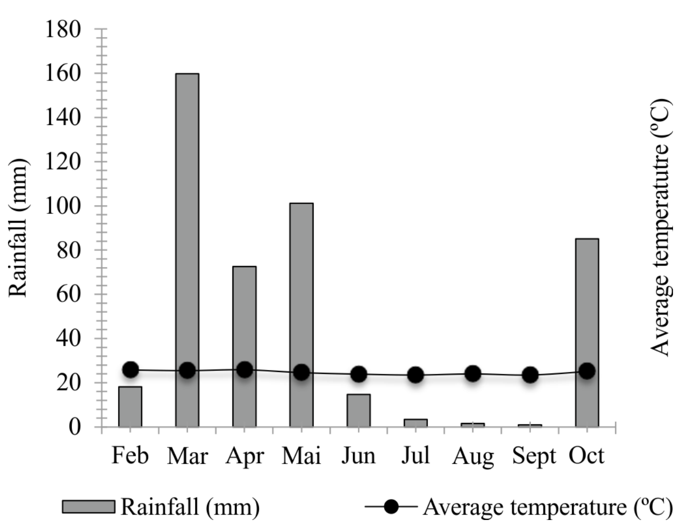


Figure 1. Data on monthly accumulated rainfall in millimeters (mm) and temperature in Celius degrees (°C) were recorded over the experiment from February 2020 to October 2020. São Cristóvão, Sergipe, Brazil.

The seeds were previously treated with CropStar insecticide (imidacloprid and thiodicarb) and inoculated in a shaded environment with commercial liquid product Azototal® (Total-bio) based on *A. brasilense* strains (AbV5 and AbV6) (guarantee of 2×10^{11} CFU L^{-1}), at a dose of 100 mL for every 25 kg of seeds, applied and homogenized directly on the grains, according to the manufacturer's specifications and sown immediately afterwards.

Mineral chemical fertilization was calculated based on soil analysis according to the recommendations of Sobral et al. (2007) for the corn crop. Nitrogen fertilization was applied in the form of urea at a dosage of 120 kg ha^{-1} (45% of N) and the inoculated treatment received 60 kg ha^{-1}. Phosphorus was applied in the form of triple superphosphate at a dose of 90 kg ha^{-1} (19% of P_2O_5), and potassium in the form of potassium chloride, at a dose of 110 kg ha^{-1} (59% of K_2O), split between sowing, at 30 and 45 days after emergence of the plants.

Green corn plants received conventional sprinkler irrigation for 40 minutes per day, with a supply of 7 mm water depth from Monday to Friday during the 85-day cycle.

The observations of yield parameters were carried out when the green corn plants reached the reproductive stage R3 (milky kernels), between 70 and 85 days after planting (DAP), containing between 70 and 80% moisture in the grains, evaluating: the height of five plants (PH, cm); total chlorophyll content (TCC) with the ClorofiLOG® portable digital chlorophyll meter model CFL 1030 (Falker Automação Agrícola®), where the data were expressed in FCI (Falker Chlorophyll Index); the yield of dry forage biomass (leaves + stem) (RBS) from the dry matter weight at 105 °C and transformed into kg ha^{-1}. The evaluations of the physicochemical parameters were as follows: determination of dry matter (DM); crude protein (CP) content through the Kjelhdahl method; mineral matter (MM) using the Weende method; neutral detergent fiber (NDF), and acid detergent fiber (ADF) (Deschamps, 1999); total digestible nutrients (TDN) using the equation % NDT= 105.2 – (0.667 × NDF) (Undersander et al., 1993).

Data were submitted to analysis of variance (ANOVA) and the means of the treatments were unfolded and compared through the test of Tukey at 5% probability with the aid of the SISVAR software (Ferreira, 2011). Data were also submitted to multivariate analysis employing principal component analysis (PCA) with the aid of the PAST software version 4.03 (Hammer et al., 2001) to verify the similarity or dissimilarity between the data and the importance of each variable over all analyzed variables.

Results and Discussion

The results showed that the height of the plants was not statistically influenced significantly by the interaction between the cropping systems with the previous crops and the fertilization, except for CT/Pearl millet/N, CT/Cowpea/N, and CT/Pigeon pea/ N, which statistically promoted greaterplant heights of 2.30, 2.35, and 2.46 m, respectively (Table 1). This increase in height specificallyrelates to the effects that nitrogen promotes on cell division, plant metabolism, and photosynthetic processes (Morais et al., 2017).

The smallest plants were identified as CT/Cowpea/I (1.80 m) and CT/Pigeon pea/I (1.56 m), as shown in Table 1. However, no statistic prominent difference was observed between these results and those obtained in the same treatment within the MT (2.00 and 2.06 m, respectively), as well as these results showed no number significant difference between the results obtained in the other treatments of the experiment. In a study carried out by Andrade et al. (2019), there was also no extreme difference in plant height when inoculated via seeds, via sowing furrow, and leaves.

Considering the total leaf chlorophyll content of green corn, it was observed that the values did not provide a statistically noteworthy difference between the interaction of the systems with the previous crops and fertilization. However, a response of nitrogen fertilization was observed in the interaction between CT/Pigeon pea/N and CT/Cowpea/N promoting higher values of 45.98 and 45.39 ICF, respectively, as shown in Table 2. The other treatments presented similar values, not seriously differing statistically from each other. There was no statistically significant effect of inoculation with *A. brasilense*. The values found for the chlorophyll index were higher than the range considered ideal and should be from 45 to 48 (Silva et al., 2021). Even with statistically similar values, it was observed that the CT/Pigeon pea/N treatment surpassed the CT/Cowpea/N by 1.3%, standing out in relation to another and other results obtained.

The rise in the chlorophyll content incorn plants can be explained by the fact that the chlorophyll index measured with chlorophyll meter presents a positive correlation with the nitrogen content as mechanisms of formation and fixation of chlorophyll in the plant are composed of nitrogen in more than 50% of the total leaf (Mortate et al., 2017; Segatto et al., 2017).

It can be seen that nitrogen fertilization was applied to corn in the three soil tillage systems, regardless of the species of the previous crop. So, it is possible that the chlorophyll content had a greater influence on nitrogen fertilization than of the previous crop, particularly because there is no statistic significant difference among the crops separately. However, it was expected that at least one of the legumes

Table 1. Summary of analysis of variance for plant height (m), BM - 3066 from Biomatrix, grown in the conventional, minimum, and no-tillage systems, using different previous crops and a combination of nitrogen fertilization and inoculation of green corn with *Azospirillum brasilense*. Experimental Farm of the Universidade Federal de Sergipe, São Cristóvão, Sergipe, Brazil, 2020 harvest.

Previous crops	Tillage systems					
	Conventional tillage		Minimum tillage		No-tillage	
	Fertilization					
	Nitrogen	Inoculated	Nitrogen	Inoculated	Nitrogen	Inoculated
Cowpea	2.35 Aa*	1.80 Ba	2.10 Aa	2.00 Ba	2.44 Aa	2.39 Aa
Pearl millet	2.30 Aa*	1.85 Ba	2.04 Aa	2.03 Aa	2.33 Aa	2.11 Aa
Sun hemp	2.31Aa	1.93 Aa	2.01 Aa	1.99 Aa	2.29 Aa	2.09 Aa
Pigeon pea	2.46 Aa*	1.56 Ba	2.14 Aa	2.06 Ba	2.11 Aa	2.07 Aa
Control	2.27 Aa	2.27 Aa	2.27 Aa	2.27 Aa	2.27 Aa	2.27 Aa

Datawith same upper-case letter in the row are not different from each other on Tukey test (p ≥ 0.05) among the soil tillage systems in the same crop and fertilization. The ones followed by same lower-case letter in the column are not different from each other on Tukey test (p ≥ 0.05) among the previous crops in the same soil tillage system and fertilization. * Indicates statistical difference on Tukey test (p > 0.05) among fertilization.

Table 2. Total chlorophyll content of green corn leaves, BM 3066 from Biomatrix, submitted to different soil tillage systems, depending on the use of previous crops, with nitrogen fertilization and inoculation of green corn with *Azospirillum brasilense*. Experimental Farm of the Universidade Federal de Sergipe, São Cristóvão, Sergipe, Brazil, 2020 harvest.

Previous crops	Growing systems					
	Conventional system		Minimum tillage		No-tillage	
	Fertilization					
	Nitrogen	Inoculated	Nitrogen	Inoculated	Nitrogen	Inoculated
Cowpea	45.39 Aa*	32.00 Ba	36.12 Aa	32.90 Aa	42.07 Aa	37.03 Aa
Pearl millet	38.14 Aa	29.26 Aa	34.72 Aa	29.43 Aa	35.20 Aa	33.04 Aa
Sun hemp	36.36 Aa	30.32 Aa	29.43 Aa	28.56 Aa	39.73 Aa	34.54 Aa
Pigeon pea	45.98 Aa*	29.52 Ba	36.11 Aa	31.69 Aa	34.30 Aa	33.73 Aa
Control	36.84 Aa	36.84 Aa	36.84 Aa	36.84 Aa	36.84 Aa	36.84 Aa

Datawith same upper-case letter in the row do not differ from each other on Tukey test (p ≥ 0.05) among the soil tillage systems, the same crop, and fertilization. The ones followed by same lowercase letter in the column did not differ on Tukey test (p ≥ 0.05) between previous crops, same soil tillage, and fertilization system. * Statistic difference in the row according to Tukey test (p > 0.05) between fertilization.

used as the previous crop would contribute to the highest total leaf chlorophyll index of green corn due to their rapid decomposition rate, therefore releasing nitrogen into the soil more rapidly (Grunewald, 2021).

A proof that nitrogen fertilization promoted higher chlorophyll content in corn can be found in a study carried out by Duarte et al. (2021) to evaluate the effect of inoculation with *Azospirillum* via seed in combination with different doses of nitrogen on the chlorophyll content in corn leaves. It has shown a significant difference statistically speaking. Andrade et al. (2019) also did not observe a statistic significant effect on the chlorophyll content when testing three different inoculation methods (via seed, via sowing furrow, and via leaves) on corn.

Similar to this study, Bravin (2018) also did not observe the effect of conventional cropping and no-tillage systems on the foliar chlorophyll content of corn plants; however, it was observed that the highest chlorophyll index was caused by nitrogen fertilization (49.6). Similar results were found by Gracia-Romero et al. (2018) after not observing a statistic prominent effect on corn leaf chlorophyll content among conventional tillage and no-tillage systems.

Regarding the dry biomass yield of green corn, it was possible to observe a statistical difference in the interaction between MT/Pearl millet/I, with a higher value of 48.76 tons ha^{-1}, in relation to the other treatments (Table 3). No significant results were observed in the triple interaction between soil tillage systems with previous crops and nitrogen fertilization on dry biomass yield.

It can be seen among the tillage systems that the interaction of CT/Millette/I and NT/Millette/I presented the lowest yields of corn dry biomass (35.96 and 37.03 tons ha^{-1}) of the study, indicating that in this treatment the soil tillage system did not have much influence considered directly and isolated and may be related to the organic matter content present in the soil for the three cropping systems.

The plants that did not receive any treatment (Control) showed dry biomass statistically similar to the plants of the plots that received the previous crops and nitrogen fertilization. These results demonstrate that the soil tillage systems and N-fertilization did not statistically significantly influence the production of dry biomass of green corn.

Although the dry biomass of green corn did not have a statistically significant influence on the previous crops alone, a higher biomass yield was observed in the treatment with millet (48.76 tons ha^{-1}), reaching approximately 30.37% more in relation to Sun hemp and Pigeon pea (37.40 tons ha^{-1}). This result may have been influenced by the greater land cover promoted by millet as it is grass compared to the other crops used in the study. It should also be considered that millet is an annual summer crop, with high nutritional value, low water requirement, and soil fertility (Jacovetti et al., 2018) and that it may have adapted well to the soil of the experimental area which has naturally poor fertility. A study carried out by Lima et al. (2021) to evaluate the microbiological attributes and the bacterial community of the soil under different cover crops, found that millet is one of the crops that present biomass (6.2 tons ha^{-1}) with greater potential to be used as cover crops, also because of its C/N ratio of 54/1.

Grasses are normally used to cover the soil, therefore promoting an improvement in its physical structure and increasing the availability of nutrients for the subsequent crop, particularly because of their high C/N ratio and also because they remain in the soil for a longer time (Biazatti, 2022). Although not a Fabaceae, millet accumulates and recycles about 163 kg of N ha^{-1}, through the amount of total N present in its biomass, 29.6 kg ha^{-1} of P, 89 kg ha^{-1} of K, 174 kg ha^{-1} of Ca, and 27.8 kg ha^{-1} of Mg (Sousa et al., 2019). According to Assmann et al. (2018) cover crops promote greater nutrient cycling in the system, depending on the developed root system, being able to promote deep rooting and the reuse of nutrients leached into the soil.

The dry biomass yield in this study was statistically significant when using half, the N dose with the inoculation, indicating the possibility of reducing N-fertilization by 50% without affecting the corn response to the production of dry biomass, promoting the less use of nitrogen fertilizers, and making this treatment economically viable for the producer. The inoculant promotes an increase in chlorophyll content,

Table 3. Dry biomass (BSY) yield of the aerial part of green corn, BM 3066 of the biomatrix, in tons ha^{-1} under different types of soil tillage, with previous crops and nitrogen fertilization and inoculation of green corn with *Azospirillum brasilense*. Experimental Farm of the Universidade Federal de Sergipe, São Cristóvão, Sergipe, Brazil, 2020 harvest.

Previous crops	Growing systems					
	Conventional tillage		Minimum tillage		No-tillage	
	Fertilization					
	Nitrogen	Inoculated	Nitrogen	Inoculated	Nitrogen	Inoculated
Cowpea	37.15 Aa	34.40 Aa	36.90 Aa	36.73 Ab	36.95 Aa	37.20 Aa
Pearl millet	36.66 Aa	35.96 Aa	36.90 Aa	48.76 Aa*	36.13 Aa	37.03 Ba
Sun hemp	36.96 Aa	37.40 Aa	36.90 Aa	36.93 Ab	37.10 Aa	37.13 Aa
Pigeon pea	37.40 Aa	37.10 Aa	36.96 Aa	37.10 Ab	36.13 Aa	37.23 Aa
Control	36.66 Aa	36.66 Aa	36.86 Aa	36.66 Ab	37.06 Aa	36.66 Aa

Data with same upper-case letter in the row do not differ from each other on Tukey test (p ≥ 0.05) among the soil tillage systems, same crop and fertilization. The ones followed by same lower-case letter in the column do not differ on Tukey test (p ≥ 0.05) between previous crops, same soil tillage and fertilization system. * Indicates statistical difference on Tukey test (p > 0.05) between fertilization.

biomass production, plant height, and corn yield (Skonieski et al., 2017) through root development, promoting greater nutrient uptake and consequently acting on crop development. Nevertheless, the sole use of the bacteria does not completely replace N fertilization in the plant (Morais et al., 2017).

These results differ from those obtained by Duarte et al. (2021) who did not observe an effect statistically significant of the inoculation or the combination of the inoculant with different N doses on the corn dry biomass yield. On the other hand, the use of N doses adopted in the experiment showed utter prominence.

Regarding the green corn forage dry matter content (DM) in the experiment, it was possible to observe that there was no direct and isolated effect of the tillage systems associated with the previous crops. However, nitrogen fertilization had a pounding effect as well as no effect of inoculation with *A. brasilense* (Table 4). The highest DM values obtained were 88.26 and 88.07% in NT/Cowpea/N and NT/Crotalaria/N, respectively. However, the first treatment surpassed the second by 0.21%, while the lowest content observed in the experiment was 85.59% in NT/Sun hemp/I.

The DM content is usually related to the age of the plant, therefore older plants will produce high DM content with low digestibility such as lignin, cellulose, hemicellulose, and other nutritional components (Burin, 2018). In an experiment carried out by Morais et al. (2017), it was observed that DM of leaves and stems had a significant effect with N fertilization in corn, unlike the combination of N with inoculation, with no statistic effect. There was also no statistically significant effect of inoculation via seed, sowing furrow, and leaf on the total dry matter of corn (Andrade et al., 2019). Both results corroborate the ones coming from this experiment, in which there has been observed an effect of nitrogen fertilization. Nonetheless, there was no effect of inoculation. There was neither an important effect on the mineral content of green corn with the triple interaction of soil tillage systems with previous crops and fertilization; nor there was on previous crops and fertilization in any treatment investigated separately. Considering the soil tillage systems, it was possible to observe the lack of statistically significant difference in the NT, regardless of the crop and fertilization, but higher and statistically similar values of 9.27 and 8.83% were obtained in the NT/Cowpea/N and NT/Pearl millet/I, respectively, in relation to the results found in the other systems. Diversely, an increase of 4.98% of the first treatment in relation to the second also came to light. The lowest content was 0.06 in MT/Cowpea/N and MT/Pigeon pea/N. In MT, lower values of minerals were observed in the treatment with cowpea (0.06%), Pearl millet (0.10%), and Sun hemp (0.08%) under nitrogen fertilization. In CT, higher mineral content was observed in the interaction of CT/Pigeon pea/N (2.74%) and a lower content of 1.92% in CT/Cowpea/N. Not with standing, these results did not differ statistically from the values detected in the interaction between Pearl millet/N and Sun hemp/N, as shown in Table 4. The highest mineral content (9.27%) observed in NT/Cowpea/N can be explained by the higher content of organic matter present in the no-tillage system as the minerals correspond to the amount of organic matter present in the forage.

Concerning crude protein content, no statistically significant effect was observed in any treatment, yet the highest content found was 4.43% in MT/Pigeon pea/I (Table 4). This percentage may have been caused by the higher

Table 4. Dry matter (DM), mineral matter (MM), nitrogen (N), and crude protein (CP) contents in the aerial part of green corn, BM - 3066 from Biomatrix, grown in different tillage systems with previous crops and fertilization nitrogen and green corn inoculation. Experimental Farm of the Universidade Federal de Sergipe, São Cristóvão, Sergipe, Brazil, 2020 harvest.

Previous crop	Dry matter (%)		Mineral matter		Crude protein (%)	
	Fertilization					
	Nitrogen	Inoculated	Nitrogen	Inoculated	Nitrogen	Inoculated
			Conventional tillage system			
Cowpea	87.99 Aa	86.99 Aa	1.92 Ba	2.73 Aa	3.62 Aa	3.21 Aa
Pearl millet	85.83 Aa	87.68 Aa	2.52 Aa	2.90 Aa	2.99 Aa	3.03 Aa
Sun hemp	88.71 Aa	88.82 Aa	2.32 Aa	2.93 Aa	2.74 Aa	3.28 Aa
Pigeon pea	88.08 Aa	87.13 Aa	2.74 Aa	1.98 Aa	3.15 Aa	2.81 Aa
			Minimum tillage system			
Cowpea	86.38 Aa	87.4 Aa	0.06 Ba	2.38 Aa	3.20 Aa	2.95 Aa
Pearl millet	86.72 Aa	87.68 Aa	0.10 Ba	2.81 Aa	3.12 Aa	3.05 Aa
Sun hemp	87.71 Aa	87.78 Aa	0.08 Ba	3.30 Aa	3.44 Aa	3.19 Aa
Pigeon pea	88.10 Aa	87.57 Aa	0.06 Aa	2.95 Aa	3.31 Aa	4.43 Aa
			No-tillage system			
Cowpea	88.26 Aa*	85.77 Ba	9.27 Aa	4.99 Aa	3.62 Aa	3.93 Aa
Pearl millet	88.39 Aa	88.12 Aa	7.36 Aa	8.83 Aa	3.29 Aa	3.15 Aa
Sun hemp	88.07 Aa*	85.59 Ba	7.87 Aa	3.77 Aa	3.53 Aa	3.10 Aa
Pigeon pea	87.90 Aa	88.19 Aa	5.93 Aa	4.94 Aa	3.78 Aa	3.62 Aa
Control	87.80 Aa	87.80 Aa	3.42 Aa	3.42 Aa	5.93 Aa	5.93 Aa

Data with same upper-case letter in the row do not differ from each other on Tukey test (p ≥ 0.05) among the soil tillage systems, same crop, and fertilization. The ones followed by same lower-case letter in the column do not differ on Tukey test (p ≥ 0.05) between previous crops, same soil tillage, and fertilization system. * Indicates statistical difference by the test of Tukey (p > 0.05) between fertilization.

percentage of stems in relation to leaves and the non-inclusion of ears in the sample. Protein contents ranged from 2.74 to 4.43%, which was considered below the acceptable levels of 7%, the minimum threshold to meet the requirement of rumen microorganisms (Van Soest, 1994; Burin, 2018). Furthermore, Delevatti et al. (2019) regarded an effect of nitrogen fertilization on the crude protein content of Marandu, which may have been caused by the increase in amino acids and protein synthesis. Although no effect of any previous crop and fertilization was observed in this study with green corn, the effect observed in the previous study may also have influenced the action of pigeon pea as it is a legume and the effect of inoculation as it was applied in combination with half the recommended dose of nitrogen.

Regarding neutral detergent fiber, there is no paramount corollary between the soil tillage systems and the previous crops. None the less there has been a significant influence of the inoculation in the NT/Pigeon pea/I, which statistically differed from the other treatments, reaching a higher value of 78.96% of NDF, as it can be seen in Table 5; unlike MT/Cowpea/N, which had the lowest content of 65.86% of NDF. Along with Silva et al. (2021) there was no significant outcome in nitrogen fertilization applied at different doses and inoculation alone, nor in their interaction on the NDF content of corn silage.

The content of NDF corresponds to the cellulose, hemicellulose, and lignin fractions found in the plant. Besides, they are related to the voluntary consumption of the animals. Values greater than 55 to 60% present a negative correlation with the DM digestibility (Van Soest, 1994), and with the crude protein content, and are positively correlated with the lignin content (Burin, 2018). Thus, even the forage with the lowest NDF content in the experiment did not reach the ideal values that would result in achieving a forage with good digestibility.

By the same token, there was the unlikelihood on inspecting and expressive effect of the interaction of the systems with the crops on the levels of ADF in CT and MT; however, a triple interaction was observed in MT/Sun hemp/N reaching a content of 51.40%. In addition, NT/Pearl millet/N with 50.80% of ADF, whose values did not statistically attain divergence from each other, but the first treatment surpassed the second one by 1.18 to 0.78% (Table 5). In the other treatments, the levels were similar and statistically higher among them, but all fertilization system produced an effect. In the study by Silva et al. (2021), 17.5% of ADF became apparent in corn silage under different doses of nitrogen, inoculation, and interaction on both. Nonetheless, there was no demonstration of results in the experiment, and despite being considered low and not corroborating the results obtained in the present study, this content demonstrates that the silage has greater digestibility.

Regarding the nutritional value of forage crops, Van Soest (1994) reports that the levels are provided by the chemical-bromatological composition of the plant, represented by the content of crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and digestibility (NDT) of dry matter.

The high ADF content is linked to the higher proportions of fibrous components in forage, resistant to digestion, such as cellulose, lignin, and cutting. Those are the structural carbohydrates responsible for decreasing plant digestibility (Van Soest, 1994). These components may be correlated

Table 5. Neutral detergent fiber (NDF), acid detergent fiber (ADF), hemicellulose (HEM), and total digestible nutrient (NDT) in (%) in the aerial part of green corn grown in different tillage systems with previous crops and nitrogen fertilization and inoculation of green corn. Experimental Farm of the Universidade Federal de Sergipe, São Cristóvão, Sergipe, Brazil, 2020 harvest.

Previous crop	Neutral detergent fiber (%)		Acid detergent fiber (%)		Total digestible nutrient (%)	
	Fertilization					
	Nitrogen	Inoculated	Nitrogen	Inoculated	Nitrogen	Inoculated
Conventional tillage system						
Cowpea	70.30 Aa	76.26 Aa	51.30 Aa	45.93 Aa	58.29 Aa	54.33 Aa
Pearl millet	69.43 Aa	73.80 Aa	46.53 Aa	50.23 Aa	58.89 Aa	57.59 Aa
Sun hemp	72.56 Aa	72.20 Aa	53.33 Aa	51.26 Aa	57.26 Aa	57.59 Aa
Pigeon pea	68.13 Aa	67.20 Ba	49.83 Aa	45.90 Aa	59.76 Aa	60.38 Aa
Minimum tillage system						
Cowpea	65.86 Aa	68.40 Aa	47.66 Aa	49.83 Aa	61.25 Aa	59.89 Aa
Pearl millet	69.80 Aa	75.96 Aa	51.80 Aa	51.76 Aa	58.82 Aa	56.47 Aa
Sun hemp	71.80 Aa	68.06 Aa	51.40 Aa*	40.50 Ba	57.30 Aa	59.79 Aa
Pigeon pea	71.70 Aa	69.60 Aa	48.20 Aa	48.80 Aa	57.38 Aa	58.77 Aa
No-tillage system						
Cowpea	69.30 Aa	69.46 Aa	39.40 Ab	47.23 Aab	58.99 Aa	58.92 Ab
Pearl millet	71.16 Aa	75.83 Aa	50.80 Aab*	36.36 Bb	57.70 Aa	55.64 Aab
Sun hemp	73.70 Aa	75.46 Aa	56.40 Aa	55.80 Aa	56.03 Aa	56.70 Aab
Pigeon pea	69.80 Aa	78.96 Aa*	52.56 Aab	61.40 Aa	58.63 Aa*	50.94 Ba

Data with same upper-case letter in the row do not differ from each other on Tukey test ($p \geq 0.05$) among the soil tillage systems, same crop, and fertilization. The ones followed by same lower-case letter in the column do not differ on Tukey test ($p \geq 0.05$) between previous crops, same soil tillage, and fertilization system. * Indicates statistical difference by the test of Tukey ($p > 0.05$) between fertilization.

with plant age and the presence of higher fractions of stems than leaves.

Higher and lower ADF content of 61.40% in NT/Pigeon pea/I and 39.40% in NT/Cowpea/N, respectively, with no effect of soil tillage systems and fertilization separately on these treatments were demonstrated, but an increase rate of 55.84% was observed between the values. Nevertheless, lower ADF content showed that a lack of fertilization treatment resulted in an interesting ADF content for a quality forage.

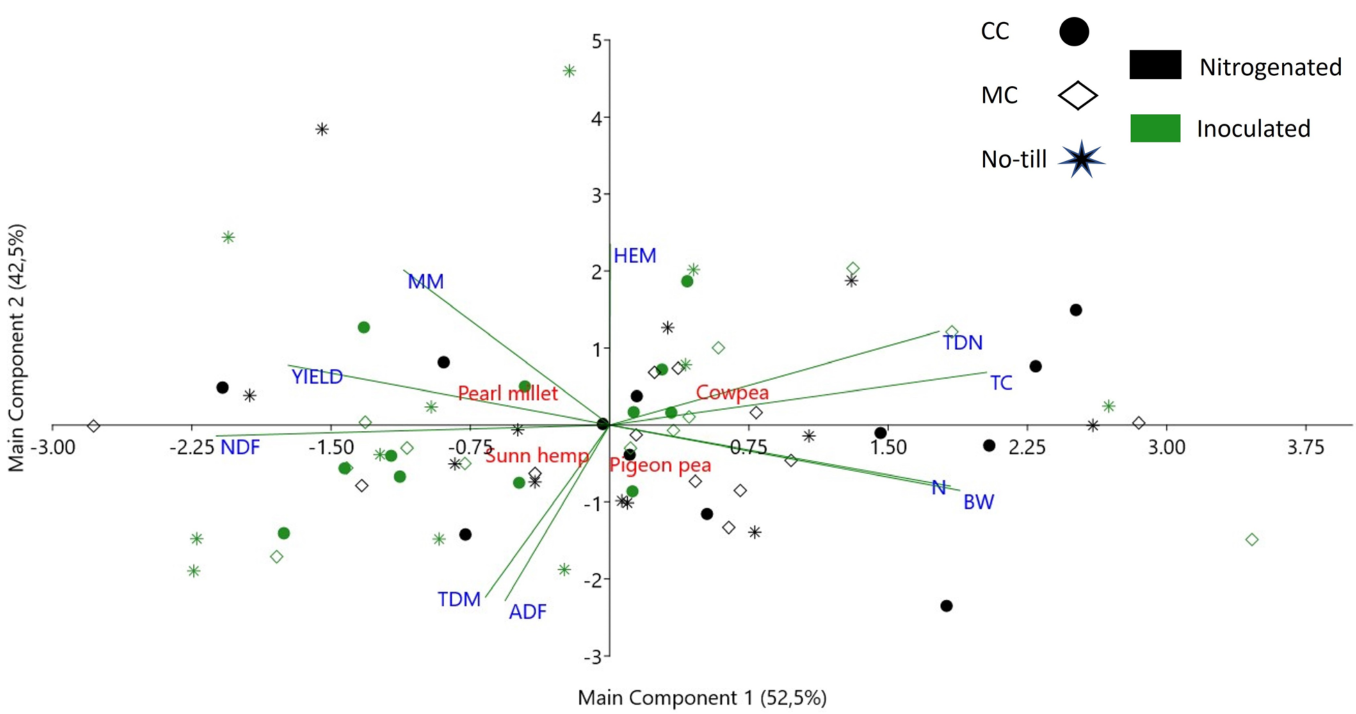
In general, it is interesting that forages should have up to 60% NDF and 40% ADF, where NDF has a negative relationship with forage intake, and high ADF content influences crop consumption and digestibility (Van Soest, 1994).

Regarding TDN, no statistically significant effect of any interaction in CT and MT was observed; however, among all treatments in the experiment, the highest content observed was 61.25% in MT/Cowpea/N; the lowest being of 50.94% in NT/Pigeon pea/I, presenting a 20.24% rate of increase between these values. There was also no significant effect of the NT and the crops individually. Nevertheless, the N-fertilization had a significant influence on the TDN content reaching 58.63% in the NT/Pigeon pea/N in relation to the other treatments within the same system (Table 5). The higher levels of NDF and lower levels of ADF and TDN obtained in the experiment result in forage with lower intake, but with good digestibility.

The Principal Component Analysis (PCA) allowed the evaluation of the most important parameters to explain the variability between the interaction of soil tillage systems with the previous crop and the combination of N fertilization and corn inoculation on the technical efficiency of green corn forage (Figure 2). In PCA, the first two axes (Components 1 and 2) showed the chemical characteristics of the forage, the total chlorophyll content, and the biomass yield, where they explained 95% of the total variability of the data, in which PC1 (X) and PC2 (Y) explained 52.5 and 42.5% of the total variance of the accumulated data, respectively, as shown in Figure 2. These results are in accordance with the parameters established by Sneath & Sokal (1973), where the number of principal components used in the interpretation must correspond to at least 70% of the total variance of the data.

It was observed that PC1 was positively correlated with the contents of TC, CP, N, and TDN, as seen in Figure 2. On the other hand, PC2 was positively correlated with HEM content.

In PC1, TC, protein, and nitrogen concentrated the data in CT, and it can be observed that the triple interaction of CT/Cowpea/Ne of CT/Pigeon pea/N promoted higher TC content. As previously addressed, the PCA data confirm that the higher TC content was mainly caused by the use of legumes as previous crops and have a high rate of decomposition in the soil and nitrogen fertilization that helps in the process of production of photoassimilates by the plant, also provided by the system where the soil is turned over. The analysis of variance did not point to a statistically significant difference in the levels of N and CP between the assessed treatments,



Caption: CC: Convencional cultivation; MC: Minimum cultivation; PD: No-Tillage; HEM: Hemicellulose; TDN: Total digestible nutrient; TC: Total chlorophyll; N: Nitrogen; BW, Crude protein; ADF: Acid detergent fiber: TDM: Total dry matter; NDF: Neutral detergent fiber; YELD: Productivity; MM: Mineral matter

Figure 2. Projection of data on chemical characteristics, total chlorophyll content, and forage yield of green corn grown under three tillage systems with four previous crops and combination of nitrogen fertilization with inoculation of green corn, submitted to principal component analysis.

as shown in Table 4. However, PC1 indicated that they were better matched in the interaction between CT/Pigeon pea/N. These results indicate that, in addition to the influence of nitrogen fertilization on the levels of N and CP, the plant may have been influenced by the effect of residual fertilization of pigeon pea within the system, especially because it is a legume. According to Lacerda et al. (2020), recent studies have shown nitrogen fertilization as a determining factor in the rise in the amino acid content and, consequently, the protein content.

The TDN corresponds to the content of digestible nutrients in the organic fractions of food. In this experiment, the results of the TDN were inversely proportional to those of the ADF, which showed a negative correlation in PCA2. According to Van Soest (1994), foods with a TDN higher than 55% can be considered ideal, with good nutritional value to be offered to the animals. These results may be associated with the retention of nutrients by the MT system, which recommends the minimized use of agricultural machinery, causing less inversion of the soil, compaction, and the use of cowpea, as it is a legume and a source of N combined with the corn inoculation that enhances the use of N by the crop.

This statement is corroborated by Peres et al. (2020) when reporting that the higher the TDN content of the food, the greater the use of the forage ingested by the animal. However, taking into account the results found by Silva et al. (2018), who then evaluated 24 corn hybrids and obtained TDN higher than 69%, also by Junqueira (2018), who found 66.31% TDN in corn forage, the results of this experiment are considered low, which may have been caused by the analysis that was carried out only on the aerial part of the corn, disregarding the commercial ears and the plant still showing poor lignification.

As a result, the PCA data demonstrate that the greatest effects on the variables analysed were through the presence of nitrogen, either in the triple interaction between the type of soil preparation, previous crop, and fertilization or evaluated separately.

Conclusions

The interaction between CT/Pigeon pea/N promotes an increase in plant height and in the leaf chlorophyll index of green corn forage.

The highest dry biomass yield was achieved in MT/Pearl millet/I, indicating that the use of a conservation system associated with a crop with good soil cover and green corn inoculation can promote higher rates of plant biomass.

The highest dry matter content was observed in the interaction between NT/Cowpea/N.

The highest crude protein content in the forage was observed in the interaction between MT/Pigeon pea/I; though, it is less than the ideal considered for the adequate ruminal functioning of the animals.

The best content of neutral and acid detergent fiber and total digestible nutrients found in this study were observed in NT/Pigeon pea/I, in NT/Cowpea, and in MT/Cowpea, respectively, indicating that conservationist systems associated with the use of legumes and maybe corn inoculation can promote better results for obtaining quality forage.

The principal component analysis identified a positive correlation in the levels of nitrogen, crude protein, total chlorophyll, and total digestible nutrients to produce quality green corn forage.

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Compliance with Ethical Standards

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