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Urochloa ruziziensis and nitrogen fertilization in corn-bean production systems[1]

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ABSTRACT

Evaluated the effect of *Urochloa ruziziensis* in association with nitrogen fertilization, in a second-crop corn and bean cultivation system. The experiment used a no-till planting system (NTPS). The treatments consisted: second-crop corn in association with *U. ruziziensis* and exclusive corn cultivation. Five doses of N (0, 25, 50, 75, and 100 kg ha^{-1}) were used in the subplots. After corn cultivation, the plots were desiccated with glyphosate, and then bean cultivation was carried out. In the bean experiment, the treatments consisted of the absence and presence of *U. ruziziensis* straw from the previous crop in the plots. In the subplots, five doses of N (0, 15, 30, 45, and 60 kg ha^{-1}) were used. The cultivation of *U. ruziziensis* at a density of 3 kg ha^{-1} in consortium with corn, second crop, in no-till, increases the amount of plant residues on the soil surface and does not alter the productivity and production components of corn and beans grown in succession. In the corn and *U. ruziziensis* intercropping system, it is not necessary to alter the N topdressing rate compared to the exclusive cultivation of corn.

Keywords: brachiaria, intercropping, nitrogen, *Zea mays*, *Phaseolus vulgaris*.

INTRODUCTION

Brazil is considered a major international power in the agricultural sector, occupying a prominent position in food production[1] Despite its large agricultural production, most of Brazil's territory consists of acidic soils with low fertility, poor in nutrients such as N, P, and K, which makes the use of fertilizers necessary.[2]

Conventional fertilizers have high solubility, which results in a rapid and effective response to increased agricultural productivity.[3] However, their large-scale use greatly increases the cost of agricultural production and the risks related to environmental contamination.[4,5]

Among the foods grown in Brazil, corn and bean production deserve special mention. Corn cultivation is fundamental to national agriculture, mainly in commercial growth combined with the subsistence farming of small producers.[6] Brazilian production has been growing since the 1970s, when less than 20 million tonnes were recorded in 1976/77, reaching an astonishing growth of 140 million tonnes in the 2024/25 harvest .[7]

Beans are of paramount importance in the Brazilian population's diet and in the production of small producers, making Brazil the third largest producer in the world and the largest producer in Latin America, with a share of over 90% in production and consumption, divided into three annual harvests, with the winter harvest standing out with a national average of 1000 kg ha^{-1}.[7] Productivity in Brazil in the 2024/25 harvest was 3.074 million tonnes.[7]

It is important to note that increasing the productivity of these crops can cause certain damage, mainly related to soil degradation, which can pose risks to food security and cause damage to the environment. Thus, it is necessary to seek ways to ensure productivity combined with the sustainability of these crops. In this regard, studies have pointed to the use of cover crops for nutrient cycling with a view to reducing the doses of N used in agricultural production.[8-10]

The cultivation of tropical forage crops, such as those of the genus Urochloa, in association with corn during the rainy season, is an alternative for increasing vegetation cover on soil, which, in addition to providing environmental benefits,[11] it also reduces production system costs.[12,13] However, for different crops, this intercropping must be evaluated so as not to obtain a decrease in crop productivity due to competition for water and nutrients, which can occur, including in subsequent crops.

However, in no-till farming (NTF) areas with plant residues and a high C/N ratio, immobilisation may predominate over mineralisation. Increasing N doses can accelerate the decomposition of plant residues and thus hinder the formation of straw[14] and also require increased nitrogen fertilization. In this case, it is important to be aware of the possible environmental pollution problems caused by water eutrophication and greenhouse gas emissions.[15]

Thus, the use of efficient nitrogen fertilization practices in production systems is of great importance in the current scenario, especially due to the high costs of nitrogen fertilizers. The hypothesis of this study is that intercropping second-crop corn with *U. ruziziensis*, associated with increasing doses of nitrogen in topdressing, promotes a supply of straw in the system capable of benefiting the subsequent bean crop without compromising the agronomic performance of the corn due to interspecific competition, provided that the N dose compensates for the initial immobilization caused by the straw with a high C/N ratio.

Based on the above, the objective of this study was to evaluate the effect of *Urochloa ruziziensis* as a cover crop, planted during the sowing of the second corn crop and in association with nitrogen fertilization, in a second corn crop and winter bean cultivation system.

MATERIAL AND METHODS

The experiment was conducted in the field, on a property located in southern Minas Gerais, in the municipality of Alfenas, Brazil (latitude 21°25'35‘ S, longitude 46°02'30’ W, altitude 809 m), from February to October 2020. The experimental area was located on a plot with clayey soil, irrigated with a centre pivot, cultivated for more than 10 years with cereals, using no-tillage, without soil preparation and using high technology. In the last two agricultural years, the following crop succession was used in the area: first crop soybeans (summer), second crop corn intercropped with *U. ruziziensis*, and third crop or winter beans.

The climatic conditions (temperature and precipitation) during the experiment are shown in Figure 1.

At the beginning of the 2019/2020 agricultural year, 12 simple samples were collected with a Dutch auger for a composite soil sample, in the 0 to 0.2 m layer, for chemical analysis,[16] the values of which are presented in Table 1.

The soil of the experimental area was classified as a Latossolo Vermelho distrófico according to the Brazilian

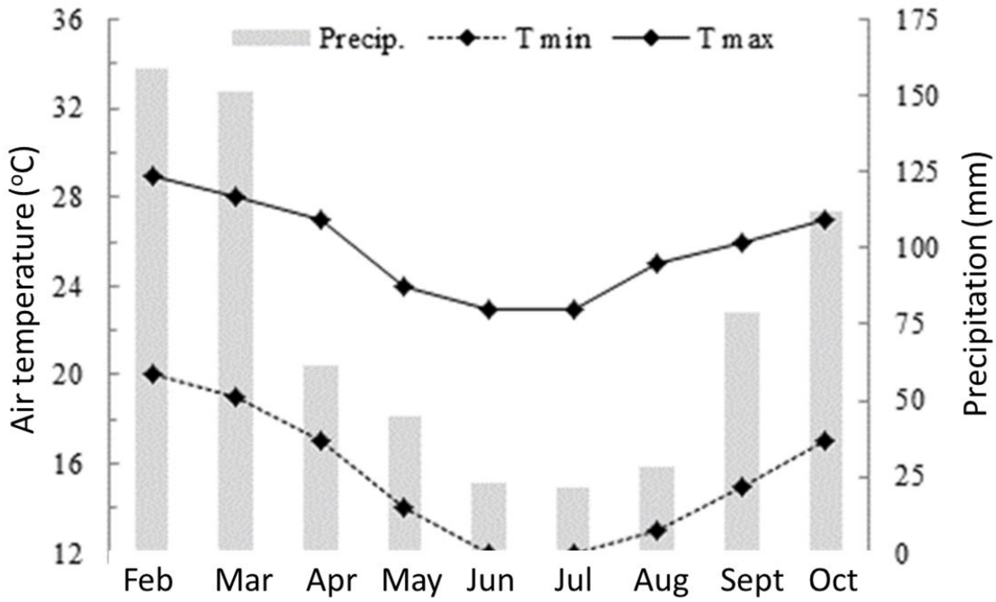


Figure 1. Air temperature and precipitation during the experiment period.

Table 1. Initial chemical characterisation of the soil in the experimental area

OM	**pH $CaCl_2$**	**P-resin**	**K^+**	**Ca^{2+}**	**Mg^{2+}**	**H+Al**	**SB**
g dm^{-3}		mg dm^{-3}			**$mmol_c$ dm^{-3}**		
39	5.9	34	2.7	52	20	22	75
CEC	**V**	**$S\text{-}SO_4^{2-}$**	**B**	**Cu**	**Fe**	**Mn**	**Zn**
$mmol_c$ dm^{-3}	%				**mg dm^{-3}**		
97	77	13	0.38	5.0	24	8.6	4.4

OM – organic matter; H+Al – potential acidity; SB – sum of bases; CEC – cation exchange capacity at pH 7.0; V – base saturation.

Soil Classification System (SiBCS). The average clay content of the soil is 300 g kg^{-1}. Before the experiment was set up, soybeans were grown in the area. The experimental area had been cultivated with grains for approximately fifteen years prior to the study, under a no-tillage system. The cultivation history included corn and soybean planting.

A randomized block design was used, in a split-plot scheme. The treatments consisted of two cultivation methods: second-crop corn intercropped with *U. ruziziensis* (CU) and exclusive corn cultivation, without intercropping with *U. ruziziensis* (EC single corn); and in the subplots, five doses of N were used, at 0, 25, 50, 75, and 100 kg ha^{-1} of N.

Each experimental unit consisted of six rows 10 m long with 0.5 m spacing between rows, totalling 30 m2. The usable area of each experimental unit consisted of the central six metres of the four central rows (12 m²). The sowing of the super-early hybrid corn 2A401PW was carried out in February 2020, using a mechanical method, distributing three seeds per metre, and the final stand was 56,000 plants ha^{-1}.

Sowing fertilization was carried out in accordance with Cantarella et al.[17] aiming for grain productivity above 10,000 kg ha^{-1}, with 17 kg ha^{-1} of N and 85 kg ha^{-1} of P_2O_5 applied in the form of MAP (10% N; 50% P_2O_5), in addition to 90 kg ha^{-1} of K_2O, as KCl (60% K_2O), broadcast immediately after sowing. The application of KCl broadcast on the surface, instead of localized in the furrow, was strategically adopted to mitigate the saline effect of this fertilizer on corn. The risks of KCl leaching resulting from center pivot irrigation were minimized by the clayey texture of the soil and its high CEC.

Thus, *U. ruziziensis* was broadcast simultaneously with corn at a density of 3 kg ha^{-1}, using seeds with a high degree of purity and encrusted and scarified germination, employing an MS40-CR Ikeda fertilizer spreader attached to the front of the tractor.

In plots with exclusive corn cultivation, the forage crop was eliminated with glyphosate herbicide immediately after emergence. At the V4 stage of the corn, top dressing was carried out according to the treatments, using urea containing urease inhibitor (45% N) as the N source. Top dressing with N was carried out manually, in rows, alongside the plants.

Cultural practices (weed, pest and disease control, and foliar spraying with micronutrients) were carried out according to crop requirements. Irrigation via a central pivot was carried out on four occasions throughout the crop cycle, depending on soil moisture, using a 15 mm blade for each irrigation, in accordance with the methodology used, in this case, the tensiometer.

At 135 days after sowing the corn, the ears were harvested in the usable area of each experimental unit to determine grain yield, with moisture corrected to 13%. In 20 ears from each experimental unit, taken at random, the diameter of the ears, number of grains per row, and number of rows per ear were evaluated to determine the number of grains per ear and the mass of 1,000 grains.

After the corn harvest, plant material was collected from the soil surface at two points in the usable area of each experimental unit, using a 0.5 m² square. The plant material (*U. ruziziensis* and spontaneous vegetation) was cut close to the soil surface and dried in a forced-air oven at 65ºC to quantify the dry matter production of the plant material (straw), whose values were extrapolated to kg ha^{-1}. The plots with *U. ruziziensis* were desiccated by applying the herbicide glyphosate at a dose of 2 L ha^{-1}.

To evaluate the effect of *U. ruziziensis* forage straw, bean cultivation was carried out in the experimental area in succession to corn, using the same plots as in the previous cultivation. In this case, a randomized block experimental design with subdivided plots and four replicates was also used.

The treatments consisted of the absence and presence of *U. ruziziensis* straw from the previous crop in the plots; and in the subplots, five doses of N were applied as top dressing, 0; 15; 30; 45 and 60 kg ha^{-1} of N, arranged in the same sequence as the previous crop. The bean crop, cultivar IAC 1850 medium cycle material, was sown mechanically in July 2020, with a spacing of 0.5 m between rows, distributing 12 seeds per linear metre, and the final stand was 200,000 plants ha^{-1}.

For sowing fertilization, 15 kg ha^{-1} of N, 75 kg ha^{-1} of P_2O_5, in the form of MAP (10% N; 50% P_2O_5), and 60 kg ha^{-1} of K2O, as KCl (60% K2O), were applied by broadcasting immediately after sowing. Nitrogen fertilization was carried out according to the treatments when the bean plant had 3 to 4 developed leaf trifoliates, in the same way as described for corn, using urea containing urease inhibitor (45% N) as the source of N.

Cultural practices (weed, pest and disease control) were carried out according to crop requirements. Central pivot irrigation was carried out on 5 occasions throughout the bean cycle, depending on soil moisture, using a 15 mm blade in each irrigation according to the information obtained using the tensiometer. The tensiometer readings were used strictly as an indicator of irrigation timing (irrigation trigger), monitoring the soil's matric potential. Once the need for irrigation was indicated by tensiometric readings, a fixed 15 mm irrigation depth was applied at each event.

At the time of bean flowering, soil samples were collected at a depth of 0-20 cm at five points in the usable area of each experimental unit using a Dutch auger to determine soil moisture.

Thus, 115 days after sowing the beans, the pods were harvested in each experimental moisture area to determine grain yield, with moisture corrected to 13% and a mass of 1,000 grains. In 20 plants from each experimental unit, taken at random, the number of pods per plant and the number of grains per pod were evaluated.

The planting scheme for the second corn crop in consortium with *U. ruziziensis* and exclusive corn cultivation, and for beans grown in succession, can be seen in Figure 2.

The results obtained for each crop were submitted to analysis of variance using the F test and polynomial regression analysis using Agroestat software.

RESULTS AND DISCUSSION

There was no significant interaction ($p > 0.05$) between corn cropping systems, second-crop, intercropped with *U. ruziziensis* or monoculture, and nitrogen fertilization doses for the variables evaluated.

A linear increase in corn grain yield was observed in response to N doses, in topdressing, regardless of the cropping system used, intercropped with *U. ruziziensis* or monoculture (Figure 3A). According to the regression model, corn grain yield ranged from 12,412 kg ha^{-1} (in the absence of N) to 13,489 kg ha^{-1} (at a dose of 100 kg ha^{-1} of N), which corresponds to an increase of 8.7% when comparing the extreme treatments.

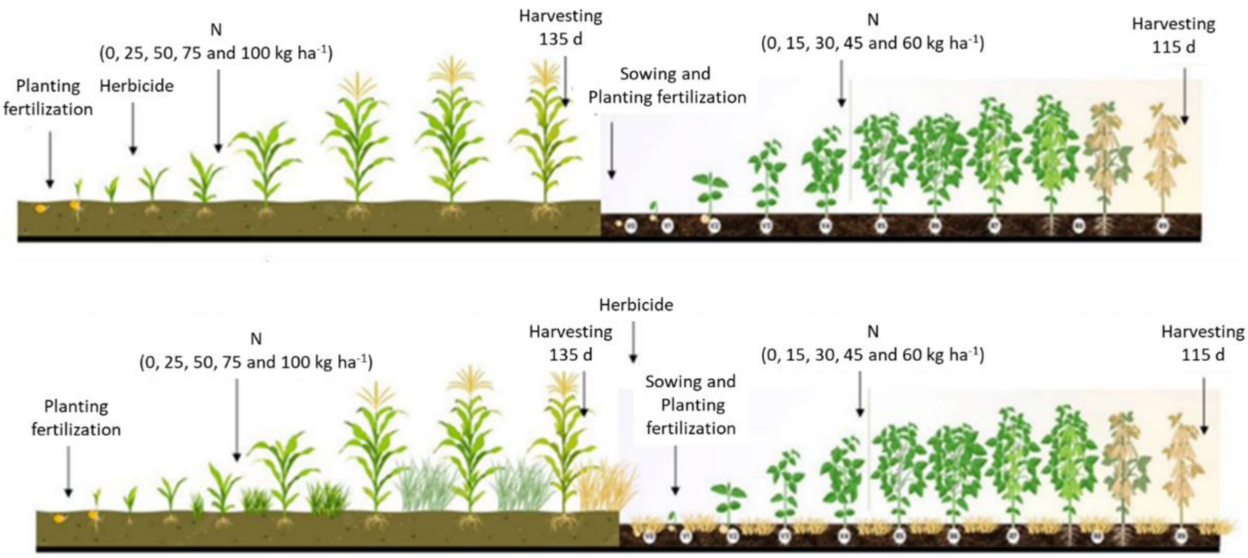


Figure 2. Outline of the study conducted. Planting scheme for the second crop: A. exclusively corn; B. corn cultivation in consortium with *U. ruziziensis*, as well as for the successive cultivation of beans.

The corn productivity, second crop, obtained in this study exceeds the average productivity of the State of Minas Gerais (4,401 kg ha^{-1}) and the Southeast (4,214 kg ha^{-1}) and Central-West regions of Brazil (4,349 kg ha^{-1}) in the 2019/2020 crop season.[7] This superior productive performance reflects the high technological level of the management adopted, characterized by the use of a high genetic potential hybrid (2A401PW), strategic water supply via center pivot and, fundamentally, and due the good soil fertility conditions (Table 1).

With the highest dose of N, 17.95 more bags of corn were obtained in production compared to the lowest dose, taking into account the price of corn at R$ 93.00 per bag,[18] there was an increase in revenue of R$ 1669.35/ha. Protected urea 45% was the source of N used at a cost of R$ 3700.00 per tonne,[19] 222 kg was used to obtain 100 points of N at an approximate cost of R$ 821.40/ha, resulting in a net profit per hectare of R$ 847.95 when comparing the treatments that received the lowest and highest doses of N, at 0 and 100 kg ha^{-1}. This result validates the economic viability of high technology in irrigated off-season crop systems in southern Minas Gerais.

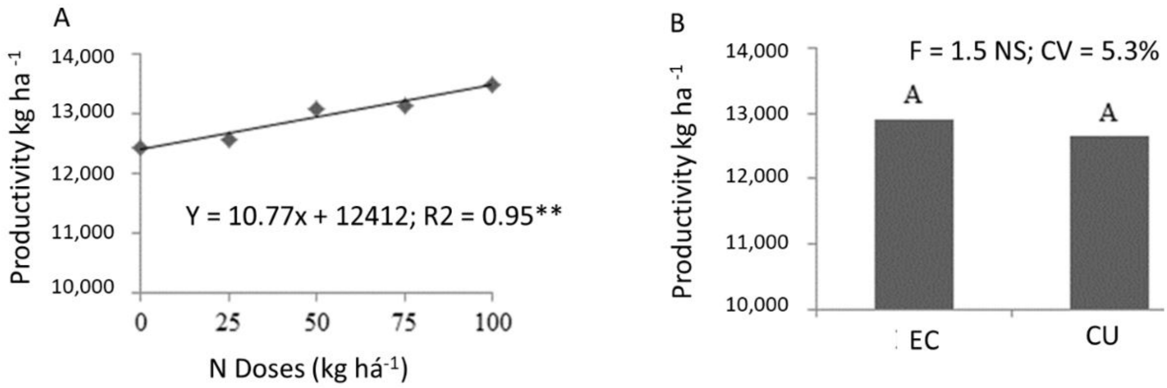
The productivity of corn grains in intercropping with *U. ruziziensis* did not differ from the productivity of corn in exclusive cultivation, with the average value considering the two cultivation systems used being 12,783 kg ha^{-1} (Figure 3B). These results show that it is not necessary to change the N top dressing rate when growing corn in intercropping with *U. ruziziensis*, compared to exclusive corn cultivation, and that sowing the forage crop at a density of 3 kg ha^{-1} in intercropping with corn does not reduce the yield of the main crop, compared to exclusive cultivation.

The results obtained in the present experiment corroborate those obtained in the studies by Pariz et al.[20] and Marques et al.,[11] which found no influence on corn productivity when grown in intercropping with *U. ruziziensis*. In contrast, Ceccon et al.,[21] when using a density of 8 kg ha^{-1} of forage crop in the intercropping system, observed a decrease in corn growth and productivity.

Mingotte et al.[22] state that although intercropping corn with *U. ruziziensis* does not generate immediate economic returns for the producer, there are many advantages to its use in production systems, such as breaking the cycle of diseases and pests that affect agricultural crops, improving the physical and chemical properties of the soil, and maintaining a quality no-till system.[11,23]

The components of corn production (ear diameter and weight of 1,000 grains) were not altered by the top dressing doses of N and the cropping systems used (corn intercropped with *U. ruziziensis* and corn monocropping), with the average values obtained in the experiment being 5.3 cm and 424 g, respectively (Figure 4). This demonstrates that the cultivation conditions were ideal for corn production, *i.e.*, intercropping did not adversely affect the corn harvest.

Regarding the number of grains per ear, there was a linear increase with N doses, regardless of the cultivation system used, with values ranging from 485 to 509 g, which corresponds to an increase of 5% when comparing the



Identical letters do not differ according to the F test ($p < 0.05$). EC – exclusive corn cultivation, CU – corn intercropped with *U. ruziziensis*.

Figure 3. Corn grain productivity, second harvest, as a function of: A. N doses and B. cultivation system.

extreme treatments (0 and 100 kg ha^{-1} of N). Knowing that ear diameter and row number are defined early (stages V4 to V6) and grain mass is regulated by the final filling rate, the increase in the total number of grains per ear demonstrates that nitrogen topdressing directly reduced ovule abortion in the middle and apical thirds of the ear. The continuous supply of N ensured the maintenance of photosynthetic activity and carbohydrate flow towards the reproductive sink during pollination, without the presence of *U. ruziziensis* diverting assimilates from the main crop.

According to Cunha Coelho et al.,(24) in the no-till system, there is an increase in potentially mineralisable N in the soil, causing an increase in total levels in the surface layers of the soil and a decrease in losses due to immobilisation, gradually releasing the nutrient to crops. However, when this practice is carried out in savannah regions, it can pose risks to crop productivity due to heavy rains, which can cause leaching and volatilisation of the nutrient.(25)

The cultivation of *U. ruziziensis* in intercropping with second-crop corn did not interfere with corn production and production components, compared to the exclusive cultivation of corn. In addition, the cost of implementing intercropping with *U. ruziziensis* is low, as there is only the expense of the forage seed.

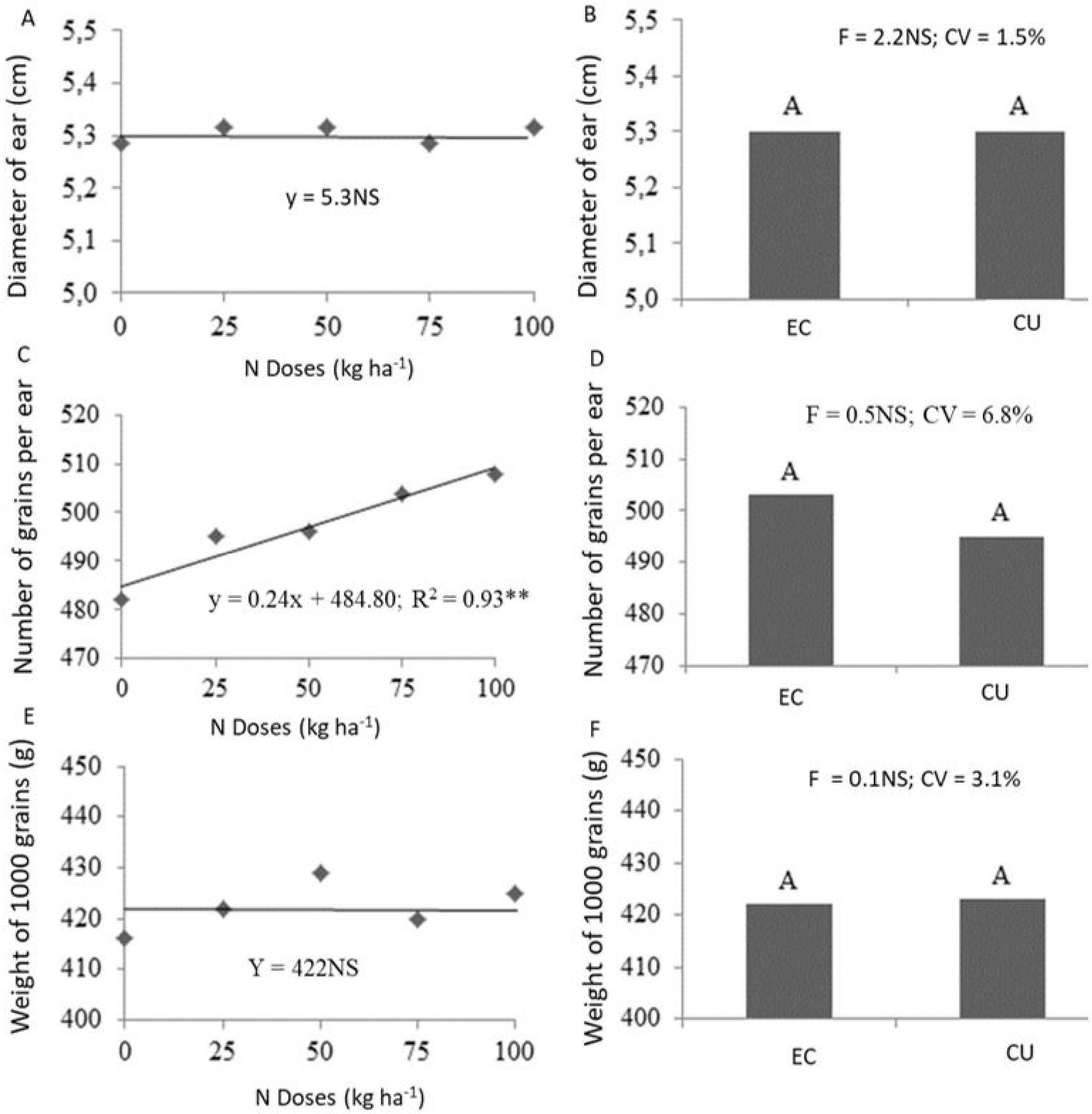
There was a linear increase in the dry matter production of *U. ruziziensis* with the N doses in the cover, with values ranging from 2,357 to 2,639 kg ha^{-1} (Figure 5 A). It was also found that the cultivation of *U. ruziziensis* in intercropping with corn increased soil vegetation cover by approximately 2,300 kg ha^{-1} of dry matter, compared to the exclusive cultivation of corn (Figure 5B).

These results show that growing *U. ruziziensis* in consortium with corn contributes to increasing the amount of straw on the soil surface, which brings benefits to the NTFS, such as a reduction in soil loss due to erosion, a decrease in soil temperature, an increase in soil microbial activity and diversity, and improvements in the physical and chemical attributes of the soil over time.(24) However, the application of high doses of free mineral N (such as urea) can reduce the microbial C/N ratio and accelerate the activity of cellulolytic fungi and bacteria, stimulating the decomposition rate of surface straw.(14)

Regarding soil moisture content, there was no response to nitrogen fertilization, with an average soil moisture value of 21% (Figure 6A). However, when comparing the cultivation systems, a higher moisture content was found in the surface layer of the soil (0-20 cm) in the treatments where the corn - *U. ruziziensis* intercropping was used compared to the exclusive cultivation of corn. This phenomenon is explained by the physical barrier exerted by the mulch.

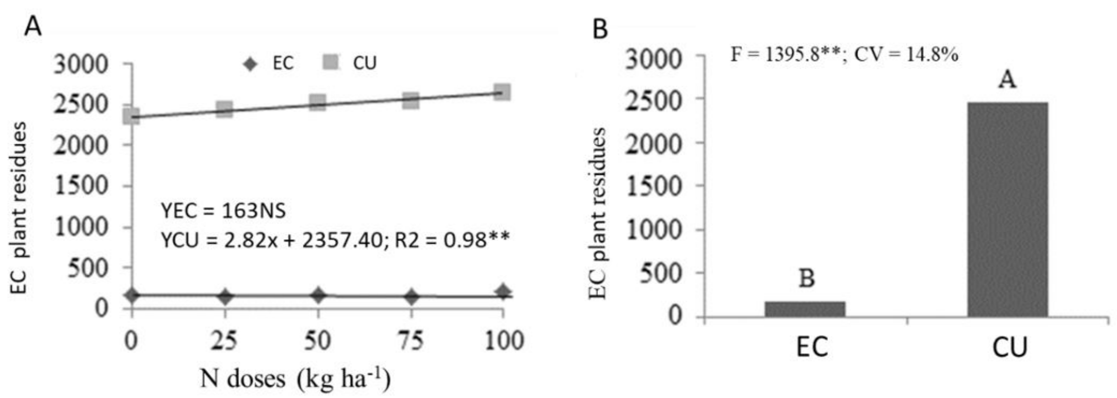
The straw acts by dissipating the kinetic energy of raindrops or water from the center pivot, favoring infiltration and reducing the formation of surface sealing. Simultaneously, the straw layer drastically reduces the direct incidence of solar radiation on the soil surface, decreasing the sensible heat flux and, consequently, minimizing water losses through direct evaporation from the 0-20 cm layer.(24,26)

Nitrogen fertilization, both in the absence and presence of *U. ruziziensis* straw from the previous crop, linearly increased the grain yield of beans grown in succession to corn, with values ranging from 857 to 1,103 kg ha^{-1}, corresponding to an increase of 29% when comparing the extreme treatments, 0 and 60 kg ha^{-1} (Figure 7A).



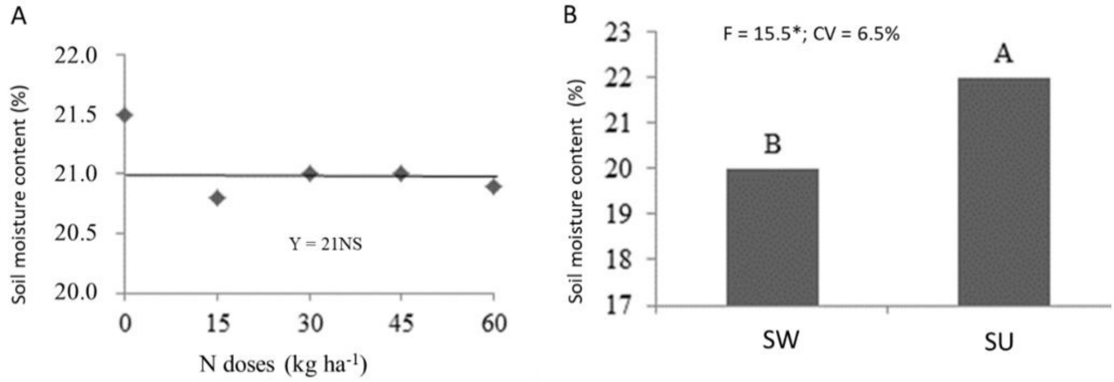
Identical letters do not differ according to the F test ($p < 0.05$). EC - exclusive corn cultivation, CU - corn intercropped with *U. ruziziensis*.

Figure 4. Corn production components as a function of N doses and cultivation system: A and B. average cob diameter, C and D. average number of kernels per cob, E and F. average weight of 1,000 kernels.



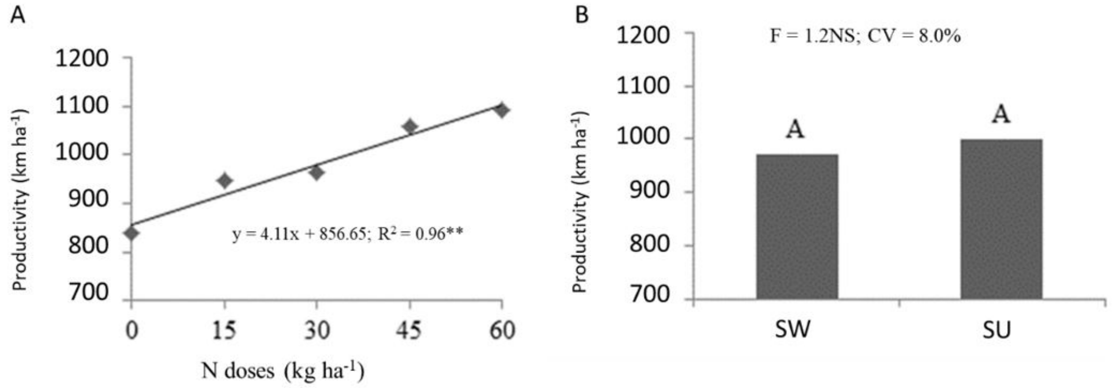
Identical letters do not differ according to the F test ($p < 0.05$). EC - exclusive corn cultivation, CU - corn intercropped with *U. ruziziensis.*

Figure 5. Dry matter of plant residues (brachiaria grass and weeds) on the soil surface after corn harvest, as a function of: A. N doses and B. cropping system.



Identical letters do not differ according to the F test ($p < 0.05$). SW – soil without *U. ruziziensis* straw. SU – soil with *U. ruziziensis* straw, previously cultivated in intercropping.

Figure 6. Soil moisture content as a function of: A. N doses and B. cultivation system.



Identical letters do not differ according to the F test ($p < 0.05$). SU – soil with *U. ruziziensis* straw, previously cultivated in intercropping; SW – soil without *U. ruziziensis* straw.

Figure 7. Bean grain productivity as a function of: A. N doses and B. cultivation system.

This linear response, superior to that observed in corn, stems from the physiology of the common bean (more superficial root system and short cycle) combined with the dynamics of N immobilization. The straw of *U. ruziziensis* has a high C/N ratio, which stimulates the temporary biological immobilization of soil N by the decomposing microbiota. Thus, the application of mineral N as topdressing was essential to saturate the microbial demand and make nitrate ions available in the soil solution during the critical phases of floral bud differentiation and pod filling.

The bean grain yield obtained in this experiment was lower than the average bean yield obtained in Brazil in the third harvest, which is 1,358 kg ha^{-1}.[7] This occurred even though the area was irrigated with a centre pivot and using high technology, and can possibly be explained by the low temperatures during the bean grain filling phase, which caused a light frost at the experiment site.

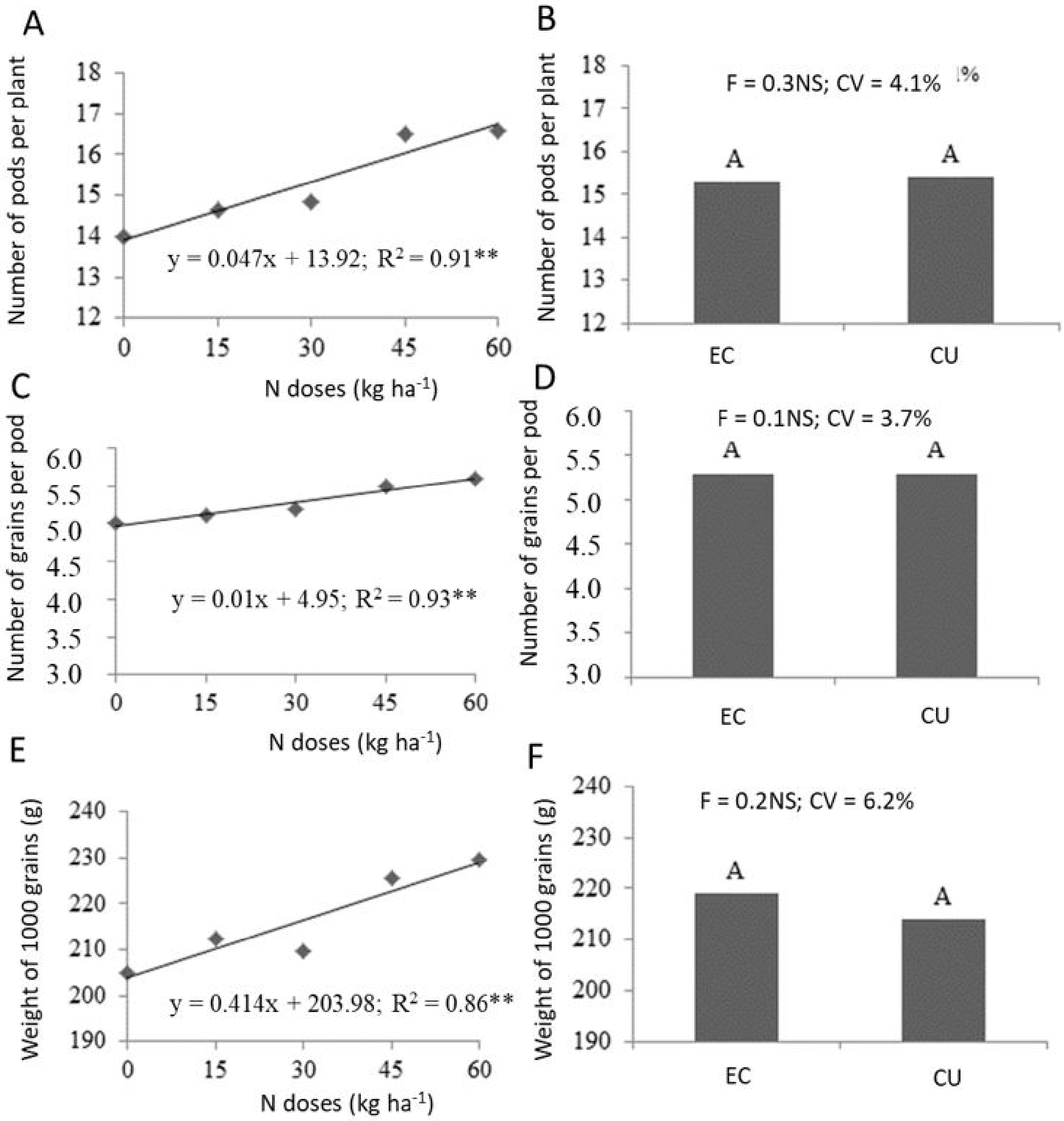
The common bean is a thermophilic species highly sensitive to cold stress; temperatures below 12 °C reduce the net photosynthetic rate, cause flower abortion, and restrict the transport of photoassimilates to the pods, drastically limiting the final grain mass.[27]

Concerning the cultivation system, there was no difference ($p < 0.05$) in bean grain yield between treatments with and without *U. ruziziensis* straw from the previous crop (Figure 7B). Tebaldi[28] found the same result, in which the previous intercropping of corn + *U. ruziziensis* did not affect the number of pods per plant and the number of grains per plant of cowpea in succession. This result can possibly be explained by the irrigation of the area with a central pivot, which minimises differences in soil moisture between treatments with and without *U. ruziziensis* straw, and also by the fact that the amount of *U. ruziziensis* straw from the previous crop was not high, as several years of intercropping with forage crops are necessary to obtain permanent soil cover in tropical regions.

Nitrogen fertilization, as top dressing, increased the production components of the bean plant in a linear fashion:

number of pods per plant; number of grains per pod and weight of 1,000 grains (Figure 8). Mingotte et al.[8] observed that, in the second year of NTFS, nitrogen fertilization only influenced bean productivity when grown in succession to single corn, and the highest yields were obtained on *U. ruziziensis* alone or in consortium, without the effect of nitrogen fertilization. Mingotte et al.[8] emphasize that the physical benefits and ideal synchrony of nutrient release by stable brachiaria straw manifest themselves cumulatively, requiring multiple successive years of intercropping to consolidate statistically significant productivity increases in subsequent annual crops.

According to the regression equations, the values ranged from 14 to 17 pods per plant, 5 to 6 grains per pod, and 204 to 229 g when comparing the treatment without N fertilization with the one that received the highest dose of N, 60 kg ha^{-1}. The absence and presence of *U. ruziziensis* straw from the previous crop did not influence ($p < 0.05$) the production components of the bean plant: number of pods per plant, number of grains per pod, and weight of 1,000 grains (Figure 8). The absence of a response from these variables to the presence of straw corroborates the fact that the center pivot homogenized the water status of the system, while the thermal energy balance modified by the straw and mitigated by irrigation stabilized the impact of cold in both cultivation environments.



Identical letters do not differ according to the F test ($p < 0.05$). EC – soil without *U. ruziziensis* straw. CU – soil with *U. ruziziensis* straw, previously cultivated in intercropping.

Figure 8. Bean production components as a function of N doses and cultivation system: A and B. average number of pods per plant, C and D. average number of beans per pod, E and F. average weight of 1,000 beans.

CONCLUSION

The cultivation of *Urochloa ruziziensis* at a density of 3 kg ha^{-1} in consortium with corn, second crop, in no-till, increases the amount of plant residues on the soil surface and does not alter the productivity and production components of corn and beans grown in succession.

In the corn and *Urochloa ruziziensis* intercropping system, it is not necessary to alter the N topdressing rate compared to the exclusive cultivation of corn.

FULL DISCLOSURE

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The authors declare that all data are contained within the article.

AUTHOR CONTRIBUTIONS

Conceptualization: Edson da Silva, José Ricardo Mantovani.

Data curation: Edson da Silva, José Ricardo Mantovani.

Formal analysis: Edson da Silva, José Ricardo Mantovani.

Investigation: Edson da Silva.

Project administration: José Ricardo Mantovani.

Writing - original draft: Edson da Silva.

Writing - review & editing: José Ricardo Mantovani, Adriano Bortolotti da Silva.

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