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# Performance of soybean cultivated following intercropped corn under varying nitrogen levels

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**Abstract**

The intercropping of second-crop corn with ruzigrass or showy rattlebox associated with an increase in the nitrogen (N) rate can improve the performance of soybean in succession. This study aimed to evaluate the soybean performance in succession to second-crop corn cultivated under N application rates, with or without intercropping with ruzigrass (*Urochloa ruziziensis*) or showy rattlebox (*Crotalaria spectabilis*). The experimental design was a complete randomized block design with a split-plot scheme with four replicates. The plots were composed of the cultivation of either sole corn (AG 9010 PRO) or corn intercropped with ruzigrass or showy rattlebox, and the subplots consisted of different N topdressing rates (0, 60, 120, 180, and 240 kg ha$^{-1}$). Soybean (BRS 1003 IPRO) was grown in succession to corn under a no-tillage system (NTS). The evaluated variables were growth and yield. The increase in N rate in second-crop corn, with or without intercropping with ruzigrass or showy rattlebox, increased the growth and yield of soybean in succession under NTS. Second-crop corn intercropped with ruzigrass provided a greater amount of straw under NTS than sole corn or intercropped with showy rattlebox. However, intercropped systems did not influence the growth and yield of soybean grown in succession. Therefore, the corn intercropped with ruzigrass promotes the sustainability of NTS and the N fertilization in second-crop corn, which subsequently improves soybeans performance.

**Keywords:** Cover crops; *Crotalaria spectabilis; Glycine max*; *Urochloa ruziziensis; Zea mays*.
**Abbreviations:** N_nitrogen; NTS_no-tillage system.

**Introduction**

Adopting management practices to promote benefits to the soil-plant systems can minimize the problems caused by successive cultivation and maximize grain yield. The use of the no-tillage system (NTS), intercropping among grain and cover crops (Gitti et al., 2012), and more diversified production models are examples of techniques that contribute to sustainable crop management and soil conservation. The NTS predominates the Brazilian soybean production areas. Its efficiency depends on the quantity and diversity of the shoot and root biomass produced by the soil covers crops (Balbinot Junior et al., 2017). The quantity and persistence of plant residues on the soil are relevant to provide protection and improvement of the soil structure, reflecting an increase in water infiltration, a reduction in the soil surface temperature, and an increase in the soil aggregation stability (Silva et al., 2011).

In this context, the cultivation of second-crop corn intercropped with cover crops such as ruzigrass or showy rattlebox is very promising. Ruzigrass species (*Urochloa* genus) have great biomass production capacity, with high C/N ratio, providing adequate soil coverage, high cycling and nutrient release (Calonego et al., 2012) and suppression of weeds (Mechi et al., 2018).

The use of legumes can increase the content and availability of N in the soil due to the biological fixation of N. Also, legumes can increase nutrient cycling and the control of nematodes in the case of showy rattlebox cultivation, mainly *Crotalaria spectabilis* (Gitti et al., 2012).

Intercropping of second-crop corn with ruzigrass or showy rattlebox could favor the soybean crop in succession. It can improve soil physical attributes through a vigorous root growth and production of larger amounts of shoot biomass in comparison to sole corn (Genovesi et al., 2019; Balbinot Junior et al., 2017; Yokoyama et al., 2018). However, the use of cover crops intercropped with corn alters the nutrient demand. Thus, an adequate nutritional supply such as N is important in intercropping systems (Sapucay et al., 2020).

In Brazil, farmers usually suppress or reduce N rates in second-crop corn because of the limited yield potential caused by low temperatures and rainfall. However, when the second-crop corn is topdressed with N, the corn and the intercropped cover crops increase growth and benefit of soybean grown in succession (Kappes et al., 2009). In such

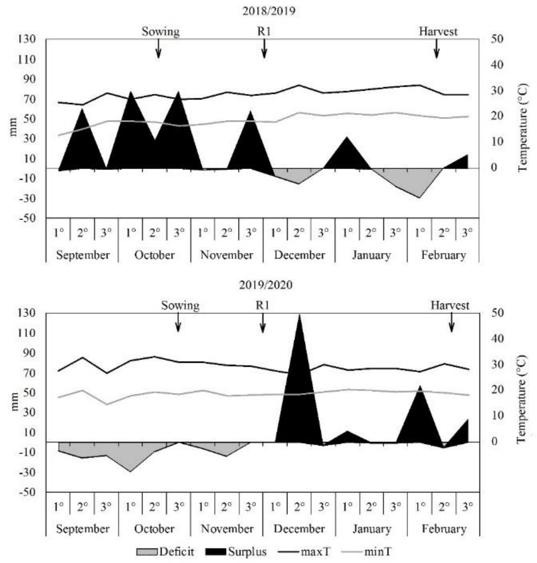


**Fig 1.** Sequential climatological water balance (mm), maximum (maxT), and minimum (minT) temperature during the 2018/2019 and 2019/2020 growing seasons, from September 1 to February 29, according to Thornthwaite and Mather (1955), with a 75 mm available water capacity, considering the data from the weather station located in Londrina, Paraná state, Brazil. Total precipitation from corn sowing to harvest: 2018/2019 growing season – 556 mm and 2019/2020 growing season – 712 mm.

context, the intercropping of second-crop corn with ruzigrass or showy rattlebox associated with an increase in N in the second crop can increase biomass production, resulting in a better agronomic performance of soybean in succession under NTS.

This study aimed to evaluate soybean performance in succession to second-crop corn cultivated under N application rates, with or without intercropping with ruzigrass (*Urochloa ruziziensis*) or showy rattlebox (*Crotalaria spectabilis*).

## Results and Discussion

The rainfall of 556 mm in 2018/2019 and 712 mm in the 2019/2020 growing season was adequate for obtaining high yields of soybean. However, the precipitation distribution was insufficient in the 2018/2019 growing season (Fig 1). In 2018/2019, there was an interaction effect between the cultivation systems and N rates on the corn dry mass, total dry mass (corn + cover), soybean dry mass and the number of pods $m^{-1}$ at R5.1. There was an effect of N rates on the ruzigrass dry mass, showy-rattlebox dry mass, NDVI of soybean at R2 and R5.1, and soybean grain yield. In the 2019/2020 growing season, the interaction occurred in the corn dry mass, total dry mass, NDVI at R5.1, and the dry mass of soybean at R5.1. There was an isolated effect of cultivation systems on the SPAD index at R5.1 and N rates on the SPAD index at R2, dry mass at R2, plant height, number of grains per square meter, and soybean grain yield. There was no effect on the soybean's plant density, the leaf area index, the first pod height insertion, or the one thousand grain mass in either growing season.

### *Mass production*

The dry mass of corn intercropped with ruzigrass in the absence of topdressing N was lower than the dry mass of sole corn and corn intercropped with showy rattlebox by 18% and 16%, respectively. However, this difference no longer existed with the use of topdressing N in the 2019/2020 growing season (Fig 2B). This result indicates that topdressing with N fertilization in corn reduced interspecific competition in intercropping with ruzigrass. Thus, there is a need to complement the N fertilization in this type of system since the N used in sowing (34 kg $ha^{-1}$) and the N from the soil and decomposition of plant residues were insufficient to sypply both crops demands. This result corroborates with Almeida et al. (2017) findings that a N rate greater than 100 kg $ha^{-1}$ was necessary to maintain the corn growth when intercropped with *U. ruziziensis.*

The increase in the N rate resulted in a quadratic response of the corn dry mass intercropped with the showy rattlebox in the 2018/2019 growing season (Fig 2A), while in 2019/2020, the response of the corn dry mass was linear in the corn-ruzigrass intercropping system by increasing the N rate (Fig 2B). Lange et al. (2014) verified a linear response of dry mass to the topdressing N rates in corn intercropped with *U. brizantha* with simultaneous sowing in the second-crop season, confirming the relevance of N fertilization in topdressing for the accumulation of the corn dry mass in an intercropping system.

In the 2018/2019 growing season, N fertilization in second-crop corn influenced the accumulation of dry mass in the cover crops (Fig 2C and 2D). This contribution of biomass from cover crops in the second-crop season is an alternative to increasing the amount of straw and the percentage of soil cover in the NTS (Mendonça et al., 2015). The showy rattlebox quadratic response to N indicates dry mass accumulation up to the maximum point, 126 kg $ha^{-1}$ of N (Fig 2C). From that point on, increasing N rates caused a reduction in dry mass, possibly due to a detrimental interference in the biological N fixation (Hungria et al., 2006).

The response to ruzigrass was linear with an increasing N application rate (Fig 2D). In the absence of topdressing N fertilization in second-crop corn, the dry mass production of the ruzigrass was 2,812 kg $ha^{-1}$, with an increased rate of 59 kg $ha^{-1}$ for every 10 kg $ha^{-1}$ of N applied. This response may have occurred due to the low competition capacity of corn in relation to ruzigrass under the water deficit conditions of

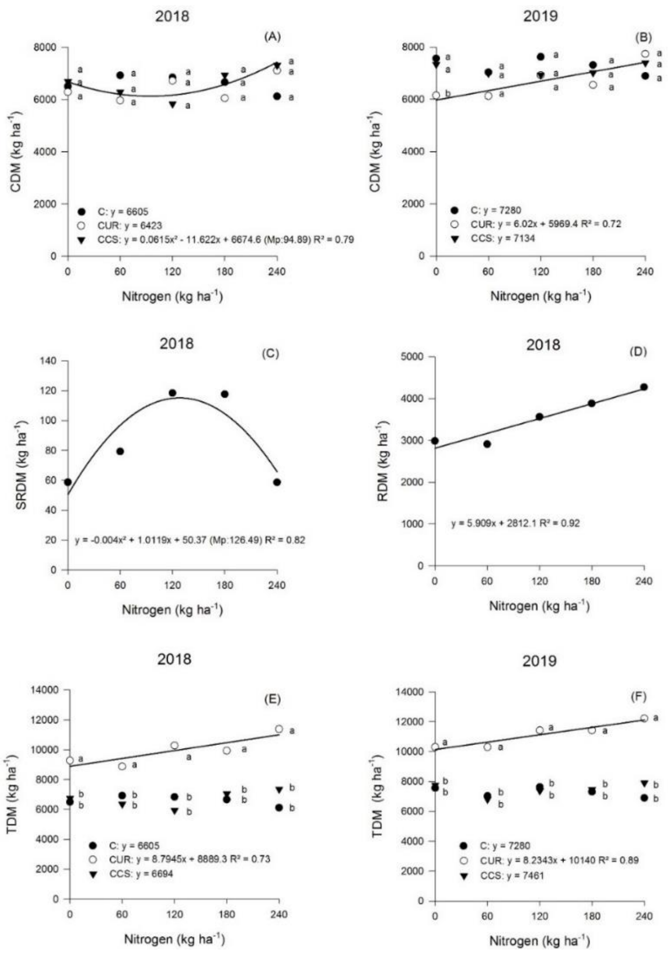


**Fig 2.** Corn dry mass (CDM) (A and B), showy rattlebox dry mass (SRDM), ruzigrass dry mass (RDM) (C and D), and total dry mass (TDM) (E and F) as function as cultivation systems (C: corn monocropping; CUR: corn + *Urochloa ruziziensis*; and CCS: corn + *Crotalaria spectabilis*) and/or topdressing N rates (0, 60, 120, 180 and 240 kg ha$^{-1}$) in second-crop corn. Means followed by the same letter within each N rate do not differ from each other by the Tukey test at 5 % of probability. Mp: minimum or maximum point.

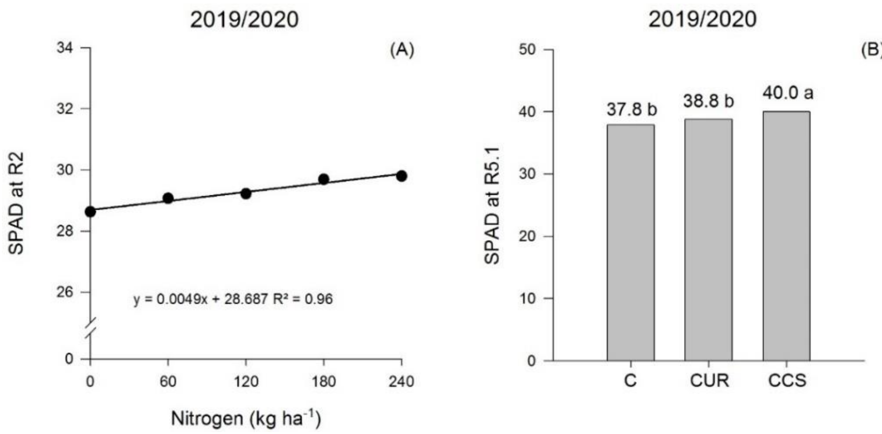


**Fig 3.** Soybean SPAD index at R2 (A) and R5.1 (B) as function as cultivation systems (C: corn monocropping; CUR: corn + *Urochloa ruziziensis*; and CCS: corn + *Crotalaria spectabilis*) or topdressing N rates (0, 60, 120, 180 and 240 kg ha$^{-1}$) in second-crop corn. Means followed by the same letter within each cultivation systems do not differ from each other by the Tukey test at 5 % of probability.

the 2018 growing season, enabling ruzigrass to respond to N rates. This result corroborates Batista et al. (2011), who evaluated the accumulation of dry mass and nutrients from forages intercropped with second-crop corn as a function of N fertilization and obtained a positive linear response to ruzigrass dry mass.

There was an increase in the total dry mass in the corn-ruzigrass intercropping by increasing the N rate in both growing seasons (Fig 2E and 2F). In the absence of N, the total dry mass production was 8,889 and 10,140 kg ha$^{-1}$ in the 2018/2019 and 2019/2020 growing seasons, respectively. For every 10 kg ha$^{-1}$ of N applied, there was an increase of 87 kg ha$^{-1}$ and 82 kg ha$^{-1}$ in the total dry mass.

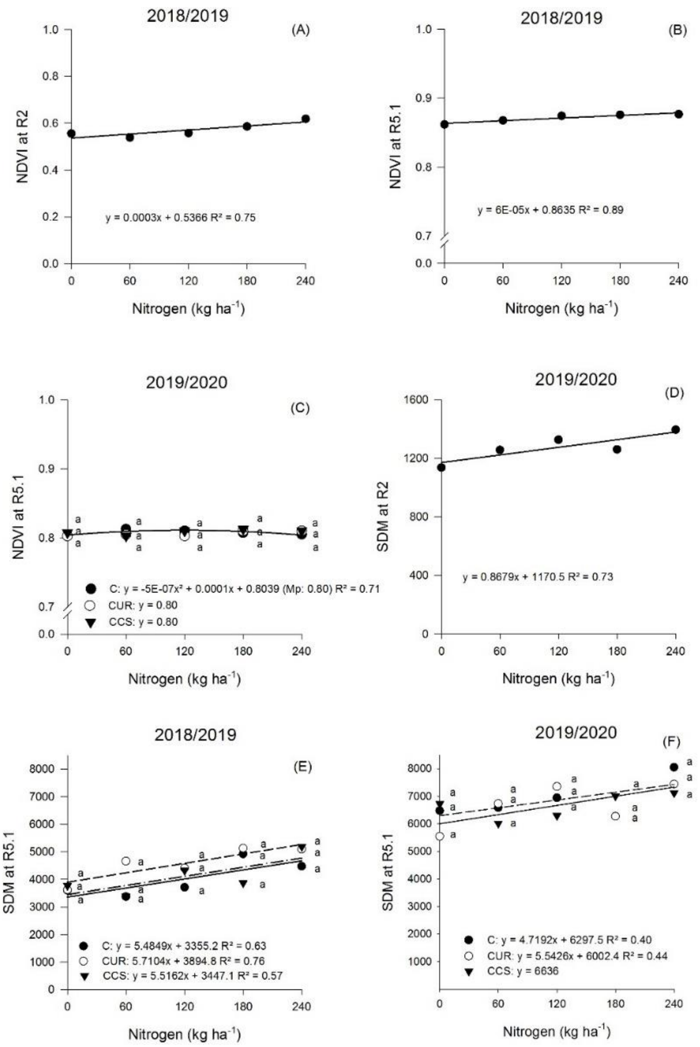


**Fig 4.** Soybean normalized difference vegetation index (NDVI) at R2 (A) and R5.1 (B and C), soybean dry mass (SDM) at R2 (D) and R5.1 (E and F) as function as cultivation systems (C: corn monocropping; CUR: corn + *Urochloa ruziziensis*; and CCS: corn + *Crotalaria spectabilis*) and/or topdressing N rates (0, 60, 120, 180 and 240 kg ha$^{-1}$) in second-crop corn. Means followed by the same letter within each nitrogen rate do not differ from each other by the Tukey test at 5 % of probability. Mp: maximum point.

Also, at all rates of N, the corn-ruzigrass intercropping system formed more dry mass than the other cultivation systems. These results demonstrate the great potential of this production system for mass production in NTS (Batista et al., 2019).

***Effects of treatments on the soybean crop***

The soybean SPAD index at R2 in the 2019/2020 growing season increased with increasing N application rate (Fig 3A). Yokoyama et al. (2018), studied the effect of second-crop on soybean grown in succession and found differences in the soybean SPAD index from the vegetative phase to R1. After R1, the authors did not find any differences for SPAD values between the treatments. The SPAD index of soybean grown after corn intercropped with showy rattlebox was higher than that of soybean grown after corn sole or corn intercropped with ruzigrass at R5.1 (in 2019/2020) (Fig 3B), probably because of the ability of the legume to fix atmospheric N (Ananthi et al., 2017).
The NDVI increased linearly with the increasing N application rate at R2 and R5.1 in the 2018/2019 growing season (Figs 4A and 4B). Although soybean showed low variation in the NDVI, there was a quadratic response to the topdressing N rate applied to corn sole in 2019/2020 (Fig 4C). These results show an increase in vegetation cover as a function of N rates as soybean develops (Franchini et al., 2015).
In the 2019/2020 growing season, the soybean dry mass increased with the increasing N application rates at R2 (Fig 4D). The response was also higher for all cropping systems at R5.1 in the 2018/2019 growing season (Fig 4E) and after the growth of sole corn or corn-ruzigrass in 2019/2020 (Fig 4F). Nitrogen fertilization in corn intercropped with ruzigrass provided higher biomass input to the system (Fig 2E and 2F) as noted by Almeida et al. (2017), favoring the accumulation of soybean mass (Fig 4E and 4F).
The soybean plant height responded positively to the N rates in corn, with no effects of cultivation systems on this variable in the 2019/2020 growing season (Fig 5A). We also observed similar results in the number of grains per square meter (Fig 5C). The number of soybean pods in 2018/2019 increased with the increasing topdressing N rate in second-crop corn intercropped with ruzigrass without adjustments for the other systems (Fig 5B). Genovesi et al. (2019) observed an increase of 60% in the numberof pods in soybean grown in succession with corn intercropped with *U. ruziziensis* compared to sole corn or corn intercropped

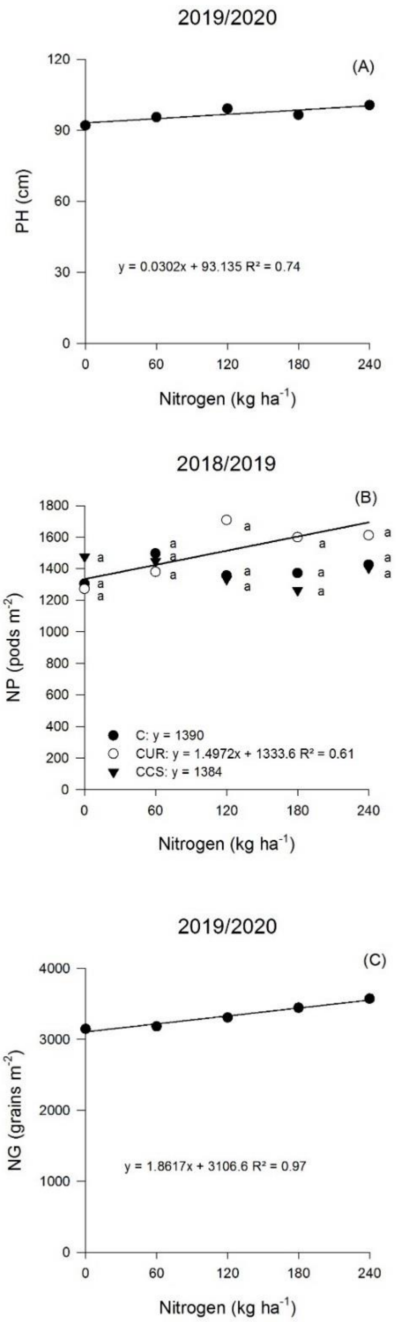


**Fig 5.** Soybean plant height (PH) (A), number of pods per square meter (NP) (B), and number of grains per square meter (NG) as function as cultivation systems (C: corn monocropping; CUR: corn + *Urochloa ruziziensis*; and CCS: corn + *Crotalaria spectabilis*) and/or topdressing N rates (0, 60, 120, 180 and 240 kg $ha^{-1}$) in second-crop corn. Means followed by the same letter within each nitrogen rate do not differ from each other by the Tukey test at 5 % of probability.

with *Crotalaria spectabilis*. The higher amount of straw on the soil in the corn-ruzigrass intercropping allowed better soil conditions for the growth and development of soybean, resulting in taller plants, which provided a larger number of pods per plant than in other cultivation systems.

The soybean yield was increased with an increasing N rate in topdressing at second-crop corn cultivation in both growing seasons (Figs 6A and 6B). In 2018/2019, when corn was not fertilized with N, succeeding soybean yield was 12% lower compared to the maximum rate of 240 kg $ha^{-1}$ of N applied to corn. In 2019/2020, the yield difference between no N and the maximum N rate was 7%.

The yield in 2018/2019 was lower than in 2019/2020 (Fig 6A and 6B) due to the water deficit in the grain filling period (Fig 1). This effect appeared in the one thousand grain mass recorded in 2018/2019 compared to that in 2019/2020, with 106 and 161 g, respectively.

Mineral N fertilization during the soybean cultivation does not increase yield since it can impair the efficiency of FBN (Hungria et al., 2006; Yokoyama et al., 2018). However, soybean growth and yield performance in NTS will indirectly receive benefit from the N application to the second-crop corn that precedes it. This is probably due to the increment of corn roots and corn straw production, besides higher nutrient cycling. Soybean is efficient in using N from the mineralization of organic matter, mainly when it participates in production systems with a large amount of straw in NTS (Câmara, 2014; Genovesi et al., 2019). Soybean shows better growth and higher yield performance to N applied to the preceding corn crop. Thus, the indication of the N rate in second-crop corn should consider this benefit to soybean in succession.

In the present study, it was not possible to detect any influence of the second-crop corn system (sole corn or corn intercropped with *Urochloa ruziziensis* or *Crotalaria spectabilis*) on soybean yields. This result is different from the observed in other studies (Pacheco et al., 2017; Genovesi et al., 2019). It is important to emphasize that the benefits of crop diversification in the soybean/corn production systems with cover crops, intercropped with corn, increase over time (Miguel et al., 2018). Crops intercropped in successive cycles can increase the accumulation of organic matter and nutrients in the soil, which is obtained over time, resulting in better conditions for crops in succession (Costa et al., 2015). Besides, the cultivation of intercropped corn provides other benefits to the NTS not evaluated in the present study, such as increased coverage and protection of the soil against water erosion (Engel et al., 2009; Seidel et al., 2017) and reduced infestations of weeds that are difficult to control between corn harvest and soybean sowing (Mechi et al., 2018).

**Material and Methods**

***Description of study area***

The experiment was carried out in Londrina, Paraná state, Brazil (23°11'S, 51°11'W and altitude of 620 m), during the 2018/2019 and 2019/2020 growing seasons in the same experimental area. The soil of this area is classified as Latossolo Vermelho Distroférrico (Santos et al., 2018) or Rhodic Eutrudox (Soil Survey Staff, 2014), with a particle size distribution consisting of 710, 82, and 208 g $kg^{-1}$ clay, silt, and sand, respectively, managed under NTS for ten years. Soil samples were collected at a depth of 0-20 cm before the experiment was set up to perform the chemical analysis, which presented the following results: pH ($CaCl_2$): 5.1; P: 13.9 mg $dm^{-3}$ (Mehlich 1); organic matter: 28.9 g $kg^{-1}$ (Walkley Black); Al: 0.0 $cmol_c$ $dm^{-3}$; H+Al: 5.0 $cmol_c$ $dm^{-3}$; K: 0.59 $cmol_c$ $dm^{-3}$; Ca: 4.2 $cmol_c$ $dm^{-3}$; Mg: 2.1 $cmol_c$ $dm^{-3}$; sum of bases: 6.8 $cmol_c$ $dm^{-3}$; cation exchange capacity: 11.8 $cmol_c$ $dm^{-3}$; and base saturation: 57%.

According to the Köppen classification, the regional climate is type Cfa, described as a subtropical humid mesothermal climate, with warm summers and infrequent frosts (Alvares et al., 2013). The precipitation and temperature data used to

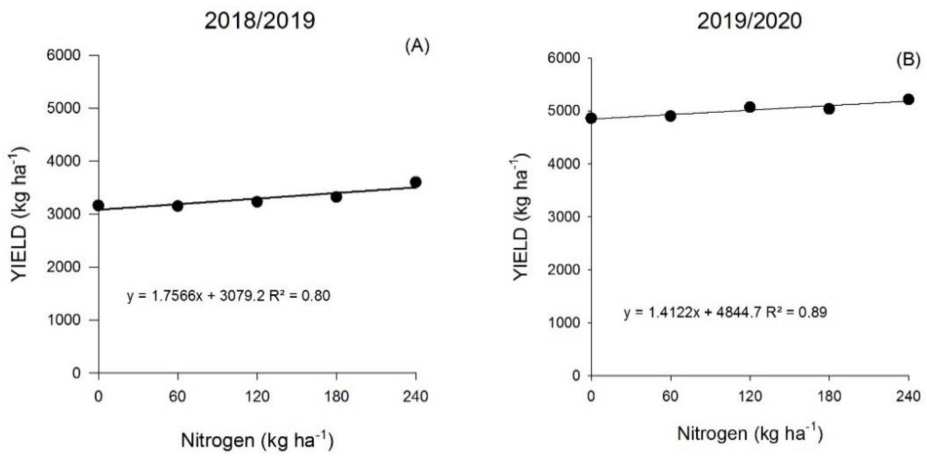


**Fig 6.** Soybean grain yield as function as topdressing N rates (0, 60, 120, 180, and 240 kg $ha^{-1}$) in second-crop corn.

calculate the sequential climatological water balance (Thornthwaite and Mather, 1955) during the trial period came from a weather station located 500 meters away from the experimental area. The soil's available water capacity was 75 mm (Fig 1).

***Experimental design and treatments***

The experimental design was a completely randomized block design with a split-plot scheme with four replicates. The plots were composed of sole corn (cv. AG 9010 PRO) or corn intercropped with ruzigrass (*Urochloa ruziziensis*) or showy rattlebox (*Crotalaria spectabilis*), and the subplots consisted of topdressing N rates (0, 60, 120, 180, and 240 kg $ha^{-1}$) as ammonium nitrate (33% N). Soybean (cv. BRS 1003 IPRO) was grown in succession with corn.

The subplot was composed of six rows with eight meters of corn spaced at 0.85 m. The corn was sown on March 16, 2018, and March 6, 2019, using a seed-cum-fertilizer drill with furrow-opening mechanisms to place the fertilizer and lagged double discs to place the seeds. The sowing machine set for a density of 65 thousand plants $ha^{-1}$.

***Crop management***

Base fertilization in corn was 310 $kg^{-1}$ ha of the formula NPK 08-28-16 ($N$-$P_2O_5$-$K_2O$) in the 2018 growing season, while in 2019 it was, 420 kg $ha^{-1}$ of 08-20-20. The sowings of ruzigrass and showy rattlebox intercropped with corn were made concomitant as the corn sowing, using a machine having an additional box for small seeds, with distribution through helical grooved rotors centered in the corn inter rows. The seeding rates for ruzigrass and showy rattlebox were 10 and 25 kg $ha^{-1}$ of viable seeds, respectively.

The broadcast topdressing N fertilization, split into two applications (50% + 50%), occurred when the plants were at V4 and V8. Additionally, all the treatments received 60 kg $ha^{-1}$ potassium chloride (60% $K_2O$) during the second broadcast N application in both growing seasons. After the corn harvest, the ruzigrass and showy rattlebox were kept in the field for straw formation until desiccation with the herbicide glyphosate (2.4 kg a.e. $ha^{-1}$), 25 days before sowing the soybeans.

The soybean subplots consisted of ten soybean rows (eight meters long) spaced at 0.45 m, considering the eight central rows as useful plot area, with 0.5 m at each end discarded as borders. The BRS 1003 IPRO (undeterminate growth) from the maturity group 6.3 was used. Before sowing, the soybean seed treatments were Thiamethoxam (0.7 g a.i. kg of $seed^{-1}$) and liquid inoculant containing *Bradyrhizobium elkanii*, SEMIA 587, and SEMIA 5019 at a concentration of 5 x $10^9$ UFC $ml^{-1}$ (5 ml kg of $seed^{-1}$).

The soybean was sown in the second half of October using a seed-cum-fertilizer drill with furrow-opening mechanisms to place fertilizer and lagged double discs to place the seeds, regulated to distribute 16 seeds per meter at 4 cm depth. The fertilization rate at sowing was 350 kg $ha^{-1}$ of the formulated fertilizer (NPK 00-20-20). One day after sowing, Paraquat (400 g a.i. $ha^{-1}$) was applied to control weeds. At stage V3, foliar application of cobalt and molybdenum was carried out (2 g $ha^{-1}$ Co and 12 g $ha^{-1}$ Mo). Control of pests, diseases, and weeds was according to the needs and recommendations for the crop.

***Evaluations***

To evaluate the total dry mass of corn straw at harvest maturity, when the grain moisture content reached 22%, three randomly selected corn plants were harvested at ground level in the subplots within different cultivation systems and nitrogen rates. This allowed for the quantification of the dry masses of stalks, leaves, ears without grains (consisting of straw and cob), and tassels. One day before the desiccation of ruzigrass and showy rattlebox plants, for sowing soybean, samples (0.85 $m^2$) were collected per subplot by cutting the plants close to the soil. The mass weighing of the ruzigrass and showy rattlebox plants was in a precision scale after drying in a forced-air ventilation oven at 60 °C for 72 h. The total dry mass was the sum of the dry masses of the corn and the cover crops.

At the V2 soybean stage, the plants in two meters taken at random from three soybean rows in the plot useful area were counted and extrapolated to plants per hectare. Evaluations at the R2 and R5.1 soybean stages were: a) SPAD index obtained between 8:30 and 10:00 am, with a Konica Minolta™ Spad 502 chlorophyll meter, in the central leaflet of the first leaf fully developed from the apex, in ten soybean plants per plot; b) normalized difference vegetation index (NDVI) given by the ratio NDVI=(NIRR-R)/(NIRR+R), where R refers to the reflectance in the red region (680 nm) and NIRR refers to the near-infrared reflectance (770 nm), from the Green Seeker™ 505 Handheld Sensor equipment positioned on the central row of each subplot; c) leaf area index (LAI): determined with a plant canopy analyzer, LI-COR™ LAI-2200 through an A reading (above the canopy of the central line plants in the middle of the subplot) and three B readings (between the lines and close to the surface of the soil), on clear sky days with intermittent clouds or full sun, avoiding underestimating or overestimating the values; d) soybean dry mass: a collection of the plant shoots in a linear meter of one of the subplot rows. The dry mass was weighed on a precision scale after drying in a forced-air ventilation oven at 60 °C for 72 h, and the value extrapolated to kilograms per hectare.

At the soybean physiological maturity, plants were collected from one meter of row per subplot to evaluate: a) first pod height insertion, measured from the neck of the plant to the insertion of the first pod; b) plant height, measured from the plant neck to the apex of the stem; c) number of pods per square meter, manual pod counting and extrapolation to the square meter; d) number of grains per square meter, manual grain count and extrapolation to the square meter; e) one thousand grain mass, an average weight of eight repetitions of one hundred grains, obtained in a precision scale and extrapolation to one thousand grain. Three rows of the useful area were harvested with a plot harvester at the R8 stage to determine the grain yield. The harvested grain weight was adjusted to an average water content of 130 g $kg^{-1}$ of grains and extrapolated to kilograms per hectare to represent the yield.

### *Statistical analysis*

The data were submitted to normality and homoscedasticity tests, which indicated fulfillment of the statistical assumptions, and submitted to analysis of variance. The $p \leq 0.25$ was considered for the interaction effect and $p \leq 0.05$ for the isolated effect of factors (Perecin and Cargnelutti Filho, 2008). The means of the variables were compared with the Tukey test for the qualitative factor (cultivation systems) and subjected to regression analysis ($p \leq 0.05$) for the quantitative factor (N rates) using Sisvar statistical software (Ferreira 2011).

## Conclusions

The increase in the N rate in second-crop corn, with or without intercropping with ruzigrass or showy rattlebox, increases soybean growth and yield in succession under the no-tillage system.

Second-crop corn intercropped with ruzigrass provides a higher amount of straw under the no-tillage system than sole corn or corn intercropped with showy rattlebox. However, intercropped systems do not influence the growth and yield of soybean grown in succession.

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