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# Maize-ruzigrass intercropping, nitrogen fertilization and plant density improve the performance of soybean grown in succession[1]

## Milho consorciado com braquiária sob adubação nitrogenada e densidade de plantas melhora o desempenho da soja em sucessão

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*HIGHLIGHTS:*

*Intercropping of maize with ruzigrass increases straw yield, nitrogen cycling, and soybean yield in successive crops.*
*Nitrogen fertilization of second-crop maize increases the yield of soybean grown in succession.*
*An increase in plant density of second-crop maize increases straw yield but not soybean yield.*

**ABSTRACT:** Second-crop maize-ruzigrass (*Urochloa ruziziensis*) intercropping, nitrogen (N) fertilization, and high maize plant densities enhance biomass production and N cycling, which may favor soybean growth and yield in the following season. This study aimed to assess the effects of second-crop maize-ruzigrass intercropping, N top dressing, and maize plant density on straw production in autumn/winter, N cycling, and agronomic performance of soybean crops grown in succession. Field experiments were installed in the 2018/2019 and 2019/2020 seasons using a randomized complete block design with split-split plots and four replications. The following factors were investigated: cropping system (sole maize and maize intercropped with ruzigrass), N top dressing (0 and 80 kg ha$^{-1}$), and maize plant density (40, 60, 80, and 100 thousand plants ha$^{-1}$). Maize-ruzigrass intercropping improved straw yield (2,365 kg ha$^{-1}$) and N cycling (50 kg ha$^{-1}$), and increased soybean yield in the following season (232 kg ha$^{-1}$). N fertilization of maize increased soybean grain yield by 180 kg ha$^{-1}$. Maize plant density did not influence the performance of succeeding soybean crops, regardless of the growing season.

**Key words:** *Urochloa ruziziensis*, nitrogen supply, cover crop, plant population, *Glycine max*

**RESUMO:** O consórcio milho segunda safra com braquiária ruziziensis (*Urochloa ruziziensis*), adubação com nitrogênio (N) e alta densidade de plantas do milho aumentam a produção de biomassa e a ciclagem de N, o que pode favorecer o crescimento e a produtividade da soja na safra seguinte. Este estudo teve como objetivo avaliar os efeitos do consórcio milho segunda safra com *Brachiaria ruziziensis*, aplicação de N em cobertura e densidade de plantas de milho sobre a produção de palha no outono/inverno, ciclagem de N e desempenho agronômico da soja em sucessão. Os experimentos de campo realizados nas safras 2018/2019 e 2019/2020, em delineamento de blocos completos casualizados com parcelas subdivididas e quatro repetições, investigaram os seguintes fatores: sistema de cultivo (milho solteiro e milho consorciado com *Brachiaria ruziziensis*), cobertura de N (0 e 80 kg ha$^{-1}$) e densidade de plantas de milho (40, 60, 80 e 100 mil plantas ha$^{-1}$). O consórcio milho-*Brachiaria ruziziensis* melhorou a produtividade de palha (2.365 kg ha$^{-1}$) e a ciclagem de N (50 kg ha$^{-1}$) e aumentou a produtividade de soja em sucessão (232 kg ha$^{-1}$). A adubação nitrogenada do milho aumentou a produtividade de grãos de soja em 180 kg ha$^{-1}$. A densidade de plantas do milho não influenciou o desempenho da soja cultivada em sucessão, independentemente da safra.

**Palavras-chave:** *Urochloa ruziziensis*, nitrogênio, planta de cobertura, população de planta, *Glycine max*

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## Introduction

Intercropping *Urochloa* species with maize is a way to diversify maize/soybean cropping systems. Crop diversification improves soil cover and nutrient cycling, minimizes soil compaction, reduces water erosion, suppresses weeds, and reduces soil thermal amplitude (Balbinot Junior et al., 2008; Beillouin et al., 2021). Sowing of ruzigrass (*Urochloa ruziziensis* syn. *Brachiaria ruziziensis*) during autumn/winter can increase the yield of succeeding soybean crops under no-tillage systems (Franchini et al., 2015; Balbinot Junior et al., 2017; Garbelini et al., 2022).

Nutrient cycling and grain yield in the succeeding crop depend on available soil nitrogen (N) (Bernardon et al., 2020). Autumn/winter fertilization aimed at meeting the nutrient requirements of the cropping system increases N use efficiency by plants and their nutrient cycling ability, thereby enhancing nutrient availability to subsequent crops (Momesso et al., 2019). There is evidence that the supply of N to maize significantly increases the yield of soybean crops grown in succession (Franchini et al., 2015; Balbinot Junior et al., 2017; Costa et al., 2021).

Adjustment of plant density is an important management strategy for harnessing the productive potential of maize (Sangoi et al., 2019). For sole maize, high plant density promotes biomass (Shao et al., 2018) and nutrient accumulation in aerial parts of successive plants (Ciampitti & Vyn, 2013). This process can be intensified by N top dressing and intercropping with ruzigrass (Ciampitti & Vyn, 2013). The association of ruzigrass intercropping with N fertilization and high maize plant density may provide substantial yield gains for soybean crops. Such knowledge is critical for a robust analysis of the viability of management practices encompassing the whole production system.

This study aimed to assess the effects of second-crop maize-ruzigrass intercropping, N top dressing, and maize plant density on straw production in autumn/winter, N cycling, and agronomic performance of successive soybean crops.

## Material and Methods

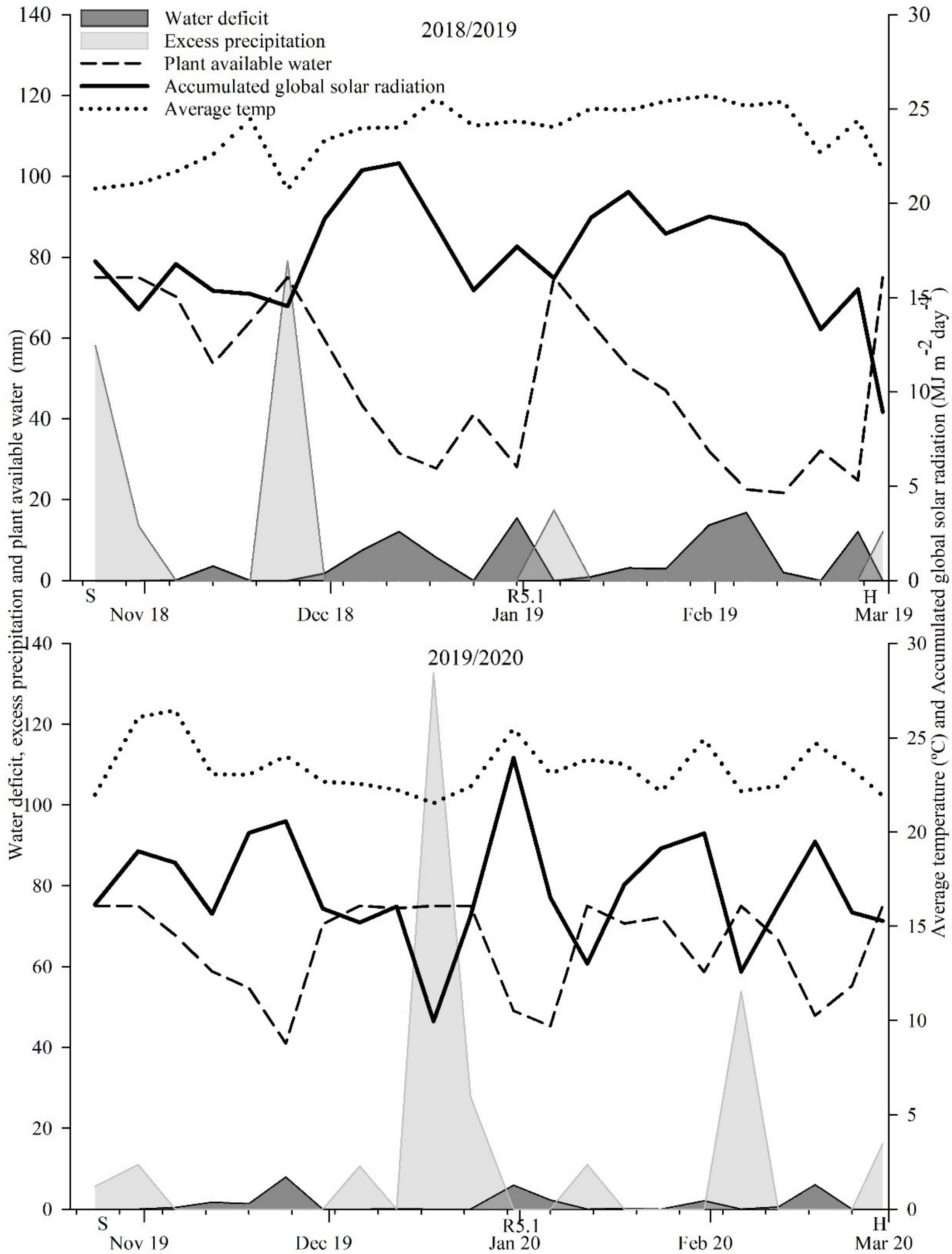
The field experiment (23° 11’ 57” S 51° 10’ 40” W, 585 m a.s.l.) was conducted in Londrina, Paraná State, Brazil, during the 2018/2019 and 2019/2020 growing seasons. The soil of the experimental area is classified as an Oxisol with clayey texture, “Latossolo Vermelho distroférrico” in the Brazilian classification system (EMBRAPA, 2018) and a Rhodic Eutrudox in the American classification system (United States, 2014). Soil chemical properties when the experiment was installed were as follows: total organic carbon, 18.11 g $dm^{-3}$; pH in $CaCl_2$, 5.11; Ca, 3.7 $cmol_c$ $dm^{-3}$; Mg, 1.87 $cmol_c$ $dm^{-3}$; Al, 0.0 $cmol_c$ $dm^{-3}$; K, 0.39 $cmol_c$ $dm^{-3}$; P (Mehlich), 28.82 mg $dm^{-3}$; cation-exchange capacity, 11.11 $cmol_c$ $dm^{-3}$; and base saturation, 53.65%.

According to Koppen’s classification (Alvares et al., 2013), the regional climate is of the Cfa type (humid subtropical mesothermal), with hot summers and rare frosts. Figure 1 shows the average temperature, cumulative global daily radiation, and sequential water balance according to the method described by Thornthwaite & Mather (1955), assuming a plant available water capacity of 75 mm. Water deficiency was determined from the potential evapotranspiration by considering how much the soil-plant system decreased the potential evapotranspiration. Water excess corresponded to water not retained and drained in-depth (gravitational water). Soil available water corresponds to the amount of water stored in soil.

The experiment was conducted using a randomized complete block design with split-split plots and four replications. Two cropping systems were tested in the main plots: maize hybrid AG 9050 PRO3 sown as sole crop or intercropped with ruzigrass. Two N top dressing rates were assessed in the split plots, namely 0 and 80 kg $ha^{-1}$. Four maize plant densities were evaluated in the split-split plots, namely 40, 60, 80, and 100 thousand plants $ha^{-1}$. Split-split plots measured 5 × 8 m (40 $m^2$), of which 3.2 × 6 m (19.2 $m^2$) was considered as observation area.

Sowing of maize and ruzigrass was performed after the harvest of soybean crops on March 10, 2018, and March 1, 2019. A seeder and fertilizer spreader with a guillotine-type furrowing mechanism was used to open rows 85 cm apart and apply the fertilizer. Manual seeders were used to sow three maize seeds per hole at demarcated points. Ruzigrass seeds were sown between maize rows (42.5 cm away from each row), without fertilization, by using a mechanized system with double discs and comprising a seed grader adjusted to deliver 5 kg $ha^{-1}$ on a viable seed basis. The basal fertilizer (25 kg $ha^{-1}$ N, 80 kg $ha^{-1}$ $P_2O_5$, and 80 kg $ha^{-1}$ $K_2O$) was chosen based on soil chemical properties and recommendations of the Paraná State Center of the Brazilian Society of Soil Science for a maize yield ceiling of 10 Mg $ha^{-1}$ (Moreira et al., 2017). When maize plants reached the V2 stage, they were thinned to the target plant density of each treatment. Weed control was performed with glyphosate (1.5 kg ai $ha^{-1}$) before maize and ruzigrass sowing and with atrazine (1.75 kg ai $ha^{-1}$) when maize plants were at the V3 stage. The pyrethroid insecticide zeta-cypermethrin (105 g a.i. $ha^{-1}$) was applied to maize plants at V3 and V6 stages for insect control. Maize yield ranged from 5.6 to 9.4 Mg $ha^{-1}$ in 2018/2019 and from 6.8 to 12.2 Mg $ha^{-1}$ in 2019/2020.

Soybean sowing was carried out on October 16, 2018, and October 25, 2019, after the desiccation of existing vegetation with glyphosate at a rate of 2 kg $ha^{-1}$ and a spray volume of 200 L $ha^{-1}$. A seeder-fertilizer spreader was mounted with a guillotine furrow opener for fertilizer application and with dephased double discs for sowing. The sowing density was 300 thousand viable seeds $ha^{-1}$ with a row spacing of 0.45 m. The soybean cultivar was BRS 1003 IPRO, which has an indeterminate growth habit, belongs to the 6.3 relative maturity group, and exhibits compact plant architecture. The fertilizer applied to soybean at the time of sowing was composed of 70 kg $ha^{-1}$ $P_2O_5$ and 70 kg $ha^{-1}$ $K_2O$ (0-20-20 NPK formulation). Fertilizer rates were defined based on soil chemical properties and technical recommendations of the Paraná State Center of the Brazilian Society of Soil Science for soybean crops (Moreira et al., 2017). Seeds were inoculated with *Bradyrhizobium japonicum* on the day of sowing. Weed, insect, and disease management procedures were applied




S, sowing; R5.1, beginning of grain filling; H, harvest

**Figure 1.** Sequential water balance, as assessed according to the method described by Thornthwaite & Mather (1955)

throughout the entire cycle of soybean plants and followed technical recommendations for the crop.

When maize crops reached the R6 stage (Ritchie et al., 1986), three plants were harvested from each split-split plot to determine dry matter accumulation, excluding grain weight. Before pre-sowing desiccant application, ruzigrass plants were collected along one linear meter from each split-split plot to determine ruzigrass dry weight. Total autumn/winter straw yield was determined by adding the dry weight of maize at R6 and ruzigrass dry weight.

Quantification of N content in maize straw was performed using the Kjeldahl method after sulfuric acid digestion. Straw N accumulation in autumn/winter was calculated from maize dry weight and straw N content.

Number of pods per area, grains per area, grains per pod, and thousand-grain weight were determined in one linear meter per split-split plot, sampled when plants were at the R8 stage (harvest maturity). The apparent harvest index (HI) was calculated from the relationship between grain dry matter production and total dry matter production of plants sampled for component analysis. Grain yield was determined by harvesting three 8 m long rows from each spit-split plot on February 20, 2019, and February 28, 2020. Grain weight was corrected to 13% moisture and expressed in kg ha$^{-1}$.

Data were analyzed for normality (Shapiro-Wilk test) and homogeneity of variance (Hartley's test) and then subjected to analysis of variance by the F-test ($p \leq 0.05$). Whenever rejection of the null hypothesis occurred, Tukey's mean comparison test and polynomial regression analysis were applied at the 0.05 significance level ($p \leq 0.05$). Statistical analyses were performed using R software (R Core Team, 2021).

## Results and Discussion

In the 2018/2019 season, soybean crops faced a water deficit of 26.3 mm at the V5 stage, concentrated in December (Figure 1A). From the R5.2 stage onward, the water deficit intensified, aggravated by high temperatures. In the 2019/2020 season, there was low water supply at the beginning of vegetative growth (Figure 1B) compared with 2018/2019. In general, the 2019/2020 crop season had adequate water supply, resulting in a better agronomic performance of soybean crops compared with 2018/2019.

A summary of the results of analysis of variance of the studied variables is presented in Table 1. Total straw yield in the autumn/winter season was affected by the interaction effects of maize density and intercropping. In sole maize, straw yield increased linearly by 33 kg ha$^{-1}$ for every 1000 plants ha$^{-1}$ in 2018 (Figure 2A) and showed a quadratic behavior in 2019, with a maximum estimated straw yield of 9.5 Mg ha$^{-1}$ at a density of 81 thousand plants ha$^{-1}$ (Figure 2B). When maize was intercropped with ruzigrass, straw yield was not affected by maize density. The maize-ruzigrass system had higher straw yield than the sole maize system, except at a maize density of 100 thousand plants ha$^{-1}$ in 2018 and 80 thousand plants ha$^{-1}$ in 2019.

N cycling was influenced by the interaction of maize density and intercropping and by the main effects of N top dressing in both growing seasons. In 2018, straw N content increased linearly with increasing plant density in the sole maize system (Figure 2C). However, in 2019, this effect was not significant (Figure 2D). In both seasons, in intercropped maize, there was a negative quadratic response of straw N cycling to increasing plant density (Figures 2C and D). Maize intercropped with ruzigrass cycled more N in autumn/winter than sole maize. This difference tended to decrease as maize density increased. Application of N led to an increase of 14% in 2018 (Figure 2E) and 31% in 2019 (Figure 2F) in N straw cycling in autumn/winter compared with treatments without N fertilization.

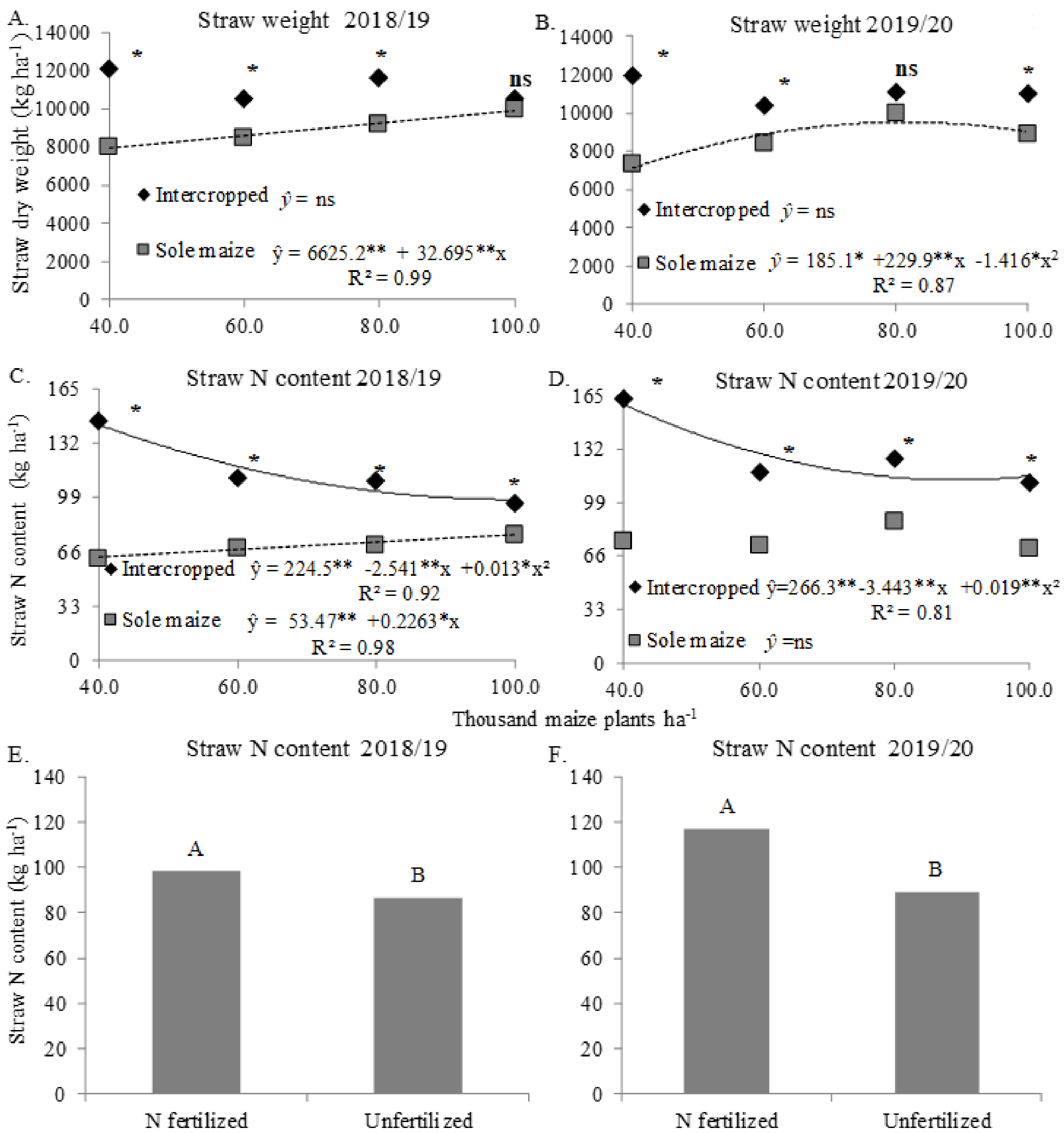
In 2018/2019, the studied factors did not influence the number of pods per square meter (overall mean = 1682), number of grains per square meter (overall mean = 4250), or number of grains per pod (overall mean = 2.53). The interaction between maize plant density and N top dressing influenced soybean thousand-grain weight. The triple interaction between maize density, intercropping, and N top dressing affected soybean HI.

Thousand-grain weight was not affected by maize density (Figure 3A). Thousand-grain weight was higher in N-fertilized plots with a maize density of 40 and 60 thousand plants ha$^{-1}$. Soybean planted after fertilized intercropped maize grown at a density of 40 and 100 thousand plants ha$^{-1}$ had the highest HI (Figure 3C).

In 2019/2020, the interaction between maize density and N fertilization influenced number of grains per area. When grown after unfertilized maize, soybean crops had fewer grains per area, decreasing linearly at a rate of 14 grains m$^{-2}$ for every 1000 plants ha$^{-1}$ (Figure 3B). In soybean grown in succession to fertilized maize, maize density did not affect number of grains per area. Soybean succeeding fertilized maize planted at 80 thousand plants ha$^{-1}$ presented the highest number of grains per area. Soybean grown after unfertilized maize showed a 3% increase in HI.

**Table 1.** Summary of analysis of variance (p-values) of agronomic variables as a function of cropping system, nitrogen top dressing, and maize plant density

| Item | Straw weight | | Straw N content | | Number of pods | | Number of grains | |
|---|---|---|---|---|---|---|---|---|
| | 2018/2019 | 2019/2020 | 2018/2019 | 2019/2020 | 2018/2019 | 2019/2020 | 2018/2019 | 2019/2020 |
| Block | 0.7054 | 0.0726 | 0.1301 | 0.0219 | 0.5615 | 0.4154 | 0.8165 | 0.8359 |
| Cropping system (C) | 0.0016 | 0.0007 | 0.0001 | 0.0002 | 0.6882 | 0.6453 | 0.6743 | 0.7662 |
| Coefficient of variation (%) | 8.32 | 6.79 | 7.65 | 8.55 | 18.89 | 17.15 | 22.52 | 30.41 |
| N top dressing (N) | 0.0752 | 0.1105 | 0.0247 | 0.0018 | 0.6566 | 0.3339 | 0.7895 | 0.8914 |
| C × N | 0.3730 | 0.6181 | 0.4772 | 0.5706 | 0.9795 | 0.1604 | 0.8667 | 0.3459 |
| Coefficient of variation (%) | 9.34 | 10.02 | 17.07 | 20.32 | 14.76 | 16.08 | 13.58 | 15.33 |
| Maize plant density (D) | 0.0375 | 0.0632 | 0.0004 | 0.0001 | 0.2909 | 0.3888 | 0.9187 | 0.2845 |
| D × C | 0.0001 | 0.0016 | 0.0001 | 0.0001 | 0.6774 | 0.9185 | 0.8375 | 0.9475 |
| D × N | 0.5347 | 0.2821 | 0.2732 | 0.1332 | 0.5136 | 0.1199 | 0.7541 | 0.0214 |
| D × C × N | 0.8239 | 0.2726 | 0.3551 | 0.3166 | 0.8549 | 0.8394 | 0.9183 | 0.5440 |
| Coefficient of variation (%) | 8.50 | 12.46 | 12.25 | 13.69 | 12.37 | 15.37 | 15.07 | 16.14 |
| | Grains per pod | | Grain weight | | Harvest index | | Soybean yield | |
| | 2018/2019 | 2019/2020 | 2018/2019 | 2019/2020 | 2018/2019 | 2019/2020 | 2018/2019 | 2019/2020 |
| Block | 0.2674 | 0.7447 | 0.4533 | 0.4201 | 0.9389 | 0.8363 | 0.8228 | 0.8769 |
| Cropping system (C) | 0.5493 | 0.2820 | 0.2863 | 0.1130 | 0.3752 | 0.9500 | 0.4480 | 0.0279 |
| Coefficient of variation (%) | 4.93 | 13.13 | 8.42 | 9.54 | 5.31 | 11.11 | 7.53 | 4.90 |
| N top dressing (N) | 0.4335 | 0.0694 | 0.0050 | 0.5696 | 0.2734 | 0.0227 | 0.0198 | 0.0448 |
| C × N | 0.4655 | 0.1916 | 0.8938 | 0.4433 | 0.1053 | 0.3130 | 0.4574 | 0.9351 |
| Coefficient of variation (%) | 3.16 | 6.35 | 3.01 | 13.12 | 2.59 | 3.89 | 5.60 | 4.83 |
| Maize plant density (D) | 0.0582 | 0.2689 | 0.3698 | 0.7856 | 0.2655 | 0.6601 | 0.0590 | 0.9051 |
| D × C | 0.5620 | 0.7723 | 0.1184 | 0.6378 | 0.5178 | 0.8691 | 0.7152 | 0.1392 |
| D × N | 0.2622 | 0.2524 | 0.0061 | 0.9119 | 0.0009 | 0.7466 | 0.7120 | 0.6916 |
| D × C × N | 1.0000 | 0.5833 | 0.0717 | 0.7194 | 0.0393 | 0.6135 | 0.9554 | 0.6650 |
| Coefficient of variation (%) | 5.12 | 7.37 | 6.01 | 10.75 | 2.63 | 4.33 | 5.43 | 5.33 |



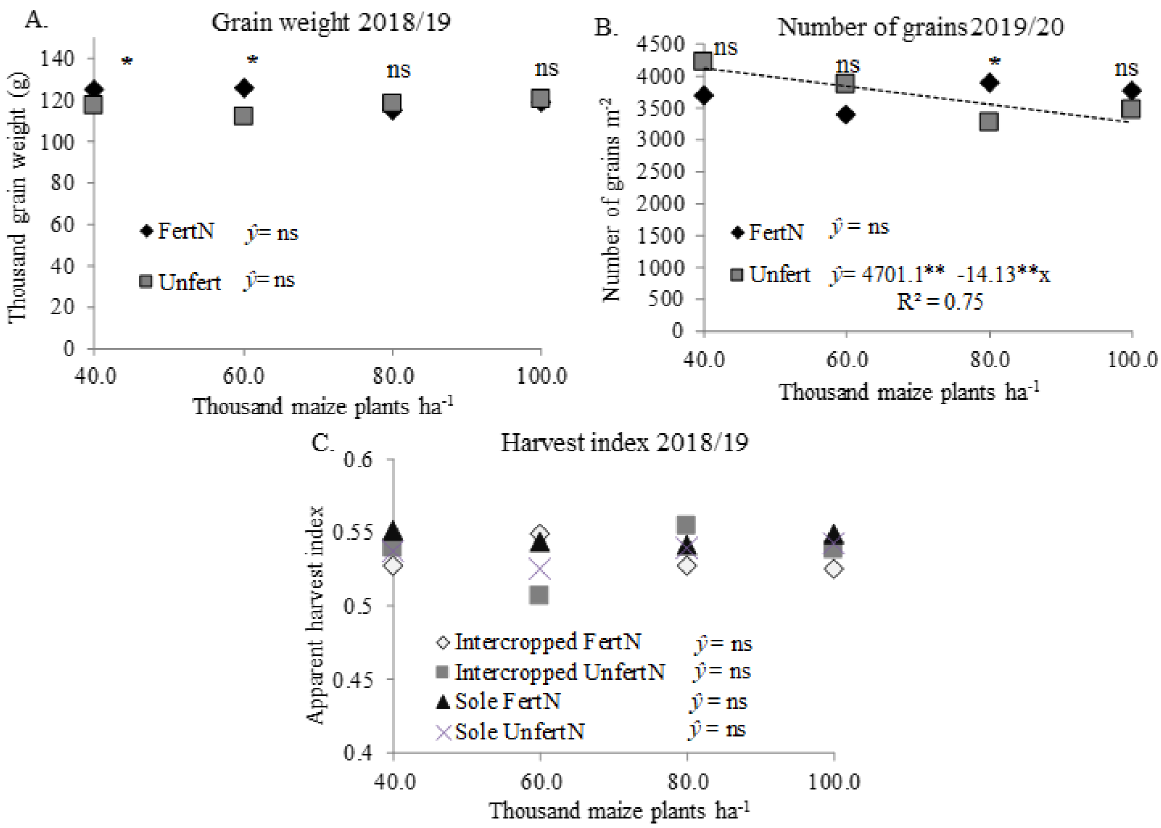

An asterisk (*) indicates significant differences between intercropping treatments by Tukey's test ($p \leq 0.05$); ns, not significant. Different uppercase letters above bars indicate significant differences between fertilization treatments by Tukey's test ($p \leq 0.05$); (*) and (**) in the equations refer to the significance of coefficients at $p \leq 0.05$ and $p \leq 0.01$, respectively

**Figure 2.** Maize and ruzigrass straw dry weight in (A) 2018 and (B) 2019, amount of nitrogen (N) cycled by straw in (C) 2018 and (D) 2019 as a function of maize plant density and ruzigrass intercropping, and amount of N cycled by straw in (E) 2018 and (F) 2019 as a function of N fertilization

In the 2018/2019 growing season, the main effects of maize density and maize N fertilization influenced soybean yield. In 2019/2020, soybean yield was affected by maize N fertilization and intercropping. Fertilization of maize with 80 kg ha$^{-1}$ N increased soybean yield by 214 kg ha$^{-1}$ in 2018/2019 (Figure 4A) and by 144 kg ha$^{-1}$ in 2019/2020 (Figure 4B). Maize plant density did not consistently affect soybean yield in either season. Soybean grown after maize intercropped with ruzigrass had a 232 kg ha$^{-1}$ higher yield than soybean grown after sole maize in 2019/2020 (Figure 4D), but there were no differences in 2018/2019 (Figure 4C).

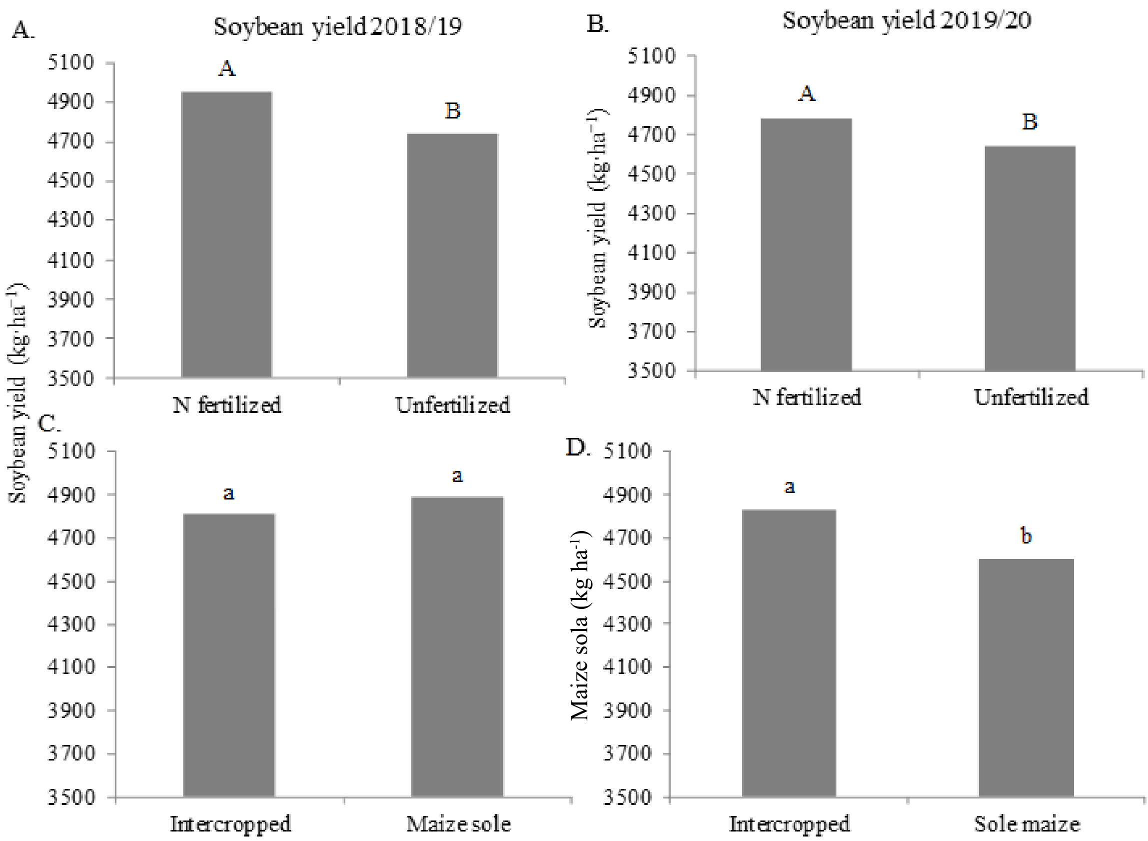
Interspecific competition between ruzigrass and maize in the intercropping system caused a reduction in N cycling and maize straw production at R6. With the increase in plant density and N fertilization, the increase in N content and straw production mitigated the impact of interspecific competition. However, in intercropping systems, an increase in maize density from 40 to 100 thousand plants ha$^{-1}$ led to a decrease in straw yield, from 11,998 to 10,751 kg ha$^{-1}$, and in N cycling, from 155 to 103 kg N ha$^{-1}$. In plots with a density of 40 thousand plants ha$^{-1}$, total straw yield was lower in sole maize than in intercropped maize, and differences decreased with increasing maize density. In plots with a density of 100 thousand plants ha$^{-1}$ in 2018 and 80 thousand plants ha$^{-1}$ in 2019, straw yield did not differ between sole and intercropped maize. Maize N fertilization increased straw N cycling by an average of 22% in both years.

Whereas maize produces a higher amount of straw than ruzigrass, ruzigrass promotes greater soybean yield in succession systems (Yokoyama et al., 2022), as it has a higher N content than maize (Mingotte et al., 2020). The increase in straw yield with intercropping, added to the increase in nutrient




FertN, N fertilized; Unfert, unfertilized; an asterisk (*) indicates significant differences between N fertilization treatments by Tukey's test (p ≤ 0.05); ns, not significant; (*) and (**) in the equations refer to the significance of the coefficients at p ≤ 0.05 and p ≤ 0.01, respectively

**Figure 3.** (A) Thousand-grain weight of soybean in 2018/2019 and (B) number of grains per square meter in 2019/2020 as a function of nitrogen (N) fertilization and maize plant density, and (C) apparent harvest index of soybean as a function of maize plant density, nitrogen fertilization, and maize-ruzigrass intercropping in 2018-2019




Different uppercase letters above bars indicate significant differences between fertilization treatments, and distinct lowercase letters above bars indicate significant differences between intercropping treatments by Tukey's test (p ≤ 0.05)

**Figure 4.** Soybean yield in 2018/2019 (A) and 2019/2020 (B) as a function of nitrogen fertilization of the previous crop and in 2018/2019 (C) and 2019/2020 (D) as a function of maize-ruzigrass intercropping

cycling (Mendonça et al., 2015), might have contributed to reducing thermal amplitude, improving water retention, protecting soil against erosion, and minimizing the incidence of weeds (Balbinot Junior et al., 2008; Beillouin et al., 2021). N fertilization in the autumn/winter period favored N cycling (Figures 2E and F), which is advantageous for succeeding crops (Momesso et al., 2019; Costa et al., 2021; Pires et al., 2022).

In the 2018/2019 crop season, maize-ruzigrass intercropping did not influence soybean yield. Soybean grown in succession to intercropped maize had a 6% higher leaf area index at R5.1 than soybean after sole maize. However, during grain filling, soybean was subjected to severe water stress, aggravated by high temperatures (Figure 1A). In treatments with more vigorous soybean growth, water consumption might have been higher toward the end of the cycle, resulting in little or no differences between intercropped and sole maize systems. Therefore, the water deficit during soybean grain filling can help to explain the lack of increase in soybean yield following intercropping in the first year of the study.

In 2019/2020, the ruzigrass-maize intercropping system increased soybean yield by 232 kg ha$^{-1}$ compared with sole maize (Figure 4D). Such behavior may be attributed to the cumulative benefits of ruzigrass to cropping systems (Baptistella et al., 2020; Balbinot Junior et al., 2020; Garbelini et al., 2020). Furthermore, the high water supply during grain filling (Figure 1) might have contributed to intensifying differences between treatments. Yokoyama et al. (2022) found that soybean exhibits higher yields when grown in succession to *U. ruziziensis* rather than maize, demonstrating the contribution of ruzigrass to improving soybean agronomic performance. Intercropping of ruzigrass with maize provides benefits to soybean. However, the benefits are greater when ruzigrass is grown alone as a predecessor to soybean (Balbinot Junior et al., 2017; Yokoyama et al., 2022).

Although maize density affected total straw yield and altered the relationship between maize straw and ruzigrass straw production, the real impact of maize density on soybean yield was unclear. The higher ruzigrass straw production in systems with low maize density did not translate into an increase in soybean yield, even though ruzigrass straw has a higher nutrient content than maize straw.

Recently, farmers have reduced N fertilization of second-crop maize (Sapucay et al., 2020) because of the high agrometeorological risk (Nóia Júnior & Sentelhas, 2020), the small response of the crop to N in this growing season (Sapucay et al., 2020), and the high cost of N fertilizers (Mergener et al., 2022). However, this management strategy may be detrimental to crop yields. The application of lower N rates than those exported by maize grains generates negative N balances, which is harmful to the production system (Coelho et al., 2022). Unlike N fertilization of soybean (Mourtzinis et al., 2018), N fertilization of maize increases soybean yield compared with non-fertilization. Soybean grown in succession to fertilized maize had a 214 kg ha$^{-1}$ increase in grain yield in 2018/2019 (Figure 4A) and a 144 kg ha$^{-1}$ increase in 2019/2020 (Figure 4B). This result may contribute to decision-making, emphasizing the possible benefit of N fertilizing second-crop maize.

There were no consistent differences in soybean yield components as a function of maize cropping system. Assessment of yield components can indicate those that are most affected by the management system adopted, helping to explain grain yield differences. However, in some cases, as in the present study, management system may not always significantly influence yield components. The emphasis here is that soybean yield results from the interaction of all yield components and that similarities in yield components between treatments do not necessarily mean similarities in grain yield.

## Conclusion

1. Intercropping second-crop maize with ruzigrass increased straw yield, N cycling, and soybean yield.
2. N top dressing of second-crop maize increased the yield of succeeding soybean, regardless of intercropping with ruzigrass or maize plant density.
3. An increase in second-crop maize density increased straw yield in the second season but did not influence soybean yield.

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