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MAIZE INTERCROPPING AND NITROGEN FERTILIZATION AIMING GRAIN YIELD AND IMPLEMENT A NO-TILL SYSTEM

Abstract – Intercropping grain crops with cover crops is a sustainable cultivation strategy that is useful for ensuring straw production for the no-tillage system (NTS) implementation and supply of nutrients, especially N, for successive crops. The aim of this study was to evaluate the influence of maize (*Zea mays* L.) cropping systems (CSs), when grown alone or intercropped with sunn hemp and ruzigrass, in combination with N fertilization in topdressing, on the maize agronomic performance and straw accumulation with NTS implementation. The experiment was conducted during the 2017/2018 season with a randomized block design in a split-plot scheme with four replications. The plots comprised maize alone, intercropped with sunn hemp (*Crotalaria spectabilis*), or intercropped with ruzigrass (*Urochloa ruziziensis*). The subplots were under four N rates: 0, 70, 140, and 210 kg ha⁻¹. The intercropping systems promoted greater N accumulation and straw production and did not reduce grain yield (GY). The addition of N fertilizers increased leaf nitrogen content (LNC) and GY. Intercropping reduced maize LNC; however, higher N fertilizer application in topdressing mitigated this effect. The intercropping of maize with cover crops is a viable and sustainable alternative for agriculture, as maize GY is not affected, and there is a greater straw production and N accumulation. Therefore, NTS implementation will help in increasing N supply in successive crops.

Keywords: *Zea mays* L., *Urochloa ruziziensis*, *Crotalaria spectabilis*, nitrogen, sustainability

MILHO CONSORCIADO E ADUBAÇÃO NITROGENADA VISANDO PRODUTIVIDADE DE GRÃOS E IMPLANTAÇÃO DE SISTEMA PLANTIO DIRETO

Resumo - O consórcio de culturas de grãos com plantas de cobertura é uma estratégia de cultivo sustentável, capaz de gerar produção de palhada para a implantação do sistema de plantio direto (SPD) e fornecimento de nutrientes para os cultivos em sucessão, sobretudo nitrogênio (N). O objetivo do presente trabalho foi avaliar a influência dos sistemas de cultivo de milho exclusivo e consorciado com crotalária e braquiária, submetidos a doses de nitrogênio em cobertura quanto ao desempenho produtivo e formação de palhada visando a implantação do SPD. O experimento foi realizado em 2017/2018. O delineamento foi em blocos casualizados, em esquema de parcelas subdivididas, com quatro repetições. As parcelas foram milho exclusivo, milho consorciado com *Crotalaria spectabilis* e milho consorciado com *Urochloa ruziziensis*. As subparcelas foram quatro doses de N, sendo 0, 70, 140 e 210 kg ha⁻¹. Os sistemas consorciados promoveram maior acúmulo de N e produção de palhada e não reduziram a produtividade de grãos do milho. A adubação nitrogenada promoveu incrementos no teor de N foliar e na produtividade de grãos de milho. Os consórcios reduziram o teor de N foliar do milho, entretanto a aplicação de maiores doses de N em cobertura mitigou esse efeito. O consórcio do milho com plantas de cobertura é uma alternativa viável e mais sustentável para a agricultura, pois a produtividade do milho não é afetada e ocorre maior produção de palhada e acúmulo de N que auxiliarão na implantação de SPD e no fornecimento de N para as culturas em sucessão.

Palavras-chave: *Zea mays* L., *Urochloa ruziziensis*, *Crotalaria spectabilis*, nitrogênio, sustentabilidade.

The no-tillage system (NTS) involves cultivating plants with minimal soil disturbance, keeping the straw on the surface, implementing crop rotation in the area, and maintaining live roots in the soil. Therefore, it seeks to reduce the cost of production, increase the yield and quality of the harvested product, and preserve and recover natural resources.

The choice of cover crop is an important factor in the implementation of the NTS. Crops in the rotation scheme must permanently maintain the minimum amount of straw on the soil surface (Aidar et al., 2007). Furthermore, the decomposition of this straw can help improve the availability of nutrients such as N for the production system (Gitti et al., 2012).

Grasses represented by *Urochloa* spp. (Amaral et al., 2016) and legumes, such as sunn hemp (Teodoro et al., 2011), are widely used in the formation of straw in the NTS. However, the exclusive cultivation of cover crops is not attractive to rural producers who seek income from agricultural products. Thus, a way to ensure both straw production and economic return is through the practice of intercropping, with simultaneous cultivation of these plants and grain-producing crops (Kappes & Zancanaro, 2015).

Maize (*Zea mays* L.) is a highly economically important crop worldwide, because it is used as food, fodder, and a raw material in ethanol production. The crop is cultivated in all regions of the Brazilian territory, generating high grain yields (GYs). In the 2017/2018 harvest

season, 16.61 million ha of land was under maize cultivation, with an average yield of 4.9 t ha⁻¹, taking into account the two annual harvests (Conab, 2018). Additionally, because of its C4 metabolism, high photosynthetic efficiency, and rapid initial growth, maize is one of the main agricultural crops recommended for the intercropping system, presenting a competitive advantage in relation to cover crops grown in intercropping (Oliveira et al., 2010; Kappes & Zancanaro, 2015).

Intercropping systems of maize with *Urochloa* spp. and sunn hemp have shown significant gains in straw formation for the NTS, maintaining high GYs (Kappes & Zancanaro, 2015; Gonçalves et al., 2016; Arf et al., 2018a). In the case of maize intercropping with *Urochloa* spp., called the Santa Fé System (Kluthcouski et al., 2000), long-term improvements in the soil physical quality and straw maintenance on the surface are also promoted because of the high C/N ratio of plant residues (Amaral et al., 2016). When sunn hemp is intercropped with maize, called the Santa Brígida System (Oliveira et al., 2010), there is a greater release of nutrients through the rapid decomposition of crop residues, which have a lower C/N ratio (Maluf et al., 2015).

Moreover, sunn hemp is associated with microorganisms with the ability to biologically fix N, inserting high amounts of nutrients into the production system through mineralization and/or exudation of organic acids through its roots. This can provide nutrients for crops in succession or even in intercropping, enabling the reduction

of mineral N fertilization. This aids in cost and pollution management because of the high consumption of fossil fuels for the manufacturing of N fertilizers (Souza et al., 2011). The use of maize cropping systems (CSs) intercropped with cover crops can be a strategy for high maize and straw yields, with lower N fertilization. Therefore, the study of these interactions is important in economic and environmental areas.

Thus, the aim of this study was to evaluate the influence of maize (*Zea mays* L.) cropping systems (CSs), when grown alone or intercropped with sunn hemp and ruzigrass, in combination with N fertilization in topdressing, on the maize agronomic performance and straw accumulation with NTS implementation.

Material and Methods

The experiment was conducted at the São Paulo State University (Unesp), School of Agricultural and Veterinarian Sciences, Jaboticabal, SP, during the 2017/2018 agricultural year (21° 14' 59' S, 48° 17' 13" W and 565 meters of altitude). The local climate is of the Aw type, characterized as tropical humid with a rainy season in the summer and a dry season in the winter, according to Köppen's classification.

The soil is classified as a clayey-textured eutroferic Red Latosol (Oxisol) (500 g kg⁻¹ clay) (Santos et al., 2018). Before the installation of the experiment, soil samples were collected for fertility analysis in the 0.00-0.20 m layer, obtaining the following results (Raij et al.,

2001): pH (CaCl₂) = 5.4; P resin = 72 mg dm⁻³, OM (organic matter) = 27 g dm⁻³; K; Ca; Mg; SB (sum of bases) and H+Al = 5.8; 42; 21; 69 and 34 mmol_c dm⁻³, respectively, CTC (cation exchange capacity) = 103 mmol_c dm⁻³ and V (base saturation) = 67%.

The experimental design used was randomized blocks in a split-plot scheme, with four replications. The plots were represented by three cropping systems (CS): maize alone, maize intercropped with ruzigrass (*Urochloa ruziziensis*) and maize with sunn hemp (*Crotalaria spectabilis*). The subplots were four nitrogen rates (NR) being 0, 70, 140 and 210 kg ha⁻¹ of N, applied in top-dressing between the cropping rows in the vegetative stage V6 of the maize, using urea (45% N). Each subplot consisted of five maize rows spaced at 0.45 m and 10 m long, making a total area of 22.5 m². The area used for evaluations (12.15 m²) was the three central rows of the subplot, discarding 0.5 m from the ends.

For the experiment implementation, conventional soil tillage was carried out, with plowing (0-0.30 m), medium harrowing in the 0-0.20 m layer and leveling harrow (leveling the soil surface). The sowing of cover crops and maize took place on 11/07/2017. Cover crop seeds were broadcast using 20 kg ha⁻¹ of *Crotalaria spectabilis* (Oliveira et al., 2010) and 15 kg ha⁻¹ of *Urochloa ruziziensis* seeds (Kluthcouski et al., 2000). Then, through a seeder-fertilizer, the maize was sown on the seeds of cover crops, using the hybrid DOW 2B810 PW, cycle of approximately

140 days, with spacing interrows of 0.45 m, obtaining a population of 66,000 plants ha⁻¹. Sowing fertilization was performed according to Cantarella et al. (1997), using 25 kg ha⁻¹ of N, 89 kg ha⁻¹ of P₂O₅ and 51 kg ha⁻¹ of K₂O.

Pest control was carried out with the seeds industrial treatment with: Tiamethoxan 350 g L⁻¹, for control of caterpillar-elasm, green-bellied stink bug and maize leafhopper in the initial period of crop development. At 29 days after emergence, Thiamethoxan 141 g L⁻¹ + Lambda-cyhalothrin 106 g L⁻¹ were applied to control caterpillars, and Imidacloprid 250 g L⁻¹ + bifenthrin 50 g L⁻¹ to control leafhoppers of the maize.

Chemical weed management was carried out in the maize alone system using the herbicide glyphosate potassium 620 g L⁻¹, 25 days after emergence. The maize harvest was carried out on 04/06/2018, when it completed 151 days after sowing. The experiment was cultivated under rainfed conditions and the meteorological data recorded during the conduct of the experiment are presented in Figure 1.

The total leaf N content (LNC) (g kg⁻¹) was evaluated in the maize crop at the time of female flowering (R1) by collecting the middle third section (without the midrib) of ten leaves, below and opposite the main ear, from ten plants per subplot. The samples were washed with running water and 1% detergent, dried in an oven with forced air circulation at 60-70 °C, and then processed in a Wiley type mill to determine the N content, according to the semi-micro Kjeldahl

method (Carmo et al., 2000).

During harvest, the thousand-grain mass (TKM) (g) was determined by randomly collecting and weighing four samples of 1000 maize grains. Maize GY (t ha⁻¹) was obtained after the crop attained physiological maturity by manually harvesting the ears of the useful area in each subplot, and mechanically tracing them. The grains were weighed, and the yield was estimated in t ha⁻¹. The samples were then placed in an oven at 105 °C until a constant mass was obtained to remove all the moisture from the grains; 13% moisture was considered the standard value adopted for maize. Accordingly, the TKM and GY were corrected to 13% moisture content.

The agronomic efficiency (kg kg⁻¹) was determined according to the method described by Fageria and Baligar (2005), using the equation:

$$AE = (GY_{nf} - GY_{wf}) / (NR)$$

Where:

GY_{nf} = grain yield with nitrogen fertilizer;

GY_{wf} = grain production without nitrogen fertilizer; and

NR = amount of N applied in kg.

After maize harvest, N content, straw N accumulation, and straw yield from maize cropping systems (CSs) were determined. The crop remains corresponding to each subplot were collected using a board with internal dimensions of 0.5 m × 0.5 m. These samples were washed and dried in a forced air ventilation oven at 65-70 °C until constant mass for subsequent weighing

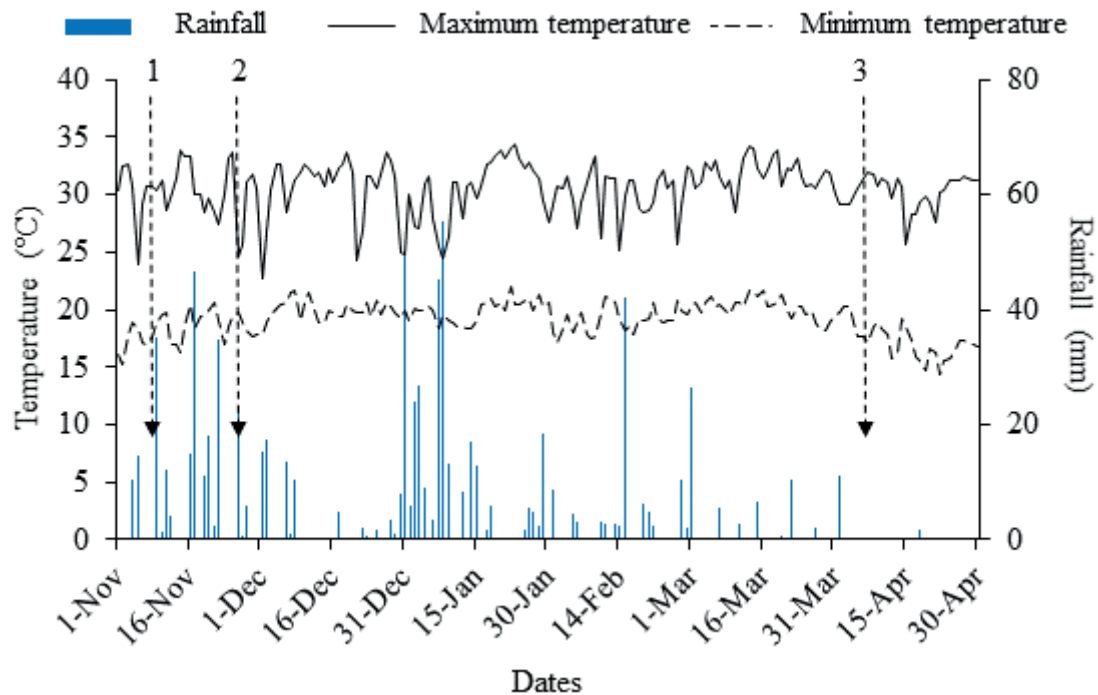


Figure 1 - Maximum and minimum air temperature (°C) and rainfall (mm) during the experimental period. The markings indicate sowing times of maize and cover crops (1), topdressing nitrogen fertilization (2) and harvest (3) of alone and intercropping maize of the 2017/2018 year, in Jaboticabal-SP. Source: Collection of the Agrometeorology area of the Department of Engineering and Exact Sciences at FCAV/Unesp.

and extrapolation of the quantity obtained ($t\ ha^{-1}$), determining yield. Thereafter, the material was ground and the N content ($g\ kg^{-1}$) was determined using the semi-micro Kjeldahl method (Carmo et al., 2000). N accumulation ($kg\ ha^{-1}$) was determined based on N content and straw yield.

Data were subjected to analysis of variance using the F test ($p \leq 0.05$) and, when necessary, the means were compared using the Tukey test ($p \leq 0.05$). Checking significant effects for N rates and interaction between cropping systems and N rate, they were evaluated by means of polynomial

regression analysis. Statistical analyzes were performed using the AgroEstat software (Barbosa & Maldonado Júnior, 2015).

Results and Discussion

The cropping systems (CSs) of maize grown alone, intercropped with ruzigrass, and intercropped with sunn hemp did not influence leaf nitrogen content (LNC), thousand-grain mass (TKM), or maize grain yield (GY) (Table 1). Similar results regarding GY were reported

Table 1. Leaf nitrogen content (LNC), thousand-grain mass (TKM), and grain yield (GY) of hybrid maize DOW 2B810 PW for maize grown alone, intercropped with ruzigrass (*Urochloa ruziziensis*), or intercropped with sunn hemp (*Crotalaria spectabilis*) cropping systems (CSs), as a function of nitrogen rates in topdressing, in Jaboticabal - SP, 2017/18.

Treatments	LNC	TKM	GY
	(g kg ⁻¹)	(g)	(t ha ⁻¹)
Cropping Systems (CSs)			
Maize alone	36.56	235.78	6.83
Maize + ruzigrass ⁽²⁾	30.57	228.44	6.37
Maize + sunn hemp ⁽³⁾	32.27	229.91	6.78
CV (%)	19.65	5.85	14.43
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(DMS) (Tukey - p ≤ 0.05)	7.06	14.69	1.04
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Nitrogen rates (NR) ⁽⁴⁾			
0	29.31 b ⁽¹⁾	221.52 b	6.02 b
70	30.87 b	228.62 ab	6.55 ab
140	36.10 a	234.24 ab	7.00 a
210	36.25 a	241.13 a	7.07 a
CV (%)	10.95	6.12	10.16
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DMS (Tukey - p ≤ 0.05)	4.03	15.84	0.75
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F test			
CS	0.0942 ^{ns}	0.3359 ^{ns}	0.3942 ^{ns}
NR	0.00001 ^{**}	0.0154 [*]	0.0022 ^{**}
CS*NR	0.0274 [*]	0.4293 ^{ns}	0.2449 ^{ns}
Overall mean	33.13	231.38	6.66

⁽¹⁾ Means followed by different letters in the columns within each factor differ by Tukey's test at 5% probability. ^{ns} Not significant by the F-test at 5% probability. ^{**}Significant by F test at 1% probability. ^{*}Significant by F test at 5% probability. (2) Maize intercropped with ruzigrass (*U. ruziziensis*) (3) Maize intercropped with sunn hemp (*C. spectabilis*). (4) Nitrogen fertilization was performed at the V6 maize phenological stage (kg ha⁻¹).

by Gonçalves et al. (2016) (7.1 t ha^{-1}) when comparing the cultivation of maize grown alone with that of maize intercropped with ruzigrass or sunn hemp in a eutrophic Red Latosol (Oxisol) in a region with climatic conditions similar to those of the present study in the summer. However, Arf et al. (2018a) verified, in a clayey dystrophic Red Latosol (Oxisol) in the summer season in a region with rainfall distribution and volume similar to that of the present study, a decrease in GY for maize intercropped with ruzigrass (8.9 t ha^{-1}) and legumes (8.8 t ha^{-1}) compared to maize alone (9.8 t ha^{-1}) over two agricultural years.

These differences between results found in the literature, in relation to maize GY, may be related to crop management and edaphoclimatic factors, as mentioned above. The present study and the study by Gonçalves et al. (2016) were carried out in eutrophic soils ($V > 50\%$) with high natural fertility, and maize intercropping did not reduce maize GY, whereas the study by Arf et al. (2018a) was carried out in a dystrophic soil ($V < 50\%$) with lower natural fertility, and the intercropping of maize with cover crops reduced maize yield. Thus, favorable soil fertility conditions can better meet the needs of plants with regard to abiotic factors, thus avoiding a reduction in GY for intercropped maize and promoting average yield values. GY values obtained in this study were mostly higher than those obtained in the state of São Paulo (6.44 t ha^{-1}) in the 2017/2018 agricultural year (Conab, 2018). For maximum maize GY, water consumption should be between 500 and 800

mm, and the optimum temperature is $25 \text{ }^{\circ}\text{C}$ to $30 \text{ }^{\circ}\text{C}$ (Embrapa, 2004), which comprise the total precipitation (766 mm) and temperature of this study during the crop cycle (Figure 1).

Regarding N topdressing, it was observed that the increase in N rates increased the nutrient content of maize leaves, thousand-grain mass (TKM), and GY (Table 1). For every 10 kg ha^{-1} of N supplied as fertilizer, there was an increase of approximately 0.40 g kg^{-1} in the LNC, 0.90 g in the TKM, and 51.7 kg ha^{-1} in the GY (Figure 2). Several studies have indicated an increase in GY with the supply of topdressing N for maize crops (Silva et al., 2010; Gonçalves et al., 2016), which is attributed to the importance of nutrients in the metabolic functions, growth, and production of plants.

The LNC was within the range considered adequate ($27\text{--}35 \text{ g kg}^{-1}$) for maize (Cantarella et al., 1997), across the CSs and N fertilizer treatments (Table 1). Furthermore, the variable was influenced by the interaction of factors behaving differently in relation to the supply of N for each CS (Figure 3). When maize was cultivated alone, the model was fitted in a second-degree equation, promoting 37 g kg^{-1} for the N rate of 162 kg ha^{-1} (Figure 3). Furthermore, in the absence of topdressing N (0), the LNC was higher for maize when grown alone (35 g kg^{-1}) than when intercropped with sunn hemp (28 g kg^{-1}) or ruzigrass (25 g kg^{-1}). This variation in the values decreased with an increase in topdressing N fertilization. Thus, the results indicated the existence of competition for N between maize

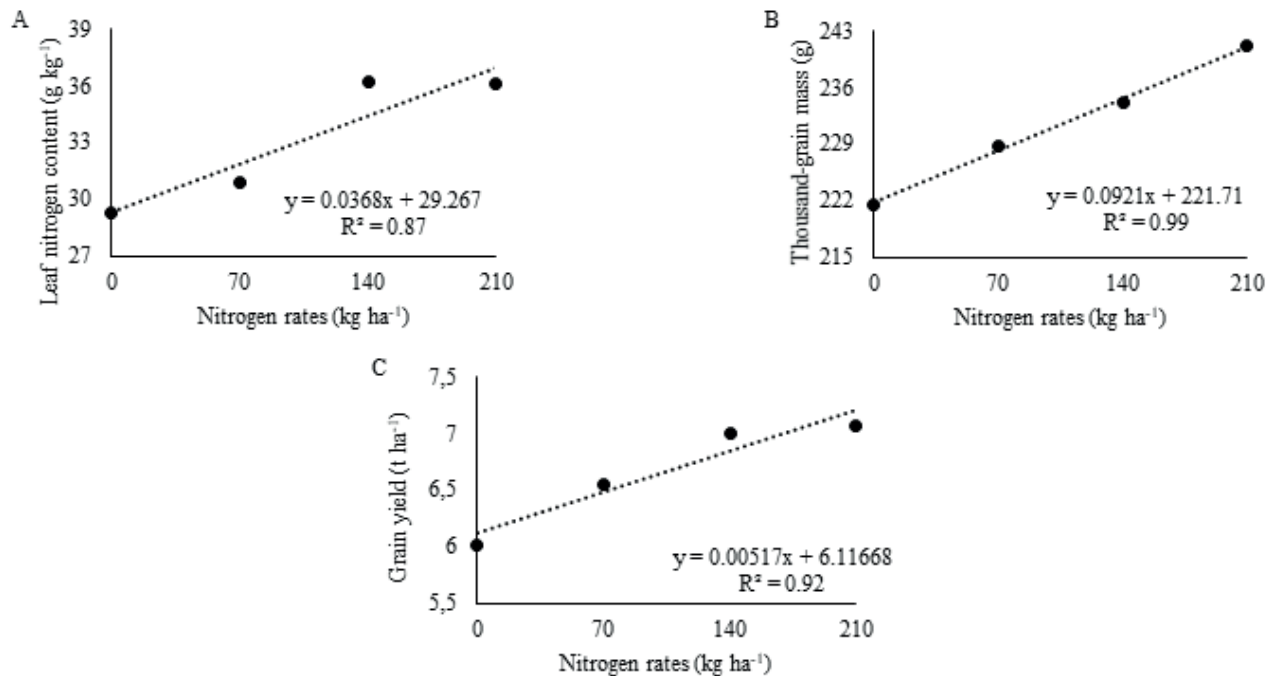


Figure 2. Leaf nitrogen content (A), thousand-grain mass (B) and grain yield (C) of the maize hybrid DOW 2B810 PW grown alone, intercropped with ruzigrass, and intercropped with sunn hemp, as a function of nitrogen rates in topdressing, in Jaboticabal – SP, 2017/18.

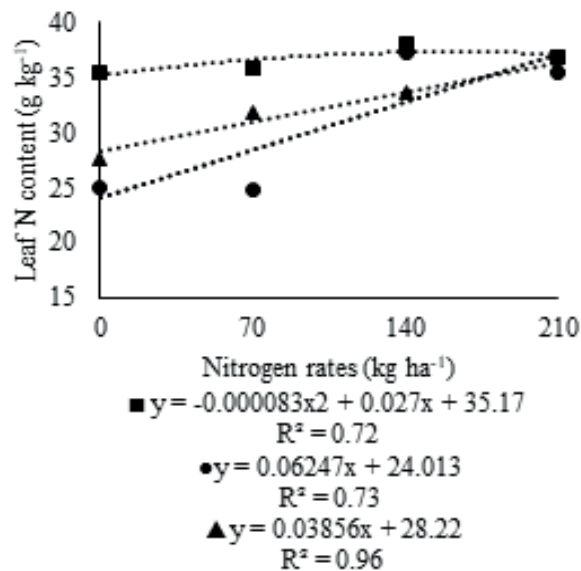


Figure 3. Breakdown of the interaction between cropping systems (CS) and nitrogen rates regarding the leaf nitrogen content (LNC) for maize grown alone (■), intercropped with sunn hemp (*Crotalaria spectabilis*) (▲), and intercropped with ruzigrass (*Urochloa ruziziensis*) (●). Jaboticabal, 2017/18.

and cover crops in intercropping systems, which could be alleviated by supplying nutrients using fertilizers, thereby meeting the nutritional demand of the crops. Competition was not reflected in GY (Table 1), possibly because it is mitigated by adequate edaphoclimatic resources such as temperature, rainfall distribution (Figure 1), and high soil fertility, as most contents are within the proper range for the crop, in addition to the fact that N was translocated from the leaves to grains (França et al., 2011).

Regarding agronomic efficiency, each CS behaved differently (Figure 4). Higher values were observed for the maize system at the three rates, being 40% higher for the 70 kg ha⁻¹ rate compared to the other systems. However, maize intercropped with sunn hemp had the lowest efficiencies for

the three rates. The intercropping maize and ruzigrass responded in an intermediate way to the other CSs, with an average value of 7.7 kg kg⁻¹ in the three rates. Agronomic efficiency reflects the amount of grain produced per kg of N supplied. For maize grown in a conventional system, Farinelli and Lemos (2010) observed a decrease in this variable as N fertilization increased, and for rates between 40 and 160 kg ha⁻¹, the agronomic efficiency decreased by approximately 30 to 10 kg kg⁻¹. The present study also displayed a decreasing trend of this variable (AE) with an increase in the supply of N, as observed by Farinelli and Lemos (2010), only for maize grown alone (13.29 kg kg⁻¹ at rate 70 to 9.36 kg kg⁻¹ at rate of N of 210) and with an increase of N in topdressing from 70 to

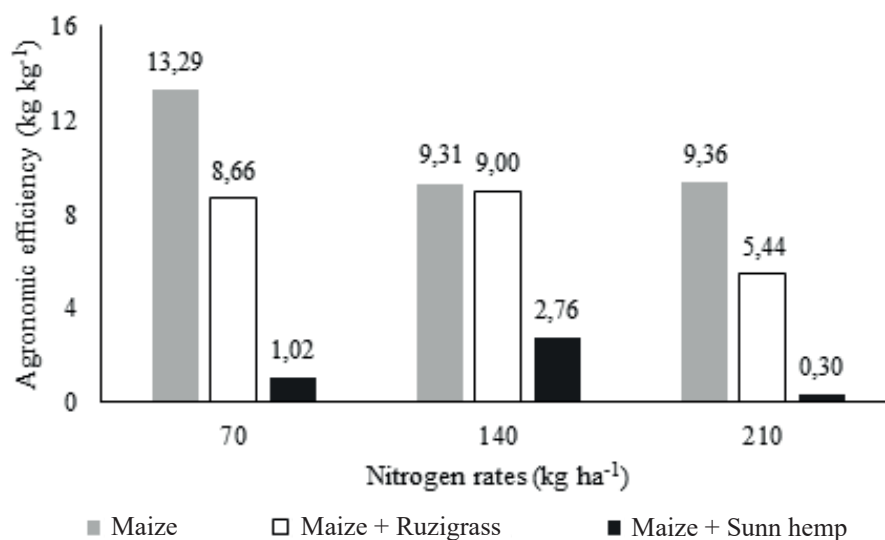


Figure 4. Agronomic efficiency of maize hybrid DOW 2B810 PW in cropping systems when grown alone, intercropped with ruzigrass, and intercropped with sunn hemp, as a function of nitrogen topdressing rates, in Jaboticabal - SP, 2017/18.

140 kg ha⁻¹. For the increase of N from 140 to 210 kg ha⁻¹, the efficiency displayed a very minimal change (9.31 kg kg⁻¹ at rate 70 to 9.36 kg kg⁻¹ at rate 210 for maize alone).

With regard to straw, only the CS influenced the yield, content, and accumulation of N (Figure 5A). There was a lower value in the straw yield from maize grown alone, which was justified by the higher number of plants in the intercropping systems compared to the sole crop. This result was also verified by Arf et al. (2018b), who compared the straw yield of maize grown in intercropping with sunn hemp, pigeon pea, jack bean, or ruzigrass in relation to maize grown alone. The presence of sunn hemp and ruzigrass increased straw yield by 38% and 41%, respectively. The minimum amount of straw necessary for soil cover in the no-till system (NTS) in the Cerrado biome is 7.0 to 8.0 t ha⁻¹, well-distributed for full soil cover (Aidar et al., 2007). The intercropping systems of maize with sunn hemp and with ruzigrass, with straw yield values close to 10 t ha⁻¹, proved to be advantageous for implementing a quality NTS. Thus, in addition to not interfering with GY, the insertion of cover crops intercropped with maize promotes greater straw production, helping to control nematodes (Leandro & Asmus, 2015) and weeds (Lamego et al., 2015), and providing a high amount of nutrients for crops grown in succession (Silva et al., 2010), factors that favor a more conservative and sustainable agriculture.

As for the N content, the straw in the intercropping system of maize with sunn hemp

was superior compared to that of the others, with values of 11.45 g kg⁻¹ for maize alone, 10.86 g kg⁻¹ for maize intercropped with ruzigrass, and 13.39 g kg⁻¹ in maize intercropped with sunn hemp (Figure 5B). This result was due to the large amount of N present in sunn hemp caused by the legume plants' ability to associate with N-fixing bacteria in the air, incorporating it into their metabolisms and leaf tissues (Quernéa et al., 2017). Thus, the high N content reflected the superiority of the N accumulation variable for straw from the maize intercropped with sunn hemp (131.80 kg ha⁻¹), while the intercropping of maize with ruzigrass also stood out in terms of accumulation (112.74 kg ha⁻¹), due to the high straw yield (Figure 5C). Compared to maize grown alone, values for N accumulation were 93% and 65% higher in the straw of maize intercropped with sunn hemp and ruzigrass, respectively. This increase represents a greater addition of N to the production system and, consequently, the availability for the crop in succession. Thus, crops grown after the intercropping of maize with ruzigrass and maize with sunn hemp will receive nutrients from the mineralization of the straw, with the possibility of reducing the necessary amount of N in mineral fertilizers.

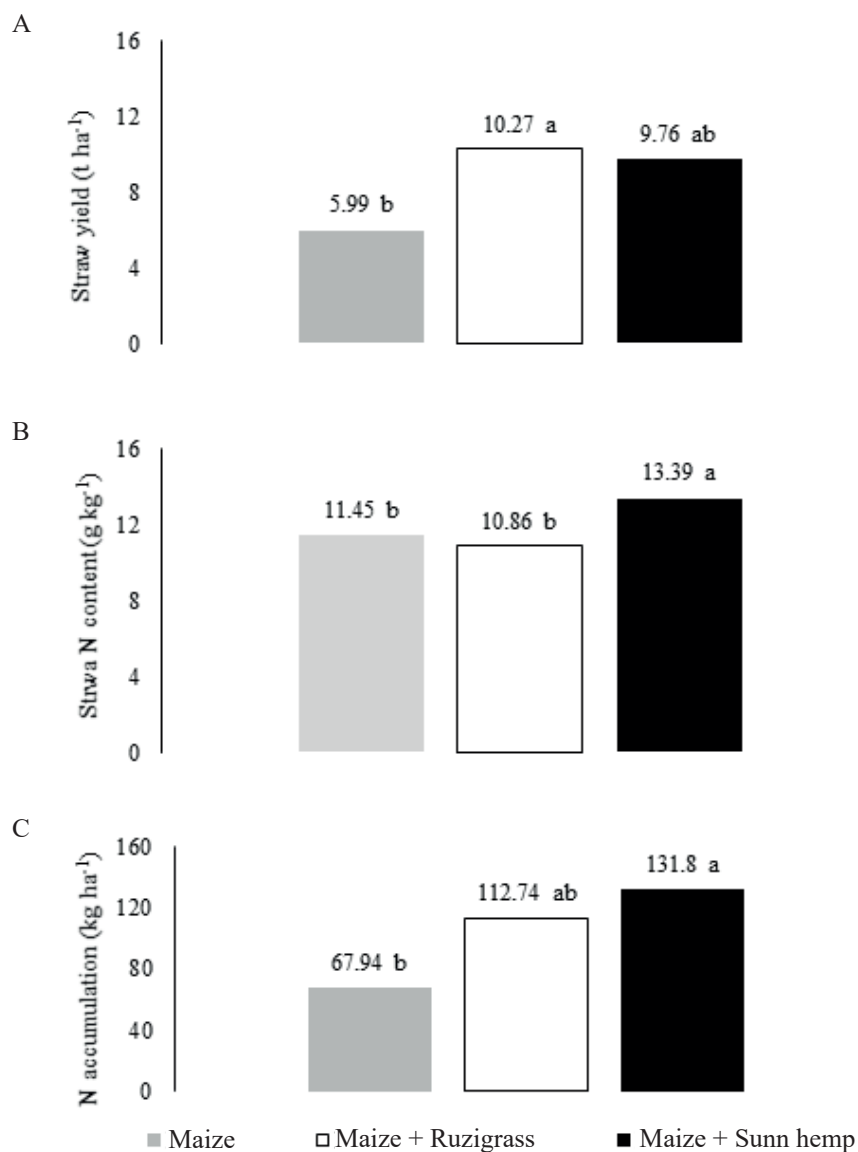


Figure 5. Straw yield (A), straw N content (B) and N accumulation (C) referring to straw from maize alone, maize intercropped with ruzigrass (*U. ruziziensis*), and maize intercropped with sunn hemp (*C. spectabilis*), in Jaboticabal, SP, 2017/18. Means followed by equal letters do not differ by Tukey's test at 5% probability. The F test and DMS test (Tukey - $p < 0.05$) for yield, N content and N accumulation were, respectively, 0.0269* and 40.70; 0.0010** and 8.64 e; 0.0178* and 43.61. **Significant by F test at 1% probability. *Significant by F test at 5% probability.

Grain yield of the maize hybrid DOW 2B810 PW was not negatively affected when the was cultivated intercropped with ruzigrass (*U. ruziziensis*) or sunn hemp (*C. spectabilis*).

The increase in N fertilization in topdressing increased leaf Nitrogen content and maize grain yield, with an increase of 51.7 kg ha⁻¹ in grain yield for every 10 kg ha⁻¹ of N applied.

The intercropping of maize with ruzigrass and sunn hemp promoted greater straw yield and N accumulation, enabling the implementation of a quality no-tillage system.

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