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DO *CROTALARIA* PLANT HEIGHT AND MAIZE INTER-ROW SPACING AFFECT INTERCROPPED MAIZE YIELD?

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Abstract – Intercropping with *Crotalaria* species may reduce maize yield; thus, evaluations must understand and explain competition in an intercropped system. The aim was to evaluate the effects of *Crotalaria* species and inter-row maize spacing on the growth and yield of intercropped maize. A randomized block design in a split-plot scheme was used. Plots comprised maize inter-row spacings of 0.45 and 0.90 m. Subplots consisted of four cropping systems: maize monoculture and three systems of maize intercropped with *C. juncea*, *C. spectabilis*, and *C. ochroleuca*. Plant heights of maize and *Crotalaria* species throughout the cycle, maize yield, and *Crotalaria* dry mass were evaluated. The critical plant height of *Crotalaria* that reduced maize yield ranged from 0.32 to 0.75 m, that is, the more advanced the maize cycle, the greater the critical plant height of *Crotalaria*. Intercropping with *C. juncea* was the only one that reduced maize yield (21%) compared to its monoculture, and inter-row maize spacing did not affect the variables. These results were due to the greater plant height (more than 100% higher) and final dry mass (more than 80% higher) of *C. juncea* compared to the other *Crotalaria* species, promoting competition with maize for water, light, and nutrients. The choice of *Crotalaria* species is essential for management in maize intercropped systems, associating the ecosystem benefits of the intercropping without reducing the cereal yield.

Keywords: *Zea mays* L., *Crotalaria juncea, Crotalaria spectabilis, Crotalaria ochroleuca,* green manure crops

ALTURA DE PLANTAS DA *CROTALARIA* E O ESPAÇAMENTO ENTRE LINHAS AFETAM A PRODUTIVIDADE DO MILHO CONSORCIADO?

Resumo - O consórcio com espécies de *Crotalaria* pode reduzir a produtividade do milho, necessitando de avaliações para entender e explicar a competição em um sistema consorciado. Objetivou-se avaliar os efeitos de espécies de *Crotalaria* e do espaçamento entre linhas sobre o crescimento e produtividade do milho consorciado. Utilizou-se um delineamento de blocos casualizados em esquema de parcelas subdivididas. As parcelas foram os espaçamentos entre linhas do milho de 0,45 e 0,90 m. As subparcelas foram quatro sistemas de cultivo: monocultivo de milho e três sistemas consorciados com *C. juncea*, *C. spectabilis* e *C. ochroleuca*. Avaliou-se a altura do milho e das espécies de *Crotalaria* ao longo do ciclo, a produtividade do milho e a massa seca final da *Crotalaria*. A altura crítica da *Crotalaria* que reduziu a produtividade do milho variou de 0,32 a 0,75 m, ou seja, quanto mais avançado o ciclo do milho, maior foi a altura crítica da *Crotalaria*. O consórcio com *C. juncea* foi o único que reduziu a produtividade do milho (21%) em relação ao seu monocultivo e o espaçamento entre linhas do milho não interferiu nas variáveis. Isso ocorreu pela maior altura de plantas (mais de 100% superior) e massa seca final (mais de 80% superior) da *C. juncea* em relação às demais espécies de *Crotalaria*, promovendo competição com o milho por água, luz e nutrientes. A escolha da espécie de *Crotalaria* é um manejo essencial em sistemas consorciados com o milho, associando os benefícios ecossistêmicos do consórcio sem reduzir a produtividade do cereal.

Palavras-chave: *Zea mays* L., *Crotalaria juncea, Crotalaria spectabilis, Crotalaria ochroleuca,* adubos verdes.

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Intercropping has been considered the fourth green revolution worldwide and can be a highly sustainable cropping system (Martin-Guay et al., 2018). Compared to monoculture, the benefits of intercropping are numerous, mainly including higher biomass production per area, soil protection against erosion, carbon sequestration, and nutrient cycling, in addition to the possibility of associating more than one economic activity in the same area and reducing the use of mineral fertilizers (Zhang & Li, 2003; Oliveira et al., 2010; Martin-Guay et al., 2018; Mingotte et al., 2020, 2021). Furthermore, intercropping consists in the production of the main species, considered to be of direct economic interest, and forage or green manure species, promoting economic and ecosystem benefits (Oliveira et al., 2010; Cambaúva et al., 2019; Borghi et al., 2013).

Due to its tall stature, high competitive ability, and C4 photosynthetic cycle, maize is the species of economic interest most used worldwide in intercropped systems (Zhang & Li, 2003; Oliveira et al., 2010). These characteristics give maize high plasticity and suitability to be used in intercropped systems. However, in specific managements and intercropping configurations, the secondary species used can reduce maize yield (Arf et al., 2018; Mingotte et al., 2021). This fact may interfere with the use of this system by producers. Thus, studies are needed to evaluate the effects of the growth of cover crops on maize yield growth to assist in the recommendation of more specific management.

Crotalaria spp. stand among the most used cover crops in intercropping with maize (Arf et al., 2018; Trevisan et al., 2021). This intercropping system is called the Santa Brígida system (Oliveira et al., 2010). It can be considered one of the most sustainable in agriculture since it associates with the cultivation of grass and legumes, integrating into the same area the benefits of cultivating these two types of plants (Liu et al., 2017; Cambaúva et al., 2019). There are several species within the genus *Crotalaria*, with plants ranging from short stature (<1.5 m) to tall stature (>2.5 m), which causes differences in the requirement and absorption of water, light, and nutrients (Allen et al., 1998; Barbosa et al., 2020; Silva et al., 2020). Through competition for these factors, these differences can interfere with the yield of intercropped maize, so the species most suitable for this cropping system should be evaluated.

In addition to the species, other factors may interfere with the success of the maize intercropped system especially the inter-row spacing used in the cereal crop (Borghi & Crusciol, 2007; Borghi et al., 2013). Since maize is sensitive to competition for light, water, and nutrients (Mao et al., 2012; Deienno et al., 2021; Trevisan et al., 2021), the use of smaller inter-row spacings can be an alternative to suppress the growth of intercropped plants, reducing competition with the cereal (Borghi & Crusciol, 2007; Borghi et al., 2013). Thus, studies involving these factors are necessary to promote recommendations for more specific management assisting producers and technicians in adopting

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more conservational agriculture.

The objective was to evaluate the effects of *Crotalaria* species and inter-row spacing on the growth and yield of intercropped maize.

Material and Methods

The experiment was conducted in the summer season of the agricultural year 2016/2017 at the São Paulo State University (Unesp), School of Agrarian and Veterinary Sciences, Jaboticabal, São Paulo, Brazil. The experimental area is near the geographic coordinates 21°14'59" S, 48°17'12" W, and at an altitude of 586 meters. According to Köppen's classification, the region's climate is Aw, characterized as a tropical climate with rainy summers and dry winters, with an average annual rainfall of 1425 mm.

The soil is classified as *Latossolo Vermelho eutroférrico* (Oxisol), of clayey texture (Santos et al., 2018). The area was under a conventional soil tillage system, consisting of plowing, heavy harrowing, and leveling harrowing. The area remained fallow in the winter-spring, with the following previous crops: lupine in the summer of the agricultural year 2014/2015 and maize in the summer of 2015/2016. Soil samples were collected to determine the chemical attributes of the 0-10 cm and 10-20 cm layers, and the results were, respectively: pH ($CaCl_2$) = 5.7 and 5.8; P (resin) = 13 and 11 mg dm^{-3}; K = 5.0 and 5.3 $mmol_c$ dm^{-3}; Ca = 34 and 37 $mmol_c$ dm^{-3}; Mg = 17 and 19 $mmol_c$ dm^{-3}; S = 8 and 10 mg dm^{-3}; organic matter = 29 and 26 g dm^{-3}; H+ Al = 24 and 18 $mmol_c$ dm^{-3}; cation exchange capacity = 80.0 and 78.7 $mmol_c$ dm^{-3}; and base saturation = 70 and 77 %.

The experimental design was randomized blocks in a split-plot scheme with four replicates, and the maize cropping systems and inter-row spacing were the sources of variation in the experiment. The plots were composed of two maize inte-rrow spacing: 0.45 m and 0.90 m, and the subplots were maize monoculture, maize + *Crotalaria juncea*, maize + *C. spectabilis*, and maize + *C. ochroleuca*. Each subplot had six maize rows and was five meters long, with the four central rows constituting the usable area.

Crotalaria species were sown broadcast manually, and incorporation was carried out during mechanized sowing of maize. The sowing density was 15 kg ha^{-1} for all *Crotalaria* species. The maize hybrid used was DOW 2B710, sown at the density of 66,000 plants ha^{-1}. The date of sowing of maize and *Crotalaria* species was November 22, 2016.

The calculations for fertilization were performed according to the recommendations suggested by Cantarella et al. (1997). For sowing fertilization, the dose used was 250 kg ha^{-1} of the formulation 8-28-16 applied to the sowing furrow. Then, top-dressing fertilization was performed in phenological stages V_4 (fourth leaf) and V_6 (sixth leaf), using the formulation 20-00-20 (V_4), with a dose of 400 kg ha^{-1}, and conventional urea (V_6), with a dose of 136 kg ha^{-1}, respectively, distributed in continuous bands at 0.10 m above the maize row. After the top-dressing application

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of the fertilizers, there were rains of 9.2 and 10.5 mm, respectively (Figure 1).

The irrigation was carried out through the conventional sprinkler system, with an interval of 3 to 4 days (depending on local climatic conditions) and irrigation depth of 10 mm per event. Irrigation was carried out up to stage V_4 of the maize crop.

Insecticides and fungicides were not sprayed in the crop, considering periodic evaluations of pests and diseases in the plants and their respective recommended control levels. Regarding weeds, manual weeding was performed in the vegetative stage V_6 of maize to avoid interferences in the *Crotalaria*/maize plants ratio.

In plants of *Crotalaria* species, height (m) was evaluated using a ruler, considering the distance from the soil level to the insertion of the last leaf. Evaluations were performed from 40 days after emergence (DAE) of maize at 40, 50, 60, 70, 80, 90, and 120 DAE with maize in the phenological stages V8, V12, R1, R2, R3, R4, and R6, respectively. In addition, the final dry mass produced by *Crotalaria* in each treatment was determined using a frame with dimensions of 0.25 x 0.25 m to collect plants, with three replicates per plot. All plants within the frame were collected to determine the total dry mass. The same procedure was performed to determine maize's final dry mass production in monoculture, which averaged 7.190 kg ha^{-1}.

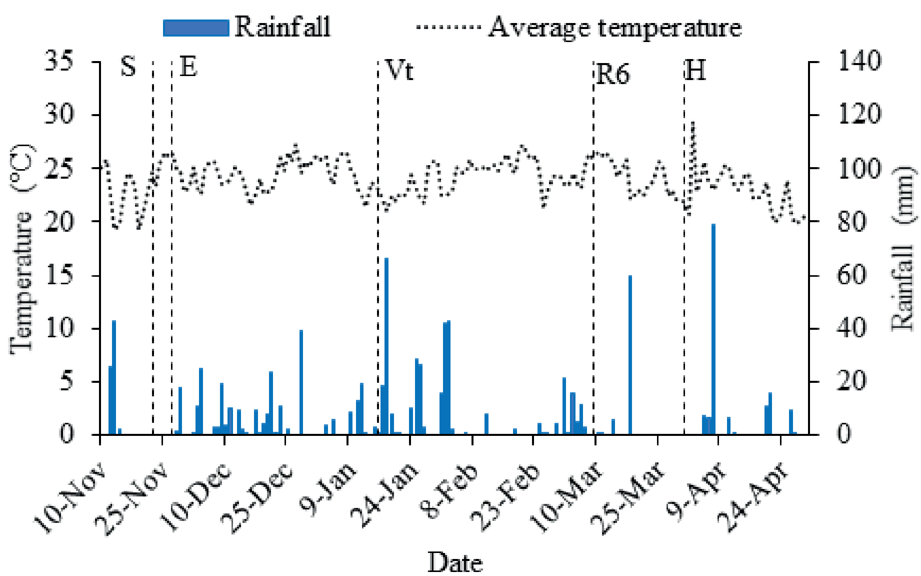

Figure 1. Daily values of rainfall and average temperature during the experiment. Sowing (S) on November 22, emergence (E) on November 27, tasseling (V_T) on January 16, physiological maturity (R_6) on March 9, and harvest (H) on March 31. Source: FCAV/UNESP Campus Agroclimatological Station – Jaboticabal, SP.

In the maize crop, plant height and grain yield were evaluated. Plant height was obtained by measuring plants at random within each subplot, using a ruler, from the soil level to the insertion of the last leaf. As performed for *Crotalaria*, the determination of maize plant height started from 40 DAE and was repeated every ten days until 120 DAE of the cereal. After the physiological maturity of maize, all ears within the usable area of each subplot were manually harvested and subjected to mechanical threshing, with subsequent weighing and calculations to determine grain yield, correcting the moisture content to 13%.

The data obtained were subjected to analysis of variance (F test), and the Tukey test compared the means at a 5% probability level. The collection period was not considered a source of variation in the univariate statistical analysis. The variation in the height of *Crotalaria* and maize plants over time was evaluated using polynomial regression analyses. Pearson's linear correlation was performed between the mean heights of *Crotalaria* and maize and the grain yield of the cereal for each evaluation from 40 DAE. In addition, regression analysis was performed between *Crotalaria* height and maize yield in each evaluation period to assess the effect of height on the cereal yield quantitatively. Statistical analyses were performed using AgroEstat software (Barbosa & Maldonado Júnior, 2015).

Results and Discussion

There were differences in plant height among the *Crotalaria* species throughout the cycle (Table 1). In all periods evaluated, *C. juncea* had the highest plant height. *C. ochroleuca* had a higher plant height than *C. spectabilis* at 50, 70, and 120 DAE. On the other hand, maize inter-row spacing did not affect the height of *Crotalaria* plants in any of the periods evaluated. There was no interaction between the cropping systems and inter-row maize spacings for *Crotalaria* height.

The quadratic model was the one that best represented the variation in plant height of *Crotalaria* species (Figure 2). The species *C. spectabilis* and *C. ochroleuca* showed very similar heights throughout the evaluation cycle, while *C. juncea* always had a greater height, with more than 100% higher values.

At the time of maize harvest, the dry mass production of *C. juncea* was 85 and 97% higher than the means observed for *C. spectabilis* and *C. ochroleuca* (Figure 3), with these last two species showing equal dry mass production. Inter-row spacing and the interaction between the studied factors did not interfere in the final dry mass of *Crotalaria*.

In general, the heights of maize plants showed no differences as a function of the cropping systems throughout the cycle (Table 2). Maize intercropped with *Crotalaria* species or in monoculture did not differ at 40, 50, 70, and 80 DAE. At 60 DAE, maize monoculture

Table 1. Heights of *Crotalaria* species over the days after emergence (DAE) of maize as a function of cropping systems (CS) and inter-row spacings (S).

Treatments	40 DAE	50 DAE	60 DAE	70 DAE	80 DAE	90 DAE	120 DAE
Cropping systems (CS)							
Maize + *C. juncea*	1.31 a	1.69 a	2.11 a	2.35 a	2.52 a	2.68 a	2.96 a
Maize + *C. spectabilis*	0.49 b	0.67 c	0.83 b	0.92 c	1.01 b	1.04 b	1.24 c
Maize + *C. ochroleuca*	0.54 b	0.77 b	0.87 b	1.05 b	1.11 b	1.16 b	1.45 b
HSD Tukey	0.07	0.06	0.11	0.09	0.12	0.20	0.20
CV (%)	6.81	4.53	7.02	5.15	5.86	9.24	8.17
Spacings (S)							
0.90 m	0.75	1.07	1.29	1.46	1.59	1.64	1.94
0.45 m	0.81	1.01	1.24	1.41	1.50	1.61	1.82
HSD Tukey	0.08	0.08	0.09	0.19	0.14	0.10	0.16
CV (%)	8.54	6.58	5.94	10.65	6.95	4.73	6.53
F test							
CS	587.91**	1127.2**	527.04**	910.38**	685.17**	291.45**	295.83**
S	4.54 ns	4.43 ns	2.62 ns	0.59 ns	4.74 ns	1.35 ns	5.41 ns
CS x S	2.08 ns	2.78 ns	1.77 ns	3.82 ns	0.14 ns	2.29 ns	3.55 ns

Means followed by the same lowercase letter in the column do not differ from each other by Tukey test at 5% probability level; *, ** significant at 5 and 1% probability levels, respectively, and ns – not significant by F-test.

differed from the intercropping with *C. juncea* and *C. ochroleuca*, which did not differ from the intercropping with *C. spectabilis*. At 90 and 120 days after maize emergence (DAE), maize monoculture showed different values compared to the system with *C. juncea*, which did not differ from the others.

The difference between the values of height caused by inter-row spacing was observed only at 40 DAE when the spacing of 0.45 m reduced the mean height of maize. There was no interaction between the cropping systems and inter-row spacings for the height of maize plants. Regarding maize yield, only the intercropping of maize + *C. juncea* differed from the others, generating a mean yield 22.5% lower than the means of the others.

As observed for the height of *Crotalaria* species, the quadratic model was the one that best represented the variation in the height of maize plants over time (Figure 4). In addition, regression analysis confirmed similarity in maize height over time in all cropping systems.

The correlation between the height of

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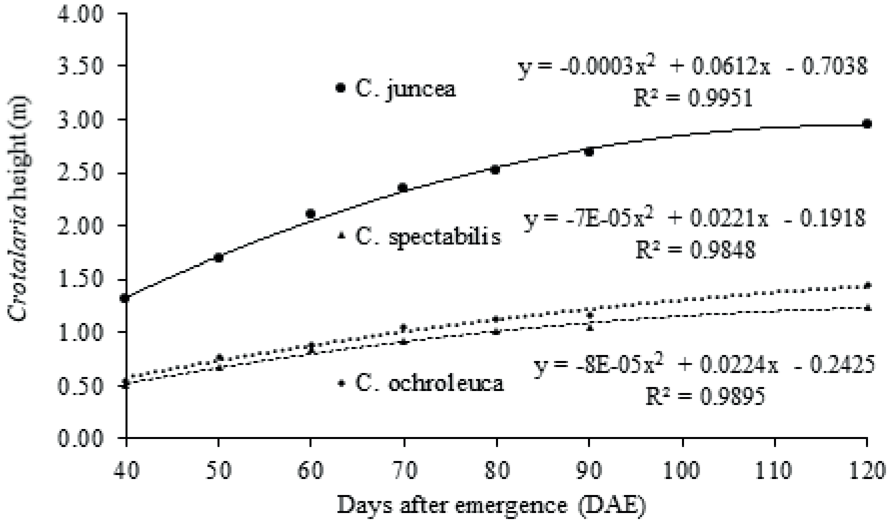

Figure 2. Heights of *Crotalaria* species as a function of the days after emergence (DAE) of maize.

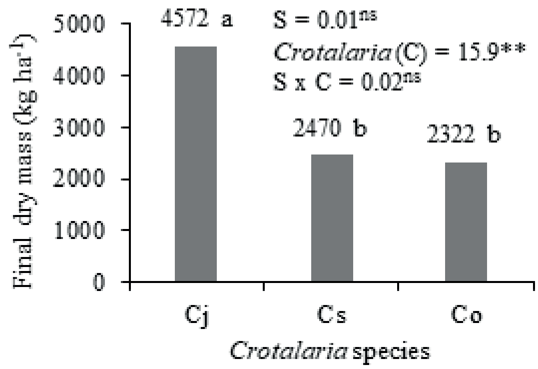

Figure 3. Dry mass produced by *Crotalaria* species at the time of maize harvest. S: inter-row spacing; Cj: *Crotalaria juncea*; Cs: *Crotalaria spectabilis*; Co: *Crotalaria ochroleuca*; Numbers indicate the F factor of the analysis of variance (F test); Means followed by the same letter do not differ from each other by Tukey test ($p \leq 0.05$)

Crotalaria plants and maize yield (Table 3) was significant and inverse for all periods evaluated, indicating that the height of *Crotalaria* contributed to the reduction in maize yield. The same was not observed for the correlation between maize height and its yield since a significant correlation was not observed for the periods evaluated.

For all periods evaluated, maize yield decreased quadratically with the increase in the height of *Crotalaria* species (Figure 5). Maize yield was reduced from a certain height of Crotalaria plants, defined as critical height. This

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Table 2. Heights of maize plants as a function of days after emergence (DAE) and yield as a function of cropping systems (CS) and inter-row spacings (S).

Treatments	40 DAE	50 DAE	60 DAE	70 DAE	80 DAE	90 DAE	120 DAE	Yield (t)
Cropping systems (CS)								
Maize + *C. juncea*	1.56 a	2.27 a	2.56 b	2.61 a	2.58 a	2.53 b	2.50 b	11.21 b
Maize + *C. spectabilis*	1.61 a	2.30 a	2.59 ab	2.61 a	2.62 a	2.59 ab	2.57 ab	14.77 a
Maize + *C. ochroleuca*	1.65 a	2.31 a	2.58 b	2.64 a	2.64 a	2.59 ab	2.55 ab	14.29 a
Maize monoculture	1.61 a	2.35 a	2.69 a	2.62 a	2.63 a	2.60 a	2.58 a	14.25 a
HSD Tukey	0.09	0.08	0.10	0.07	0.08	0.06	0.07	2.07
CV (%)	4.29	2.60	2.75	1.94	2.17	1.72	2.02	10.77
Spacings (S)								
0.90 m	1.68 a	2.30	2.58	2.64	2.61	2.56	2.52	13.26 a
0.45 m	1.53 b	2.31	2.62	2.60	2.62	2.59	2.57	14.01 a
HSD Tukey	0.08	0.84	0.09	0.07	0.03	0.06	0.13	0.96
CV (%)	4.74	5.88	3.21	2.42	1.31	2.17	4.83	6.23
F test								
CS	2.20^{ns}	2.17^{ns}	5.00*	0.40^{ns}	1.79^{ns}	3.85*	3.80*	9.80**
S	30.65*	0.01^{ns}	1.93^{ns}	2.96^{ns}	0.85^{ns}	2.01^{ns}	1.25^{ns}	6.30^{ns}
CS x S	0.82^{ns}	1.91^{ns}	2.04^{ns}	0.24^{ns}	1.98^{ns}	1.11^{ns}	0.25^{ns}	0.62^{ns}

Means followed by the same lowercase letter in the column do not differ from each other by Tukey test at 5% probability level; *, ** significant at 5 and 1% probability levels, respectively and ns – not significant by F test.

critical height ranged from 0.32 m to 0.75 m in the evaluated period from 40 to 120 DAE of maize, and the more advanced the maize cycle, the greater the critical height of *Crotalaria*. In the general mean of the regressions, the monoculture of maize (*Crotalaria height* = 0) generated a yield of 14.22 Mg ha^{-1} (Figure 5).

Within the evaluation period from 40 to 120 DAE, the maximum critical height of *Crotalaria* showed increasing linear variation (Figure 6), indicating that the more advanced the maize cycle, the greater the *Crotalaria* height must be to reduce maize yield. According to the regression (Figure 6), this value increased by 5.4 cm every ten days in the maize cycle.

The competition for water, light, and nutrients reduced maize yield due to the increase in the height of *Crotalaria* plants, and this effect was independent of the inter-row spacing used. The variation in maize yield as a function of Crotalaria height was quadratic, up to a particular plant height, called critical height; Crotalaria does not interfere in maize yield. This situation occurs because taller plants promote more shading over maize and greater competition for water and nutrients.

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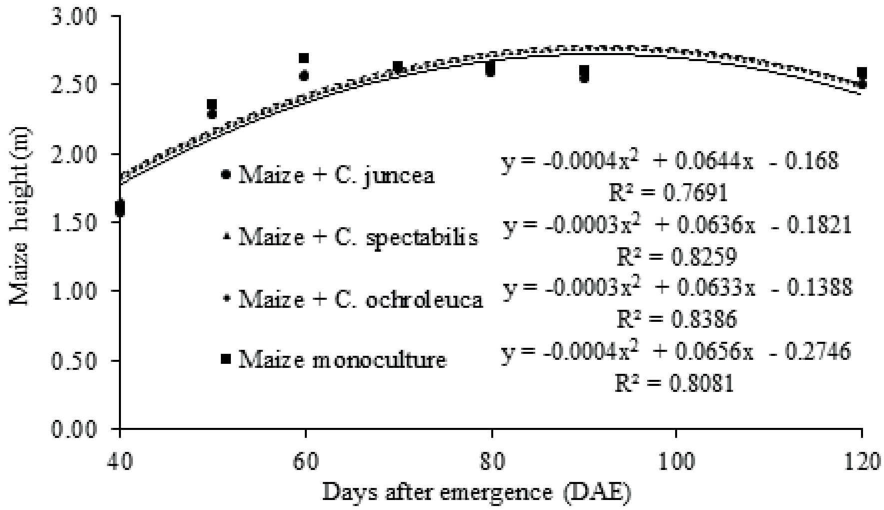

Figure 4. Heights of maize plants as a function of the days after emergence (DAE).

Table 3. Correlation coefficients (r) between heights of *Crotalaria* species and maize yield and between maize height and maize yield, as a function of days after emergence (DAE).

Evaluation periods	*Crotalaria* height vs Maize yield	Maize height vs Maize yield
40 DAE	-0.79 **	0.31 ns
50 DAE	-0.76 **	0.05 ns
60 DAE	-0.74 **	0.07 ns
70 DAE	-0.75 **	0.00 ns
80 DAE	-0.72 **	0.14 ns
90 DAE	-0.78 **	0.08 ns
120 DAE	-0.71 **	0.01 ns

** Significant ($p \leq 0.01$). * Significant ($p \leq 0.05$). ns not significant.

When evaluating the effects of shading at different phenological stages on maize yield, Cui et al. (2015) verified that maize yield and biomass accumulation decreased by up to 36% under shading conditions compared to the complete sun management factor was dependent on the shading period. Gou et al. (2017) demonstrated that the intercropping of maize and wheat reduces the radiation use efficiency of maize, affecting its biomass accumulation. Zhai et al. (2018) highlight that maize is one of the most sensitive cultivated plants to intra- and interspecific competition, indicating that competition for light with maize is harmful to its yield. In

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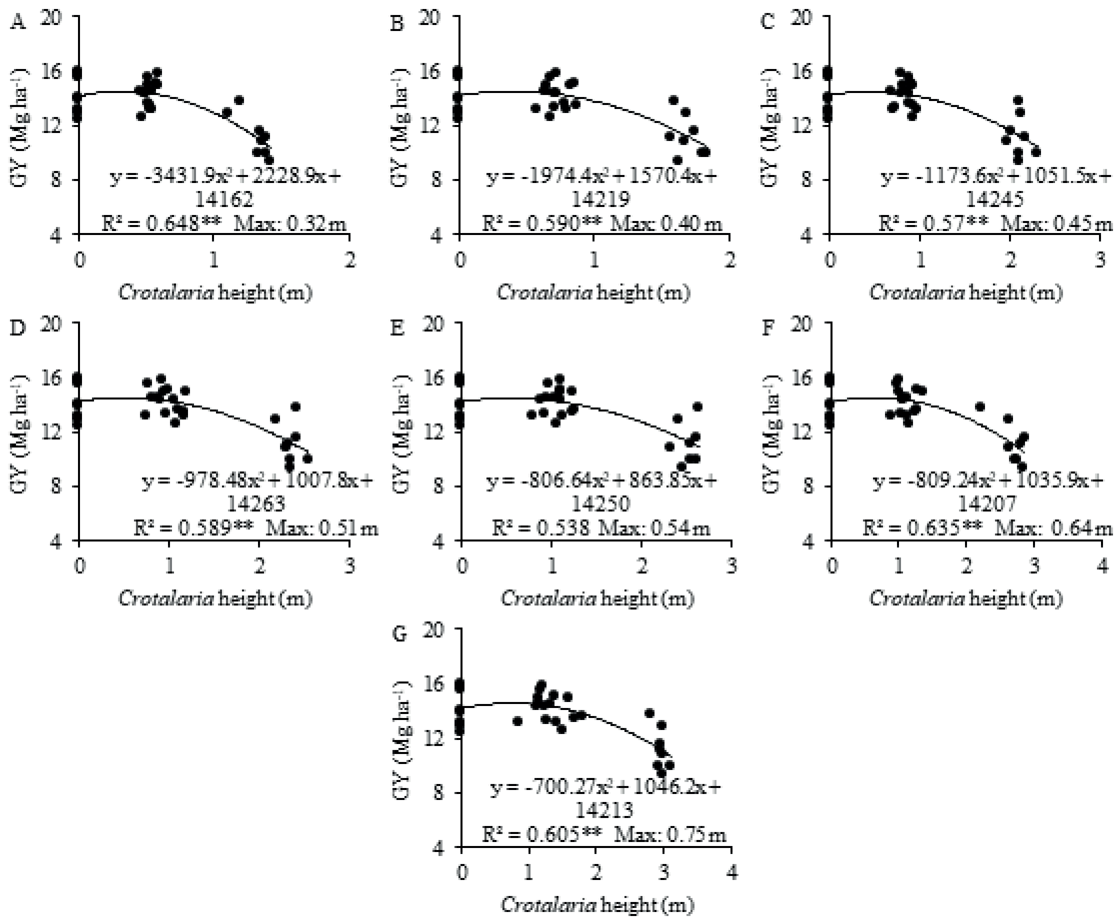

Figure 5. Variation of maize grain yield (GY) as a function of the height of *Crotalaria* species at 40 (A), 50 (B), 60 (C), 70 (D), 80 (E), 90 (F), and 120 (G) days after emergence (DAE). $^{**}p \leq 0.01$.

addition, the interception of photosynthetically active radiation by maize when intercropped with legumes (soybean) is lower, which affects its growth. Liu et al. (2017) evaluated the effect of photosynthetically active radiation interception by maize and soybean in some intercropping configurations. Although the intercropped systems had a more outstanding interception of photosynthetically active radiation in the total accumulation, the radiation specifically intercepted by maize was reduced by more than 10% compared to its monoculture. These results, associated with the agronomic performance of maize verified in the present study, demonstrate the sensitivity of this cereal to competition for radiation, especially with taller intercropped species.

Intercropping maize with tall plants can reduce the availability of water and nutrients for this cereal, given the increased demand for

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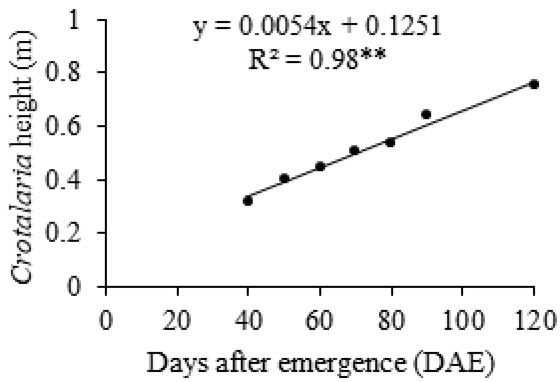

Figure 6. Variation in the critical height of *Crotalaria* does not interfere in maize yield as a function of the days after emergence. **p≤ 0.01.

these factors due to the growth of plants. In the international recommendation to guide irrigation management criteria in crops (FAO Bulletin 56), Allen et al. (1998) demonstrate that the increments in plant height and size increase leaf area per plant, leading to a higher potential for water loss due to transpiration, increasing the crop coefficient (Kc) and, consequently, the water demand per plant. In intercropped systems, this competition for water is more severe when there is a synchronism in the cycle of the intercropped crops, in which the maximum water demand of one crop can occur in a period similar to that of the maximum water demand of the other crop, causing competition for water. This fact can be verified between maize and *Crotalaria* species in the present study, given the variation similarity of their heights over time. Furthermore, the demand for nutrients follows a pattern similar to that discussed for water, according to which taller plants have a higher nutritional demand than shorter plants (Barbosa et al., 2020). In addition, competition for nutrients is also more severe when a synchronism occurs in the cycle of intercropped crops.

When evaluating the effect of sowing times of *Crotalaria* intercropped with maize, Gitti et al. (2012) verified that the intercropping of maize with *C. juncea* sown simultaneously with the cereal, as in the present study, reduced maize yield by up to 38%, a pattern similar to that observed here. The authors also verified that the sowing of *C. juncea* from the maize phenological stage V4 led to yields similar to those obtained with maize monoculture. This result is because the later sowing of *Crotalaria* breaks the synchronism for resources throughout the cycle of the two species, promoting the dominance of maize over *Crotalaria*. Silva et al. (2020) verified that intercropped systems of maize with *Urochloa ruziziensis* reduced soil water availability by more than 10% compared to maize monoculture, especially in the grain filling stage of maize, limiting its access to readily available water. This finding was also observed by Mao et al. (2012), who evaluated the intercropping of maize with pea. When evaluating the temporal variation of soil moisture in systems of maize monoculture and intercropping with *C. spectabilis*, Trevisan et al. (2021) observed that soil moisture was lower in the intercropped system at certain stages.

Regarding nutrients, Sapucay et al. (2020) observed that maize intercropped systems require more nitrogen fertilization to achieve yield levels similar to those obtained in the monoculture system. In intercropped systems with grasses, such as *Brachiaria* species, maize has greater competition for nutrients than its intercropping with legumes (Freitas et al., 2015; Sapucay et al., 2020; Deienno et al., 2021). However, even with legumes, such as *Crotalaria* species, the competition of maize for nutrients has been verified. Deienno et al. (2021) observed that the leaf N content of maize in the intercropping with *C. spectabilis* was reduced compared to maize monoculture, especially at top-dressing N doses of up to 70 kg ha^{-1}. According to the authors, this reduction in leaf N content demonstrates the competition of maize with *Crotalaria* for nutrients. However, this was not enough to reduce the yield of intercropped maize because the leaf N content was within the range considered adequate, which is between 27 and 35 g kg^{-1} (Cantarella et al., 1997).

When comparing the NPK absorption rate of *Crotalaria* species, Barbosa et al. (2020) observed that the maximum accumulation of N, P, and K by *C. juncea* reached approximately 300, 40, and 350 kg ha^{-1}, while for *C. spectabilis*, the values were approximately 150, 18 and 200 kg ha^{-1}. These results demonstrate the differences in nutrient accumulation between species and the greater capacity of *C. juncea* to absorb nutrients from the soil, directly affecting the competition with maize.

According to the literature, other species, such as *C. spectabilis* and *C. ochroleuca* (Arf et al., 2018; Galeano et al., 2021), can also reduce the yield of intercropped maize. However, several factors, such as climatic conditions of cultivation, soil type, maize hybrid, sowing density of maize and cover crops, cover crop species, and sowing time of cover crops may interfere with the results obtained. In the present study, the only species that reduced maize yield was *C. juncea*, which is directly associated with this species's higher plant height and dry mass accumulation compared to the others evaluated (Figure 2). Since this species had higher plant height and final dry mass, its demand for water, light, and nutrients was higher, competing directly with maize. As the present study was conducted in the summer season, with high availability of radiation and abundant and well-distributed precipitation (Figure 1), in the soil of high fertility and acceptable cultural practices, only *C. juncea* showed characteristics to reduce maize yield. These excellent cultivation conditions and minor stresses throughout the maize cycle can be verified by the yield obtained in the experiment, with values exceeding 14 t ha^{-1}, more than 100% higher than the average for the region in the same season (Conab, 2022).

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The excellent cultivation conditions also help explain the similarity of maize yield as a function of inter-row spacing and the absence of interaction between *Crotalaria* species and inter-row maize spacing. When comparing the intercropping of maize with *U. brizantha* ('Marandu') under different inter-row spacings (0.90 m and 0.45 m), Borghi and Crusciol (2007) observed that, depending on the year, maize cultivation at the spacing of 0.45 m promoted lower growth of the forage species, reducing competition with maize. According to the authors, smaller spacings between maize rows help control the growth of cover crops due to the faster closure of inter rows by the crop canopy, being more viable for intercropped systems with this grass. However, in the present study, inte-rrow spacing did not reduce the growth of *Crotalaria* (Table 1), which may be due to climatic conditions during the cycle and soil fertility in the experimental area, as explained earlier. Moreover, due to the greater height of *Crotalaria* species when compared to forage grasses, such as *U. brizantha* ('Marandu'), the reduction in maize inter-row spacing does not interfere much with solar radiation interception and use by *Crotalaria* plants.

Conclusions

Plant height throughout the cycle and the final dry mass accumulated by *Crotalaria* directly interfere with the yield of intercropped maize. From a certain height of *Crotalaria* plants, called critical height, the yield of maize is reduced. Throughout the maize cycle, the critical height of *Crotalaria* ranged from 0.32 to 0.75 m, with increments of 5.4 cm every ten days in the cycle; that is, the more advanced the maize cycle, the taller the intercropped *Crotalaria* plants must be to reduce maize yield. Compared to maize monoculture, only the species *C. juncea* reduced maize yield by 21% (3.04 t ha^{-1}). Moreover, maize inter-row spacing was not a significant factor for intercropping systems of maize with *Crotalaria*, not interfering in maize growth and yield. These results demonstrate the importance of evaluating the impact of different *Crotalaria* species on the yield and growth of intercropped maize, assisting producers in decision making.

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References

ALLEN, R. G.; PEREIRA, L. S.; RAES, D.; SMITH, M. **Crop evapotranspiration**: guidelines for computing crop water requirements. Rome: FAO, 1998. (FAO Irrigation and Drainage Paper, 56).

ARF, O.; MEIRELLES, F. C.; PORTUGAL, J. R.; BUZETTI, S.; SÁ, M. E. de; RODRIGUES, R. A. F. Benefícios do milho consorciado com gramínea e leguminosas e seus efeitos na produtividade em sistema plantio direto. **Revista Brasileira de Milho e Sorgo**, v. 7, n. 3, p. 431-444, 2018. DOI: https://doi.org/10.18512/1980-6477/rbms.v17n3p431-444.

BARBOSA, I. R.; SANTANA, R. S.; MAUAD, M.; GARCIA, R. A. Dry matter production and nitrogen, phosphorus and potassium uptake in *Crotalaria juncea* and *Crotalaria spectabilis*. **Pesquisa Agropecuária Tropical**, v. 50, n. 1, e61011, 2020. DOI: https://doi.org/10.1590/1983-40632020v5061011.

BARBOSA, J. C.; MALDONADO JÚNIOR, W. **AgroEstat**: sistema para análises estatísticas de ensaios agronômicos. Jaboticabal: UNESP, 2015. 396 p.

BORGHI, E.; CRUSCIOL, C. A. C. Produtividade de milho, espaçamento e modalidade de consorciação com *Brachiaria brizantha* em sistema plantio direto. **Pesquisa Agropecuária Brasileira**, v. 42, n. 2, p. 163-171, 2007. DOI: https://doi.org/10.1590/S0100-204X2007000200004.

BORGHI, E.; CRUSCIOL, C. A. C.; NASCENTE, A. S.; MATEUS, G. P.; MARTINS, P. O.; COSTA, C. Effects of row spacing and intercrop on maize grain yield and forage production of palisade grass. **Crop and Pasture Science**, v. 63, n. 12, p. 1106-1113, 2013. DOI: https://doi.org/10.1071/CP12344.

CAMBAÚVA, V.; LEAL, F. T.; LEMOS, L. B. Crescimento, produtividade e palhada de milho exclusivo e consorciado com crotalárias em diferentes espaçamentos. **Revista Brasileira de Milho e Sorgo**, v. 18, n. 1, p. 99-111, 2019. DOI: https://doi.org/10.18512/1980-6477/rbms.v18n1p99-111.

CANTARELLA, H.; RAIJ, B. van; CAMARGO, C. E. O. Cereais. In: RAIJ, B. van; CANTARELLA, H.; QUAGGIO, J. A.; FURLANI, A. M. C. **Recomendações técnicas de adubação e calagem para o estado de São Paulo**. 2. ed. Campinas: Instituto Agronômico de Campinas, 1997. p. 45-57. (Boletim Técnico 100).

CONAB. Companhia Nacional de Abastecimento. **Séries Históricas das safras**: milho 1ª safra. Available in: https://www.conab.gov.br/info-agro/safras/serie-historica-das-safras?start=20. Access in: 3 Feb. 2022.

CUI, H.; CAMBERATO, J. J.; JIN, L.; ZHANG, J. Effects of shading on spike differentiation and grain yield formation of summer maize in the field. **International Journal of Biometeorology**, v. 59, n. 9, p. 1189-1200, 2015. DOI: https://doi.org/10.1007/s00484-014-0930-5.

DEIENNO, J.; SOUZA, S. S.; COELHO, A. P.; LEMOS, L. B. Maize intercropping and nitrogen fertilization aiming grain yield and implement a no-till system. **Revista Brasileira de Milho e Sorgo**, v. 20, n. 1, p. e1225, 2021. DOI: https://doi.org/10.18512/rbms2021v20e1225.

FREITAS, M. A. M.; VALADÃO SILVA, D. V.; SOUZA, M. F.; SILVA, A. A.; SARAIVA, D. T.; FREITAS, M. M.; CECON, M. M.; FERREIRA, L. R. Levels of nutrients and grain yield of maize intercropped with signalgrass (*Brachiaria*) in different arrangements of plants. **Planta Daninha**, v. 33, n. 1, p. 49-56, 2015. DOI: https://doi.org/10.1590/S0100-83582015000100006.

GALEANO, E. J.; COSTA, C. M.; ORRICO JUNIOR, M.; FERNANDES, T.; RETORE, M.; SILVA, M. S. J.; GARCIA, R. A.; MACHADO, L. A. Z. Agronomic aspects, chemical composition and digestibility of forage from corn-crotalaria intercropping. **The Journal of Agricultural Science**, v. 59, n. 7/8, p. 580-588, 2021. DOI: https://doi.org/10.1017/S0021859621000848.

GITTI, D. C.; ARF, O.; VILELA, R. G.; PORTUGAL, J. R.; KANEKO, F. H.; RODRIGUES, R. A. F. Épocas de semeadura de crotalária em consórcio com milho. **Revista Brasileira de Milho e Sorgo**, v. 11, n. 2, p. 156-168, 2012. DOI: https://doi.org/10.18512/1980-6477/rbms.v11n2p156-168.

GOU, F.; VAN ITTERSUM, M. K.; SIMON, E.; LEFFELAAR, P. A.; VAN DER PUTTEN, P. E.; ZHANG, L.; VAN DER WERF, W. Intercropping wheat and maize increases total radiation interception and wheat RUE but lowers maize RUE. **European Journal of Agronomy**, v. 84, n. 1, p. 125-139, 2017. DOI: https://doi.org/10.1016/j.eja.2016.10.014.

LIU, X.; RAHMAN, T.; YANG, F.; SONG, C.; YONG, T.; LIU, J.; ZHANG, C.; YANG, W. PAR interception and utilization in different maize and soybean intercropping patterns. **PLoS ONE**, v. 12, n. 1, p. e0169218, 2017. DOI: https://doi.org/10.1371/journal.pone.0169218.

MAO, L.; ZHANG, L.; LI, W.; VAN DER WERF, W.; SUN, J.; SPIERTZ, H.; LI, L. Yield advantage and water saving in maize/pea intercrop. **Field Crops Research**, v. 138, n. 1, p. 11-20, 2012. DOI: https://doi.org/10.1016/j.fcr.2012.09.019.

MARTIN-GUAY, M. O.; PAQUETTE, A.; DUPRAS, J.; RIVEST, D. The new Green Revolution: sustainable intensification of agriculture by intercropping. **Science of the Total Environment**, v. 615, n. 1, p. 767-772, 2018. DOI: https://doi.org/10.1016/j.scitotenv.2017.10.024.

MINGOTTE, F. L. C.; JARDIM, C. A.; AMARAL, C. B.; COELHO, A. P.; MORELLO, O. F.; LEAL, F. T.; LEMOS, L. B.; FORNASIERI FILHO, D. Maize yield under *Urochloa ruziziensis* intercropping and previous crop nitrogen fertilization. **Agronomy Journal**, v. 113, n. 2, p. 1681-1690, 2021. DOI: https://doi.org/10.1002/agj2.20567.

MINGOTTE, F. L. C.; JARDIM, C. A.; YADA, M. M.; AMARAL, C. B.; CHIAMOLERA, T. P. L. C.; COELHO, A. P.; LEMOS, L. B.; FORNASIERI FILHO, D. Impact of crop management and no-tillage system on grain and straw yield of maize crop. **Cereal Research Communications**, v. 48, n. 3, p. 399-407, 2020. DOI: https://doi.org/10.1007/s42976-020-00051-y.

OLIVEIRA, P.; KLUTHCOUSKI, J.; FAVARIN, J. L.; SANTOS, D. C. **Sistema Santa Brígida - Tecnologia Embrapa: consorciação de milho com leguminosas**. Santo Antônio de Goiás: Embrapa Arroz e Feijão, 2010. 16 p. (Embrapa Arroz e Feijão. Circular Técnica, 88).

SANTOS, H. G.; JACOMINE, P. K. T.; ANJOS, L. H. C. dos; OLIVEIRA, V. A. de; LUMBRERAS, J. F.; COELHO, M. R.; ALMEIDA, J. A. de; ARAUJO FILHO, J. C. de; OLIVEIRA, J. B. de; CUNHA, T. J. F. **Sistema Brasileiro de Classificação de Solos**. 5. ed. Brasília, DF: Embrapa, 2018.

SAPUCAY, M. J. L. D. C.; COELHO, A. E.; BRATTI, F.; LOCATELLI, J. L.; SANGOI, L.; BALBINOT JÚNIOR, A. A.; ZUCARELI, C. Nitrogen rates on the agronomic performance of second-crop corn single and intercropped with ruzigrass or showy rattlebox. **Pesquisa Agropecuária Tropical**, v. 50, n. 1, e65525, 2021. DOI: https://doi.org/10.1590/1983-40632020v5065525.

SILVA, G. S. F.; ANDRADE JÚNIOR, A. S. D.; CARDOSO, M. J.; ARAÚJO NETO, R. B. D. Soil water dynamics and yield in maize and *Brachiaria ruziziensis* intercropping. **Pesquisa Agropecuária Tropical**, v. 50, n. 1, e59809, 2020. DOI: https://doi.org/10.1590/1983-40632020v5059809.

TREVISAN, M.; SILVA, L. F. S.; FONTANETTI, A.; GALLO, A. S.; GUIMARÃES, N. F. Temperatura e umidade do solo no consórcio de milho com *Crotalaria spectabilis* e *Cajanus cajan* em sistema orgânico. **Research, Society and Development**, v. 10, n. 14, p. e539101422443, 2021. DOI: https://doi.org/10.33448/rsd-v10i14.22443.

ZHAI, L. C.; XIE, R. Z.; MING, B. O.; LI, S. K.; MA, D. L. Evaluation and analysis of intraspecific competition in maize: a case study on plant density experiment. **Journal of Integrative Agriculture**, v. 17, n. 10, p. 2235-2244, 2018. DOI: https://doi.org/10.1016/S2095-3119(18)61917-3.

ZHANG, F.; LI, L. Using competitive and facilitative interactions in intercropping systems enhances crop productivity and nutrient-use efficiency. **Plant and Soil**, v. 248, n. 1, p. 305-312, 2003. DOI: https://doi.org/10.1023/A:1022352229863.