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RESEARCH ARTICLE

Management tendencies and needs: a joint proposal to maximize soybean grain yield

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ABSTRACT

The objective of the study was to evidence efficient management strategies in order to maximize soybean grain yield. The experiments took place at Centro de Pesquisas e Resultados Agronômicos das Missões (CPRAM), located in Entre - Ijuís - Rio Grande do Sul, Brasil. Three experiments were carried out in a randomized block design with four replications per treatment. The experiments were based on soybean crop management. Soil cover with vetch enhanced soybean grain yield. The cultivar BRS 5804RR® presented the best productive performance in the arrangements of 7 and 11 seeds m^{-1}. Artificial defoliation did not influence soybean grain yield.

Keywords: *Glycine max*, linear correlation, principal component, plant arrangement. defoliation, weed pressure.

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INTRODUCTION

Soybean (*Glycine max* L. Merr.) is one of the main sources of protein and vegetable oil in the world. Its grains have a series of purposes in the food area, both human and animal. Brazil is the world's largest producer of this commodity, with a cultivated area of 38 million hectares and a productivity of 3.517 ha^{-1} in 2020/2021 harvest (Companhia Nacional de Abastecimento [CONAB], 2021). The great expansion of the culture occurs due to the growing world demand for soybean grains. However, according to FAO, current grain production will not be sufficient to meet future food needs. Therefore, the development of genotypes with high productive performance, resilient and with wide adaptation to imposed environmental conditions are the main objectives of genetic improvement programs. There is great heterogeneity in the soil and climate conditions that guide the development of genotypes designed to constantly meet market demands, they must have high grain yields, tolerance to biotic and abiotic stresses, and be stable and nutritionally superior (Carvalho et al., 2017).

Given this context, the use of plants for ground cover is a growing management, especially in the producing regions of Brazilian South, in order to maximize the productivity of soybeans, as well as other crops. This tool promotes breaking the disease cycle, reducing weed pressure, cycling nutrients and increasing the activity of soil microorganisms. Soybeans to express their genetic potential characterized by their better growth and development, several environmental factors can influence, such as photoperiod, temperature, solar radiation, in addition to the characteristics of the cultivar such as stability, resistance or tolerance to insect pests, diseases and defoliation index. According to Owen et al. (2013), defoliation injury in soybean can reduce transpiration and photosynthesis of the plant and the ability of this oilseed to compensate for nutritional deficiencies, there is a reduction of water loss or any abiotic factor that influences soybean productivity. In this context, the objective of the study was to evidence efficient management strategies in order to maximize soybean grain yield.

MATERIAL AND METHODS

The experiment took place at Centro de Pesquisas e Resultados Agronômicos das Missões (CPRAM), located at 28º 23'17.82” S and 54º 19 '13.74” W, at an altitude of 215 meters, located in Entre - Ijuís - Rio Grande do Sul, Brasil. The soil is classified as typical dystrophic Red Latosol (Streck et al., 2008), and the environment is humid subtropical Cfa type according to Köppen.

Soil cover experiment, in a randomized blocks experimental design, composed of six soil covers: Raix 110® (oat, rye and forage radish), Raix 210® (white oat, black oat, rye, forage radish and turnip), Raix 330 ® (oat, rye and two species of vetch), Raix 520® (forage peas, rye, oats and turnip greens), vetch and barley, containing four replications. The soybean genotype used DM 5859 IPRO, sowing took place in the first half of November 2020, with a density of 14 seed m^{-1}, row spacing of 0.45 m, base fertilization of 416 kg ha^{-1} of the NPK 11-30-20 formula, with a total experimental unit of 5m^2, with standard fungicide management between treatments. Three applications took place, the first with *metominostrobin + tebuconazole,* the second with *picoxystrobin+cyproconazole* and *mancozeb* and the third with *bixafen+prothioconazole+trifoloxystrobin* and *mancozeb.*

Test of cultivars and plant arrangement, in a randomized blocks experimental design factorial scheme, with 4 plant arrangements: (arrangement 1 (7 s. m^{-1}), arrangement 2 (11 s. m^{-1}), arrangement 3 (16 s. m^{-1}) and arrangement 4 (20 s. m^{-1}). In addition, 5 soybean cultivars (BMX Zeus IPRO®, BMX Fibra IPRO®, BRS 5804RR®, BRS 5601RR® and DM 66I68 RSF IPRO®) and 4 repetitions. Sowing took place in the first half of November 2020, with a base fertilization of 416 kg ha^{-1}, of the formula. Row spacing of 0.45 m, with an experimental unit of 5 m^2, with standard fungicide management between treatments. Three applications took place: the first with *metominostrobin + tebuconazole*, the second with *picoxystrobin+cyproconazole* and *mancozeb* and the third with *bixafen+prothioconazole+trifoloxystrobin* and *mancozeb.*

Defoliation assay, in a randomized blocks experimental design, containing six treatments and four replications: check (absence of defoliation), defoliation in VC, defoliation in V3, defoliation in V6, defoliation in V8 and defoliation in V10, with defoliation intensity of 100% at each stage. After the application of defoliation, the new leaves that developed were kept on the plants. The cultivar used was DM 5958 RSF IPRO®. Sowing took place in the first half of November 2020, density of 14 seeds m^{-1}, row spacing of 0.45 m, base fertilization of 416 kg ha^{-1}, NPK formula 11-30-20. With an experimental unit of 5 m^2, with standard fungicide management between treatments. Three applications took place, the first with *metominostrobin + tebuconazole,* the second with *picoxystrobin + cyproconazole* and *mancozeb* and the third with *bixafen+prothioconazole+trifoloxystrobin* and *mancozeb.*

From the evaluation of five plants, randomly collected, per experimental unit in all experiments, the following variables were obtained: plant height (PH, cm), height of insertion of the first legume (IFL, cm), number of legumes on the main stem (NLMS, units), number of branches (NB, units), number of legumes per plant (NLP, units), weight of grains per plant (WGP, g), grain yield (GY, Kg ha^{-1}), corrected to 13% humidity and thousand grain weight (TGW, g).

Analysis of variance took place in order to verify the significance of the data, later using the Tukey at the level of 5% probability. To identify the tendency of association between the characters, a linear correlation analysis with 5% probability was performed using *t* test. Principal component analysis was performed to verify the formation of groups and associations between treatments and traits. All analyzes were performed using the R software version 4.1.3 (R Core Team, 2022).

RESULTS AND DISCUSSION

The analysis of variance revealed significant effects of the soil cover variation factor for the variables plant height, weight of grains per plant, grain yield and thousand grain weight at 5% significance by the F test. Studies have shown beneficial results from use of cover crops on soybean grain yield. According to Veronese et al*.* (2012), this is due to the production of phytomass, accumulation and consequent release of nutrients by the decomposition of the straw, in agreement with Cardoso et al. (2014), who found positive responses in soybean yield, using cover crops.

For the ground cover (Table 1), the variable plant height, the coverage Raix 330, Raix 110, Vetch, Raix 210 and barley presented superior results in relation to the coverage Raix 520. In relation to the variable number of legumes on the main stem, observe that significant differences were obtained for the coverings vetch, barley, Raix 330, Raix 110, it presents superior results to the coverings Raix 210 and Raix 520. When analyzing the weight of grains per plant and grain yield, results evidence higher for vetch coverings, according to Acharya et al. (2019), superior results evidence for this coverage as a predecessor to soybean. Regarding the thousand grain weight, superior results took for Raix 210, Raix 330, Raix 110, barley and Raix 520, in relation to vetch cover.

Table 1. Grouping of means for the different plant coverage, for the variables plant height (PH), number of legumes on the main stem (NLMS), weight of grains per plant (WGP), grain yield (GY) and thousand grain weight (TGW). Phase 1.

COVERAGES	PH	NLMS	WGP	GY	TGW
RAIX 330	105.58a[1]	59.85ab	18.03ab	4008.81ab	127.06ab
RAIX 110	105.17a	53.15ab	16.43ab	3652.59ab	131.53ab
VETCH	103.50a	68.00a	20.28a	4508.03a	114.74b
RAIX 210	102.97ab	46.70b	16.11b	3581.82b	157.60a
BARLEY	102.09ab	57.67ab	17.54ab	3898.49ab	126.59ab
RAIX 520	99.50b	48.45b	18.96ab	4215.21ab	136.19ab
CV (%)	2.15	14.21	8.76	8.76	10.82

[1]Means followed by the same lowercase letter in the column do not statistically differ treatments by the test Tukey at the 5% error probability level.

Linear correlation is one of the main techniques used to identify the association between characters; it reveals trends in direction and magnitude of association between two characters (Meier et al., 2019). This analysis identifies the linear dependence between two variables, with the magnitude of their positive or negative interrelationships, which varies from -1 to 1, that is, the closer to 1, the greater the degree of linear association between the variables and the more close to zero, the lower their linear dependence (Szareski et al., 2015).

The number of legumes on the main stem has a strong negative association (-0.89, significant at 5%) with thousand grain weight and a strong positive association (0.91) with the number of legumes per plant. A very strong negative magnitude correlation (-0.99) is found for the number of legumes per plant and the thousand grain weight, that is, the greater the number of legumes per plant, the lower the thousand grain weight. For the other variables analyzed, observe no significant correlation.

Use of principal component analysis to determine the associations of the analyzed variables, soil cover and soybean yield components. For the variables, the first two principal components accumulate a percentage of 80.9%. In coverage 2 (vetch), the soybean cultivar showed a predisposition for a variable number of legumes on the main stem and number of legumes per plant, while coverage 3 (Raix 110) showed affinity for insertion of the first legume. Soil cover 4 (Raix 210) was responsible for the lower performance of the genotypes for the traits NLMS, NLP and GY.

According to the analysis of variance, there was significance evidence at 5% of probability by the F test. In relation to the cultivars, observe significance ($p<0.05$) for the variables: plant height, insertion of the first legume, number of legumes on the main stem, number of legumes per plant, grain yield and thousand grain weight. Borges et al. (2013) and Cruz et al. (2010) also found significant differences for the variables plant height, height of insertion of the first legume and grain yield.

For the population factor, significance ($p<0.05$) was detected for the variables, plant height, insertion of the first legume, number of legumes on the main stem, number of legumes per plant, weight of grains per plant, productivity of grains and thousand grain weight.

According to the analysis of means (Table 2) for the different plant arrangements, for the variable insertion of the first legume, observe significant differences as a function of the arrangement of plants per m^{-1} and cultivars. For the arrangement of plants m^{-1}, the cultivar BMX FIBRA IPRO showed a significant difference, where the arrangement 20 seeds m^{-1} ended up standing out in relation to the other treatments. The cultivars DM 66I68IPRO® and BMX Zeus IPRO® showed no significant difference between the different seed arrangements per meter.

Table 2. Grouping of means for the different cultivars and different plant arrangements, for the variables insertion of the first legume (IFL), number of legumes on the main stem (NLMS).

ARRANGEMENTS	CULTIVARS				
	BMX FIBRA IPRO	DM 66I68IPRO	BRS 5804 RR	BMX ZEUS IPRO	BRS 5601RR
			IFL		
Arrange 1 (7 s. m^{-1})	21.19bA[1]	23.26A	14.35bB	12.59B	11.60bB
Arrange 2 (11 s. m^{-1})	23.04bAB	26.63A	20.22abBC	13.95C	15.72abC
Arrange 3 (16 s. m^{-1})	22.23bA	22.50A	17.20bAB	14.31C	19.62aAB
Arrange 4 (20 s. m^{-1})	29.80aA	24.64AB	22.07aB	14.73C	13.15bC
CV (%)			27.09		
ARRANGEMENTS			NLMS		
Arrange 1 (7 s. m^{-1})	63.87aA	69.48A	60.33A	59.93aA	71.27aA
Arrange 2 (11 s. m^{-1})	51.97abA	65.35A	57.58A	52.87abA	56.27bA
Arrange 3 (16 s. m^{-1})	61.23aA	57.85A	53.17A	52.59abA	53.27bA
Arrange 4 (20 s. m^{-1})	41.79bB	57.70A	49.28AB	41.21bB	62.30abA
CV (%)			13.80		

[1]Means followed by the same lowercase letter in the column do not statistically differ treatments by the test Tukey at the 5% error probability level.

Cultivars BRS 5804 RR, BMX ZEUS IPRO and BRS 5601RR showed the lowest IFL values in arrangement 1 (7 s. m^{-1}). On average, the cultivar BMX ZEUS IPRO exhibited the lowest IFL values in all plant arrangements. There was an increase in IFL as the number of plants per linear meter increased. (Table 2). Therefore, it can be inferred that the height of insertion of the first legume is influenced by the increase in density. According to Klein et al. (2018), the more dense the crop, the greater the height of insertion of the first legume tends to be, which increases intraspecific competition in this way, having a greater height of insertion of the first legume. Cruz et al. (2016) and Balbinot Junior et al. (2015) show that the height of insertion of the first legume increases according to the increase in sowing density.

The plant arrangement expressed for the variable insertion of the first legume a statistically significant difference in the arrangements 7 seeds m^{-1}, 11 seeds m^{-1} and 20 seeds m^{-1}, where the cultivars that presented superior results were BMX Fibra IPRO® and DM 66i68 IPRO®, in relation to the other cultivars. In the spacing of 16 seeds m^{-1}, observe a lower only for the cultivar BMX Zeus IPRO®. The increase in population causes competition for light to be greater, the insertion of the first legume is greater, reducing the productive zone of the plant, since all cultivars presented height of insertion of the first legume higher in the higher densities (Mauad et al., 2010; Ramos Junior et al., 2019).

For the variable number of legumes on the main stem, it was shown that for cultivar BMX Fibra IPRO® and BMX Zeus IPRO®, the density of 7 seeds m^{-1}, 11 seeds m^{-1} and 16 seeds m^{-1}, presented superior results. For the 20 seeds m^{-1} treatment, the cultivars BRS 5601 RR®, DM 66I68IPRO and BRS 5804 RR, in that order, showed the highest averages.

The cultivars DM 66I68 IPRO® and BRS 5804 RR® did not present statistical differences between the different plant arrangements. When analyzing the variable number of legumes on the main stem, depending on the arrangement of seeds m^{-1} and cultivars, the treatments, 7, 11 and 16 seeds m^{-1}, did not show statistical differences for the cultivars BMX Fibra IPRO®, DM 66I68 IPRO ®, BRS 5804 RR®, BMX Zeus IPRO® and BRS 5601 RR®.

However, in the arrangement of 20 seeds m^{-1}, significant differences were observed for the cultivars and BRS 5601 RR®, DM 66I68 IPRO® and BRS 5804 RR®, whereas the cultivars BMX Zeus IPRO® and BMX Fibra IPRO® showed lower results. Also, observe that with increasing density there is a decrease in the number of legumes on the main stem, Peter et al. (2021), who states that with increasing density, there is a reduction in the expression of this characteristic.

There was a statistical difference for the plant height character as a function of the cultivar, where cultivars DM 66I68 IPRO® and BMX Fibra IPRO® presented superior results in relation to the others (Table 3). For the variable number of legumes on the main stem, only cultivar BMX Zeus IPRO® presented a lower result than others did. In relation to the weight of grains per plant, there was no statistical difference between the analyzed cultivars. For the variable grain yield, it is noted that there was a statistical difference, where cultivars BRS 5601 RR® and BMX Fibra IPRO® presented lower results in relation to BRS 5804RR®. Thousand grain weight, superior result was found for cultivars BMX Zeus IPRO® and BRS 5804RR®.

Table 3. Grouping of means for the different cultivars and different plant arrangements, for the variables plant height (PH), number of legumes per plant (NLP), weight of grains per plant (WGP), grain yield (GY) and thousand grain weight (TGW).

CULTIVARS	PH	NLP	GY	TGW
BRS 5601 RR®	88.9474c[1]	74.74653 a	4294.623 b	139.041 b
BRS 5804 RR®	103.9221b	67.84752 ab	4925.664 a	169.7981 a
DM 66I68 IPRO®	116.2206a	73.04217 a	4367.782 ab	138.2878 b
BMX FIBRA IPRO®	117.7521a	64.63341 ab	3986.028 b	145.1601 b
BMX ZEUS IPRO®	97.21264b	58.06922 b	4525.822 ab	182.7493 a
CV (%)	9.09	9.92	7.78	12.98
ARRANGEMENTS	**NLP**	**WGP**	**GY**	**TGW**
Arrange 1 (7 s. m^{-1})	81.45399 a	20.91454 a	5372.124 a	171.0549 a
Arrange 2 (11 s. m^{-1})	72.06722 b	16.72088 b	4967.113 a	152.1831 ab
Arrange 3 (16 s. m^{-1})	63.7627 b	13.97001 c	4087.325 b	151.9917 b
Arrange 4 (20 s. m^{-1})	53.38171 c	12.08728 c	3253.372 c	144.7993 b
CV (%)	17.67	24.07	21.37	7.24

[1]Means followed by the same lowercase letter in the column do not statistically differ treatments by the test Tukey at the 5% error probability level.

The different plant arrangements as a function of the expression of agronomic characteristics analyzed, for the variable plant height, there was no statistical difference between treatments. For the variables number of legumes per plant and weight of grains per plant, observe a statistical difference for arrangement 1 (7 seeds m^{-1}), followed by arrangement 2 (11 seeds m^{-1}). Cruz et al. (2016) reported that with increasing density, there was a negative linear effect in relation to the number of legumes per plant, since with larger populations there are fewer branches.

In the grain yield variable, a statistical difference was observed for arrangements 1 and 2, followed by arrangement 3 (16 seeds m^{-1}), in relation to the thousand grain weight, a similar result was verified for Cruz et al. (2016), who observed that with an increase in density, there was an increase in the thousand grain weight. According to Mauad et al. (2010), both the choice of cultivar and the arrangement of plants are factors that influence soybean yield as well as the productive components of soybean.

According to the linear correlation, there is a strong positive correlation (0.79) for insertion of the first legume with plant height. In relation to the height of insertion of the first legume (IFL) it presented a negative linear correlation of moderate magnitude (-0.44 and -0.41) for the variables weight of grains per plant and thousand grain weight. The variable weight of grains per plant presented a moderate positive correlation (0.56) for the number of legumes on the main stem and thousand grain weight (0.52) and a strong positive correlation (0.74) for the number of legumes per plant. The variable number of legumes on the main stem showed a strong positive correlation (0.77) for the number of legumes per plant.

In order to determine the associations of the variables analyzed, cultivars and arrangements, there was use of principal components. For the variables, the main components accumulate a percentage of 84.7%, PC1 presented 49.8% of the explained variation between the variables, while PC2 34.9%. It is evident that the BRS 5804RR® with an arrangement of 11 seeds m^{-1} (6) and an arrangement of 16 seeds m^{-1} (7). It was followed by cultivar BMX Fibra IPRO® (18) with an arrangement of 11 seeds m^{-1}, BMX Zeus IPRO® (2) 11 seeds m^{-1} and, finally, the cultivar Fibra (19) in the arrangement 16 seeds^{-1} soybean showed a greater tendency for variable grain yield. According to Balbinot et al. (2015), sowing density can limit grain yield in soybeans.

Regarding the variables number of legumes and number of legumes on the main stem, the cultivars and arrangements that showed the greatest predisposition were BRS 5804RR® in the arrangement 7 seeds m^{-1} (5), DM 66I68 IPRO® arrangements 7 seeds m^{-1} (9) and 20 seeds m^{-1} (12) and, finally, cultivar BRS 5601RR® in the arrangement 11 seeds m^{-1} (14) and 20 seeds m^{-1} (16), where each genotype presents a different plasticity. The plant height and insertion height of the first legume, the treatments that showed the greatest tendency for these variables were DM 66I68 IPRO® in the arrangements 11 seeds m^{-1} (10) and 16 seeds m^{-1} (11), in addition to the cultivar BRS 5601RR® with arrangements of 7 seeds m^{-1} (13) and 16 seeds m$^{-1.}$ According to Ludwig et al. (2011), soybean has high plasticity, having the ability to adjust to environmental and management conditions, mainly through the arrangement of plants.

Observe significant effects at 5% probability by the F test for defoliation in relation to the variable plant height and number of legumes on the main stem. Plant height showed a statistical difference for defoliation with no defoliation and defoliation at the VC stage (cotyledon), that is, plant height was little affected by the phenology of the culture in which defoliation occurred, a reduction in height was observed from of stage V3 (Table 4). Nardino et al. (2015), concludes that with defoliation, plants tend to reduce their height. According to the stage that occurs and the intensity, Bahry et al. (2013) found a different result, where plant height showed no difference as a function of defoliation in the different phenological stages of the crop.

Regarding the number of legumes on the main stem, a statistical difference ($p < 0.05$) was identified for defoliation at the VC stage, V3 and absence. According to the more advanced stages of crop development, lower results were found V8 and V10, having a decrease in the number of legumes on the main stem on the main stem, which can be explained by the photosynthetic reduction of the plant. For the other variables analyzed, such as height of insertion of the first legume, number of branches, number of legumes per plant, weight of grains per plant, grain yield and thousand grain weight, there was no statistical difference between defoliation and phenological stages of the crop. This reveals the absence of responses for defoliation for the productive components, where defoliation in the early stages does not influence crop yield. Nardino et al. (2015), Souza et al. (2014) and Bahry et al. (2013) reported similar behavior.

Table 4. Grouping of means for defoliation at different phenological stages for the variables plant height (PH), insertion of the first legume (IFL), number of legumes on the main stem (NLMS).

Defoliation	PH	NLMS
Absence	103.80a[1]	59.45abc
VC	101.46ab	65.00a
V3	92.55bc	59.85ab
V6	87.05cd	51.12bcd
V8	82.64d	40.84d
V10	73.15e	46.35cd
CV (%)	12.89	17.13

[1]Means followed by the same lowercase letter in the column do not statistically differ treatments by the test Tukey at the 5% error probability level.

The linear associations between the characteristics studied in relation to defoliation in the soybean crop, the linear correlation showed a strong positive correlation (0.8) between the variables number of branches and number of legumes per plant and moderate negative correlation for thousand grain weight, insertion of the first legume and plant height, with values of 0.49, 0.64 and 0.66 respectively. For the variable number of legumes per plant, there was a moderate negative linear correlation for thousand grain weight and insertion of the first legume (0.56 and 0.47 respectively). The greater the height of insertion of the first legume, consequently, there is a smaller productive zone in the plant, a smaller number of reproductive nodes and a smaller proportion of flowers that provides a lower number of legumes per plant. Considering the thousand grain weight, the negative effect there is a possible explanation to a greater number of grains per legume, which leads to a smaller size and consequent smaller grain weight.

Observe a moderate linear correlation for the grain yield characteristic for thousand grain weight, so the greater the thousand grain weight of the plant, the higher the grain yield tends to be. For thousand grain weight, a moderate positive correlation with plant height (0.54) was found, according to Souza et al. (2013), this character is influenced by the characteristics of the cultivar, the cultivation environment and growth habit, on the other hand, this parameter can indirectly influence grain yield (Mauad et al., 2010). On the other hand, plant height had positively correlation with the number of legumes on the main stem (0.75), that is, plants with higher size tend to have a greater number of legumes on the main stem, which shows trends similar to Szareski et al. (2015).

In order to determine the associations of the variables analyzed, there was a use of cultivars and arrangements, principal components. For the variables, the main components accumulate a percentage of 87.3%, PC1 presented 66.4% of the explained variation between the variables, while PC2 20.9%. It was observed that treatment 1 (absence of defoliation) tends to increase the height of insertion of the first legume. For treatment 5 (defoliation in V8), the characteristics number of branches and number of legumes per plant were potentiated. Regarding treatments 3 (defoliation in V3) and 6 (defoliation in VC), there was a greater predisposition to the variables plant height, number of legumes on the main stem, thousand grain weight and grain yield. Treatments 4 (defoliation in V10) and 2 (defoliation in V6) did not enhance any trait.

CONCLUSIONS

Soil cover with vetch enhanced soybean grain yield.

The cultivar BRS 5804RR® presented the best productive performance in the arrangements of 7 and 11 seeds m^{-1}.

Artificial defoliation did not influence soybean grain yield.

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