

# Soybean morphophysiology and yield response to seeding systems and plant populations

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## ABSTRACT

Soybean (*Glycine max* [L.] Merr.) is recognized worldwide for its economic importance; it has the ability to adapt to environmental and management changes, particularly when using different spacing and plant populations. This study aimed to investigate the influence of morphological changes of the crisscross seeding system on grain growth and yield. Work was conducted at the Experimental Station of Anapolis, Goiás, Brazil, of the Technical Assistance Agency, Rural Extension and Agricultural Research of Goiás (EMATER) for the 2013-2014 harvest. The experimental design was a randomized block and  $2 \times 3 \times 3$  factorial, with four replicates. Treatments consisted of two seeding systems (conventional-in line and crossed-crisscross), three soybean cultivars with different growth habits ('BRS Valiosa RR' determined, 'NA 7337 RR' semi-determined, and 'BMX Potência RR' indeterminate) and three sowing densities (245000, 350000, and 455000 plants ha<sup>-1</sup>). Results showed that at 50 d after emergence the cross-seeding system showed higher closing among lines promoted by the increase in population. Leaf area and the leaf area index were not affected by the seeding system. Leaf area was lower with increasing plant density with no significant difference in relation to the leaf area index. The cross-system enabled a potential yield of 4504 kg ha<sup>-1</sup> corresponding to an approximate 8% increase compared with conventional sowing using equidistant lines with 0.5 m spacing.

**Key words:** *Glycine max*, spatial arrangement, growth habit, yield.

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## INTRODUCTION

Studies on spatial distribution adequacy in soybean in a cultivation area have been of interest in recent years motivated by the increase of grain yield per agricultural unit. This is justified by the ability of soybean (*Glycine max* [L.] Merr.) plants to adapt to various types of cultivation, a characteristic known as phenotypic plasticity (Heiffig et al., 2006; Akond et al., 2013; Balbinot Junior et al., 2015). Besides the need to find suitable soil and climate conditions, crop competition should be minimized; plant arrangements studies provide information on minimizing intraspecies competition and maximizing the use of environmental resources (Walker et al., 2010; Bellaloui et al., 2015).

In soybean, numbers of branches and leaves per plant are characteristics that change in each cultivar, but plants appear quite sensitive when considering changes in population density (De Bruin and Pedersen, 2008; Board and Kahlon, 2013; Suhre et al., 2014). This behavior is due to a framework of these three growth habit groups: determinate, indeterminate, and semi-determinate (Tian et al., 2010; Soares et al., 2015). Knowledge of these characteristics influences population distribution of the crop in the field, so the best space arrangement should enable high agricultural productivity (Board and Kahlon, 2013).

Cross-seeding is a new cultivation system that is being increasingly used, especially in Midwestern Brazil. It is characterized by crossing sowing lines and forming a line grid on the cultivation area. Recent studies conducted with soybean in Midwestern and Southern Brazil have shown contradictory results regarding this system, such as the study by Lima et al. (2012), whose results indicate that sowing in crossed lines under no-tillage was more productive than with non-crossed lines with an 8.6% increase with 'M7211RR' (indeterminate habit). The lack of effect of cross planting on soybean yield with indeterminate ('BRS 359 RR') and determinate ('BRS 294 RR' and 'BRS 295 RR') growth habits was verified by Procópio et al. (2013) and Balbinot Junior et al. (2015), respectively.

The aim of this study was to evaluate the influence of cross-seeding and conventional sowing on yield components of soybean cultivars with different growth habits and different population densities.

## MATERIALS AND METHODS

The experiment was conducted during the harvest of the 2013-2014 season in the experimental area belonging to Emater-GO,

Anápolis, Goiás unit (16°19'44" S, 48°18'23" W; 1017 m a.s.l.) The climate is tropical wet, Aw, according to the Köppen classification; it is characterized by dry winters and rainy summers. The experiment was established on 11 December 2013 and the prevailing weather conditions throughout the crop cycle are shown in Figure 1.

The soil of the area is classified as dystrophic Red Latosol; samples were collected at the 0-20 cm layer. Results of chemical analyses were pH 5.5, 4.3 mg P dm<sup>-3</sup>, 36 mg K dm<sup>-3</sup>, 2.7 cmol<sub>c</sub> Ca dm<sup>-3</sup>, 0.8 cmol<sub>c</sub> Mg dm<sup>-3</sup>, 0.0 cmol<sub>c</sub> Al dm<sup>-3</sup>, 0.19 mg B dm<sup>-3</sup>, 4.0 mg Cu dm<sup>-3</sup>, 42.1 mg Fe dm<sup>-3</sup>, 10.3 mg Mn dm<sup>-3</sup>, 3.0 mg Zn dm<sup>-3</sup>, base saturation 57.21%, organic matter: 31 g dm<sup>-3</sup>, 30% clay, 62% sand, and 0.8% silt texture.

## Experimental design and treatments

A completely randomized design, 2 × 3 × 3 factorial with four replicates was used. Treatments consisted of two seeding systems (conventional line and crossed criss-cross), three soybean cultivars with different growth habits and different types of growth (determinate 'BRS Valiosa RR', semi-determinate 'NA 7337 RR', and indeterminate 'BMX Potência RR'), and three sowing densities (245 000, 350 000, and 455 000 plants ha<sup>-1</sup>).

Plots consisted of five 5-m long rows with 0.45 m spacing. The usable area consisted of three central lines and 1 m was disregarded at each end.

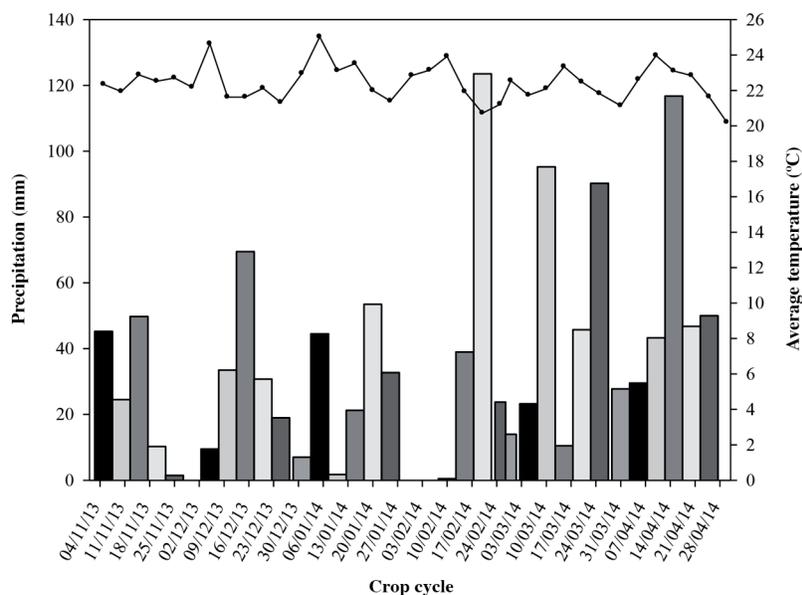
## Cultural practices

The soil was conventionally prepared with a moldboard plow and a light-screening system with overall disking harrow to incorporate crop residues of maize previously grown in the area. The area was manually plowed at a depth of approximately 0.10 m, and basic fertilization was

later done according to the recommendation for soybean cultivation to obtain 3000 kg ha<sup>-1</sup> productivity. The amount of 400 kg ha<sup>-1</sup> of NPK 04-30-16 formula was applied. Seeds were first treated with the fungicide carbendazim (15%) + thiram (35%) at a rate of 200 mL per 100 kg seed, and they were then inoculated with *Bradyrhizobium elkanii* (SEMIA 587) and *Bradyrhizobium japonicum* bacteria (SEMIA 5079) with a bacterial concentration of 5.0 × 10<sup>9</sup> CFU mL<sup>-1</sup> at a rate of 150 mL of the commercial product for 50 kg seed. Seed distribution was performed manually in the furrow with a polyester tape appropriately marked to define the distance between seeds. Later 24 kg K<sub>2</sub>O ha<sup>-1</sup> was applied 30 d after sowing (DAS). Its source was potassium chloride.

Weeds were controlled by applying glyphosate 25 DAS with the recommended rate of 3 L ha<sup>-1</sup>, and fomesafen (12.5%) + fluazifop-*p*-butyl (12.5%) 33 DAS to control spiderwort (*Commelina benghalensis* L.) and "corda de viola" (*Ipomoea* sp.) at the recommended rate of 2 L ha<sup>-1</sup>. Six applications of deltamethrin (2.5%) were carried out at a rate of 300 mL ha<sup>-1</sup> to control velvet bean caterpillar (*Anticarsia gemmatalis* Hübner, 1818), looper caterpillar (*Pseudoplusia includens*), *Nezara viridula* L., and little stink bug (*Piezodorus guildinii* Westwood, 1837), all of which often occurred during the experiment. As a preventive measure, three applications of fungicide with trifloxystrobin (10%) + tebuconazole (20%) at a rate of 500 mL ha<sup>-1</sup> in the short cycle 'NA7337 RR' and 'BMX Potência RR', four applications in the late growing cycle 'BRS Valiosa RR', were made to control powdery mildew (*Erysiphe diffusa*), Asian rust (*Phakopsora pachyrhizi* Syd. & P. Syd. 1914), blight-leaf (*Cercospora kikuchii* [Tak. Matsumoto & Tomoy.] M.W. Gardner 1927), septoria (*Septoria glycines* Hemmi 1915), anthracnose (*Colletotrichum truncatum* [Schwein.] Andrus & W.D. Moore 1935), and target spot (*Corynespora cassicola* [Berk. & M.A. Curtis] C.T. Wei 1950). Other standard farming practices were used with the crops.

Figure 1. Rainfall distribution and average daily air temperature during the field experiment. Anápolis, Goiás, 2013-2014.



## Measurements

Tracking was done of the major soybean plant growth stages for each cultivar by observing the soybean phenological scale developed by Fehr and Caviness (1977). The ground cover rate between lines was evaluated in days until reaching maximum ground cover between the lines by soybean plant foliage. It was measured with a graduated ruler every 5 d after 30 DAS.

Leaf area (LA) was determined at the R<sub>1</sub> stage for 'BRS Valiosa RR' and at the R<sub>2</sub> stage for the others. Ten plants were randomly collected on the fourth line of each plot in the lines parallel to the usable area. In the laboratory, leaves of each plant were individually detached and distributed over a white surface and immediately photographed using a digital camera (Cyber-Shot, Sony, Tokyo, Japan) with a 12.1 megapixel resolution. The reading was taken through the image analysis software ImageJ (NIMH, 2015). The leaf area index (LAI) was determined by the relationship between the sum of the area of the leaves of a plant and the soil surface it occupies as in the following expression:

$$LAI = (LA \times FS) / 1000$$

where LA is mean leaf area of evaluated soybean plants (m<sup>2</sup>) and FS is the final stand of plants ha<sup>-1</sup>.

During harvest (growth stages R<sub>8</sub> and R<sub>9</sub>), agronomic characters were assessed with 10 plants harvested in the usable area of each plot by direct counting; plant height (distance between the neck of the plant and the apical end of the main shaft) was measured with a graduated ruler and the mean height of the 10 plants was obtained. The number of branches inserted into the main stem of each of the 10 plants was counted and the mean number of branches per plant was obtained. The number of pods per plant was calculated by directly counting the total number of pods formed on each of the 10 plants and the final mean was obtained. When pods of the 10 plants in the usable area were counted, grains related to the total number of pods were also counted. Thus, the mean number of seeds per pod was obtained. Eight sub-samples of 100 seeds per plot were counted to determine mean weight using an analytical balance with a sensitivity of 0.001g. Grain yield was determined in kg ha<sup>-1</sup> by threshing all the plants in the plot. Seed mass water content was adjusted to 13%.

## Statistical analysis

Data were subjected to ANOVA; when relevant, and the Scott-Knott test at 5% probability was used to discriminate possible differences among treatments. The SISVAR 5.3 software was used for statistical analysis (Ferreira, 2011).

## RESULTS AND DISCUSSION

All treatments had 100% closed crop interline canopy at 55 DAS (Table 1). At 30 and 35 DAS, the conventional sowing system had faster closure. However, the cross-seeding system accentuated closure; it was faster and higher after 45 DAS

**Table 1. Mean values of the canopy closure rate for different cropping systems, growth habits, and soybean sowing densities.**

Treatments	Closure rate					
Seeding systems	T1	T2	T3	T4	T5	T6
Conventional	47.6a	55.4a	58.5a	60.4a	71.2b	90.0a
Crossed	44.2b	52.4b	57.18a	62.7a	78.0a	90.0a
Types of growth						
Determinate	44.5b	53.4a	58.1a	65.6a	77.0a	90.0a
Semi-determinate	48.4a	54.4a	58.9a	62.5a	76.1a	90.0a
Indeterminate	44.9b	53.2a	56.5b	56.5b	70.6b	90.0a
Sowing densities, plants ha <sup>-1</sup>						
245 000	43.7b	52.6b	55.2c	58.7a	71.6b	90.0a
350 000	45.6b	53.6b	58.1b	62.7a	75.5a	90.0a
455 000	48.4a	55.4a	60.3a	63.2a	76.7a	90.0a
Mean	45.9	53.9	57.8	61.5	74.6	90.0

Means followed by the same letter in a column did not significantly differ according to the Scott Knott test at 5% probability. Crop closure rates: T1: 30 d after sowing (DAS); T2: 35 DAS; T3: 40 DAS; T4: 45 DAS; T5: 50 DAS.

than at 50 DAS with 9.56% more closure. The LAI of the cross-seeding system was 7% higher than in the line system, which could explain better closure in the cross-system.

The faster closure in cross-lines was also observed by Lima et al. (2012), who pointed out that the crop reaches the maximum growth phase earlier under this condition. Reducing spacing and using more equidistant spacing allows an increase in light utilization at the beginning of crop development, which is caused by higher LAI and biomass production and higher productivity as a consequence (Cox and Cherney, 2011).

At 35 DAS, cultivars with semi-determinate and indeterminate growth did not differ significantly and exhibited faster closure. The increase in sowing density influenced the closure rate during the evaluation period. As the seeding rate increases, interline closure increases.

Neither LA nor LAI were influenced by the seeding systems (Table 2), demonstrating that spatial distribution in this situation did not cause morphological changes in plant architecture. These results are relevant for shade issues, leaf senescence in the lower third, and flower and pod fixation (Board and Kahlon, 2011); they are also positive for phytosanitary control (Kumudini et al., 2008) and weed management (Arce et al., 2009).

**Table 2. Mean values of leaf area (LA) and leaf area index (LAI) for different cropping systems, growth habits, and soybean seeding rate.**

Treatments	LA (m <sup>2</sup> )	LAI
Seeding systems	-	-
Conventional	0.24a	7.09a
Crossed	0.25a	7.56a
Types of growth		
Determinate	0.28a	8.40a
Semi-determinate	0.22b	6.49b
Indeterminate	0.23b	7.08b
Sowing densities, plants ha <sup>-1</sup>		
245 000	0.32a	7.61a
350 000	0.24b	7.74a
455 000	0.17c	6.62a
Mean	0.24	7.32

Means followed by the same letter in a column did not significantly differ according to Scott Knott test at 5% probability.

The cultivar with a determinate growth habit had higher LA (19.83%) and LAI (15.7%) values compared with the indeterminate growth habit and semi-determinate cultivars due to the higher number of lateral branches observed in the determinate growth cultivar (Table 2). The LAI did not differ across different population levels because this index is compensated between LA and number of plants per area, which is attributed to the high capacity of soybean morphological adaptation. These results differ from those obtained by Heiffig et al. (2006).

The cultivation system did not affect plant height because intraspecific competition did not increase in the line (Table 3) and there were no significant differences in LA and LAI among systems. On the other hand, the cultivar with a determinate height was 16 cm higher than the other cultivars. This may be explained by higher competition among individuals as observed in higher LA, LAI, and number of branches. In response to increased sowing density, there was a 3.3 cm increase in height from the smallest to the largest population (Table 3); this confirms results found by De Bruin and Pedersen (2008), who observed a 6 cm increase in the final population from 258 600 to 402 700 plants.

The number of branches was 7% higher in the line planting system, but the difference was nonsignificant. This result is confirmed because there were nonsignificant differences in the results for LA, LAI, and plant height.

The number of branches per plant was higher in determinate growth habit cultivars and lower in indeterminate and semi-determinate growth habit cultivars (Table 3). These results can be explained by higher LA and LAI obtained by determinate growth cultivars and the highest number of branches, which supports other research results (Robinson and Wilcox, 1998; Kilgore-Norquest and Sneller, 2000).

The increased competition between plants within the line resulted in a change in the number of branches per plant. The increase in seeding rate decreases the emission of the number of branches, unlike the density of 245 000 plants ha<sup>-1</sup>, which had the highest number of branches (Table 3). Cox

and Cherney (2011) also obtained a 20% reduction in the number of branches per plant by increasing sowing density from 321 000 to 421 000 plants ha<sup>-1</sup>. In a soybean crop study on different sowing densities and different row spacing, Procópio et al. (2013) found that competition in the line more significantly affects the number of branches than spacing between lines. In their study, the change from 375 000 seeds to 562 500 seeds was more harmful than changing spacing from 0.40 to 0.60 m. For Procópio et al. (2013) and Balbinot Junior et al. (2015), using higher densities promotes greater competition among plants due to lower emissions of lateral branches, thus reducing productivity per plant. In addition, higher plant density in the line provides more competition for natural resources essential for vegetative growth and lesser grain formation.

Regarding the number of pods, nonsignificant differences were found between seeding systems (Table 3). However, in relation to the growth habit, the indeterminate growth cultivar showed a lower number of pods per plant in response to fewer branches, 107% less than the determinate growth cultivar. For several issues, Specht et al. (1999) state that the differences between cultivars are explained by genetic constitution and environmental influence. Branches are more important for indirect selection of productive cultivars.

In response to fewer side branches, the number of pods per plant was reduced as sowing density increased. Sowing density of 245 000 plants showed a higher number of pods than the 350 000 and 455 000 plant densities, which decreased by 22% and 37%, respectively. The same relationship was observed in a study conducted by Heiffig et al. (2006) when separately analyzing 0.20 m spacing between lines; the number of pods per plant decreased from 106 to 29 when seeding density was altered from 70 000 to 350 000 plants. However, the reduced number of pods was more significant (72.9%) when spacing was reduced.

Thousand-grain weight was nonsignificantly influenced by either the seeding system or density, but only by cultivar (Table 3). The determinate growth cultivar showed the best result for 1000-grain weight (159.3 g); it was superior to semi-determinate (5.7%) and indeterminate (8.33%) cultivars, respectively, that is, 150.675 and 147.04 g, which did not differ significantly. Lima et al. (2012), in a cross-seeding study, also found nonsignificant differences in 100-grain weight in two cultivars, 'TMG Anta82 RR' with semi-determinate growth and 'M 7211 RR' with indeterminate growth. However, results in the literature about the effects of plant population on 1000-grain weight vary; Cox and Cherney (2011) found nonsignificant differences in changing spacing and plant density. Suhre et al. (2014) showed that plant density in the line increases linearly with seed mass, but the difference was higher in newer cultivars. Characteristics, such as number of seeds per pod and 1000-seed weight, are mostly influenced by genetic factors.

Productivity results enabled us to observe that the cross-seeding system allowed obtaining higher grain yield, 4509 kg ha<sup>-1</sup>, while the conventional system showed a value of 4186 kg ha<sup>-1</sup>, that is, a positive difference of 322.55 kg ha<sup>-1</sup>

**Table 3. Mean values for plant height (PH), number of branches per plant (NBP), number of pods per plant (NPP), 1000-seed weight (TSW), and grain yield (YIELD) as related to the seeding system, growth habit, and soybean seeding rate.**

Treatments	Agronomic characteristics				
	PH	NBP	NPP	TSW	Yield
	cm			g	kg ha <sup>-1</sup>
Seeding systems					
Conventional	92.82a	5.05a	58.88a	149.85a	4 186.47b
Crossed	93.77a	4.73a	59.69a	151.64a	4 509.02a
Determinate	104.86a	7.37a	64.85a	159.30a	4 111.76b
Semi-determinate	88.71b	3.74b	65.66a	150.67b	4 529.54a
Indeterminate	86.30c	3.57b	47.34b	147.04b	4 411.95a
Sowing densities, plants ha <sup>-1</sup>					
245 000	91.58c	5.75a	73.62a	149.67a	4 422.32a
350 000	93.40b	4.75b	57.59b	150.69a	4 434.12a
455 000	94.90a	4.18b	46.65c	151.87a	4 186.81a
Mean	93.29	4.89	59.28	151.34	4 348.99

Means followed by the same lower-case letter in a column did not significantly differ according to the Scott Knott test at 5% significance.

or 7.7% (Table 3). Results are close to those found by Lima et al. (2012) also under Cerrado conditions, whereas the cross-seeding system showed a productive increase of 8.6% or 287 kg ha<sup>-1</sup> compared with conventional planting. Mean yield in cross-seeding, 4509 kg ha<sup>-1</sup>, was 53% higher than the national productivity for the 2012-2013 crop and 50% higher than mean productivity of the Midwest, 3012 kg ha<sup>-1</sup> (Conab, 2014). Therefore, regardless of the extrapolation of results obtained in experimental areas, the reflection on the potential of the cross-seeding technique on yield from genetic materials currently used on a large scale by farmers is evident; moreover, regardless of the growth habit and population densities used, intensified technological actions that allow achieving higher yields are made possible.

The change in seeding density did nonsignificantly influence yield, which is consistent with results obtained by De Bruin and Pedersen (2008), who verified that changes in the final population did not cause changes in final soybean production. Other studies have also found that there was no increase in soybean grain yield with higher seeding density (Lee et al., 2008). The fact that soybean has the capacity to compensate space in the canopy and maintain yield can be seen as the probable hypothesis to explain this behavior (Heiffig et al., 2006; Akond et al., 2013; Balbinot Junior et al., 2015).

## CONCLUSIONS

There was a better distribution of plants over the cultivation area in the cross-seeding system because of the rapid closure between lines even with nonsignificant differences between the systems in relation to leaf area, leaf area index, plant height, and number of branches per plant. The cross-seeding system allowed increasing grain yield in semi-determinate and indeterminate growth cultivars. Increased planting density and growth habit did not promote an increase in soybean yield.

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