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Soybean agronomic performance in narrow and wide row spacing associated with NPK fertilizer under no-tillage

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The purpose of this research was to evaluate soybean agronomic traits performance under row spacing associated with NPK fertilizer. The experimental design was set up in a randomized complete block and the treatments were arranged with factorial concept, consisting of four NPK (02-20-18%) fertilizer rates (0; 200; 400 and 600 kg ha^{-1}) and five row spacing (0.35; 0.45; 0.50; 0.60 and 0.70 m), with three replications. The measurements were performed in two consecutive cropping seasons. The following variables were determined: time of canopy closure; plant height; the height of the first pod insertion; number of pods per plant; number of branches per plant; number of grains per pod; 1000-grain weight; and grain yield. The narrow row spacing (below than 0.40 m) may be a profitable alternative to reduce intraspecific plant competition resulting in improvement of soybean agronomic performance, resulting faster canopy closure and relative equidistance among soybean plants. Narrow rows promoted increase in soybean grain yield. The row spacing of 0.35 m associated with 600 kg ha^{-1} of NPK fertilizer was the profitable combination to achieve the highest soybean grain yield. The wide row spacing demand more fertilizer to remain the same performance than in 0.35 m spacing row.

Key words: *Glycine max* L., soil fertility, cropping season, soil science.

INTRODUCTION

Soybean is largely cultivated in Brazil, which is the most important grain crop. This fact had as precedent the success of soybean cultivation in Brazilian Cerrado biome being result of a sum of important environmental factors, as appropriate photoperiod and favorable rainfall seasons. However, the development of studies and technologies in the correction and conservation of the soil, genetic improvement, selecting late cultivars for low latitude, and agricultural practices have been helpful in achieving so expressive productivity (Spehar and Trecenti, 2011). On average, the grain yield of soybean in the highest soybean producer State of Brazil (Mato Grosso) is 3,069 kg ha^{-1}, although grain yield can achieve values above 4,000 kg ha^{-1} (Ensinas et al., 2015).

The challenge to increase crop yield is increasing around the world, to feed a growing population is necessary more than improvement of new cultivars. The possibility to increase the crop production with alteration in soybean plant arrangement can be a profitable alternative to obtain increment in grain yield with low investment for farmers. Sowing is one of the key factors that influence the success of any crop establishment and productivity. The optimization of row spacing and in-row plant density is a simple procedure with a low cost but has a significant influence on yield (Soratto et al., 2012) and is essential to maximize grain production.

A high plant density may result in overgrown plants and subsequently lodging, whereas a low plant population may enable weed infestation. Light interception by plants strongly influences the crop yield when other environmental factors are favorable, and it is modified by the plant spatial distribution in a given area. Soybeans have the ability to regulate growth and yield component production in response to changes in plant population and competition.

Increase in plant population density often results in higher soybean grain yield, but this is dependent on a number of factors, including climatic conditions of the growing region, plant size and leaf area, plant maturity and soil fertility. Higher soybean grain yields can be associated with the optimization of sunlight interception during the initial vegetative and breeding stage. The number of pods per plant may decrease in case of shadow during the bloom stage (Kurosaki and Yumoto, 2003), and consequently the grain yield decrease.

In Brazil and many other countries, the traditional row spacing in soybean is 0.45 m (Rosa et al., 2015; Freitas et al., 2016). The narrow row spacing can possibly improve the soybean performance and sunlight interception due to better plant distribution in the field. As reported by Moreira et al. (2015), wider rows spacing increases the soil temperature and decreases plant height, chlorophyll content and transpiration rates. Besides, the plant arrangement allows increasing soybean performance; another factor can be the improvement in soil fertility, because the alteration in row spacing can affect the nutritional demand of the plant.

Different approaches have been used to increase crop yield, such as increasing the amount of fertilizer, application of high-density resistant cultivars, uniformity of row spacing distribution (Liu et al., 2016). The soil fertility in Brazil shows low fertility, which is associated with the weathering in the process of soil formation. Highly weathered soils, such as most Brazilian soils are inherently infertile, with low cation exchange capacity, pH generally ranging around 4 to 5.5 and mineralogical assembly predominantly of iron oxides (Fe) and aluminum (Al). The immediate consequence of these intrinsic properties of tropical soils is the high sorption capacity of anions, which results in low concentration of P in soil solution (Pavinato et al., 2009; Abdala et al., 2015).

The knowledge about relationship between the row spacing and fertilizer on soybean development are insufficient, based on it, the purpose of this research was to evaluate soybean agronomic traits performance under row spacing associated with NPK (02-10-18) fertilizer in two consecutive cropping seasons.

MATERIALS AND METHODS

Location and soil description

This research was carried out in 2011/2012 and 2012/2013 cropping seasons in a Rhodic Hapludox classified according to Santos et al. (2013), sandy texture, and clay mineralogy constituted mainly by Al/Fe oxy-hydroxides. Located in the municipality of Ponta Porã, State of Mato Grosso do Sul, Brazil (approximately 22°34'09" S latitude, 54°48'2" W longitude, average altitude 553 m above sea level).

Weather condition in the experimental location

The data of rainfall and temperature in the experimental location are shown in Figure 1. The period of data collection was initiated in January, 2010 and ended in December, 2013. The region is classified as tropical climate of type Cwa, with rainy summer and dry winter, according to (Köppen, 1948).

Historic of the experimental area

The farm area has been cultivated or 10 years with crop succession of soybean in spring-summer and maize in fall-winter season. The fertilization was applied topdressing according to soil chemical analysis. The soil chemical properties analyzed before the establishment of the experiment in July, 2011 are in Table 1. The textural analysis showed the following results: 110, 70, and 820 g kg^{-1} of clay, silt and sand respectively, according to Claessen (1997). Before the experiment implementation, the correction of soil acidity was performed in September, 2010. The recommendation of liming rate was based on the soil chemical analysis results (Table 1), which was necessary to apply 500 kg ha^{-1} of liming in topdressing. The dolomitic lime showed calcium carbonate

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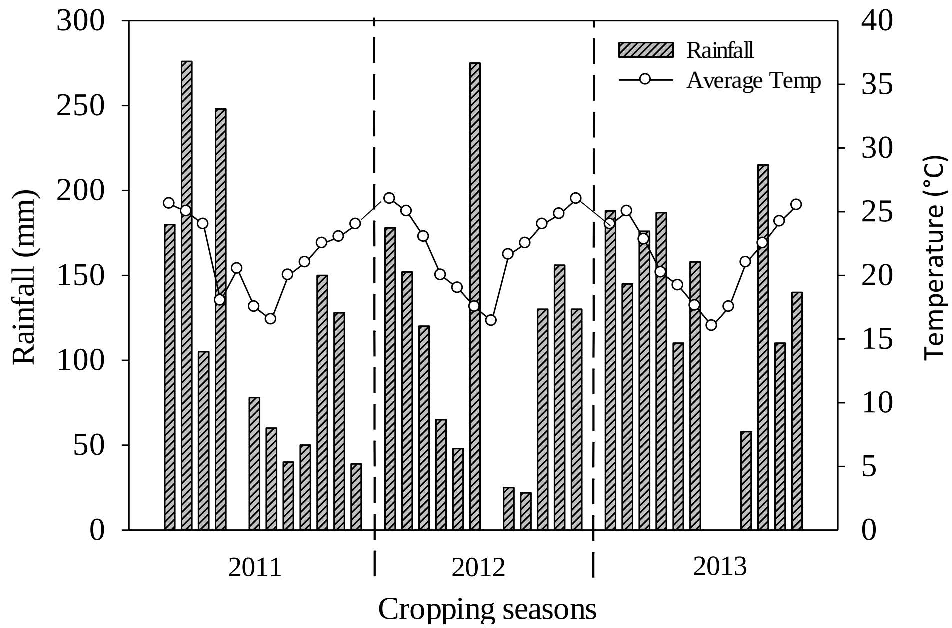

Figure 1. Rainfall and average monthly temperature in the period from January, 2011 to December, 2013.

Table 1. Soil chemical analysis under the experimental area before the experiment implementation, in 0-20 cm depth.

pH	$P_{Mehlich-1}$	OM	K	Ca	Mg	Ca+Mg	H	Al	H+Al	SB	CEC	BS
$CaCl_2$	mg dm^{-3}	g dm^{-3}	------------------------------- cmol$_{(c)}$ dm^{-3} -------------------------------------									%
5.69	46.26	15.33	0.07	2.00	1.00	3.00	1.68	0.00	1.68	3.07	4.75	64.63

OM_Organic Matter; Exchangeable (KCl 1 mol L^{-1}) Ca^{2+}, Mg^{2+} and Al^{3+}; total acidity pH 7.0 (H^{+}+Al^{3+}); SB_Sum of bases=∑cations; CEC_Cation Exchange Capacity; BS_Base Saturation=(∑cations/CEC)x100.

equivalent (CCE) of 80% (33% calcium oxide and 15% magnesium oxide). Previously the soybean seeding, the desiccation of the cover crops was conducted with herbicide chlorimuron-ethyl (20 g a.i. ha^{-1}), 2.4-D (967 g a.i. ha^{-1}) and glyphosate (1,440 g a.i. ha^{-1}). After the soil fertilization and cover crops being dissected, the seeding period started in October (soybean) and February (maize).

Experimental design and treatments

The experimental design was set up in a randomized complete block design and the treatments were arranged in factorial concept, consisting of four NPK (02-10-18) fertilizer rates (0; 200; 400 and 600 kg ha^{-1}) and five row spacing (0.35; 0.45; 0.50; 0.60 and 0.70 m), with three replications. The experimental units had dimensions of 15 m length by 9 m width. All operations were executed with a tractor wheel of 112 HP (Horsepower). The useful area to agronomic measurements was five central rows of each experimental plot, in which was disregarded 5 m initial and 5 m were ended in each row, in both cropping seasons. For the seeding procedure, the grain drill was used with the rows spaced according to experiment treatments. The fertilizer application in the experimental area was performed three days before the seeding. The drill had 26 rows and 0.17 m row spacing, and the application of fertilizer was deeper in soil at 8 cm depth, following the recommendation of the fertilizer treatments rates, which were allocated under and apart the seed to avoid contact. The seeding of soybean (*Glycine max* cv. BMX-Potência RR) crop was established on November 5th, 2011 and November 10th, 2012, both cropping season under no-till system. Soybean germination and purity of the seed were 95 and 99%, respectively. The seed density was 350,000 plants per hectare, the row spacing changed from 0.35 to 0.70 m according to the treatments of row spacing in soybean. The soybean seeds were treated with fungicide [Pyraclostrobin (25 g a.i. ha^{-1}) + Thiophanate-methyl (22.5 g a.i. ha^{-1})], insecticide [Fipronil (25 g a.i. ha^{-1})], micronutrients [cobalt (2.32 g L^{-1}) and molybdenum (40.6 g L^{-1})], and these rates were in gram of active ingredient per 80 kg of seeds. Besides, the seeds were inoculated before the sowing with inoculant in turf, which contained the bacteria *Bradyrhizobium elkani* (Race Semia 5080) and *Bradyrhizobium japonicum* (Race Semia 5079) in the concentration of $5x10^9$ viable cells per gram of inoculant. It was used 100 g of inoculate per 50 kg of soybean seed.

Assessed parameters and statistical analysis

Ten days after plant emergence was evaluated the initial stand, through the plant counting in each row. The time of canopy closure was measured weekly by observation in the field, in which was

Table 2. Rule for interpreting the size of Person's correlation coefficients based on Hinkle et al. (2003).

Size of correlation	Interpretation
0.90 to 1.0 (-0.90 to -1.0)	Very high positive (negative) correlation
0.70 to 0.90 (-0.70 to -0.90)	High positive (negative) correlation
0.50 to 0.70 (-0.50 to -0.70)	Moderate positive (negative) correlation
0.30 to 0.50 (0.30 to -0.50)	Low positive (negative) correlation
0 to 0.30 (0 to -0.30)	Negligible correlation

considered the number of days after soybean emergence to establish the time of canopy closure. When the soybean plant reached R8 reproductive stage (full maturation), 50 plants in each plot were measured and determined the following variables: plant height (PH); the height of the first pod insertion (HFPI); number of pods per plant (NPP); number of branches per plant (NBP); number of grains per pod (NGP); 1000-grain weight (1000-GW); and grain yield (GY).

The soybean grain yield was measured by the manual harvest in the experimental unit in a dimension of 5 m by 0.9 m in the center of each experimental unit. The grains were weighted and the grain yield was shown in kg ha^{-1}. Before the harvest, the final stand counting the plants in the useful row was evaluated. After the soybean harvest, the following variables were measured: number of failed pods; number of grains per pod; number of pods per plant; number of grains per plant (NGPl). The soybean grain yield was determined harvesting all the plants in 2 rows with 7 m length. The grain moisture and weight was determined at seed laboratory, and the moisture was corrected for 13%. In order to obtain the 1000-GW, it was collected 10 sub-samples with 100 grains per plot.

The variables evaluated in the experiment were submitted to the analysis of variance (ANOVA) by the *F*-test. The response surface was adjusted in case of significant interaction ($p \leq 0.01$) between row spacing with NPK rates. The correlation matrix of dependent variable was performed to obtain the degree of relationship between them. In case of significant correlation ($p \leq 0.01$ or 0.05), the strength was defined as Table 2. These statistical analyses were carried out with the assistance of ASSISTAT software.

RESULTS AND DISCUSSION

Statistical analysis of assessed variables

In order to assess and compare the results in two cropping seasons, it was measured the same soybean agronomic traits in both cropping seasons [2011/2012 (CS-1) and 2012/2013 (CS-2)]. In both cropping seasons, the variables studied were more affected by row spacing than NPK fertilizer rates or the interaction between both treatments. The number of failed pods per plant (NFPP) and 1000-grain weight did not show any significant difference ($p>0.05$) in the treatments evaluated in both cropping seasons (CS-1 and CS-2) (Table 3).

The significant interaction ($p<0.01$), between row spacing and NPK fertilizer, was noted just in CS-2, for the following variables: number of branches per plant (NBP), number of pods per plant (NPP), number of grains per plant (NGPl), and grain yield (GY) (Table 3). The cropping seasons affected the performance of soybean for the most variables assessed, as follow: time for canopy closure (TCC), plant height (PH), height of the first pod insertion (HFPI), number of failed pods per plant (NFPP), and number of grains per plant (NGPl). However, the grain yield did not alter between the cropping seasons (Table 3).

Agronomic traits of soybean affected by rows spacing

The row spacing showed higher effects on soybean performance than NPK fertilizer rates in both cropping seasons (CS-1 and CS-2). The experiment was initially defined with 350,000 plants per hectare, which changed the initial and final stand (FS) increasing the number of plants per meter as the row spacing increased from 0.35 to 0.70 m (Figure 2A). In 0.35 m row spacing, the FS was 9.2 and 9.6 plants m^{-1}, for CS-1 and CS-2, respectively. On the other hand, in 0.70 m row spacing was noted the FS of 20.2 and 18.4 plants m^{-1}, for CS-1 and CS-2, respectively (Figure 2A). In comparison between cropping seasons, no significant difference ($p>0.05$) was observed in FS (Table 4).

Narrow rows (0.35 m) resulted in faster time of canopy closure (TCC) in both cropping seasons (Figure 2B), and the canopy with total closure by soybean plants occurred 72.9 and 66.5 days after emerged plant, in CS-1 and CS-2, respectively. On the other hand, in the wide rows (0.70 m) the total canopy closure occurred at 118.4 and 85.7 days after emerged plant, respectively for CS-1 and 2 (Figure 2B). The faster TCC by soybean plants may improve the capitation of sunlight and efficiency of nutrients and water used by soybean plants.

The increase in plant distribution in soil can avoid the intraspecific plant competition in narrow rows (less than 0.50 m), which may result in better plant performance. The faster canopy closure in narrow spacing contributes to decrease the incidence of weeds. As reported by Wells et al. (2014), in wider row spacing (0.76 m) the incidence of weeds were significantly higher in comparison to narrow row spacing (0.19 and 0.38 m). The plant height (PH) increased in wider rows in CS-1, but did not show any significant effect in CS-1 (Figure 2C). In CS-1 the PH average was 88.9 (CS-1) and 68.6 cm (CS-2), in both cropping seasons PH did not achieve the height for

Table 3. Summary of analysis of variance (ANOVA).

Variables	----------2011/2012 Cropping season--------				----------2012/2013 Cropping season---------			
	Source of variation							
	Block	NPK	RS	NPKxRS	Block	NPK	RS	NPKxRS
df	2	3	4	12	2	3	4	12
	--Mean of squares---							
FS	0.2^{ns}	0.32^{ns}	217.55**	0.72^{ns}	4.92^{ns}	1.74^{ns}	147.92**	1.78^{ns}
TCC	96.80^{ns}	28.55^{ns}	4589.40**	16.33^{ns}	29.26*	28.68^{ns}	732.73**	16.9^{ns}
PH	42.81^{ns}	4.48^{ns}	127.79**	14.33^{ns}	57.95^{ns}	60.23^{ns}	58.31^{ns}	23.23^{ns}
HFPI	0.05^{ns}	0.23^{ns}	5.29*	0.44^{ns}	6.11^{ns}	2.95^{ns}	0.64^{ns}	0.88^{ns}
NBP	0.01^{ns}	0.03^{ns}	0.21*	0.04^{ns}	0.09^{ns}	0.01^{ns}	0.14**	0.9**
NFPP	052^{ns}	0.55^{ns}	0.14^{ns}	0.28^{ns}	0.01^{ns}	0.36^{ns}	0.24^{ns}	0.24^{ns}
NGP	0.24*	1.02**	0.85**	0.10^{ns}	0.26^{ns}	0.32^{ns}	0.23^{ns}	0.17^{ns}
NPP	0.03^{ns}	0.59^{ns}	3.52**	0.94^{ns}	3.37*	4.90*	1.84**	1.24**
NGPl	0.06^{ns}	1.47^{ns}	9.21**	2.52^{ns}	8.66*	13.42*	4.75**	3.19**
GY	0.18^{ns}	0.35^{ns}	2.36**	0.91^{ns}	5.57^{ns}	6.59*	4.37**	1.57**
1000GW	0.05^{ns}	0.06^{ns}	0.15^{ns}	0.13^{ns}	0.38^{ns}	0.01^{ns}	0.19^{ns}	0.17^{ns}

*df*_degree of freedom. *Significant at 0.05 probability level. **significant at 0.01 probability level by *F*-value. ^{ns}no significant at 0.05 probability level by *F*-value. FS_final stand; TCC_time for canopy closure; PH_plant height; HFPI_height of the first pod insertion; NBP_number of branches per plant; NFPP_number of failed pods per plant; NGPl_number of grains per plant; GY_grain yield; 1000GW_1000-grain weight.

cultivar BMX-Potência RR, which implies that other factors reduced the plant development.

As reported by Freitas et al. (2016), the soybean cultivar BMX-Potência RR with height of 1.03 m is ideal for this cultivar development without water restriction. In CS-1 the average of plant height was 64.27 cm in the space between rows of 0.35 m, which was below the acceptable values of 0.91 to 1.03 m in average (Franchini et al., 2014; Rosa et al., 2015; Freitas et al., 2016). The relationship between plant heights measured at the end of plant cycle, the lowest plant height in narrow rows may be associated with reduction of intraspecific plant competition avoiding blanching resulting in smaller PH. The narrow rows, below 0.40 m, may decrease the plant height noting smaller lodgings and higher percentage of surviving plant. The higher plant height in CS-2 in relation to CS-1 probably occurred in function of better weather conditions in CS-2 (Table 4).

The optimization of row spacing and in-row plant density is a simple procedure with a low cost but has a significant influence on yield. However, Berger-Doyle et al. (2014) observed that row spacing did not have any effect on any major agronomic traits, indicating that specialty soybeans can be equally productive in either narrow or wide rows. However, soybeans planted in narrow-row spacing might be more profitable due to less herbicide and water costs than traditional wide-row spacing in the United States (that is, >70 cm). The narrow rows spacing promoted higher height of first pod insertion (HFPI) (Figure 2D). The HFPI did not show any significant difference (p>0.05) in both cropping seasons. The average HFPI was 11.65 cm, this height is in accordance to the expected for BMX-Potência RR. As reported by Ramteke et al. (2012), the adequate value for HFPI would be above 12 cm. Freitas et al. (2016) found in average 12.74 cm. The importance of HFPI in relation to the mechanical harvest of soybean, because in sloping land the loss of grain during the harvest is high due to the impossibility to harvest below 10 cm. Cunha et al. (2013) suggested 10 to 12 cm of HFPI in flat slope and above 15 cm in sloping land to avoid loss during the harvest.

The space between rows did not affect HFPI in both cropping seasons (Figure 2D). The number of failed pods per plant (NFPP) was statistically higher in CS-2, but in both cropping seasons no difference among the row spacing was noted. The CS-1 showed 2.5 times more failed pods per plant than in CS-2 (Table 4). The lowest NFPP in CS-1 may be associated with the drought stress occurred in this cropping season what maybe decreased the capacity of biomass accumulation by plant and grain fill. The narrow rows promoted higher number of branch per plant (NBP) (Figure 2E). No significant statistic difference (p>0.05) was noted for NBP between the cropping seasons, but HFPI was higher in CS-1 (Table 4). The higher values of number of branches per plant (NBP) noted in the narrow rows has been associated with many factors, as: the better water use due to the shelter of branches on soil surface, better root distribution in soil, decline of intraspecific plant competition, uniform exploration of soil fertility and higher sun radiation interception (Kuss et al., 2008). As reported by Rambo et al. (2004), the uniformity of the plant distribution may result in increasing the number of pods per square meter majority in R1 and R5 breeding stage. As reported by De

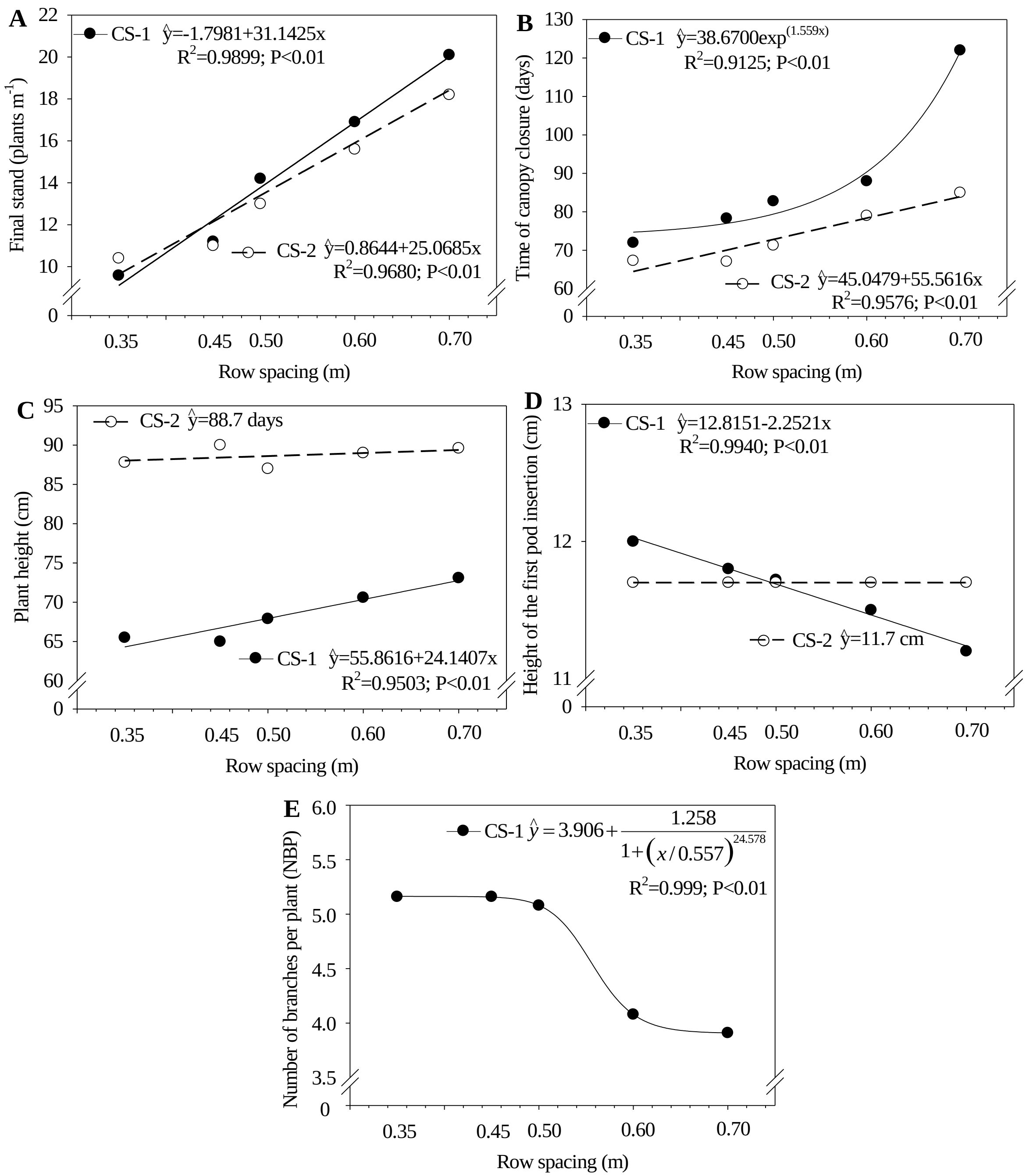

Figure 2. Row spacing in soybean affected soybean agronomic traits in two cropping seasons. CS-1 (2011/2012 cropping season) and CS-2 (2012/2013 cropping season); (A) final stand (FS); (B) time of canopy closure (TCC); (C) plant height (PH); (D) height of the first pod insertion (HFPI); (E) number of branches per plant (NBP).

Bruin and Pedersen (2008), the increase in row spacing can promote the decreasing in soybean grain yield.

Row spacing and NPK fertilizer affected some agronomic traits of soybean

The number of grain per pod (NGP) was not affected by row spacing in CS-2 and no significant difference was observed between cropping seasons (Table 4), the average of NGP was 2.5 for both cropping seasons. On the other hand, in CS-1 was possible to adjust the logistic model for the data, which showed decreasing in NGP in wider row spacing (Figure 3A). NGP showed very high negative correlation with number of plants per meter (FS), TCC, and PH (Table 5). NPP, and NGPI decreased

Table 4. Test of mean for soybean agronomic traits in two cropping seasons.

Cropping seasons	FS (pl m^{-1})	TCC (days)	PH (cm)	HFPI (cm)	NBP	NFPP	NGP	NPP	NGPI	SGY (kg ha^{-1})	1000GW (g)
2011/2012	14.4^a	88.7^a	88.9^a	11.7^a	4.7^a	5.9^a	2.5^a	56.4^b	146.6^b	3800^a	0.16^a
2012/2013	13.9^a	73.9^b	68.6^b	11.2^b	4.9^a	3.4^b	2.5^a	62.5^a	162.5^a	4200^a	0.16^a
CV (%)	26.0	17.5	6.5	10.6	9.8	22.1	7.8	12.1	12.1	25.6	2.4
F-value	0.5^{ns}	32.1**	461.1**	5.4*	0.8^{ns}	26.2**	0.1^{ns}	5.3*	5.5*	2.5^{ns}	0.1^{ns}

*Significant at 0.05 probability level. **significant at 0.01 probability level by *F*-value. ^{NS}no significant at 0.05 probability level by *F*-value. FS_final stand; TCC_time for canopy closure; PH_plant height; HFPI_height of the first pod insertion; NBP_number of branches per plant; NFPP_number of failed pods per plant; NGPI_number of grains per plant; GY_grain yield; 1000GW_1000-grain weight.

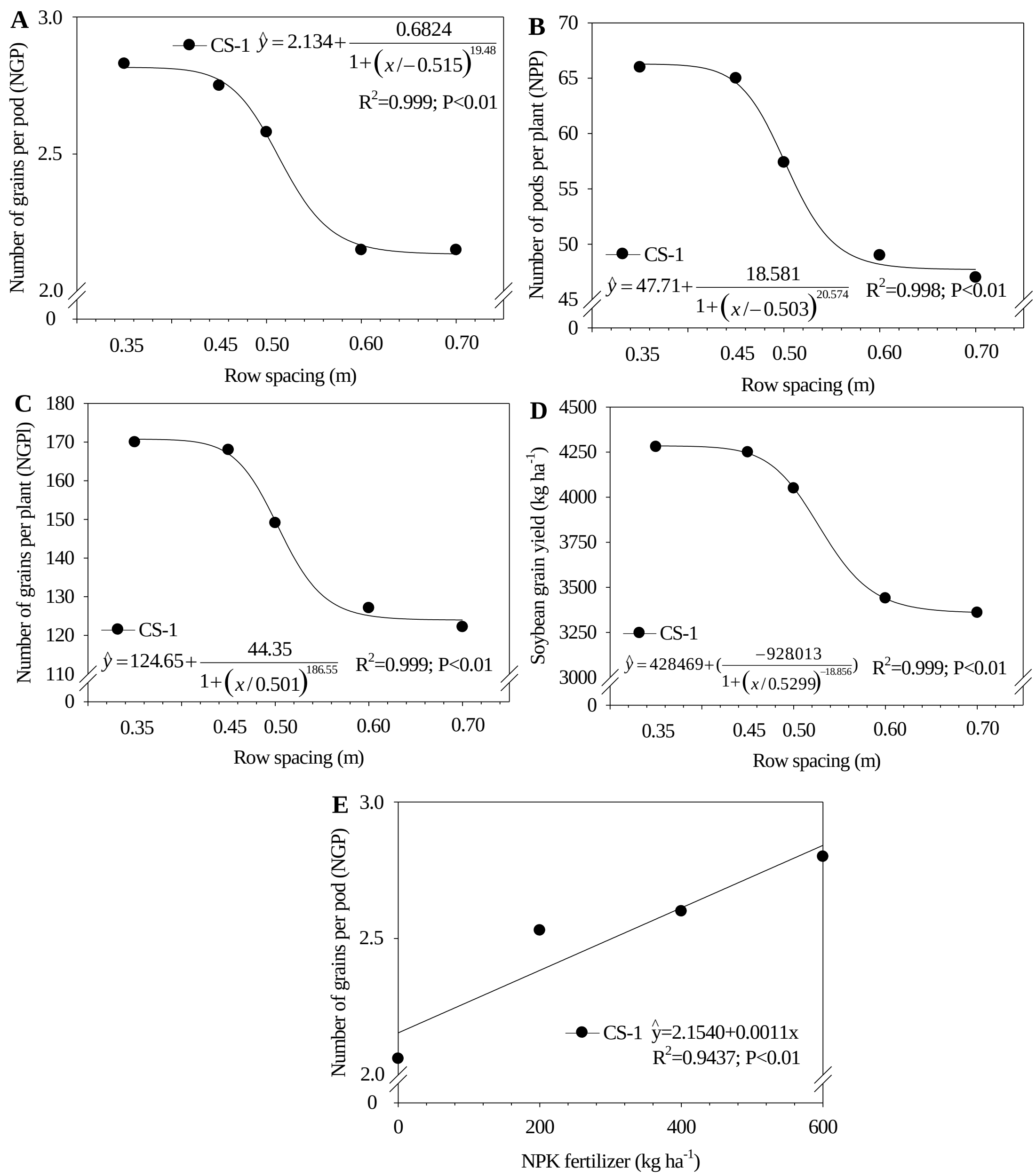

Figure 3. Row spacing in soybean and NPK fertilizer affected soybean agronomic traits. CS-1 (2011/2012 cropping season); (A) NGP_number of grains per pod; (B) NPP_number of pods per plant; (C) NGPI_number of grains per plant; (D) GY_grain yield; (E) NGPI_number of grains per plant.

Table 5. Simple matrix of Person's correlation between dependent variables.

	FS	NGPl	TCC	NPPl	PH	NGP	HFPI	GY	NBP
FS	1	-0.955**	0.913**	-0.932**	0.981**	-0.929**	-0.987**	-0.921**	-0.921**
NGPl		1	-0.787**	0.999**	-0.975**	0.955**	0.872**	0.955**	0.938**
TCC			1	-0.791**	0.9021**	-0.790**	-0.948**	-0.747**	-0.831**
NPP				1	-0.976**	0.957**	0.876**	0.956**	0.939**
PH					1	-0.955**	-0.953**	-0.9365**	-0.948**
NGP						1	0.925**	0.994*	0.969**
HFPI							1	0.885**	0.910**
GY								1	0.976**
NR									1

FS_final stand; NGPl_number of grains per plant; TCC_time for canopy closure; NPPl_number of pods per plant; PH_plant height; NGP_number of grains per pod; HFPI_height of the first pod insertion; GY_grain yield; NBP_number of branches per plant. Significance effects are at P<0.05 (*), <0.01 (**), and P>0.05 (^{ns}).

in wider row spacing in CS-1, and no significant difference was observed in CS-2. In CS-1, NPP, and NGPl were 10.82 and 9.74%, respectively, lower than CS-2 due to the drought stress occurred during the breeding stage (Table 5). The logistic model was adjusted to the data of NPP, NGPl, and GY (Figure 3B, C, and D). Observing the logistic model is quite evident the decreasing of NPP, NGPl, and GY in wider row spacing, which is not favorable to obtain high soybean production in same area and with the same economic budged.

In CS-1, NPK fertilizer rates showed significant effects on NGP (Figure 3E). NPK fertilizer rates did not affect the NGP in CS-2. The absence of effects in CS-2 for NGP might be associated with the optimal rainfall distribution (Figure 1), resulting in no effects of NPK fertilizer. With rainfall constraints the treatments with higher NPK dose may contribute to increase plant nutrition and higher capacity to resist to drought stress, thus in the highest NPK dose (600 kg ha^{-1}) NGP was 33.33% higher than in absence of NPK fertilizer (Figure 3E). As reported by Marschner (2012), plants with profitable nutrition may be more tolerate to environment factor, as the case of drought in breeding stage. NGP, NPP, and NGPL showed very high positive correlation with soybean GY (Table 5).

The reduction of NGP, NPP, and NGPl may be associated with intraspecific competition in row due to the higher number of plant per meter, obtained in wider row spacing than narrow row spacing (Figure 2A). On the other hand, the soybean GY showed very high negative correlation with FS, PH, and high negative correlation with TCC (Table 5).

The grain yield of soybean was negatively correlated with TCC, resulting in higher grain yield in narrow row spacing. With faster TCC, the radiation interception might be optimized during the vegetable and in the beginning of the breeding stage, thus avoiding flowers abortion in the stage R3. The grain yield decreased with the increasing in TCC, NGP, and NGPl. The grain yield in CS-1 showed better result in row spacing of 35 cm (4383.9 kg ha^{-1}) in comparison to 70 cm (3338.2 kg ha^{-1}). In CS-2, the significant (p<0.01) interaction between the row spacing and NPK fertilizer rates promoted the adjustment of the response surface, this way CS-2 is exposed in separate sub-heading and not discussed herein. The highest soybean GY in narrow row spacing may be associated with decreasing in intraspecific competition promoted by better spatial distribution of the plants in the area. Rambo et al. (2003) obtained higher grain yield in narrow row spacing of 20 cm when compared to 40 cm with the same plant population. Rambo et al. (2003) inferred higher GY are associated with decreasing in intraspecific plant competition. Possibly, the higher GY in narrow row spacing may be associated to higher radiation intercepted during the growth stage of the plant avoiding the abortion of flowers and pods, resulting in higher grain yield (Mattioni et al., 2008). Therefore, major agronomic traits may vary from year to year, but selection of proper varieties for a particular production environment is important in achieving high yield, proper seed size, and plant height (Berger-Doyle et al., 2014).

Surface response for interactive effect of row spacing in soybean and NPK fertilizer rates

Only in CS-2 was observed significant (p<0.01) effect of the interaction between row spacing and NPK fertilizer rates for NBP, NGP, NPP, and soybean GY. The interaction between independent variables promoted the response surface adjustment to the data of NBP, NGP, NPP, and soybean GY (Figure 4). The highest NBP was observed in the highest NPK fertilizer dose and narrow row spacing (35 cm), resulting in 5.7 branches per plant, and 4.2 branches per plant in row spacing of 70 cm associate with NPK fertilizer rates of 161 kg ha^{-1} of NPK (Figure 4A). Higher NGPl (170.10) and NPP (65.88) were

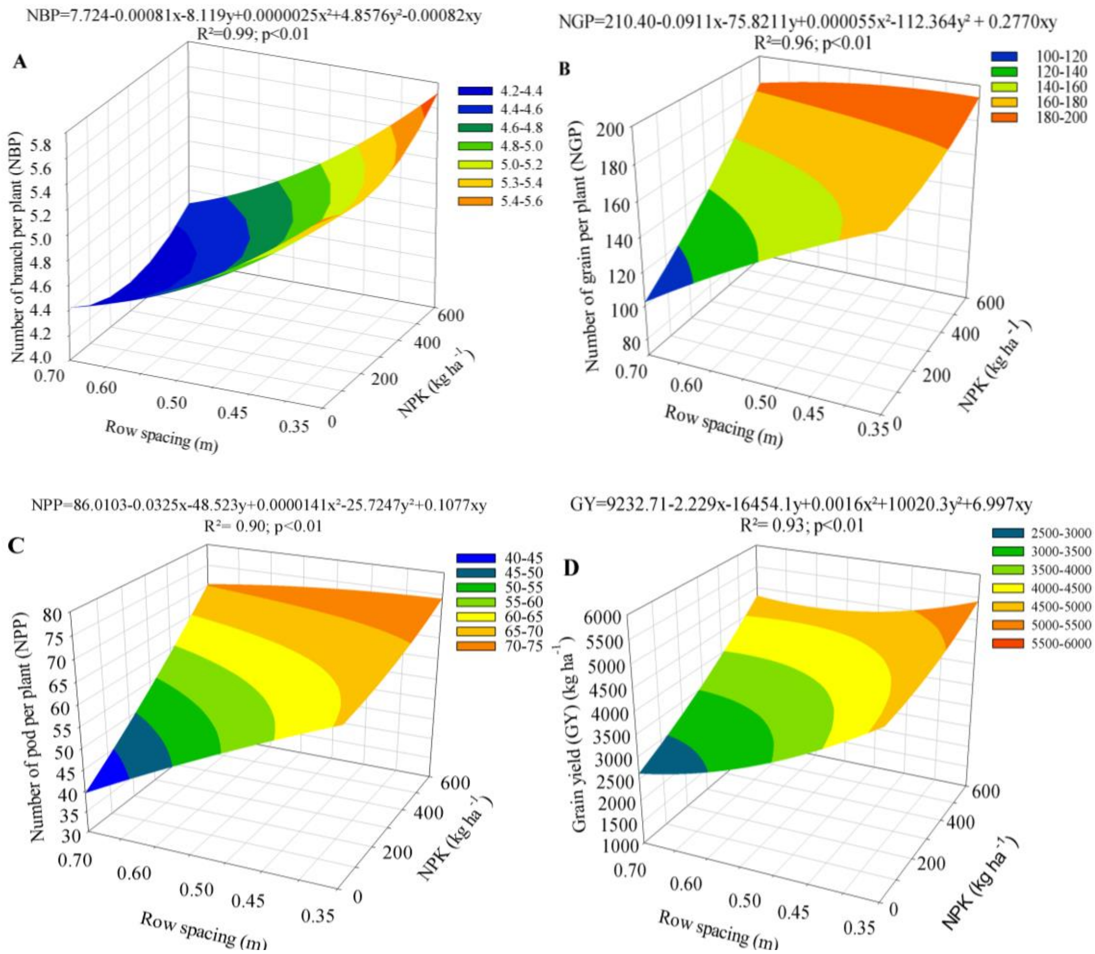

Figure 4. Agronomic traits of soybean under row spacing and NPK fertilizer. (A) number of branch per plant (NBP); (B) number of grain per plant (NGPl); (C) number of pod per plant (NPP); (D) grain yield (GY).

obtained in the narrowest row spacing (0.35 m) in the highest NPK fertilizer rates (Figure 4B and C).

In row spacing of 0.70 m in absence of NPK fertilizer the NPP and NGPl declined 40% and 40.19%, respectively, in comparison to row spacing of 0.35 m and absence of fertilizer. This decline was higher than in NPK dose of 600 kg ha^{-1}, which showed a little difference between the row spacing in soybean. To remain the same NPP and NGPl in row spacing of 0.35 and 0.70 m, it is necessary to apply 600 kg ha^{-1} of NPK fertilizer rates. The grain yield increased in narrow row spacing and increment in NPK dose. The highest grain yield (5417.4 kg ha^{-1}) was obtained with the association of 600 kg ha^{-1} of NPK dose with row spacing of 0.35 m. In the case of absence of NPK fertilizer and row spacing of 0.70 m the lowest yield obtained was 2624.7 kg ha^{-1}, which corresponded to 51.55% of decline in grain yield (Figure 4D). The increasing in grain yield in narrow row spacing may be attributed to higher water and nutrient use efficiency, lower weed competition relate to small time of canopy closure, decreasing in intraspecific plant competition, and higher light intercept (Pedersen, 2008).

Conclusions

The narrow row spacing (less than 0.40 m) may be a profitable alternative to reduce intraspecific plant competition resulting in improvement of soybean agronomic performance, resulting faster canopy closure and relative equidistance among soybean plants. Narrow rows promoted increase in soybean grain yield. The row spacing of 0.35 m associated with 600 kg ha^{-1} of NPK (02-20-18) fertilizer was the profitable combination of factors to achieve the highest soybean grain yield. The wider row spacing demands more fertilizer to remain the same performance than in 0.35 m spacing row.

Conflict of Interests

The authors have not declared any conflict of interests.

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Abbreviations

NTS, No-tillage system; **FS,** final stand; **TCC,** time for canopy closure; **PH,** plant height; **HFPI,** height of the first pod insertion; **NBP,** number of branches per plant; **NFPP,** number of failed pods per plant; **NGPl,** number of grains per plant; **GY,** grain yield; **1000GW,** 1000-grain weight.

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