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Cropping systems and soybean plant population in Brazilian C*errado*

Sistemas de cultivo e população de plantas de soja no Cerrado brasileiro

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ABSTRACT
The growing demand for soybean has led producers to adopt different plant arrangements. However, this technology information in *Cerrado* conditions is scarce and further studies in order to understand the effects of soybean crop are necessary. Therefore, the objective of this study was to evaluate different cropping systems, with and without addition of plant population using a soybean variety of

semi determinate growth habit in Brazilian *Cerrado* conditions. The experiments were carried out in the crop years 2013/14 and 2014/15 in Rio Verde - GO, Brazil, in randomized block design with 4x2 factorial arrangement, consisting of four sowing systems (traditional; reduced; double rows and cross) associated to two plant populations (recommended and increase of 33%) of the Anta 82 RR® variety. The results showed that in the 2013/14 season due the better water distribution, the use of double row implantation system presented greater grain yield than the others. Also, with lower rainfall, the 2014/15 season was not influenced by implantation system. The increase in plant population to 665,000 plants ha^{-1} demonstrated that the densification in the semi-determinate soybean variety was not an interesting technique.

Keywords: Double rows, *Glycine max,* plant arrangement, reduced spacing, yield components.

RESUMO
A crescente demanda por soja levou os produtores a adotar diferentes arranjos de plantas. Entretanto, as informações sobre essa tecnologia nas condições do Cerrado são escassas, sendo necessário mais estudos para entender os efeitos da cultura da soja. Portanto, o objetivo deste estudo foi avaliar diferentes sistemas de cultivo, com e sem acréscimo na população de plantas recomendada utilizando uma variedade de soja de hábito de crescimento semi-determinado nas condições do Cerrado brasileiro. Os experimentos foram realizados nas safras 2013/14 e 2014/15 em Rio Verde - GO, Brasil, em delineamento de blocos ao acaso com arranjo fatorial 4x2, composto por quatro sistemas de cultivo (tradicional; reduzida; fileiras duplas e cruzadas) associados a duas populações de plantas (recomendada e acréscimo de 33%) da variedade Anta 82 RR®. Os resultados mostraram que, na safra 2013/14, devido à melhor distribuição da água, o uso do sistema de cultivo em fileiras duplas apresentou maior rendimento de grãos que os demais. Além disso, com menor precipitação, a safra 2014/15 não foi influenciada pelo sistema de implantação. O aumento da população de plantas para 665.000 plantas ha^{-1} (acima da recomendada) demonstrou que a densificação na variedade semi-determinada de soja não é uma técnica interessante.

Palavras-chave: Fileiras duplas, *Glycine max,* arranjo de plantas, espaçamento reduzido, componentes de produtividade

1 INTRODUÇÃO

In the past years, increasing soybean production has been observed due to increased demand for food production. Due to opening restrictions of new areas for farming in Brazil, there is a need to optimize cropping areas in order to obtain higher yields. The adoption of different soybean sowing systems by farmers of Brazilian *Cerrado* has been used as a strategy to maximize profit with the cultivation of this oleaginous.

The distance between rows association with the distribution of plants in the sowing row is consisted of plant arrangement (Pires et al., 1998). In this context, plant population interferes in inter and intra-specific competition of these plants by soil resources, especially water and nutrients, and in addition, cause morpho-physiological changes (Argenta et al., 2001), such as plant height (Komori et al., 2004), number of branches, pods per plant and grains per pod (Tourino et al., 2002).

In general, Brazilian farmers have adopted distance between rows from 0.40 to 0.50 m and average population of 400,000 plants ha^{-1} for soybean cultivation. The reduced distance between rows has become a promising practice to increased yield (Rambo et al., 2002), because besides reduce soil water loss by evaporation (Caliskan et al., 2007), provides greater light interception in early plant development (Dalley et al., 2004).

Recently, some soybean farmers have adopted cross-sowing system in crop, which consists of making two sowing operations in perpendicular direction. However, few works report performance of varieties in this system with responses to increased grain yield (Balbinot Júnior et al., 2015; Souza et al., 2016), since increase in the severity of soybean rust were observed (*Phakopsora pachyrhizi*) (Lima et al., 2012), a plant disease common in *Cerrado* conditions. The obtained results suggest that in most cases there is no significant increase in grain yield with the adoption of this sowing system, and in addition does not provide profit (Silva et al., 2015) and increase consumption fuel, the need for machinery and causes greater soil degradation.

The double row is another system that has been explored in soybean cultivation. In this system, there is greater penetration of light and defensive in plant canopy, with increased photosynthetic rates, better health and longevity of leaves of plant lower third, thus favoring higher grain yields (Rambo et al., 2003).

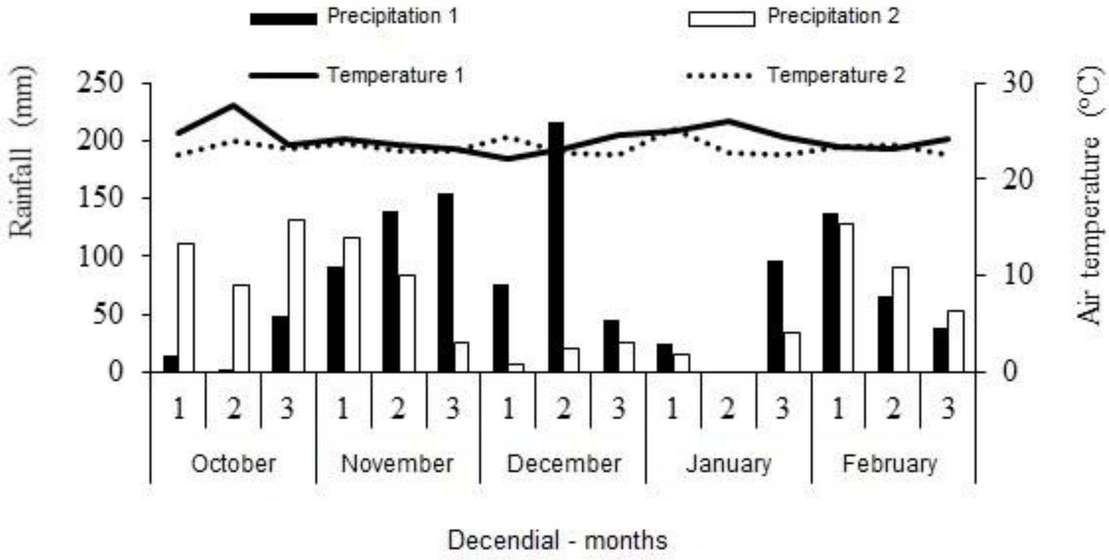
Redefinition of plant arrangement in soybean, by reducing the distance between rows, added to increased plant population, it may be a producer strategy to increase profitability, without significant increased production costs (Pereira et al., 2008). Due to the continuous increase of soybean varieties adapted to cultivation in Brazilian *Cerrado*, there is the need to assess the possible effects of sowing systems in variety of semi-determinate growth habit and whether these changes provide increase in grain yield.

Thus, the objective of the study was evaluated different sowing systems associated with increased plant population of soybean variety with semi-determinate growth habit cultivated in Brazilian *Cerrado*.

2 MATERIAL AND METHODS

The experiments were performed in field at Brazilian *Cerrado* conditions in the municipality of Rio Verde - GO (17°47’53”S; 51°55’53”W; and altitude of 756 m) in the crop seasons of 2013/14 and 2014/15 in soil under no-tillage system. Prior to the implementation of the experiment, sorghum was cultivated as preceding crop to soybean in both seasons. Rainfall data and average temperature during experiment are shown in Figure 1.

Figure 1 - Rainfall values and average air temperature during the conduction of the experiment. Rio Verde, Goias state, soybean seasons of 2013/14 (1) and 2014/15 (2) (Source: Weather Station at the University of Rio Verde-UniRV/INMET, Rio Verde, Goias state). Total rainfall: 1015 mm (season 2013/2014) and 515 mm (season 2014/2015)



The experimental design was a randomized block with a 4x2 factorial scheme and four replications. The factor A corresponded to four soybean sowing systems (traditional: 0.5 m of distance between rows; reduced: 0.25 m of distance between rows; double rows: 0.25/0.75 m – 0.25 m of distance within double row and 0.75 m between double rows; and cross: distance of 0.5 m between rows in the first pass e and perpendicular to the first sowing), associated to two populations of plants (recommended and increase of 33% of recommended population; 500,000 and 665,000 plants ha^{-1}; respectively, in both seasons) of Anta 82 RR® variety, which has semi-determinate growth habit and 7.4 maturity group.

Plots consisted of 5.0 m length and 3.5 m width. The useful area was obtained disregarding 0.75 m on each side and 1.0 m from of length, totaling 6.0 m^2. Therefore, it was considered as useful for plots, four rows for the traditional distance, double and crossed rows and eight rows for reduced.

Before soybean sowing, weeds were desiccated using trailed sprayer with 1,920 g g i.a.ha^{-1} of glyphosate, 0.12 kg of flumioxazim and 1.5 L ha^{-1} of S-metolachlor in 150 L ha^{-1} spray volume. On sowing day, seeds were treated with [fipronil + pyraclostrobin + thiophanate methyl] (6, 54 and 60 g, respectively], thiamethoxam (105 g), liquid fertilizer based on colbat and molybdenum (0.2 L) and inoculant consisted of 509 and 5080 Semia strains at a concentration of 6x10^9 colony forming units (0.1 L) for the treatment of 100 kg of seeds.

The soybean sowing was carried out on 13 November 2013 and 03 November 2014. In this operation, sower of seven rows was used, 0.25 m spaced, with increase in the amount of seeds depending on germination results obtained in laboratory tests.

The fertilizer applied at sowing was NPK 02-20-18 at a rate of 500 kg ha^{-1} in both seasons according to soil analysis results. At 10 days after emergence (DAE), plant thinning was performed in order to adjust the population in each treatment. The crop management practices for the weeds pests and diseases control were carried as required by soybean crop.

At harvest, yield was evaluated in the useful area of plots (harvest and plant track with subsequent weighing and moisture correction to 13%) and the thousand grains mass was evaluated (moisture correction to 13%). Sixteen continuous plants were collected to quantify the number of secondary stems, total pods, and primary and secondary rods (counting the total number of pods, with pods of separation resulting from primary and secondary stems), grains per pod (counting of average number of grains per pod), and plant height and first pod height (measurement from the soil to the insertion of the last floral raceme and the first pod in the main stem, respectively).

Initially, all variables were submitted to residual variances homogeneity verification. Subsequently, analysis of variance and comparison of treatment means was performed using Tukey test at 5% of probability.

3 RESULTS AND DISCUSSION

According to the analysis of variance (Table 1), in the 2013/14 season, only yield, total number of pods, number of pods on the main and secondary stem showed a significant effect of the interaction: implantation system *versus* population. On the other hand, mass of thousand grains only has a significant effect on the implantation system factor, while the number of secondary stems was significant on the population factor. However, 2014/15 season, there was no effect of the interaction for the all the variables. Only population had significant effect in the following variables: number of secondary stems, total number of pods, number of pods in the main and secondary stem and insertion of the first pod height. The response in the 2014/15 season related only to the plant population, may be associated with the presence of a lower water regime (515 mm compared to 1015 mm in the 2013/14 season) in this period, a fact that increases the competition between plants by environment source (Carmo et al., 2020).

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Table 1: Summary of variance analysis of yield characteristics (YIELD) and mass of thousand grains (MTG), number of secondary stems (NST), number total of pods (TNP), number of pods on the main (NPMS) and secondary (NPSS) stem, number of grains per pod (NGP), plant height (PH) and insertion of the first pod height (IFPH) of soybean with different sowing systems and plant populations in the crop year of 2013/14 and 2014/15, Rio Verde – GO.

SV	YIELD	MTG	NST	TNP	NPMS	NPSS	NGP	PH	IFPH
					--- 2013/14 ---				
Systems	**	*	ns	**	ns	**	ns	ns	ns
Population	ns	ns	**	ns	ns	ns	ns	ns	ns
Syst*Pop	*	ns	ns	**	**	**	ns	ns	ns
CV (%)	5.2	7.0	33.6	9.5	9.3	27.2	4.7	10.8	15.6
					--- 2014/15 ---				
Systems	ns	ns	ns	ns	ns	ns	ns	ns	ns
Population	ns	ns	**	*	*	**	ns	ns	**
Syst*Pop	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	18.6	7.0	50.0	15.7	14.6	60.8	6.3	7.5	10.4

**; *; ^{ns}: Significant at 1% and 5% probability and not significant, respectively, by F test. Source of variation (SV), Coefficient of variation (CV).

In the 2013/14 season, the crossed system provided lower grain yield in both plant populations (Table 2). This effect may be resulted of the need for the seeder to pass twice in the area so that rows cross, favoring soil compaction (Rocha et al., 2018). Also, it was observed irregular seed distribution in the crossed system (data not shown), caused by the second sowing operation.

Table 2: Grain yield (YIELD), number of total pods (NTP), number of pods on the main (NPMS) and secondary (NPSS) stem of soybean with different sowing systems and plant populations in the crop year of 2013/14, Rio Verde - GO

	Population (plants ha^{-1})		Population (plants ha^{-1})	
Implementation Systems	500,000	665,000	500,000	665,000
	YIELD (kg ha^{-1})		NTP	
Traditional	1889 Abc	1971 Aa	19.3 Bab	23.7 Aa
Reduced	2031 Ab	1962 Aa	19.7 Aab	17.7 Ab
Double rows	2267 Aa	2080 Ba	22.8 Aa	15.7 Bb
Crossed	1689 Ac	1756 Ab	17.2 Ab	18.4 Ab
	NPMS		NPSS	
Traditional	17.3 Bab	19.8 Aa	2.0 Bb	3.8 Aa
Reduced	18.7 Aab	17.1 Aab	1.0 Ab	0.6 Ab
Double rows	19.8 Aa	14.8 Bb	3.0 Aa	0.8 Bb
Crossed	15.5 Ab	17.2 Aab	1.7 Ab	1.3 Ab

* Means followed by the same letters, upper case in lines (population) and lower case in columns (implementation systems), do not differ by Tukey test ($p<0.05$).

In the recommended population (500,000 plants ha^{-1}), the double rows system presented greater yield, that indicated a potential use for soybean crop. This can occur due the greater distance between double rows (0.75 m), that promote higher incidence of radiation in plant canopy, favoring higher grain yields. Also, the highest value obtained in reduced system in relation to the crossed (Table 2) can be assigned to better equidistance of plants in the area by increased distance between the same planting rows (decreased density of plants on row), favoring higher incidence of radiation on canopy in the early soybean development (Dalley et al., 2004; Edwars et al., 2005). Therefore, double rows and reduced systems provided less competition for light in the sowing row in the early plant development (Bruns, 2011; Procópio et al., 2014), thus favoring higher grain yields.

In higher plant population (665,000) for 2013/14 season, there were no significant differences in grain yield among traditional, reduced and double rows systems (Table 2). This fact probably can be explained by phenotypic plasticity of this soybean variety Anta 82 RR® (Procópio et al., 2014). This demonstrates the variety ability for adoption of different arrangements by morphological changes and formation of yield components.

The greatest value of grain yield, observed in double row system in the lowest plant population in 2013/14 season, can be explained by the increase in the number of total pods, since it was higher in relation to crossed sowing system (Table 2). In contrast, for the same season, the higher plant population presented the highest value of number of total pods in the traditional system, however these differences were not enough to provide greater yield. It is important to point that the differences in soybean yield imposed by implantation system come from a set of factors.

The obtained results allow included effect of pod number on the main and secondary stem for the interaction of sowing systems and plant population in the 2013/14 season (Table 2). For the smaller plant population (recommended population to the variety), the largest number of pods on the main and secondary stem was observed in the double row system in relation to the crossed sowing system, which contributed to higher grain yield, as discussed previously. When population of plants was increased, it was not possible to observe this relationship, probably due to phenotypic plasticity of Anta 82 RR® (Ferreira Junior et al., 2010; Procópio et al., 2014). In this situation, the traditional system was the one that provided higher number of pods on the main and secondary stem, surpassing the double row system, with no effects on grain yield. Between plant populations in double rows system, a higher number of pods on the main stem on the smallest population were observed, in contrast that observed for the traditional system.

The mass of thousand grains was only affected by sowing systems in the 2013/14 season (Table 1). In this condition, the highest value was obtained in the reduced system, which was higher than the double rows (Table 3). This behavior can be inferred that the largest grain mass does not contribute to increased yield. The lower grain mass value in double rows system resulted in higher grain yield, which suggests that other components of the Anta 82 RR® variety may be contributing for increase in yield. In contrast of what occurred in the 2013/14 season, the anticipation of Anta 82 RR® deployment in the following season caused no significant differences for the mass of thousand grains.

Table 3: Mass of thousand grains (MTG) of soybean with different sowing systems in the crop year of 2013/14, Rio Verde - GO

Implementation Systems	MTG (g)
Traditional	96.0 ab
Reduced	102.1 a
Double rows	91.1 b
Crossed	95.0 ab

* Means followed by the same letter do not differ by Tukey test (p<0.05).

Soybean implantation systems did not affect the formation of secondary stems, however this variable was influenced only by plant population in both seasons (Table 4). As expected, increased number of plants caused reduction in the formation of secondary stems when compared to the recommended plant population. This can be attributed to greater self-shading in the highest plant population, which resulted in the elimination of emissions of side shoots (Procópio et al., 2014).

In the 2014/15 season, the smallest population of plants provided greater total number of pods and number of pods on the main stem (Table 4), without however influencing grain yield (Table 2). In the same season, among sowing systems, no differences were found in this variable, proving the phenotypic plasticity of Anta 82 RR® variety. This absence of significant differences between the systems can be caused due to the long period of water stress in this season, which provided a difficult environment for plant development in all sowing systems. However, this period of water stress caused variation in population results due to limited resources in the environment, with competition favored when the plant population increases (Walker et al., 2010). That is, the larger the plant population, the less resources will be available for each individual plant.

Table 4: Number of secondary stems (NST), number total of pods (NTP), number of pods on the main (NPMS) and secondary (NPSS) stem and insertion of the first pod height (IFPH) of soybean with different plant populations, Rio Verde - GO

Population (plants ha^{-1})	NST		NTP	NPMS	NPSS	IFPH (cm)
	2013/14	2014/15	2014/15	2014/15	2014/15	2014/15
500,000	2.6 a	0.8 a	22.4 a	20.5 a	1.9 a	15.0 b
665,000	1.8 b	0.4 b	19.3 b	18.4 b	0.9 b	17.1 a

* Means followed by the same letter do not differ by Tukey test (p<0.05).

The total number of pods in secondary stem was greater in the smaller plant population (Table 4). This result was already expected because on smaller population there is a greater number of secondary stems and consequently influenced the number of pods. In addition, the smaller population contributes to the lowest abortion of flowers and pods due to higher incidence of radiation in plant canopy (Bruns, 2011), favoring ripening and development of inflorescences. However, this characteristic was not enough to increase grain yield.

Although it was observed effect of plant population in the formation of pods, both on the main and secondary stem in the 2014/15 season, no effects on the formation of grain number per pod was observed in both seasons (Table 1). This fact shows the low environment influence on the analyzed variable (Luca and Hungria, 2014).

In the evaluation of insertion of the first pod height, also there was only effect of plant population in the 2014/15 season (Table 4). In this condition, the largest population of Anta 82 RR® caused increase of first pod insertion, as evidenced by Mauad et al. (2010). This fact is justified by etiolation due to the higher number of plants in the sowing row, favoring increased competition for light. Besides, the insertion of the first pod height are not limiting to perform mechanized harvesting (Ritchie et al., 1997) for both plant populations, which could result in losses by no pod harvest located closer to the ground level.

For all this presented, the results obtained with this study allowed to verify that the plant implantation systems may lead to changes in yield components, and that was variable in agricultural seasons and also depending the climate characteristic of each year. It was also evident the contribution of the formation of higher number of pods in main and secondary stems in order to obtain increase in grain yield in a variety of semi-determinate growth habit, especially when Anta 82 RR® was deployed in double rows system and the season presented great rainfall distribution.

It is worth noting that the greater distance between double rows (0.75 m) compared to the distance within rows (0.25 m) allowed increased radiation effect on plant canopy (Bruns, 2011). This favors the distribution of the spray mixture in plant canopy. In the 2013/14 season, the system of double rows favored the larger pod formation of Anta 82 RR® in the smallest plant population, both main and secondary stem. This allowed increased grain yield, even being found lower mass of thousand grains in double rows system.

It is important to note that sowing in reduced system enabled increase in grain yield in the Anta 82 RR® variety (2013/14 season). Since this condition causes smaller plants (although with no significant differences observed), the reduction of distance between rows favored the leaf closing (Heiffig et al., 2006) compared to traditional and double row systems. Thus, the faster closing favors soil protection against erosion, better use of spray solution for insecticides, fungicides and leaf fertilizers application, in addition to greater suppression of weeds in the early stages of soybean development (Nelson, 2007; Bianchi et al., 2010). On the other hand, the earlier application of fungicides is necessary (preventive application), mainly for the control of soybean rust (*Phakopsora pachyrhizi)* (Lima et al., 2012) due to disease pressure in the *Cerrado* conditions, being favored by faster closure of the canopy of soybean plants.

Another important point, is that in the double rows system there is the need for machinery adaptation for soybean deployment. The crossed system proved unfeasible, as evidenced in other researches (Balbinot Junior et al., 2015; Silva et al., 2015). In this case, various factors can be assigned such as the increased time for culture implementation, the irregular seed distribution, the greater soil inversion and the difficulty of performing the deposition of seed at second sowing operation in the presence of straw on soil surface.

4 CONCLUSIONS

The climatic conditions influence the results of soybean seasons. With presence of adequate rainfall distribution (2013/14 season) the use of the implantation system with double row offers greater yield for semi-determinate soybean variety. Also, with presence of water stress (2014/15 season) the implantation systems does not influence the soybean performance.

The increase in the plant population beyond the recommended does not provide an increase in the soybean grain yield.

Finally, crossed sowing system proved unfeasible for Anta 82 RR® variety in *Cerrado* conditions.

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