Research, Society and Development, v. 9, n. 11, e1789119639, 2020
(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i11.9639

Plant arrangement in soybean crops with indeterminate growth in brazilian Cerrado

Arranjo de planta em culturas de soja com crescimento indeterminado no Cerrado brasileiro

Arreglo vegetal en cultivos de soja con crecimiento indeterminado en el Cerrado brasileño

Received: 10/28/2020 | Reviewed: 11/03/2020 | Accept: 11/06/2020 | Published: 11/11/2020

Alessandro Guerra da Silva
ORCID: https://orcid.org/0000-0002-9556-0312
Universidade de Rio Verde, Brasil
E-mail: silvaag@yahoo.com.br
Paula Daiane de Sena Martins
ORCID: https://orcid.org/0000-0001-5771-4774
Universidade de Rio Verde, Brasil
E-mail: pauladaiane.eng@gmail.com
Eduardo Lima do Carmo
ORCID: https://orcid.org/0000-0001-8023-5245
Universidade de Rio Verde, Brasil
E-mail: eduardo@unirv.edu.br
Sérgio Oliveira Procópio
ORCID: https://orcid.org/0000-0002-4350-7288
Embrapa Meio Ambiente, Brasil
E-mail: procopio.so@gmail.com
Luis Carlos Barcellos
ORCID: https://orcid.org/0000-0002-6807-7384
Universidade Federal de Goiás, Brasil
E-mail: barcellos@ufg.br
Camila Jorge Bernabé Ferreira
ORCID: https://orcid.org/0000-0001-5006-9661
Universidade de Rio Verde, Brasil
E-mail: camilajbferreira@gmail.com
Osmaria Ribeiro Bessa
ORCID: https://orcid.org/0000-0001-6423-7080

Instituto Federal Goiano, Brasil

E-mail: osmaria.agro@gmail.com

Abstract

The suitability of the spatial arrangement of soybean is a tool capable of promoting better use of the agricultural environment, allowing the crop to express its yield potential. Therefore, the aim of this study was to evaluate different implementation systems with and without an increase in the plant population of soybean with indeterminate growth habit variety cultivated in the Brazilian Cerrado. The experiments were performed in the 2013/14 and 2014/15 seasons in Rio Verde, Goias state. The experimental design was randomized blocks with four replication in a 4x2 factorial scheme. The treatments presents four implementation systems (traditional, reduced, double rows and crossed) associated with two populations of BMX Potência RR® (recommended and increased by 33%) with presented indeterminate growth habit. The results indicate that the reduced system has an adoption potential for soybean with indeterminate growth habit. The increase in the plant population in the 2013/2014 season, increased 20% of soybean yield in relation to the recommended population, proving to be a promising technique since it considerate the costs involved.

Keywords: Yield components; Interrow spacing; Reduced; Double rows; *Glycine max*; Cross-seeding.

Resumo

A adequação do arranjo espacial da soja é uma ferramenta capaz de promover melhor aproveitamento do ambiente agrícola, permitindo que a cultura expresse seu potencial produtivo. Portanto, o objetivo deste estudo foi avaliar diferentes sistemas de implantação com e sem aumento na população de plantas da variedade de soja com hábito de crescimento indeterminado cultivada no Cerrado brasileiro. Os experimentos foram realizados nas safras 2013/14 e 2014/15 em Rio Verde, Goiás. O delineamento experimental foi em blocos casualizados com quatro repetições em esquema fatorial 4x2. Os tratamentos apresentam quatro sistemas de implementação (tradicional, reduzido, fileiras duplas e cruzado) associados a duas populações de BMX Potência RR® (recomendado e aumentado em 33%) com hábito de crescimento indeterminado. Os resultados indicam que o sistema reduzido tem potencial de adoção para soja de hábito de crescimento indeterminado. O aumento da população de plantas, na safra 2013/2014, elevou em 20% a produtividade da soja em relação à população

recomendada, mostrando-se uma técnica promissora desde que considerado os custos envolvidos.
Palavras-chave: Componentes de produção; Espaçamento entrelinhas; Espaçamento reduzido; Linhas duplas; *Glycine max;* Semeadura cruzada.

Resumen

La adecuación de la ordenación espacial de la soja es una herramienta capaz de promover un mejor uso del medio agrícola, permitiendo que el cultivo exprese su potencial productivo. Por lo tanto, el objetivo de este estudio fue evaluar diferentes sistemas de implantación con y sin aumento de la población de plantas de la variedad de soja con hábito de crecimiento indeterminado cultivadas en el Cerrado brasileño. Los experimentos se realizaron en las cosechas 2013/14 y 2014/15 en Rio Verde, Goiás, el diseño experimental fue en bloques al azar con cuatro repeticiones en un esquema factorial 4x2. Los tratamientos tienen cuatro sistemas de implementación (tradicional, reducida, doble y cruzada) asociados a dos poblaciones de BMX Potência RR® (recomendadas y aumentadas en un 33%) con un hábito de crecimiento indeterminado. Los resultados indican que el sistema reducido tiene potencial de adopción para la soja de hábito de crecimiento indeterminado. El aumento de la población de plantas, en la cosecha 2013/2014, incrementó la productividad de la soja en un 20% en relación a la población recomendada, resultando una técnica prometedora ya que se consideran los costos involucrados.
Palabras clave: Componentes de producción; Espaciamiento entre líneas; Espaciado reducido; Líneas dobles; *Glycine max*; Siembra cruzada.

1. Introduction

In recent years, soybean crops had their cultivation area significantly expanded in the Cerrado region of Brazil, and farmers have sought alternatives to increase grain yield. Among the technologies used, the implementation of different arrangements of plants has been adopted by changing the spacing between plants in rows and interrow seeding (Silva et al., 2020).

Associated with implementation systems, the variation in the plant population interferes the inter- and intra-specific competition for water, light and nutrients and causes morphological and physiological changes in plants (Argenta et al., 2001), such as changes in plant height, the number of branches and pods per plant and the number of grains per pod (Tourino et al., 2002).

In the Brazilian Cerrado, farmers usually adopt a 0.4-0.5 m interrow spacing and population of 300,000 to 500,000 plants ha^{-1} for soybean cultivation. However, the reduction of interrow spacing is a promising practice to increase grain yield (Carmo et al., 2018). This is because it provides increased light interception at the beginning of the crop development cycle (Dalley et al., 2004) in addition to allowing a decrease of soil water loss by evaporation (Caliskan et al., 2007).

In addition to this system, some farmers have adopted cross-seeding for the implementation of soybean crops. In this system, two seeding operations are performed in a perpendicular direction, which provides better light distribution to the third lower leaves of plants. This contributes to photosynthetic processes with a significant increase in the production of assimilates and, consequently, grain yield (Rambo et al., 2003). However, there are few studies analyzing the performance of varieties with increases in grain yield (Balbinot Junior et al., 2015). Further reports observed an increase in the severity of soybean rust disease (*Phakopsora pachyrhizi*) (Lima et al., 2012). However, this system increases the consumption of fuel and equipment for soybean planting (Silva et al., 2015).

Another system that has aroused the interest of researchers is double rows. Apparently, there is a greater penetration of light and defensive factors into the canopy, as plants in double rows are more widely spaced. This allows for increases in the photosynthetic rate, health and longevity of the lower third leaves of the plant, which may help to achieve a higher yield.

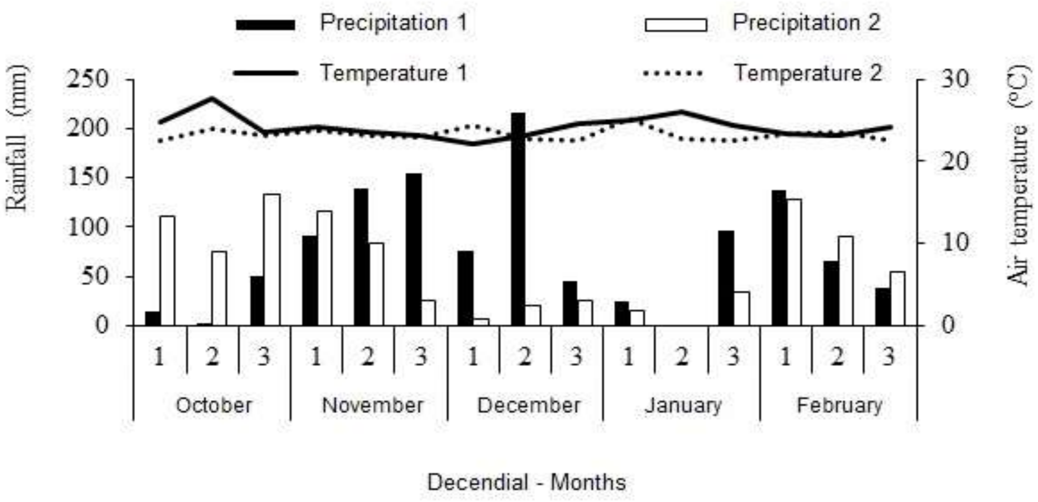
Resetting the plant arrangement by reducing the row spacing, coupled with an increase in the plant population, may be a strategy for producers to increase the profitability of soybean cultivation without significant increases in production costs (Pereira et al., 2008). However, this increase in grain yield must be accompanied by agricultural practices that enable the sustainability of the soybean production chain. In this scenario, there is a need to evaluate possible changes that implementation systems cause to soybean varieties with indeterminate growth and whether or not such changes provide increases in grain yield.

In this context, it is necessary to evaluate different spatial arrangements and groups of qualified plants for the best use and benefits for soybean culture in the Cerrado region. Thus, the hypothesis of this study is that changes in the population and spatial arrangement of soybean plants with indeterminate growth habit can contribute to the improvement in the performance of the crop. For this, the objective of the study was to evaluate different implementation systems with and without increases in the plant population regarding a variety of soybean with indeterminate growth cultivated in the Brazilian Cerrado region.

2. Material and Methods

The experiments were conducted in a field in the municipality of Rio Verde, Goias state (17°47'53" S of latitude, 51°55'53" W of longitude and altitude of 756 m) during the 2013/14 and 2014/15 growing seasons in soil with no-tillage system. Prior to implementation of the experiments, grain sorghum was grown as the preceding crop to soybeans in both seasons. Rainfall and average air temperature data during the experiment are shown in Figure 1.

Figure 1. Rainfall values and average air temperature during the experiment in the growing season of 2013/14 (1) and 2014/15 (2). Rio Verde, Goiás state, Brazil. Source: INMET Weather Station at the *Universidade de Rio Verde*.



Source: Authors.

The methodology of the experiments was made according Pereira et al. (2018). In both experiments, randomized blocks with a 4x2 factorial design with four replications were adopted. They corresponded to four implementation systems: traditional system: 0.5 m inter-row spacing; reduced system: 0.25 m inter-row spacing; double rows system: 0.25/0.75 m - 0.25 m spacing within double rows, and 0.75 m between double rows; and crossed system:

0.5 m spacing inter-row on the first pass and perpendicular to the first sowing. These systems were associated with two plant populations for the soybean varietu BMX Potência RR® (recommended population and increased by 33% with 500,000 and 665,000 plants ha^{-1} for the first season and 450,000 and 598,500 plants ha^{-1} for the second season, respectively). This variety has indeterminate growth habit and is present maturity group of 6.7 for the region in which the experiment was implemented.

The plots were 5.0 m long and 3.5 m wide, with a useful area selected by choosing 2.0 m wide and 3.0 m long central rows, disregarding 1.0 m at each side, resulting in 6.0 m^2 for all implementation systems.

Before implementation, weeds were desiccated using a tractor sprayer with 1,920 g a.e. ha^{-1} of glyphosate, 0.12 kg of flumioxazin and 1.5 L ha^{-1} of S-metolachlor with a spray volume of 150 L ha^{-1}. At sowing, the seeds were treated with [fipronil + pyraclostrobin + thiophanate methyl] (6, 54 and 60 g, respectively], 105 g of thiamethoxam and 0.20 L of liquid fertilizer Nutragin in a proportion recommended for the treatment of 100 kg of seeds.

Considering the availability of rainfall in the region, seeds were sown on November 13, 2013 and November 03, 2014. In this operation, a plot seeder was used with seven lines spaced 0.25 m apart, with two passes over each plot and a 20% increase in the amount of seeds as a function of germination test results obtained in the laboratory.

At sowing, a mechanized and broadcast application of 500 kg of 02-20-18 (N-P_2O_5-K_2O) fertilizer was performed according to the results of chemical analysis of the soil. In growing seasons, at 10 days after seedling emergence (DAE), manual thinning of the plants was performed to adjust the population for each treatment. Cultural practices for weeds control, pests and diseases were performed as required.

At harvest, yield (harvest and tracking of plants, with subsequent weighing and moisture correction to 13%) and mass of thousand grains (counting and weighing of a thousand grains from the sample yield, with moisture correction to 13%) were evaluated in the useful area of each plots. From the sample of sixteen continuous plants in the sowing line, the number of secondary stems and of pods on the main and secondary stems and total pods per plant (total number of pods, with separation of pods from the primary and secondary stems), number of grains per pod, height of plants and insertion of the first pod (measured from the base of the plant to the insertion of the last floral raceme and the first pod in the main stem, respectively) were evaluated.

Initially, all variables were submitted to verify the homogeneity of variances. Subsequently, analysis of variance (ANOVA) was performed and the Tukey's test was applied at 5% probability level for comparison of means, using Sisvar statistical software (Ferreira, 2011).

3. Results and Discussion

The results obtained for grain yield allowed observing a significance for implementation systems in both agricultural years and for the plant population in 2013/14 (Table 1). The reduced system presented superior performance of the variety BMX Potência RR for both seasons. In addition, in the 2013/14 season, the largest plant population showed a yield increase of 20% compared with the recommended population (Table 2).

Table 1. Summary of the analysis of variance of the plant arrangement experiment with the variety BMX Potência RR in the growing seasons 2013/14 and 2014/15. Rio Verde, Goiás state, Brazil.

Source of variation	YIELD	MTG	NSS	TNP	NPMS	NPSS	NGP	PH	HIFP
--- Growing season 2013/14 ---									
Systems (S)	**	ns	ns	**	**	**	ns	ns	ns
Population (P)	**	**	ns	**	ns	**	ns	ns	*
S*P	ns	ns	ns	**	ns	**	ns	ns	ns
CV (%)	7.7	3.7	37.5	12.2	12.5	16.3	5.3	7.3	6.6
--- Growing season 2014/15 ---									
Systems (S)	*	ns	*	**	**	*	ns	ns	ns
Population (P)	ns	*	**	**	ns	**	ns	*	ns
S*P	ns	*	Ns	**	ns	ns	ns	ns	ns
CV (%)	8.9	4.5	26.5	10.3	14.7	44.1	5.5	8.6	13.2

MTG = mass of thousand grains; NSS = number of secondary stems; TNP = total number of pods; NPMS = number of pods on the main; NPSS = number of pods on secondary stems; NGP = number of grains per pod; PH = plant height; HIFP = height of insertion in the first pod. **; *; ^{ns}: Significant at 1% and 5% probability and not significant, respectively, by F test.
Source: Authors.

Table 2. Average values for yield, mass of thousand grains and number of secondary stems of the plant arrangement experiment with the variety BMX Potência RR in the growing seasons 2013/14 and 2014/15. Rio Verde - GO state.

Systems	Yield (kg ha^{-1})		MTG (g)	NSS
	2013/14	2014/15	2013/14	2014/15
Traditional	2196 b	2562 ab	132 a	1.63 ab
Reduced	2515 a	2786 a	126 a	1.89 a
Double rows	2243 b	2432 b	131 a	1.23 b
Crossed	2215 b	2466 b	132 a	1.49 ab
Recomended	2081 b	2617 a	128 b	2.06 a
Increased	2503 a	2506 a	133 a	1.06 b

MTG = mass of thousand grains; NSS = number of secondary stems. * Means followed by the same letter do not differ by Tukey's test at 5% probability. Source: Authors.

The response to the increase in grain yield in the reduced system is attributed to the best equal distance of plants in the area, i.e., the increase in the distance between plants in planting rows (decrease in the number of plants), resulting in less competition for light on rows during the early development of the plants (Bruns, 2011; Procópio et al., 2014). Carmo et al. (2020) found similar results for corn cultivated in the second season that observed greater corn yield using reduced system in the Brazilian Cerrado.

The increase in grain yield due to the increase in plant population occurred because of the late time of implementation of BMX Potência RR in the region, which depended on the availability of rainfall. The modern architecture of the variety (more compact size, more tapered leaflets, lower insertion angle on the main stem and higher precocity) associated with the sowing performed in mid-November resulted in smaller plants. This resulted in proper conditions to obtain significant increases in grain yield with the increase in plant population, as noted by Edwards, Purcell and Karcher (2005). In addition, the population densification in the soybean crop also contributes to earlier closing interrow that can promote the cultural control of weeds (Braz et al., 2019). Conversely, Silva et al. (2020) observed that the increase in the population of plants in soybeans with semi-determined growth was not a promising practice, showing the importance of considering the soybean variety to determine the plants population.

We observed that implementation systems in double rows and the cross-seeding system had the lowest grain yield (Table 2). In the first system, there was a need to adapt the machinery for soybean sowing, and in the second system, there was an increase in the cultivation time due to the crossing of the rows. In addition, there is greater soil disturbance and lower uniformity of seed distribution caused by the second pass of the sower. Therefore, the impossibility of adopting these two implementation systems is evident, especially cross-seeding (Balbinot Junior et al., 2015; Silva et al., 2015), for the variety BMX Potência RR.

The mass of thousand grains was higher in the increased plant population in the first season in agreement with the results of grain yield. In this season, there were no differences among implementation systems (Table 2). During the 2014/15 season, the highest values of mass of thousand grains was observed for the smaller population of plants in double rows, without showing significant differences compared to the other implementation systems when comparing plant populations (Table 3). In this season, only cross-seeding, regarding the highest population, provided a higher grain weight in relation to the double row system. The differences observed between treatments may be attributed to the relation between the variable under study and other yield components (number of pods and grains per pod), characterizing the phenotypic plasticity of BMX Potência RR.

Table 3. Average values for number of pods on the main and secondary stems, plant height and height of insertion of the first pod of the plant arrangement experiment with the variety BMX Potência RR in the growing seasons 2013/14 and 2014/15. Rio Verde - GO state.

Systems	NPMS		NPSS	PH	HIFP
	2013/14	2014/15	2014/15	2014/15	2013/14
Traditional	19.1 ab	12.8 b	4.7 ab	64.8 a	14.4 a
Reduced	21.8 a	16.8 a	5.6 a	68.3 a	15.0 a
Double rows	21.5 a	16.0 ab	2.7 b	72.6 a	15.0 a
Crossed	17.0 b	17.2 a	4.0 ab	71.5 a	15.0 a
Recomended	20.6 a	16.4 a	2.2 b	66.9 b	14.3 b
Increased	19.1 a	15.0 a	6.3 a	71.6 a	15.4 a

NPMS = number of pods on the main stems; NPSS = number of pods on secondary stems; PH = plant height; HIFP = height of insertion of the first pod. * Means followed by the same letter do not differ by Tukey's test at 5% probability. Source: Authors.

It was expected that change in the distance between soybean plants, depending on plant arrangements, could affect the emission of secondary stems. However, this was observed only in the 2014/15 season (Table 2). In this condition, the reduced implementation system provided a larger number of secondary stems in relation to double rows. This was also observed for the smallest plant population regardless of the implementation system, corroborating with results reported by Procópio et al. (2014). Because of the greater distance of plants in rows in the reduced system, there was a higher incidence of radiation in the canopy of plants during early development (Dalley et al., 2004; Edwars et al., 2005), favoring the emission of branches. It is noteworthy that even the highest number of secondary stems observed in this system favored obtaining a higher grain yield (Table 2).

For 2013/14 season, the traditional implementation system presented greater total number of pods than crossed for recommended plant population, while, for the increased plant population the reduced and double rows systems presented the greater values (Table 4). In the second season, the reduced system was higher compared to the traditional and double row systems for recommended plant population. As might be expected, the adoption of a lower plant population provided a greater number of pods in all treatments in the 2014/15 season, as well as in the traditional sowing in the 2013/14 season. The differential response among treatments, in both growing seasons, may be attributed to the ratio of formation of yield components as function of the time of sowing of BMX Potência RR, confirming the effects of the environment and the phenotypic plasticity of the variety under study (Ferreira Junior et al., 2010).

(CC BY 4.0) | ISSN 2525-3409 | DOI: http://dx.doi.org/10.33448/rsd-v9i11.9639

Table 4. Average values for the total number of pods of the plant arrangement of the variety BMX Potência RR in the growing seasons 2013/14 and 2014/15. Rio Verde – GO.

	Total number of pods			
Implementation Systems	--- 2013/14 --- Plants population		--- 2014/15 --- Plants population	
	Recomended	Increased	Recomended	Increased
Traditional	30.0 Aa	19.6 Bb	17.9 Ac	17.1 Aa
Reduced	27.4 Aab	27.4 Aa	26.6 Aa	18.1 Ba
Double rows	26.2 Aab	26.1 Aa	21.8 Abc	15.5 Ba
Crossed	22.6 Ab	19.6 Ab	24.7 Aab	18.0 Ba

* Means followed by the same letters, lowercase in lines (plant population) and upper case in columns (implementation systems), do not differ by Tukey's test at 5% probability. Source: Authors.

To understand the influence of different plant arrangements in the number of pods per plant, the formation of pods was analyzed on the primary and secondary stems. In this analysis, greater quantities of pods were found on the main stem in the reduced system and double rows for 2013/14 season and reduced system and crossed-sowing in the 2014/15 (Table 3). Importantly, the higher number of pods on the main stem, because of a more equal distance between plants in the reduced system, contributed to higher grain yields in both seasons. Moreover, no effects on the plant population regarding the variable under study were verified.

The number of pods on the secondary stems showed a significant interaction considering the implementation systems and plant populations in the 2013/14 season (Table 1). In this case, the lower plant population of BMX Potência RR in the traditional system provided a greater formation of pods in the secondary stems in relation to other implementation systems, while this was verified for the reduced and double row systems in the increased plants population (Table 5). In 2014/15, the reduced system provided a greater number of pods in relation to the double row system (Table 3). This suggests that this variable helped to obtain a higher grain yield. It was also noted for the same season that the largest population of plants showed an increased formation of pods in the secondary stems.

Table 5. Average values for mass of thousand grains and the number of pods on the secondary stems of the plant arrangement experiment with the variety BMX Potência RR in the growing seasons 2013/14 and 2014/15. Rio Verde - GO state.

Implementation Systems	--- MTG (g) (2014/15) --- Plants population		--- NPSS (2013/14) --- Plants population	
	Recomended	Increased	Recomended	Increased
Traditional	125 Aa	123 Aab	8.2 Aa	3.2 Bb
Reduced	126 Aa	123 Aab	6.1 Ab	5.0 Aa
Double rows	129 Aa	113 Bb	4.6 Ab	4.8 Aa
Crossed	123 Aa	126 Aa	4.8 Ab	3.5 Bab

MTG = mass of thousand grains; NPSS = number of pods on the secondary stems. * Means followed by the same letters, lowercase in lines (plant population) and upper case in columns (implementation systems), do not differ by Tukey's test at 5% probability. Source: Authors.

As seen, plant populations and implementation systems influenced grain mass, number of branches and the formation of pods on the primary and secondary stems, also observed by Procópio et al. (2014). However, in both harvests, there were no effects of implementation systems and plant populations on the number of seeds per pod (Table 1). This demonstrates a low influence of the environment (Luca & Hungria, 2014) and variety for this variable.

The increase in plant population in the 2014/15 season caused greater plants height and first pod height, as noted by Mauad et al. (2010). However, the implementation systems presented no effects on both growing seasons for these variables (Table 1 and 3). The greater plant height in soybean plants with increased population is attributed to an increased competition by plants for light due to the higher number of plants in a row. It is important to note that these effects on the plant height of the variety BMX Potência RR did not cause lodging of the plants. In addition, for the first pod height, the lowest value found was 0.14 m, which avoids losses of pods not harvested when a mechanized harvest is performed (Ferreira Junior et al., 2010; Mauad et al., 2010). The height of the insertion of the first pod below 0.1 m may cause losses of 5% in grain yield (Ritchie et al., 1997). The problem worsens when plant lodging occurs (Guimarães et al., 2008).

Considering the above, we observed that implementation systems influenced the grain yield components of the soybean variety with indeterminate growth habit. These, in turn, positively influenced higher yields in the reduced system in both growing seasons. This response may be directly associated with the modern architecture of the variety.

In addition, the reduced system allows a faster leaf closing of soybean interrows (Heiffig et al., 2006) compared to the traditional and double row systems. This favors the protection of the soil against erosion, the increased use of spray solution for spraying insecticides, fungicides and foliar fertilizers, in addition to a greater suppression of weeds at the early stages of soybean development (Bianchi et al., 2010). However, due to the anticipated closing of the interrows in relation to the traditional system and the high pressure from diseases, it is necessary to anticipate the application of fungicides (preventive application) to control soybean rust (Lima et al., 2012), mainly when soybean is grown in the Cerrado.

Therefore, increases in grain yield in the reduced system are expected in varieties with morphological characteristics similar to BMX Potência RR. This becomes more evident when soybeans are implemented under conditions that cause a reduction in plant height, i.e., in a very early or very late sowing in relation to the recommended time. Therefore, we conclude that adoption of the reduced system should be associated with the use of soybean varieties that have a modern architecture, enabling the producer to obtain higher profits in the cultivation of soybeans in the Cerrado region.

4. Conclusions

The reduced system provides great grain yield of soybean variety with indeterminate growth habit.

The increase in the number of pods on the main and secondary stems, as well as the increase in the number of secondary stems of the variety BMX Potência RR, favors obtaining higher grain yields. They were influenced only by implementation systems. Implementation systems did not influence plant height, insertion of the first pod, mass of thousand grains and the number of seeds per pod.

The increased of soybean plans population above the variety recommendation in 2013/14 season is a promising alternative in terms of grain yield.

Based on the findings, future work needs to be carried out on plant arrangement in different agricultural crops in order to improve the production system.

References

Argenta, G., Silva, P. R. F., & Sangol, L. (2001). Arranjo de plantas em milho: análise do estado da arte. *Ciência Rural*, 31(6), 1075-1084. https://doi.org/10.1590/S0103-84782001000600027

Balbinot Júnior, A. A., Procopio, S. O., Debiasi, H., Franchini, J. C., & Panison, F. (2015). Semeadura cruzada em cultivares de soja com tipo de crescimento determinado. *Semina: Ciências Agrárias*, 36(3), 1215-1226. https://doi.org/10.5433/1679-0359.2015v36n3p1215

Bianchi, M. A., Fleck, N. G., Lamego, F. P., & Agostinetto, D. (2010). Papéis do arranjo de plantas e do cultivar de soja no resultado da interferência com plantas competidoras. *Planta Daninha*, 28(especial), 979-991. https://doi.org/10.1590/S0100-83582010000500006

Braz, G. B. P., Machado, F. G., Carmo, E. L., Rocha, A. G. C., Simon, G. A., & Ferreira, C. J. B. (2019). Desempenho agronômico e supressão de plantas daninhas no sorgo em semeadura adensada. *Revista de Ciências Agroveterinárias*, 18(2), 170-177. https://doi.org/10.5965/223811711812019170

Bruns, H. A. (2011). Comparisons of single-row and twin-row soybean production in the Mid-South. *Agronomy Journal*, 103(5), 702-708. https://doi.org/10.2134/agronj2010.0475

Caliskan, S., Arslan, M., Uremis, I., & Caliskan, M. E. (2007). The effects of row spacing on yield and yield components of full season and double-cropped soybean. *Turkish Journal of Agriculture and Forestry*, 31, 147-154.

Carmo, E. L., Braz, G. B. P., Simon, G. A., Silva, A. G., & Rocha, A. G. (2018). Desempenho agronômico da soja cultivada em diferentes épocas e distribuição de plantas. *Revista de Ciências Agroveterinárias*, 17(1), 61-69. https://doi.org/10.5965/223811711712018061

Carmo, E. L., Rocha, A. G. C., Ferreira, C. J. B., Ribeiro Junior, L. F., Simon, G. A., Sousa, J. V. A., & Vieira Neto, D. F. (2020). Spatial arrangements of corn grown in Brazilian savanna conditions. *Semina: Ciências Agrárias*, 41(5), 1483-1494. . http://dx.doi.org/10.5433/1679-0359.2020v41n5p1483

Dalley, C. D., Kells, J. J., & Renner, K. A. (2004). Effect of glyphosate application timing and row spacing on corn (*Zea mays*) and soybean (*Glycine max*) yields. *Weed Technology*, 18(1), 165-176. https://doi.org/10.1614/02-150A

Edwards, J. T., Purcell, L. C., & Karcher, D. E. (2005). Soybean yield and biomass responses to increasing plant population among diverse maturity groups. *Crop Science*, 45(5), 1778-1785. https://doi.org/10.2135/cropsci2004.0570

Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, 35(6), 1039-1042. http://dx.doi.org/10.1590/S1413-70542011000600001

Ferreira Junior, J. A., Espindola, S. M. C. G., Gonçalves, D. A. R., & Lopes, E. W. (2010). Avaliação de genótipos de soja em diferentes épocas de plantio e densidade de semeadura no município de Uberaba - MG. *FAZU em Revista*, 7, 13-21.

Guimarães, F. S., Rezende, P. M. De, Castro, E. M. De, Carvalho, E. A., Andrade, M. J. B. De, & Carvalho, E. R. (2008). Cultivares de soja [*Glycine max* (L.) Merrill] para cultivo de verão na região de Lavras-MG. *Ciência e Agrotecnologia*, 32(4), 1099-1106. http://dx.doi.org/10.1590/S1413-70542008000400010

Heiffig, L. S., Câmara, G. M. S., Marques, L. A., Pedroso, D. B., & Piedade, S.M.S. (2006). Fechamento e índice de área foliar da cultura da soja em diferentes arranjos espaciais. *Bragantia*, 65(2), 285-295. http://dx.doi.org/10.1590/S0006-87052006000200010

Lima, S. F., Alvarez, R. C. F., Theodoro, G. F., Bavaresco, M., & Silva, K. S. (2012). Efeito da semeadura em linhas cruzadas sobre a produtividade de grãos e a severidade da ferrugem asiática da soja. *Biocience Journal*, 28, 954-962.

Luca, M. J., & Hungria, M. (2014). Plant densities and modulation of symbiotic nitrogen fixation in soybean. *Scientia Agricola*, 71(3), 951-962. http://dx.doi.org/10.1590/S0103-90162014000300002

Mauad, M., Silva, T. L. B., Almeida Neto, A. I., & Abreu, V. G. (2010). Influência da densidade de semeadura sobre características agronômicas na cultura da soja. *Revista Agrarian*, 3, 175-181.

Pereira, F. R. S., Cruz, S. C. S., Albuquerque, A. W., Santos, J. R., & Silva, E. T. Da. (2008). Arranjo espacial de plantas de milho em sistema de plantio direto. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 12(1), 69-74. https://doi.org/10.1590/S1415-43662008000100010

Pereira, A. S. (2018). *Metodologia da pesquisa cientifica*. [e-book]. Santa Maria: UAB/NTE/UFSM. Disponível em: https://www.ufsm.br/app/uploads/sites/358/2019/02/Metodologia-da-Pesquisa-Cientifica_final.pdf.

Pires, J. L. F., Costa, J. A., & Thomas, A. L. (1998). Rendimento de grãos de soja influenciado pelo arranjo de plantas e níveis de adubação. *Pesquisa Agropecuária Gaúcha*, 4, 183-188.

Procópio, S. O., Balbinot Junior, A. A., Debiasi, H., Franchini, J. C., & Panison, F. (2014). Semeadura em fileira dupla e espaçamento reduzido na cultura da soja. *Revista Agro@mbiente*, 8(2), 212-221. http://dx.doi.org/10.18227/1982-8470ragro.v8i2.1469

Rambo, L., Costa, J. A., Pires, J. L. F., Parcianello, G., & Ferreira, F. G. (2003). Rendimento de grãos da soja em função do arranjo de plantas. *Ciência Rural*, 33(3), 405-411. https://doi.org/10.1590/S0103-84782003000300003

Ritchie, S. W., Thompson, H. E., & Benson, G.O. (1997). Como a planta de soja se desenvolve. POTAFOS: Arquivo do Agronômo.

Silva, P. R., Tavares, L. A., Sousa, S. F., Correia, T. P. D. S., & Riquetti, N. B. (2015). Rentabilidade na semeadura cruzada da cultura da soja. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 19(3), 293-297. https://doi.org/10.1590/1807-1929/agriambi.v19n3p293-297

Silva, A. G., Martins, P. D. S., Carmo, E. L., Procópio, S. O., Bessa, O. R., & Ferreira, C. J. B. (2020). Cropping systems and soybean plant population in Brazilian Cerrado. *Brazilian Journal of Development*, 6(7), 51124-51135. http://dx.doi.org/10.34117/bjdv6n7-670

Tourino, M. C. C., Rezende, P. M., & Salvador, N. (2002). Espaçamento, densidade e uniformidade de semeadura na produtividade e características agronômicas da soja. *Pesquisa Agropecuária Brasileira*, 37(8), 1071-1077. https://doi.org/10.1590/S0100-204X2002000800004

Percentage of contribution of each author in the manuscript

Alessandro Guerra da Silva – 25%

Paula Daiane de Sena Martins – 25%

Eduardo Lima do Carmo – 10%

Sérgio Oliveira Procópio - 10%

Luis Carlos Barcellos – 10%

Camila Jorge Bernabé Ferreira – 10%

Osmaria Ribeiro Bessa -10%