ON-FARM EXPERIMENTATION CASE STUDY IN BRAZIL: EVALUATION OF SOYBEAN SEEDING RATE USING RESOURCES AVAILABLE AT THE FARM

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A paper from the Proceedings of the
16th International Conference on Precision Agriculture
21-24 July 2024
Manhattan, Kansas, United States

Abstract.

In order to maximize grain yield in soybean (Glycine max [L.] Merr.) it is necessary that the plant population is correctly defined. Production environments differ spatially, and cultivar holders suggest plant populations across macroregions and in broad ranges. Refinements of planting seasons and populations are carried out through tests on many properties, often costly and sometimes unrepresentative of most fields. Tools for managing spatial variability are ways to conduct more appropriate experiments, taking into account local variability. Our objectives were (i) to obtain the seeding rate in order to optimize grain yield, and (ii) to validate the on-farm experimentation technique for soybean production. The case study was developed in a commercial soybean production area, in the state of Mato Grosso, Brazil, which presents variability in particle size composition. Five plant populations (200, 244, 289, 333 and 378 thousand seeds ha^{-1}) were evaluated in three distinct regions (low, medium, and high yield environment). The effects of treatments were evaluated on plant vigor and soybean grain yield. The year was considered optimal in terms of climatic conditions. It was observed that the normalized difference vegetation index (NDVI) obtained by satellite images collected in V6 increased according to the increase in seeding rate. However, there was no difference in soybean grain yield between seeding rate treatments, which on average was 3.9 Mg ha^{-1}. This result was explained because at V6 the crop had not expressed yet its plasticity in production of branches and stems at lower seeding rates, hence higher seeding rate led to higher biomass production. Nevertheless, later in the cycle, the crop was able to compensate for the lower

The authors are solely responsible for the content of this paper, which is not a refereed publication. Citation of this work should state that it is from the Proceedings of the 16th International Conference on Precision Agriculture. EXAMPLE: Cyrineu, I. M., Franchi, M. R. A., Taira, F. K., Hunhoff, L., Gimenez, L. M. (2024). On-Farm Experimentation Case Study in Brazil: Evaluation of Soybean Seeding Rate Using Resources Available at the Farm. In Proceedings of the 16th International Conference on Precision Agriculture (unpaginated, online). Monticello, IL: International Society of Precision Agriculture.

seeding rate by increasing its branches and stems production, maintaining its yield. Overall, as a result of management, it was demonstrated that a population smaller than the property's standard could have been used at a single rate. The standard population of the property was more appropriate than that suggested by cultivar holders.

Keywords.
plant population, crop physiology, spatial variability

Introduction

In 2022, the gross domestic product (GDP) of the cultivated soybean (*Glycine max* [L.] Merr.) production chain raised US$ 130 billion for the Brazilian economy (CEPEA, 2023). Among the states that produce soy in Brazil, Mato Grosso is the largest producer with 12.1 million hectares cultivated (EMBRAPA, 2023). To increase and maintain yield, it is necessary that the plant population is in accordance with the genetic potential and the environment in which the soybean is being cultivated (Rigsby & Board, 2003; Vitantonio-Mazzini et al., 2020). In addition to aspects related to agronomic performance, increasing investments in seeds and their correct definition constitutes an opportunity to reduce production costs (CONAB, 2023a). In the region of Sorriso, MT, the average cost of seeds represented US$ 152 per hectare, 9.3% of production cost expenses (CONAB, 2023), therefore reductions in the seeding rate without compromising yield bring significant reductions in cost, increasing producer's profit.

Soybean is a plant with high plasticity in its production of branches and stems, hence, a reduction in population induces a greater expression of these characteristics, while in larger populations the effect is opposite (Balbinot Jr et al., 2018; Cox, et al ., 2010). Furthermore, in several environments it has been reported that there is no production loss in cases of reduced seeding rate (Rigsby & Board, 2003; Vitantonio-Mazzini et al., 2020; Silva, E., et al., 2021). However, it is common for farmers to follow recommendations offered by seed companies to establish the stand (Silva, E., et al., 2022). Therefore, local adjustments of plant populations must be sought.

The optimization of crop management through techniques that consider the spatial variability of production factors has been reported for decades in the literature (Robert, 1993). On-farm experimentation is a technique in which the experiment is carried out considering the spatial variation present in the area (Bullock et al., 2019). In this way, the aim is to contemplate the real conditions of the productive area, with the sampling units distributed in different zones, in order to obtain results appropriate to each management zone (Grego et al., 2022). This technique has already been used in sugarcane and cotton production systems in Brazil, having made it possible to evaluate different seeding rates in areas with different productive potentials and with repetitions (Grego et al., 2022; Speranza et al., 2022). The technique has the potential to define the best seeding rate locally. Seeking to evaluate the opportunity to optimize the seeding rate, a field study was conducted in the city of Primavera do Leste-MT inside of a commercial farm. Plots were implemented with five different populations in three different management zones with different yield potentials with the objective of (i) obtaining the seeding rate in order to optimize yield, and (ii) validating the on-farm experimentation technique to this type of assessment.

Material and Methods

The experiment was conducted on a rural property in the municipality of Primavera do Leste-MT (15.23°S, 54.48°E) during the 2022-2023 harvest. The experimental area occupied 20 hectares within a plot of land inside the commercial farm. The area is managed with no-till management, in which the usual crop rotation in soybean as main crop, followed by corn as second crop. The average yield of the studied plot was 3.7 Mg ha^{-1} for the last four years of soybean cultivation. A commercially available variety adapted for the area and widely used in the region was used (DM81i84, GDM®), sowing was carried out on 10/22/2022 and harvest on 03/08/2023, totaling the crop cycle with 137 days. The standard population adopted by the farmer's technicians in the area where the experiment was carried out was 289,000 seeds ha^{-1}. According to the seed supplier, the recommended population for the farm conditions was 250,000 – 320,000 seeds ha^{-1}. During the crop cycle, the accumulated precipitation was 1335 mm, between the months of October and March, with November being the month with the lowest rainfall, 85 mm, therefore there was potentially no water stress throughout the cycle. The plots were 22 m wide and 90 m long and were planted using a Case FastRiser 6148 planted with 48 rows with 0.45 m spacing between rows, with a Precision Planting Vset metering system driven by a hydraulic motor interconnected with a prescription map on the AFS Pro 1200 monitor and Case brand Steiger 540 tractor.

The experimental area had three portions with distinct yield and textural characteristics, thus being separated into differentiated management zone (low yield potential, medium yield potential, and high yield potential). The portions were subdivided using electrical conductivity data, plant vigor obtained from satellite images and yield data from previous years. Within each management unit, the seeding rate treatment was organized following a randomized block design with ten replications per management zone (n=50 per management zone). The seeding rates chosen were 200, 244, 289, 333 and 378 thousand seeds ha^{-1} (9, 11, 13, 15 and 17 seeds per linear meter respectively) (Figure 1). Totaling then 150 plots. In order to check the plant stand after emergence, plants were counted in random positions in the experiment.

Figure 1 - Sketch of the experimental area showing seeding rate treatments and management zones of the area. Each plot measured approximately 21.6 m by 90 m.

Yield values were obtained through data from the mapping systems present in the two combines that harvested the area. The CR585 model from the manufacturer New Holland® and the S550 model from the manufacturer John Deere® were used.

For data from each combine, data with zero, negative yield or above three times the maximum yield expected for the region (e.g. above 20 Mg ha^{-1}) were removed; these values were considered as collection errors. Following, values considered discrepant were removed, where yield values above and below the average added and subtracted by three standard deviations were considered discrepant. To eliminate the effect of combine calibration, the yield values of the combine that harvested the smallest area were corrected based of the other combine. To this end, the average yield of side-by-side passes of the two harvesters was calculated and, by a ratio between these averages, a coefficient was obtained used to correct the discrepancy, (e.g. the yield values of each point of the adjusted combine were multiplied by the coefficient).

Subsequently, 10 meters were removed at the beginning and end of each plot in order to eliminate data representing the transition between treatments. Data with less than 4 meters of lateral distance between plots was also removed, as this could characterize that the combine platform was harvesting two plots simultaneously.

As a way to conduct an indirect assessment of canopy biomass production, Planet Scope satellite images were selected during the crop cycle, with a spatial resolution of 3 meters. The red (590–670 nm) and near infrared (NIR) (780–860 nm) bands were used to calculate the normalized difference vegetation index (NDVI) (e.q 1). For the analysis, images without the presence of clouds was chosen. The average value of each plot was taken to perform the statistical analysis. Geoprocessing was carried out using the geographic information system QGIS 3.28.3.

$$\text{NDVI} = (\text{Red- NIR}) \ / \ (\text{Red} + \text{NIR}) \tag{1}$$

where: NDVI = normalized difference vegetation index, Red = reflectance value of the red band (780-860nm), and NIR = reflectance value of the near infrared band (780-860nm)

Statistical analysis was performed using the R 4.2.2 software. The analysis of variance (ANOVA) was composed of seeding rate as a fixed factor, and management zone, block and interaction between management zone and seeding rate as a random factor, in addition the block was hierarchical in relation to the management zone. ANOVA was conducted using the “lmerTest” package. If there was a significant difference between treatments, post-hoc tests were conducted using Tukey’s Test of Honestly Significant Difference (HSD). The “lsmeans” package was used to calculate the HSD and “multcomp” to perform mean comparisons. The graphs were generated using the “ggplot2” package.

Results and Discussion

During the crop cycle, satellite images from V5 to R3 were collected. However, due to high occurrence of clouds during the months of December-2022 and January-2023, a 47 day gap was observed between the usable images in the dataset. The NDVI value collected in V5 (11/18/2022) was significantly affected by the management zone and seeding rate treatment (Figure 2A, B and Table 1), in which the management zone with low yield potential resulted in a low NDVI value, while the management zone with high yield potential resulted in a high NDVI value. The pattern was also observed at V7 (12/01/2022) (data not shown). This result can be attributed to the sensitivity of NDVI to biomass changes. Management zones appear to have influenced the amount of biomass produced by soybeans at these initial stages (Farias et al., 2023). Furthermore, it was also observed that larger populations resulted in an increase in NDVI. This result can be supported by several studies that indicate an increase in biomass in soybeans caused by the increase in population at younger stages (Silva, A., et al., 2021; Werner, et al., 2016). This increase in biomass in the vegetative period can be attributed to the fact that the canopy closure has not yet occurred and thus the plant has not yet had enough time to express plasticity in the production of branches and stems, since subsequently there were no differences in biomass between populations, as reported in the literature (Cox, et al., 2010; Werner, et al., 2016). Later in the crop cycle, R3, the collected images were unable to quantify differences in NDVI values, which possibly was caused by saturation of the values (Table 1).

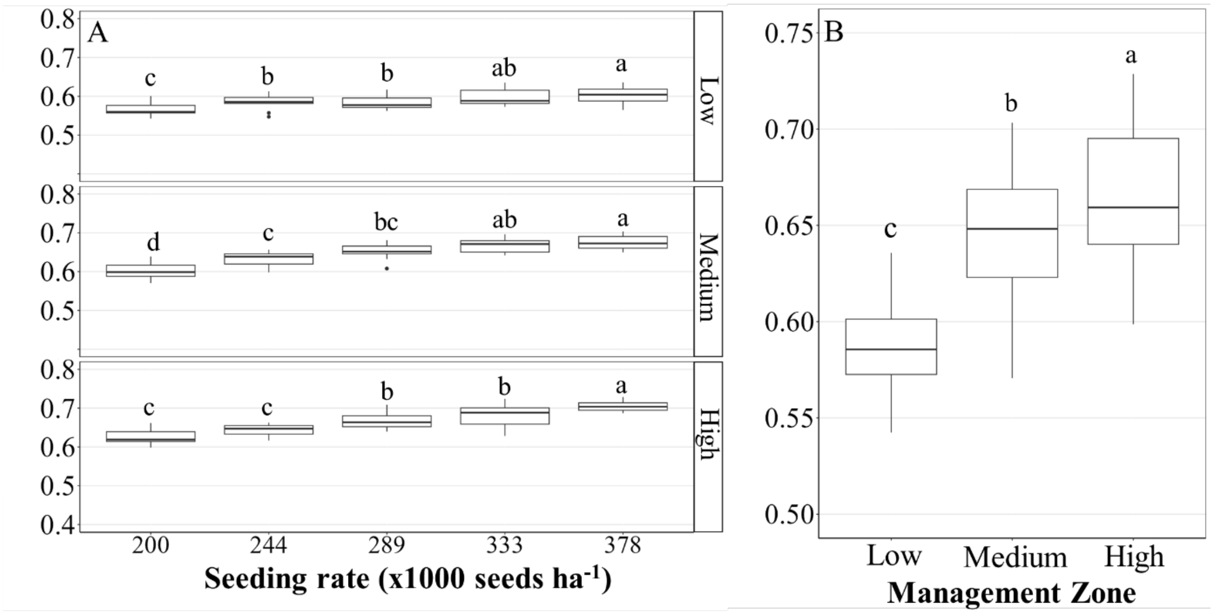

Figure 2. NDVI for each population within each management zone (A). NDVI for each management zone (B). Means followed by the same letter indicate that they are not statistically different according to Tukey's $HSD_{0.05}$ test.

Table 1. Descriptive Statistics of Grain Yield and NDVI values across the crop season

		NDVI				
	Grain Yield	11/18/2022	12/1/2022	1/17/2023	1/20/2023	2/14/2023
Maximum	4.6	0.73	0.87	0.88	0.90	0.89
Average	3.9	0.63	0.77	0.87	0.89	0.87
Median	3.9	0.64	0.78	0.87	0.89	0.87
Minimum	3.1	0.54	0.63	0.87	0.87	0.84
SD	0.3	0.05	0.07	0.00	0.01	0.01
C.V.	9%	7%	9%	0%	1%	1%

The average soybean yield for the case study was 3.9 Mg ha^{-1} (Table 1), with a maximum yield value of 4.6 Mg ha^{-1} and a minimum yield of 3.1 Mg ha^{-1}. Although it was observed differences in NDVI among treatments, regarding yield, no statistical difference was observed for the different management zones and the seeding rate treatments tested, with no significant interaction between these two factors (Table 2). The lack of difference between zones with different yield potential can be explained by the favorable climate in the 2022-2023 harvest, with a record harvest in the region (CONAB, 2023a). The main difference between the management zones was the texture, in which the area with low yield potential had a sandy texture, while the area with high yield potential had a higher clay content. Considering that the crop cycle was considered high in rainfall, the difference in soil texture possibly did not condition differences in yield between regions (Moore & Lawrence, 2013; Bocuti, et al., 2021).

In the literature there is no consensus regarding soybean yield in response to variation in plant population, some studies report that population has a positive effect on yield even at high seeding rates (Schutte & Nleya, 2018; Chen & Wiatrak , 2011; Purucker & Steinke, 2020), but there are others who report no effect of population reduction on grain yield (Cox & Cherney, 2011; Rigsby & Board, 2003; Vitantonio-Mazzini et al., 2020; Silva, E., et al., 2021). In the present study, it was found that there was no significant difference between the tested populations. Therefore, it is possible to observe that under the conditions of this experiment it would be possible to reduce the plant population and thus reduce production costs while maintaining yield. However, Cox & Cherney (2010) observed that although yield is not affected by reducing seeding rates, thinning already emerged plants causes a greater yield reduction effect in smaller populations. Therefore, in the event of pest attacks or other factors that could reduce the final population of plants (e.g., hail, erosion), the reduction in yield may be greater in smaller populations, increasing the producer's risk.

Considering the average cost of seeds being BRL 789 ha^{-1} (USD 152 ha^{-1}, as of 5/28/2024 exchange rate) (CONAB, 2023b) with the standard population of the plot of 289,000 seeds ha^{-1}, changing the plant population to the lowest rate used in the work would allow the reduction of BRL 243 ha^{-1} (USD 47 ha^{-1}) in production cost.

Finally, it was observed that the on-farm experimentation methodology was successful in its proposal to carry out an experiment with different populations in a commercial soybean area. And that the methodology can be adopted for ongoing work aimed at characterizing responses in years with different climatic conditions in order to identify which plots and regions can be managed more profitably with varied plant populations.

Table 2. Result of analyze of variance for the effects of management zone, block, seeding rate and the interaction between seeding rate and management zone on yield and NDVI

S.V.	DF	SS	MS	F	P	SS	MS	F	P
		NDVI				Grain Yield (Mg ha^{-1})			
Management Zone	2	0.16	0.08	68.23	0.00	0.17	0.08	0.30	0.74
Block (Management Zone)	27	0.03	0.00	4.97	0.00	7.61	0.28	3.35	0.00
Seeding rate	4	0.07	0.02	77.50	0.00	0.07	0.02	0.21	0.93
Seeding rate: Management Zone	8	0.01	0.00	4.71	0.00	0.14	0.02	0.20	0.99

where: S.V., sources of variation; DF, degrees of freedom; SS., sum of squares; MS, mean square; F, F-value; P, P value

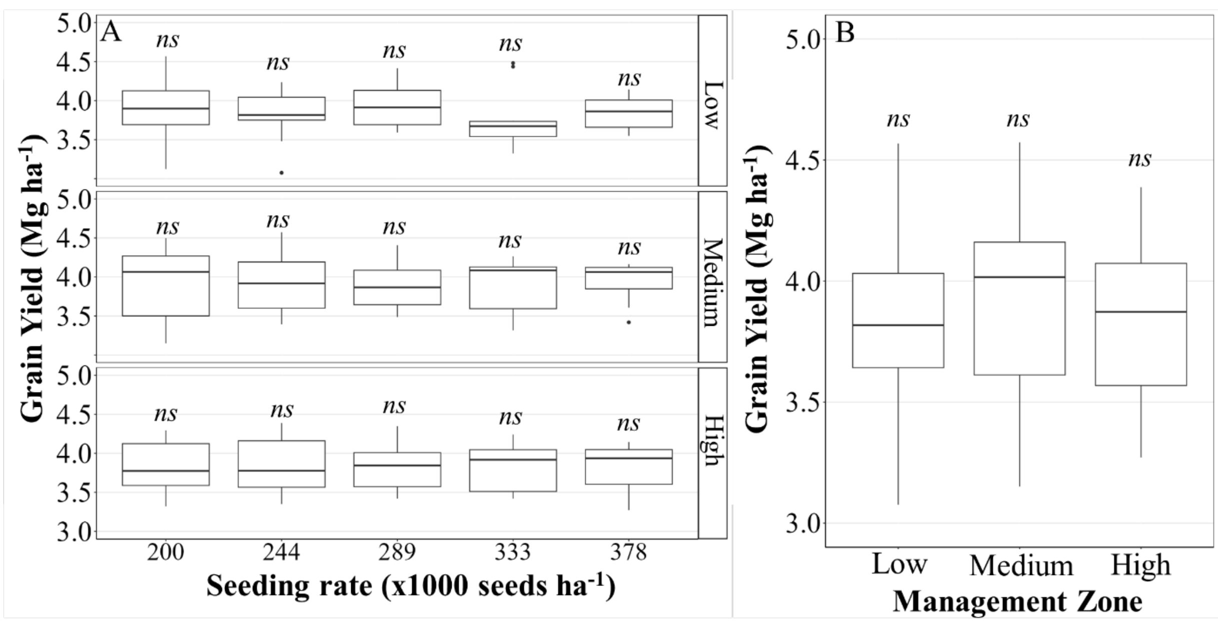

Figure 3. Grain yield for each seeding rate within each management zone (A). Grain yield for each management zone (B). ns. no significant difference between treatments using Tukey's $HSD_{0.05}$ test.

Conclusion

Yield was not affected by changing seeding rate over a wide range. For early soybean stages, NDVI was a useful tool to identify plots with distinct populations. On-farm experimentation with precision agriculture tools proved to be viable for conducting experiments with farmer's machines and in commercial production field conditions. For the conditions evaluated, it would be possible to reduce the seeding rate without losses in yield. The results obtained are restricted to climatic conditions and their repetition is necessary to understand the effects with different climatic scenarios.

Acknowledgments

We thank the Carlos Alberto Polato Group (GCAP) for supporting the research on a production area and also the partners and owners of GeoMec, Leandro Zancanaro and David Valendorff, for encouraging the company's employees to carry out research applied to field problems.

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