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Management of the fertilization in Brazilian Savannas with phosphorus and potassium in the succession of soybean, millet and common bean irrigated with center-pivot system

Pedro Marques da Silveira[1], Adriano Stephan Nascente[1]*, Luís Fernando Stone[1], Maria da Conceição Santana Carvalho[1]

[1]Brazilian Agricultural Research Corporation (EMBRAPA), Embrapa Arroz e Feijão, PO Box 179, 75375-000, Santo Antônio de Goiás, State of Goiás, Brazil

***Corresponding author: adriano.nascente@embrapa.br**

Abstract

In Brazilian Savannas (Cerrado), soil is managed in a sustainable way with built fertility and the demand for new fertilization will essentially involve the replacement of exported compounds through harvested products. The objective of this study is to improve criteria for fertilization with phosphorus and potassium in the soybean (summer)/millet (off-season)/irrigated common bean (winter) agricultural system. The study was carried out for three growing seasons under randomized blocks design with five treatments and five replications. The treatments consisted of T1= NPK common bean (recommended fertilization) + PK soybean (recommended fertilization); T2= NPK common bean (recommended fertilization) + soybean (without fertilization); T3= Common bean (without fertilization) + soybean PK (recommended fertilization); T4= NPK common bean (recommended fertilization) + P (amount exported by soybean) + soybean K (recommended fertilization); T5= NPK common bean (recommended fertilization) + P and K (amount exported by soybean) + soybean (without fertilization). The treatments T4 and T5 provided common bean and soybean yields (2945 and 4485 kg ha^{-1} and 2829 and 4412 kg ha^{-1}, respectively) similar to the treatment T1 (2830 and 4353 kg ha^{-1}), in which these crops received pre-fixed doses of recommended fertilization. It was necessary to make the fertilization only once in the year, and not in common bean and thereafter in soybean. We concluded that once there is no need to supply constant seeder with fertilizers for soybean, these treatments can be considered as fertilization management options in the soybean/millet/irrigated common bean agricultural system, which aims at greater operational profitability in planting activities.

Keywords: *Phaseolus vulgaris*, *Glycine max*, fertilization management, constructed fertility soils.
Abbreviations: NTS_No tillage system; N_nitrogen; P_phosphorus; K_potassium.

Introduction

Soybean (*Glycine max*) and common bean (*Phaseolus vulgaris*) crops are of great global importance in terms of cropped area and production volume. World values of production, harvested area and productivity in the soybean crop, in 2019, were 333,671,692 t, 120,501,628 ha and 2.76 t ha^{-1}, respectively (FAOSTAT, 2021), while the Brazilian values, in 2020/21 growing season, were 136,000,000 t, 37,800,000 ha and 3.59 t ha^{-1} (CONAB, 2021). In the common bean crop, the world values of production, harvested area and productivity, in 2019, were 28,902,672 t, 33,066,183 ha and 0.87 t ha^{-1}, respectively (FAOSTAT, 2021), while the Brazilian values, in the 2020/21 harvest, were 3,300,000 t, 2,900,000 ha and 1.13 t ha^{-1} (CONAB, 2021). It is noted that in the periods between 2019 and 2021, Brazil contributed with 18.4% and 8.8% to the cultivated world area of soybeans and beans, respectively, with yields 30.0% and 29.9% higher than the world average.

The Brazilian Savannas (Cerrado) occupies 207 million hectares of Brazilian territory, which represents approximately 4% of the world's tropical region (Resck, 1999; Silva and Siqueira, 2022). The most representative soils in this Biome are Latosols (46%), Argisols (15%) and Quartzarenic Neosols (15%) (Reatto et al., 1998; Santos et al., 2018). These soils are similar to that in African savannas, with the characteristics of weathered, and their outstanding characteristics are: low nutrient content, high acidity and predominance of low-activity clays (kaolinites and Fe and Al oxy-hydroxides) (Frazão et al., 2008).

The sustainable use of natural resources, especially soil and water, has become a topic of increasing relevance, due to the increase in human activities (Araújo et al., 2007). Significant increases in agricultural productivity can be achieved with soil correction and adequate and balanced supply of nutrients to crops, through the use of fertilizers (Fageria et al., 2010; Melém Júnior et al., 2011; Fageria and Nascente, 2014). Thus, it is estimated that currently fertilizers are responsible for 40-60% of all agricultural production (Johnston and Bruulsema, 2014).

Despite the chemical limitations of the Cerrado soils, the availability of nutrients for the development of agriculture in the region was improved through the correction of soil acidity and the application of fertilizers. The use of appropriate techniques to transform the Cerrado into a food-producing hub was so successful that the region is now one of the main food production sites in the world (Martins et al., 2015). The set of these techniques to be referred to as management for "building soil fertility", which can be broken down into several procedures to be performed based on the interpretation of soil analysis results (Resende et al., 2016).

As there is no greater loss of nutrients from the system by erosion, leaching or volatilization, the demand for new fertilization will essentially consist of the replacement of what was exported through the harvested products. The "built fertility" of soil starts to act as a nutrient reservoir, whose maximum capacity depends on the nature of its constituents and the management received (Resende et al., 2016). The no-tillage system, crop rotation and cover crops play an important role in the process, along with the analysis of nutrient inputs and outputs over successive seasons (Silva et al., 2022). Setting criteria that take the soil analyzes and export estimates into account are essential. Without that farmers tend to use the same fertilizers in fixed doses for a long period, which ends up increasing the risk of imbalance in the system's stocks.

In the case of nutrients, nitrogen (N) and potassium (K) can be easily lost from the root zone by leaching, and application anticipations cannot be carried out in any condition, depending on factors such as soil, climate and culture. The phosphorus (P), is not lost by leaching, since most of it is fixed by clay minerals, aluminum and iron oxides. As a result, its supply in fertilizers always exceeds the export of crop grains.

In the irrigated soybean/millet/ common bean agricultural system, which are widely used in central Brazil, N is not applied to soybeans, planted soon after the bean harvest. The application of P and K exported by soybeans in bean planting is quite feasible since in winter, when irrigated beans are planted, the possibility of losing these nutrients through leaching (potassium) is lower than in the summer period, when soybeans are planted in the rainy season. Therefore, the operational yield of soybean planting would be high, since all the work of transporting the fertilizer and constant filling of the seeder-fertilizer with fertilizers at the time of planting is not necessary.

The calculation of fertilization with P and K for soybean, to be carried out in the bean crop, will depend on the amount of nutrients exported through the grains. According to Embrapa (2013), the export of P and K by soybeans is equivalent to 10 kg ha^{-1} of P_2O_5 and 20 kg ha^{-1} of K_2O for every 1000 kg of grains. However, a difficulty that still exists in the implementation of system fertilization is the unavailability of fertilizers formulated in the market to meet the necessary amounts of nutrients to be applied. The mixing of fertilizers by the producer on the property becomes a negative point in the process. On the other hand, an advantage in fertilizing systems and placing the nutrients needed for all crops of the agricultural year in a crop saves time of planting operation. The objective of this study was to improve criteria for fertilization with phosphorus and potassium in the soybean/millet/ common bean agricultural system irrigated with center-pivot system.

Results and Discussion

Grain yield

In the common bean crop, the treatment without fertilization (2,638 kg ha^{-1}) showed significantly lower grain yield than the other treatments (2,830 kg ha^{-1} (T1), 2,968 kg ha^{-1} (T2), 2,945 kg ha^{-1} (T4), 2,829 kg ha^{-1} (T5) with fertilizer (Table 1). In soybean, all treatments had similar behavior and did not differ statistically from each other (4,353 kg ha^{-1} (T1), 4,512 kg ha^{-1} (T2), 4,717 kg ha^{-1} (T3), 4,485 kg ha^{-1} (T4), 4,412 kg ha^{-1} (T5). It is observed that the two treatments of fertilization management (application of fertilizer only once in the year) reached grain yields similar to the treatment in which the common bean and soybean crops received individual fertilization.

Treatment 2 (T2), had no fertilization in the soybean planting and also did not receive additional fertilizer in the previous common bean planting. However, it was not sustainable over time, although it used the fertility of the constructed soil, despite obtaining equal productivity, as it can cause soil depletion. The lack of proper fertility management can cause serious consequences such as soil depletion, due to the reduction in soil nutrient contents.

Two treatments can be considered as improved fertilization options for the soybean/millet/irrigated bean agricultural system, including T4, in which the P exported by soybean grains was added to the fertilizer in the common beans, and K applied as topdressing on soybean, and treatment 5, in which the two nutrients were previously added in the common bean crop. These two treatments will provide greater operational yield in soybean planting since there is no need to transport fertilizer to the field and supply the seeder-fertilizer, without causing a reduction in soybean productivity or depletion of nutrients in the soil. Treatment 4 proved better in sandy soils because the K applied to common bean is more subject to soil losses. The application of K to soybean in topdressing avoids a probable K toxicity to the seeds in the planting furrow, due to its high saline index, as observed by Kappes and Silva (2022).

Soil macronutrients

There was no effect of different fertilization strategies on soil pH and Ca, Mg, K (Table 2). On the other hand, there was an effect on the levels of P. Regarding the similarity in the values of soil pH, Ca, Mg, K indicated that the soil had enough amounts of the nutrients for providing adequate crop grain yield without soil fertilization. However, this is not sustainable. Farmers should monitor the soil fertility annually and make the reposition of nutrients, when necessary to avoid soil depletion. On the other hand, there was an effect on the levels of P. Thus, it appears that in Treatment 1, in which the two crops received the recommended doses of P individually, it favored the increase of the levels of this nutrient in the soil compared to other treatments. Recommended amounts of P in fertilization are always higher than the amounts exported in nutrients by grains, as the nutrient is highly fixed by the soil (Leite et al., 2017).

At the end of the study, there was an increase in pH in two treatments and in Ca in all treatments. This is explained because limestone was applied in the experimental area (June 11th, 2020). According to Fageria and Nascente (2014), the use of limestone provides increases in soil calcium levels and pH elevation. K amount significantly decreased at the end of the study compared to the initial value in the soil (109.8 mg kg^{-1}). It is known that the soybean crop is highly demanding in K (Foloni and Rosolem, 2008), and thus the quantities of the nutrient recommended and exported were not sufficient for the crop, which had to remove it from the soil reserve. The reason for this is that amount of K_2O

Table 1. Common bean and soybean grain yield as a result of the fertilization system. Santo Antônio de Goiás, average of the growing season years 2019/20, 2020/21 and 2021/22.

Common bean		Soybean	
Treatment Fertilization	Grain yield (kg ha^{-1})	Treatment Fertilization	Grain yield (kg ha^{-1})
1:NPK recommended	2830 a[1]	1:PK recommended	4353 a
2:NPK recommended	2968 a	2: no fertilization	4512 a
3: no fertilization	2638 b	3:PK recommended	4717 a
4:NPK + P exported by soybean	2945 a	4: K exported by soybean	4485 a
5:NPK + P and K exported by soybean	2829 a	5: no fertilization	4412 a
CV	5.23		4.60

[1]Means followed by the same letter do not differ from each other by the Scott-Knott's test at 5% probability. CV – Coefficient of variation.

Table 2. Initial (May 2019) and final (February 2022) pH values, Ca, Mg, P and K contents of the soil due to the fertilization system used in three agricultural years (2019/20, 2020/21 and 2021/22).

Year	Treatment[1]	pH	Ca	Mg	P	K
		H_2O	$cmol_c\ dm^{-3}$		mg dm^{-3}	
2022 (final)	T1	6.11 a*[3]	36.7 a*	13.04 a*	16.30 a*	59.2 a*
	T2	6.10 a[2]	34.2 a*	12.41 a	9.74 b	56.6 a*
	T3	6.04 a	34.3 a*	12.63 a	10.51 b	55.8 a*
	T4	6.13 a*	34.2 a*	12.41 a	9.77 b	70.1 a*
	T5	6.00 a	32.7 a*	11.83 a	10.95 b	70.2 a*
CV		2.94	10.77	14.64	28.63	15.76
2019 (initial)		5.91	20.3	12.15	8.89	109.8

[1]T1. Common bean NPK (recommended fertilization), soybean PK (recommended fertilization); T2. NPK common bean (recommended fertilization), soybean (without fertilization); T3. Common bean (without fertilization), soybean PK (recommended fertilization); T4. NPK common bean (recommended fertilization) + P (exported soybean), soybean K (exported); T5. NPK common bean (recommended fertilization) + P and K (exported soybean), soybean (without fertilization), [2]Means followed by the same letter do not differ from each other by the Scott-Knott's test at 5% probability, [3]Means followed by an asterisk differ from the initial value by the test t at 5% probability. CV – Coefficient of variation.

Table 3. Soil Cu, Zn and Mn values, initial (May 2019) and final (February 2022) due to the fertilization system used in three agricultural years (2019/20, 2020/21 and 2021/22).

Year	Treatment[1]	Cu	Zn	Mn
			mg dm^{-3}	
2022 (final)	T1	0.93 a*[3]	4.99 a	10.62 a
	T2	1.10 a[2]	5.23 a	10.47 a
	T3	1.22 a	5.52 a	10.33 a
	T4	1.09 a	5.27 a	9.63 a*
	T5	1.01 a	5.35 a	10.60 a
C.V.		15.07	11.63	12.79
2019 (initial)		1.10	5.14	11.26

[1]T1. Common bean NPK (recommended fertilization), soybean PK (recommended fertilization); T2. NPK common bean (recommended fertilization), soybean (without fertilization); T3. Common bean (without fertilization), soybean PK (recommended fertilization); T4. NPK common bean (recommended fertilization) + P (exported soybean), soybean K (exported); T5. NPK common bean (recommended fertilization) + P and K (exported soybean), soybean (without fertilization), [2]Means followed by the same letter do not differ from each other by the Scott-Knott's test at 5% probability, [3]Means followed by an asterisk differ from the initial value by the test t at 5% probability. CV – Coefficient of variation

exported through the soybean grains was 20 kg ha^{-1} for every 1 ton of grain, with the estimated productivity in the study being 3,600 kg ha^{-1} fixed for all three years, and the productivity achieved was higher, an average of 4,496 kg ha^{-1}. Therefore, the amount of K_2O applied was lower than the crop's need, which explains this decrease in soil K at the end of the study. Therefore, quantification of the K_2O fertilization of the crop should be done with the estimated grain yield and adjusted every year to avoid reduction of its content in the soil.

Soil micronutrients

Regarding micronutrients, there were no differences between treatments (Table 3). The absence of differences between treatments in the micronutrients contents could be explained by being a fertility soil built in all nutrients and by the use of cover crops in the off-season. Besides, millet is a cover crop widely used in the Cerrado, mainly due to its rapid growth and the possibility of nutrient cycling (Pacheco et al., 2017). According to Resende et al. (2016), plants such as millet, with a robust root system, conveniently contribute to the upward and downward mobilization of nutrients, recovering those eventually displaced to lower zones and assisting in the incorporation of less mobile ones, in addition to providing carbon and adding the benefits of organic matter in deeper layers.

Final considerations

The data from this work carried out for three agricultural years indicate that it is possible to fertilize cropping systems based on the calculation of the export of nutrients by the grains. Additionally, it appears that the application of phosphorus and potassium only in the common bean crop is advantageous for the farmer. This strategy makes it possible to increase the operating yield of soybean planting, since there is no need to constantly supply the seeder with fertilizers. It is worth mentioning that in the constructed fertility, the fertilization of the system does not eliminate the need to carry out the annual monitoring of the soil fertility and the development of the plants to identify the need for supplementation of nutrients via fertilization.

Materials and methods

Site characterization

The experiment was carried out for three agricultural years in 2019/20, 2020/21 and 2021/22, at the Experimental Station of Embrapa Arroz e Feijão, located in Santo Antônio de Goiás, GO, Brazil, coordinates 16º28'00" S and 49º17' 00" W, and at an altitude of 823 m. The climate is tropical savanna Aw (tropical with humid summers and dry winters) according to the Köppen's classification. The average annual precipitation is between 1500 and 1700 mm, and the average annual temperature is 22.7 °C, varying annually from 14.2 °C to 34.8 °C.

The soil was classified as Acric Red Latosol (Santos et al., 2018). Soil analysis at the beginning of the study showed pH (H^2O) = 5.9; contents of Ca and Mg, respectively 20.3 and 12.2 $cmol_c\ dm^{-3}$, P, K, Cu, Zn and Mn of, respectively, 8.89; 109.8; 1.1; 5.14 and 11.26 g dm^{-3}, levels classified by Souza and Lobato (2004) as adequate to high, characterizing a soil of built fertility. The sand, silt and clay contents were, respectively, 496; 95 and 409 g kg^{-1} (clayey) and organic matter 30.7 g kg^{-1}.

Experimental design and treatments

The study was carried out for three consecutive years (2019/20, 2020/21 and 2021/22) with the irrigated common bean (autumn-winter) in succession with soybean (summer-harvest) and millet (off-season). Five fertilization treatments consisting of fertilizer doses recommended for common bean and soybean crops, combined or not with amounts exported by soybean, were evaluated in a randomized block design with five replications. The treatments were: T1. NPK common bean (recommended fertilization), PK soybean (recommended fertilization); T2. NPK common bean (recommended fertilization), soybean (without fertilization); T3. Common bean (without fertilization), soybean PK (recommended fertilization); T4. NPK common bean (recommended fertilization) + P (amount exported by soybean), soybean only K at topdressing (recommended fertilization); T5. NPK common bean (recommended fertilization) + P and K (amount exported by soybean), soybean (without fertilization). The plots were fixed for the treatments over the years of the study and had dimensions of 7.0 meters long by 4.0 meters wide.

Based on the chemical analysis of the soil at the beginning of the study, the recommended fertilization for common bean was 300 kg ha^{-1} of the 5-30-15 formula (N-P_2O_5-K_2O). To meet the common bean treatments T4 and T5, triple superphosphate was added to the common bean fertilization. At topdressing fertilization, 90 kg ha^{-1} of N were applied, at the V4 stage (third open trefoil). In the case of Treatment T5 of beans, the K_2O exported by soybeans was also applied in topdressing. K_2O in soybean Treatment T4 was also applied as topdressing. The recommended doses of P_2O_5 and K_2O for soybean were 90 kg ha^{-1} and 60 kg ha^{-1}, respectively. For the P and K treatments exported by the grains, Embrapa (2003) guidelines were followed, which reported 10 kg ha^{-1} of P_2O_5 and 20 kg ha^{-1} of K_2O for every 1000 kg of grains. Soybean yield was expected to be 3,600 kg ha^{-1} and so the amounts of fertilizers were 80 kg ha^{-1} of triple superphosphate (45% P_2O_5) and 120 kg ha^{-1} of KCl (60% K_2O). Soybean did not receive nitrogen fertilization in topdressing. On June 11th, 2020, 2,000 kg ha^{-1} of limestone and 1,000 kg ha^{-1} of agricultural gypsum were applied throughout the experimental area (Sousa and Lobato, 2004).

Crop management

The first common bean sowing was done on June 10th, 2019 (harvesting September 9th, 2019), the second on June 8th, 2020 (harvesting September 15th, 2020) and the third on May 31st, 2021 (harvest September 9th, 2021). Soybeans were planted on December 5th, 2019 (harvesting February 2nd, 2020), November 3rd, 2020 (harvesting February 22nd, 2021) and November 4th, 2021 (harvesting February 22nd, 2022). To meet the proposed agricultural system, millet was planted in 2020 (planting on March 3nd, 2020 and harvesting on May 25th, 2020) and in 2021 (planting on March 4th, 2021 and harvesting on May 18th, 2021), right after the soybean harvesting and before the planting of the irrigated common bean crop. A plot seeder-fertilizer was used. The millet was not fertilized and at harvesting it was cut and the straw was left on the soil surface. The common bean cultivars used were BRSMG Uai (1st planting) and BRSFC 402 (2nd and 3rd plantings). Soybean cultivar were BRS112-25533 (1st planting) and NS 6906 IPRO (2nd and 3rd plantings).

Macro and micronutrients soil evaluation

Soil samples were taken in February 2022 (after harvesting the last soybean crop) in the 0-0.20 m layer. Eight simple samples per plot were randomly taken to form a composite sample using a Dutch auger. The composite samples were air-dried and sieved (2 mm mesh). Subsequently, they were submitted to analysis to determine pH (water), organic matter, P, Al, Ca, K, Cu, Fe, Zn and Mn exchangeable according to the methodology proposed by Embrapa (Donagema et al., 2011). The nutrient contents in the soil were compared with the initial contents, by the t test (Student) at 5% probability.

Grain yield

Grain yield (130 g kg^{-1} of moisture) was evaluated by harvesting 3 central rows of 5 meters in each plot, disregarding 0.50 m on each side.

Statistical analysis

Yield data and crop production component were subjected to analysis of variance, and when significant, the means were compared using the Scott-Knott's test.

Conclusions

The treatments in which the amount of P or P and K exported by the soybean was added to the recommended fertilizer dose for the common bean and in which the soybean was fertilized only with K or not fertilized reached similar yields to the treatment in which common bean and soybean received pre-fixed doses of recommended fertilization. Once there is no need to constantly supply the seeder with fertilizers for soybean, these treatments can be considered as improved fertilization management for the soybean/millet/irrigated common bean agricultural system.

Fertilization based on the export of the element by the grains has to be calculated annually and consider the productivity achieved in the previous planting combined with the estimate of future productivity to supply what will be exported through the grains and avoid a decrease in soil fertility.

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