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SOYBEAN YIELD UNDER NO-TILLAGE SYSTEM WITH AN EARLY *Eleusine coracana* FERTILIZATION[1]

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ABSTRACT - The possibility of early soybean fertilization carried out on the predecessor crop has several benefits, mainly operational ones, making the production system more conservationist and balanced. An experiment was carried out at the Anhumas Experimental Station, Luiz de Queiroz College of Agriculture (USP/ESALQ), located in Piracicaba, SP, Brazil, during 2001/2002, 2002/2003, and 2003/2004 agricultural years on a typic Hapludox aiming to evaluate the effects of the early fertilization on soybean yield. The fertilization consisted of applying 90 kg ha^{-1} of P_2O_5, 50 kg ha^{-1} of K_2O, and micronutrients (Co, Cu, Fe, Mn, Mo, and Zn). The experiment was conducted in a randomized complete block design with three replications and 12 treatments consisting of different levels of early soybean fertilization carried out on the finger millet crop: T1, no fertilization; T2, conventional soybean fertilization; T3, early 50% K fertilization; T4, early 100% K fertilization; T5, early 50% P fertilization; T6, early 50% P and K fertilization; T7, early 50% P and 100% K fertilization; T8, early 100% P fertilization; T9, early 100% P and 50% K fertilization; T10, early 100% P and K fertilization; T11, early 100% P and K fertilization + micronutrients; and T12, early leaf fertilization with micronutrients. The results showed that the early soybean sowing fertilization with phosphorus and potassium carried out during finger millet sowing does not interfere with the thousand-seed weight and soybean yield.

Keywords: *Glycine max* (L.) Merrill. *Eleusine Coracana* (L.) Gaertn. Phosphorus. Potassium. Fertilizer management.

PRODUTIVIDADE DA SOJA EM SEMEADURA DIRETA COM ANTECIPAÇÃO DA ADUBAÇÃO NA CULTURA DE *Eleusine coracana*

RESUMO - A possibilidade da antecipação da adubação da soja em uma cultura antecessora traz inúmeros benefícios, principalmente, operacionais e colabora para que o sistema de produção seja mais conservacionista e equilibrado. Com o objetivo de avaliar os efeitos da adubação antecipada sobre a produtividade da cultura da soja foi conduzido o presente experimento na Estação Experimental Anhumas, Escola Superior de Agricultura "Luiz de Queiroz" (USP/ESALQ), em Piracicaba-SP, nos anos agrícolas 2001/2002, 2002/2003 e 2003/2004, em Latossolo Amarelo distrófico. A adubação consistiu da aplicação de 90 kg ha^{-1}de P_2O_5, 50 kg ha^{-1} de K_2O e de micronutrientes (Co, Cu, Fe, Mn, Mo e Zn). O experimento adotou delineamento em blocos completos casualizados com três repetições e 12 tratamentos que consistiram em diferentes níveis de antecipação da adubação da soja para a cultura do capim-pé-de-galinha: T1= nenhuma adubação; T2= adubação convencional na soja; T3= antecipação de 50% de K; T4= antecipação de 100% de K; T5= antecipação de 50% de P; T6= antecipação de 50% de P e K; T7= antecipação de 50% de P e 100 % de K; T8= antecipação de 100% de P; T9= antecipação de 100% de P e 50% de K; T10= antecipação de 100% de P e K; T11= antecipação de 100% de P e K + micronutrientes; T12= antecipação da adubação foliar com micronutrientes. Conclui-se que a antecipação da adubação de semeadura com fósforo e potássio da cultura da soja para a semeadura do capim-pé-de-galinha não interfere com a massa de mil sementes e nem com a produtividade agrícola da soja.

Palavras-chave: *Glycine max* (L.) Merrill. *Eleusine coracana* (L.) Gaertn. Fósforo. Potássio. Manejo de fertilizantes.

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INTRODUCTION

Soybean is one of the most important oilseeds in the world, with an estimated and registered world production of 365.256 million tons in the 2020/2021 growing season (USDA, 2021). Brazil has stood out as the world's largest soybean producer, with a sown area of 38.93 million hectares and a production of 137.32 million tons in the 2020/2021 growing season (CONAB, 2021).

Soybean is a basic raw material whose processing gives rise to crude oil and meal. The processing of these primary products allows obtaining a series of secondary products, which are used as industrial inputs in several other processing lines, thus enabling a series of use options for soybean (HEIFFIG-DEL AGUILA et al., 2020).

Brazil has a broad technological base for soybean production, a qualified technical staff, and new expansion areas, mainly degraded pasture areas in the Cerrado region of states in Central Brazil. These areas have favorable climate conditions, with virtually no limitations on temperature and solar radiation, but show problems related to rainfall distribution and soil fertility (high acidity and aluminum saturation). The way this exploration has been made and its results has been widely discussed and studied, as the soils show low fertility, with typical and adapted vegetation and high susceptibility to erosion. The advancement of knowledge, innovation, and the increase of new technologies have made these areas promising, with the achievement of high soybean yields while the agroecosystem has been managed using conservationist practices.

Thus, the implementation of a production system that is less aggressive to the soil, such as the no-tillage system, which is as productive or more productive than conventional production systems, meets the needs of these areas, avoiding excessive degradation and preventing the deterioration of these soils, thus maintaining this enormous natural resource in good conditions for the use of future generations (SAMARAJEEWA; HORIUCHI; OBA, 2006; CHIODEROLI et al., 2012; TEIXEIRA et al., 2012; WEYERS et al., 2021).

The improvement of other cultural techniques, such as crop fertilization, and the need to develop the no-tillage system and obtain new genetic materials adapted to these conditions are required (GUARESCHI et al., 2011; MARIANI et al., 2012; ROSSI et al., 2013; SANTOS et al., 2014; SHELTON; JACOBSEN; McCULLEY, 2018; ZHANG et al., 2020).

Some farmers, even on a small scale, have adopted the technique known as system fertilization or early agroecosystem fertilization. It consists of the total or partial anticipation of the application of the fertilizer destined for a certain summer crop, being applied by broadcasting or in the row of the predecessor crop on which the summer crop will be sown under a no-till system.

The early agroecosystem fertilization allows the handling and movement of the fertilizers to be anticipated, providing a faster and more efficient sowing operation of the summer crop (ROSSI et al., 2018; SAKREZENSKI et al., 2018; SHELTON; JACOBSEN; McCULLEY, 2018). Another advantage of early fertilization over a predecessor crop is the formation of straw or covering for direct seeding, as the system generates a higher increase in the organic material production for the agroecosystem, favoring soil conservation, moisture maintenance, reduction of soil thermal amplitude, and nutrient recycling, which will be transferred to forms available to the summer crop in succession via organic matter mineralization (ASSMANN et al., 2014; ZIECH et al., 2015; LIMA et al., 2017).

In this context, *Eleusine coracana* (L.) Gaertn was chosen because it is a responsive crop adapted to this environment. Originating in Uganda, it is a very widespread crop in Africa and Asia, with great expression and importance in India (ODELLE, 1994), mainly in the exploration of the grain production used for human and animal food (AGRAWAL; SIAME; UPRICHARD, 1994; MITARU; KARUGIA; MUNENE, 1994; MULATU; KEBEDE, 1994) and forage, used in animal feed (MUSHONGA; MUZA; DHLIWAYO, 1994). This species was introduced in Brazil in 1995 in the state of Mato Grosso by farmers aiming to use it as a straw-forming crop, which was also proven by Francisco (2002) in a production system under no-tillage.

Considering all this information and the search for techniques that contribute to a more conservationist, sustainable, and functional agroecosystem management, this study aimed to investigate the effects of early soybean fertilization carried out on the finger millet crop.

MATERIAL AND METHODS

This study was carried out under the no-tillage system of soybean grown on finger millet (*Eleusine coracana*) straw at the Anhumas Experimental Station of the Luiz de Queiroz College of Agriculture (USP/ESALQ), in the municipality of Piracicaba, SP, Brazil, located in the Barra Bonita accumulation basin, with 460 m of altitude and the geographic coordinates 22°50′25″ S and 48°01′65″ West.

The experiment was carried out under field conditions during the 2001/2002 (year 1), 2002/2003 (year 2), and 2003/2004 (year 3) agricultural years, with finger millet sowing on September 6, 2001, September 23, 2002, and August 14, 2003, respectively, and desiccation on November 21, 2001, November 30, 2002, and October 20, 2003, respectively. Soybean sowing was carried out on December 6, 2001, December 12, 2002, and December 11, 2003, while its harvest was carried out on April 12, 2002, April 14, 2003, and April 17, 2004, for years 1, 2, and 3, respectively (Table 1).

Table 1. Schedule for conducting the experiment under field conditions, during the 2001/2002 (year 1), 2002/2003 (year 2), and 2003/2004 (year 3) agricultural years.

Practice	Year 1	Year 2	Year 3
Finger millet sowing	9/6/2001	9/23/2002	8/14/2003
Finger millet desiccation	11/21/2001	11/30/2002	10/20/2003
Soybean sowing	12/6/2001	12/12/2002	12/11/2003
Soybean Harvest	4/12/2002	4/14/2003	4/17/2004

The soil in the experimental area is classified as a typic Hapludox, deep, with good drainage, low clay texture, and containing 200 g kg^{-1} of total clay, 80 g kg^{-1} of silt, and 720 g kg^{-1} of sand. The chemical characteristics of this soil were determined at the Laboratory of Soil Chemical Analysis of the Department of Soil Science at USP/ESALQ, based on its sampling (Tables 2 and 3).

Table 2. Chemical composition of the soil in the experimental area at depths of 0–20, 20–40, and 40–60 cm (2001).

Depth	pH	OM	P	S	K	Ca	Mg	Al	H+Al	SB	T	V	m
(cm)	($CaCl_2$)	(g dm^{-3})	(mg dm^{-3})		(mmol$_c$ dm^{-3})							(%)	
0–20	5.4	31	6	19	1.9	22	15	1	22	38.9	60.9	64	3
20–40	3.9	21	4	32	1.2	9	6	12	47	16.2	63.2	26	43
40–60	4.5	16	3	35	0.9	6	3	16	42	9.9	51.9	19	62

Table 3. Micronutrient contents of the soil in the experimental area at depths of 0–20, 20–40, and 40–60 cm (2001).

Depth (cm)	B	Cu	Fe	Mn	Zn
	mg dm^{-3}				
0–20	–	0.8	88	4.4	0.9
20–40	–	2.2	47	0.4	2.8
40–60	–	1.1	35	0.6	1.1

The results of the soil chemical analysis (Table 2) showed that liming was not necessary for the experiment implementation (RAIJ et al., 1985). Nitrogen was applied in the total area at a dose equivalent to 30 kg ha^{-1} aiming at the full finger millet development and formation of straw. This dose was established considering the results found by Rao, Rao and Rao (1989) and Linge Gowda et al. (1994) from experiments evaluating the response of different *Eleusine coracana* cultivars to different nitrogen fertilization levels, also considering the history of several soybean growing seasons in the experiment implementation area. The micronutrient boron was not detected by the chemical analysis due to its low soil contents (Table 3).

Agricultural gypsum was used before the experiment implementation only in the first year at a dose of 500 kg ha^{-1} in an attempt to minimize possible interference of high aluminum saturation in the subsurface (EMBRAPA, 2001).

The finger millet cultivar ANSB Pé-de-Galinha 5352, belonging to the species *Eleusine coracana* (L.) Gaertn, a rustic grass tolerant to water stress, capable of producing straw, and with good results in soybean areas of the state of Mato Grosso, was used. The soybean cultivar BRS-133 (Table 4), with excellent yield levels in agricultural regions of the state of São Paulo, was used in this experiment.

The experimental design consisted of randomized blocks with 12 treatments (levels of early fertilization), with three replications. The experimental plot was dimensioned to obtain 18 rows of soybean spaced at 0.5 m, with 12.0 m in length, totaling an area of 108 m^2.

The base fertilization of the soybean crop was partially and totally anticipated during the finger millet sowing (Table 5).

Table 4. Characterization of the soybean cultivar BRS-133.

Cultivar	BRS-133
Origin	Embrapa
Lineage	Ft-Abyara x BR 83-147
Cycle (days)	120 to 130 days
Cycle (classification)	Semi-early
Growth habit	Determinate
Plant height (cm)	82
Flower color	White
Pubescence color	Brown
Integument color	Yellow
Lodging	Resistant
Recommended sowing time	10/15 to 12/15
Reaction to pests and diseases	
Stem canker	Resistant
Bacterial pustule	Resistant
Powdery mildew	Moderately susceptible
Mosaic virus	Resistant
Frogeye leaf spot	Resistant
Bacterial blight	Moderately resistant

Source: Embrapa, 2000.

Table 5. Experimental treatments related to the early soybean fertilization carried out in the finger millet crop.

Treatment	Finger millet	Soybean	Total
T1	00 P + 00 K	00 P + 00 K	00 P + 00 K
T2	00 P + 00 K	90 P + 50 K[1]	90 P + 50 K[1]
T3	00P + 25 K	90 P + 25 K[1]	90 P + 50 K[1]
T4	00 P + 50 K	90 P + 00 K[1]	90 P + 50 K[1]
T5	45 P + 00K	45 P + 50 K[1]	90 P + 50 K[1]
T6	45 P + 25 K	45 P + 25 K[1]	90 P + 50 K[1]
T7	45 P + 50 K	45 P + 00 K[1]	90 P + 50 K[1]
T8	90 P + 00 K	00 P + 50 K[1]	90 P + 50 K[1]
T9	90 P + 25 K	00 P + 25 K[1]	90 P + 50 K[1]
T10	90 P + 50 K	00 P + 00 K[1]	90 P + 50 K[1]
T11	90 P + 50 K[1]	00 P + 00 K	90 P + 50 K[1]
T12	00 P + 00 K[1]	90 P + 50 K	90 P + 50 K[1]

[1] Leaf fertilization with micronutrients: boron, copper, zinc, manganese, molybdenum, and cobalt.

Some observations are necessary to understand the treatments shown in Table 5. Total fertilization refers to the recommended fertilization for the soybean crop, considering soil fertility and estimated yield for the cultivar (3,000 to 3,400 kg ha^{-1}), which corresponded to 90 kg ha^{-1} of P_2O_5 and 50 kg ha^{-1} of K_2O (MASCARENHAS; TANAKA, 1996), using triple superphosphate and potassium chloride at sowing as sources, respectively. Leaf application of cobalt and molybdenum was also carried out at a dose of 150 mL ha^{-1} of the commercial product (Co: 3.83 g ha^{-1}; Mo: 38.25 g ha^{-1}), in addition to the leaf application of boron, copper, manganese, and zinc at a dose of 4 L ha^{-1} (split into two applications at phenological stages V_5 and V_9, respectively) of the commercial product (B: 25.20 g ha^{-1}; Cu: 25.20 g ha^{-1}; Mn: 151.20 g ha^{-1}; Zn: 252.00 g ha^{-1}). The micronutrients were applied to the finger millet or soybean at the same doses, according to the treatment. Nitrogen was supplied by the natural biological fixation system from seed inoculation with peat inoculant at a dose corresponding to a minimum of 320,000 *Bradyrhizobium* cells per seed in the first year and 160,000 *Bradyrhizobium* cells in the other years (EMBRAPA, 2001). The recommended total fertilization was added to all treatments, except for the control treatment (T1).

The experiment was implemented at the same site in the three agricultural years, always following the distribution of treatments carried out during the first year, without any additional soil corrections.

The fertilization of plots with fertilizer treatments was carried out after soil tillage. The broadcast fertilization was carried out manually, followed by finger millet sowing in the total area using a pendular seed spreader. Subsequently, a leveling harrow was used to incorporate the seeds and fertilizer into the soil.

Coarse and dry sand was mixed with the seeds at a proportion of 20 L of coarse sand for each 1.0 kg of seeds to obtain a better distribution in the area and facilitate the equipment adjustment.

Irrigation was carried out whenever necessary as a complement in periods when there were dry spells for more than 10 days, with an estimated depth of 30 mm. The total rainfall and daily average air temperature registered for ten-day periods at the Anhumas Experimental Station during 2001/2002, 2002/2003, and 2003/2004 experimental periods are shown for finger millet (Figure 1) and soybean (Figures 2 and 3).

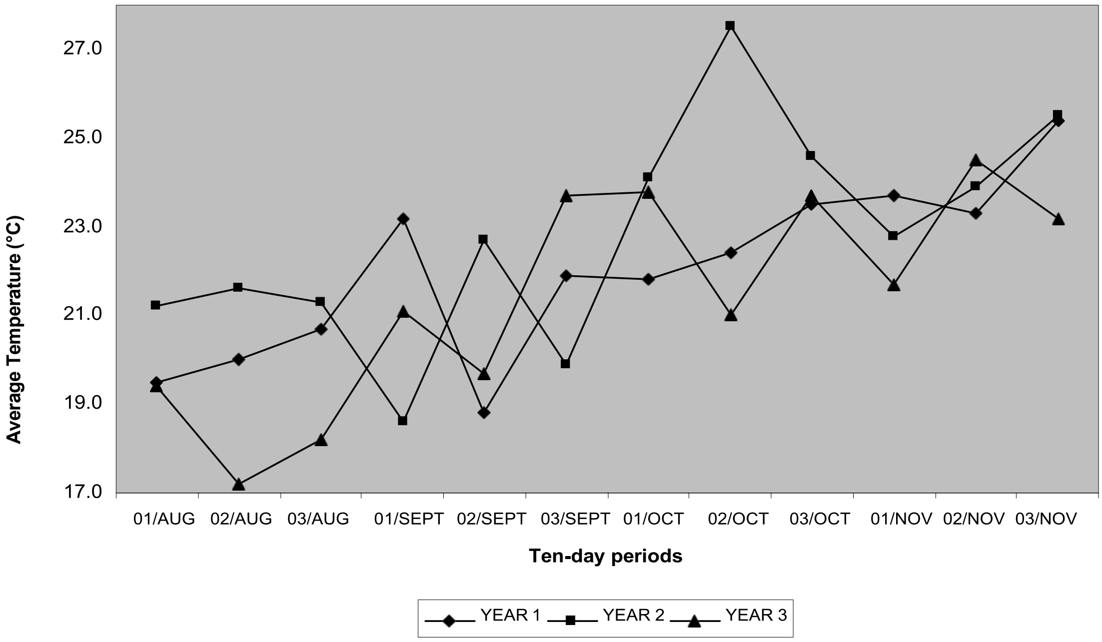

Figure 1. Average air temperature for ten-day periods from August to November 2001, 2002, and 2003 related to finger millet cultivation.

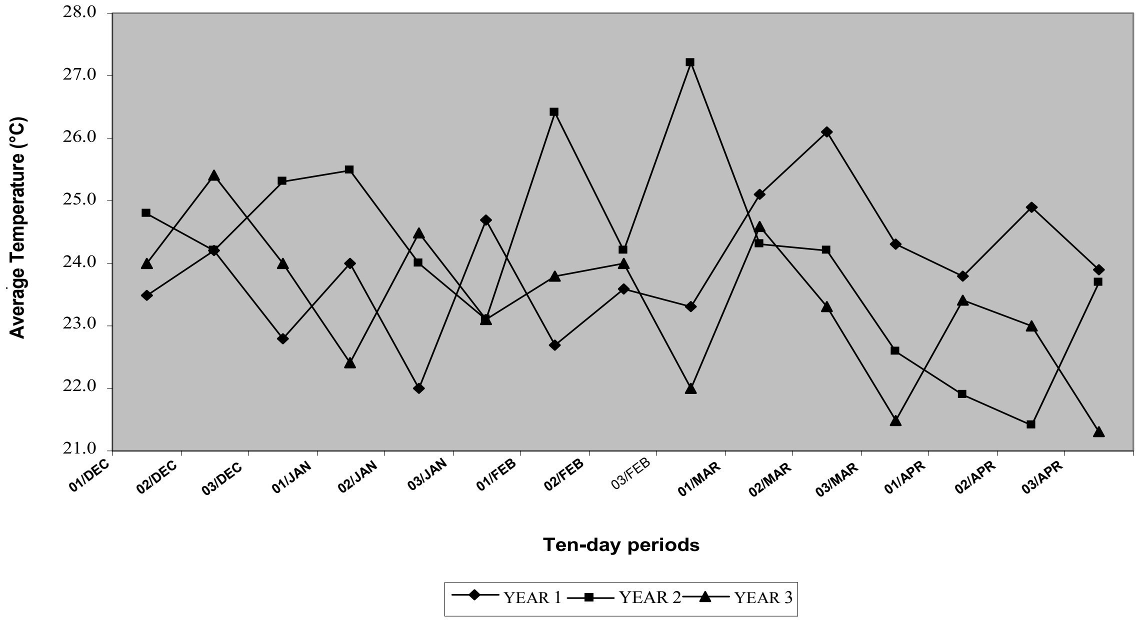

Figure 2. Average air temperature for ten-day periods from December to April 2001, 2002, and 2003 related to soybean cultivation.

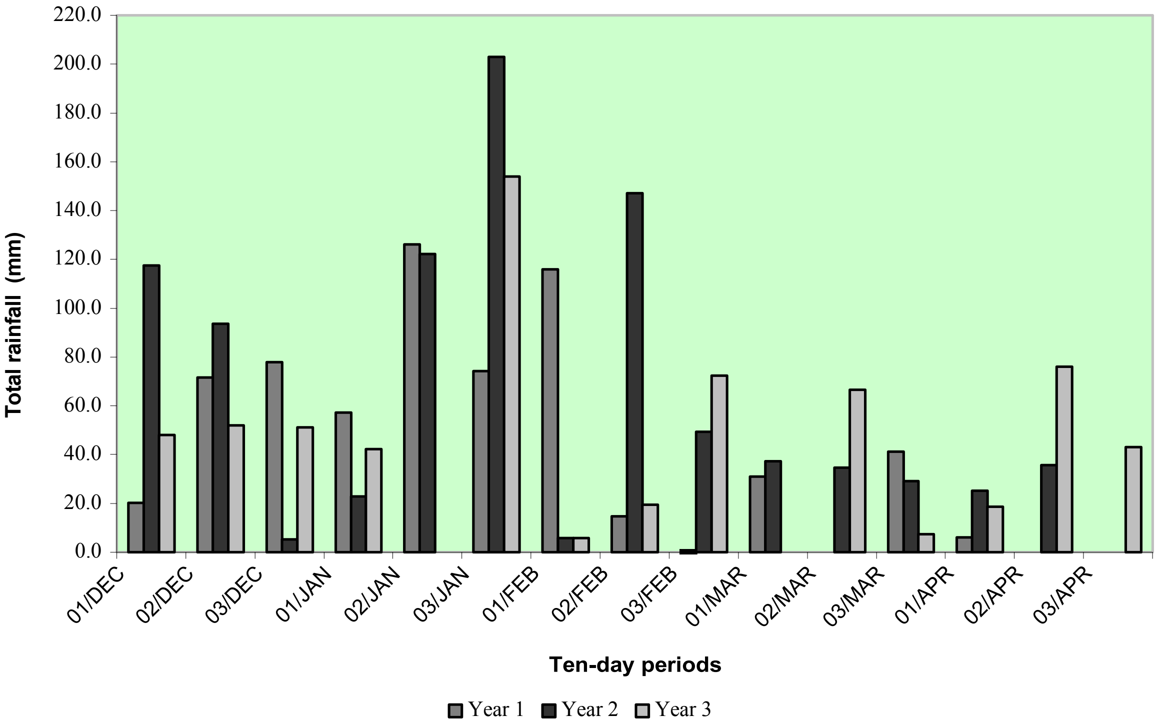

Figure 3. Total rainfall (mm) for ten-day periods from December to April 2001, 2002, and 2003 related to soybean cultivation.

The finger millet crop was chemically desiccated at 70 days after sowing by spraying the systemic herbicide glyphosate in the total area at a dose equivalent to 2.4 kg ai ha^{-1}, with a spray solution flow rate of 300 L ha^{-1}.

Treatments related to the partial fertilization of the system had the respective fertilization complemented at soybean sowing, as shown in Table 5.

The fertilization of treatments that received fertilizer at soybean sowing was carried out manually by applying the fertilizer in the furrow opened by the plot seed drill at a depth of approximately 10 cm before sowing, with subsequent closure of the furrows.

Before sowing, the soybean seeds were treated with the fungicides carboxin + thiram at the commercial product dose equivalent to 0.3 L 100 kg^{-1} of seeds and then inoculated. The soybean sowing under the no-tillage system was carried out immediately after seed inoculation using a plot seed drill, whose distribution components were spaced at 0.5 m from each other. Soybean sowing was carried out at a depth of 3 to 4 cm aligned with the furrow where fertilization was carried out. The seeds were distributed to obtain an initial stand of 20 to 22 plants meter^{-1}, corresponding to an initial population of 400,000 to 440,000 plants ha^{-1} and final population of 400,000, 340,000, and 280,000 plants ha^{-1} for years 1, 2, and 3, respectively, regardless of the treatments.

The cultural management applied to the plots was the same applied to the soybean crop, with chemical management of weeds, pests, and diseases, according to field surveys carried out for these biotic elements. Thus, the population monitoring of the main soybean pests (defoliating caterpillars and stink bug complex) was carried out using the beating cloth technique, adopting as a criterion for economic damage the presence of a maximum of two stink bugs and 40 caterpillars (larger than 1.5 cm), on average, at the sampling time (EMBRAPA, 2001).

The plants of the useful area of each plot (six rows of 10 linear meters) were harvested with a plot harvester at the maturity time in the field (FEHR; CAVINESS, 1977). Subsequently, the seeds were sent to the laboratory for cleaning and packing in paper bags. Then, they were sent to the Laboratory of Support for Research in Crop Production at USP/ ESALQ to determine moisture, thousand-seed weight, and yield. The 1000-seed weight was determined using eight sub-samples of 100 seeds per plot, which were weighed on a scale with a sensitivity of hundredths of a gram, as established by the Rules for Seed Testing (BRASIL, 1992). The yield was determined by weighing the seeds produced in each plot and transforming the values into kg ha^{-1} at 13% moisture correction.

Statistically significant effects by the F-test applied to the analysis of variance were analyzed by Tukey's test for comparison of means at the 5% probability level, using the SAS statistical program.

RESULTS AND DISCUSSION

Table 6 shows the mean values observed for the thousand-soybean seed weight. Year 1 had no difference between the different treatments, showing that the early phosphorus and potassium fertilization for finger millet did not affect the thousand-soybean weight.

Table 6. Mean values for 1000-soybean seed weight (g) in years 1, 2, and 3 and mean of the three-year trial (significant interaction treatments x years).

Treatment	*Eleusine coracana*	Soybean	Year 1	Year 2	Year 3	Three-year mean
1	00 P + 00 K	00 P + 00 K	145.9 A[4]	151.1 b[3]A	148.3 b[3]A	148.5
2	00 P + 00 K	90 P + 50 K[1]	140.4 B	176.2 a A	170.8 a A	162.5
3	00P + 25 K	90 P + 25 K[1]	146.2 B	181.5 a A	170.7 a A	166.2
4	00 P + 50 K	90 P + 00 K[1]	146.3 C	186.2 a A	173.7 a B	168.7
5	45 P + 00K	45 P + 50 K[1]	143.4 B	179.7 a A	168.8 a A	163.9
6	45 P + 25 K	45 P + 25 K[1]	144.6 B	182.5 a A	173.1 a A	166.7
7	45 P + 50 K	45 P + 00 K[1]	141.3 B	182.9 a A	171.1 a A	165.1
8	90 P + 00 K	00 P + 50 K[1]	146.1 B	182.2 a A	170.4 a A	166.3
9	90 P + 25 K	00 P + 25 K[1]	142.7 B	182.1 a A	171.7 a A	165.5
10	90 P + 50 K	00 P + 00 K [1]	145.9 B	179.9 a A	174.7 a A	166.8
11	90 P + 50 K[1]	00 P + 00 K	147.6 B	178.2 a A	170.0 a A	165.2
12	00 P + 00 K[1]	90 P + 50 K	142.9 B	178.6 a A	171.4 a A	164.3
Mean			144.4	178.4	169.6	164.1
F-test			n.s.[2]	*	*	
CV (%)			3.25	2.01	1.67	2.30

[1]Leaf fertilization with micronutrients: cobalt, molybdenum, boron, copper, manganese, and zinc; [2] Not significant by analysis of variance; [3] Means followed by different lowercase letters in the column differ from each other by Tukey's test at 5%; [4] Means followed by different uppercase letters in the row differ from each other by Tukey's test at 5%.

Carvalho et al. (2004) studied soybean in succession to green manure under no-tillage and conventional planting systems in the Cerrado region and also obtained an absence of interference of the green manure in the thousand-grain weight in two agricultural years of experimentation. Garcia et al. (2014), Cortez et al. (2019), and Guera, Fonseca, and Harkatin (2020) also found comparable results of non-interference of early fertilization.

Only treatment 1 (without fertilization) in years 2 and 3 showed low values of thousand-seed weight, which is explained by the non-use of fertilizer during the three-year trial (Table 6). Borba, Vianna, and Popinigis (1980) also studied this response to phosphorus and potassium fertilization on seed dry matter weight and concluded that phosphorus positively influenced this variable, unlike potassium, which showed no influence.

On the other hand, Lima (2009) stated that the thousand-soybean seed weight, among the production components, is the variable that presents the smallest percentage variation due to changes in the cultivation environment, such as fertilization, as the main biological objective of the plant is the perpetuation of the species. In this sense, the plant tends to form a smaller number of grains in the fixed pods in cases of restriction instead of many malformed grains.

A significant interaction was observed between treatments and years. The treatments with early fertilization or not had a thousand-seed weight higher in years 2 and 3, except for treatment 1 (control), which presented a similar performance during the three-year trial.

Table 7 shows the mean values of soybean yield. No statistical difference was observed between treatments in the first year of experimentation, indicating that the partial or total anticipation of phosphorus and potassium fertilization for soybean sowing carried out at finger millet sowing, in its first application, did not interfere with the yield of the soybean cultivar BRS-133.

Treatment 1 (control) received no fertilizer, and its yield did not differ statistically from treatments with early fertilization or not, with no fertilization response.

Most studies have shown a lack of response of potassium fertilization on soybean yield, especially in soils with medium to high nutrient contents (SILVA; LAZARINI, 2014; RIBEIRO et al., 2019). The lack of soybean response to phosphorus fertilization at sowing is also widely reported by different authors in the bibliography. The discussion of this subject based on the presentation of results of important scientific studies is timely and relevant, as it can contribute to the current agricultural system, especially regarding nutrient rationalization.

Table 7. Mean values of soybean yield (kg ha^{-1}) in years 1, 2, and 3 and mean of the three-year trial (significant interaction treatments x years).

Treatment	*Eleusine coracana*	Soybean	Year 1	Year 2	Year 3	Three-year mean
1	00 P + 00 K	00 P + 00 K	3.354 A[4]	2.808 b[3]A[4]	3.168 b[3]A[4]	3.110
2	00 P + 00 K	90 P + 50 K[1]	3.304 B	3.713 a AB	4.051 a A	3.689
3	00P + 25 K	90 P + 25 K[1]	3.696 A	3.933 a A	4.030 a A	3.886
4	00 P + 50 K	90 P + 00 K[1]	3.479 A	3.819 a A	3.930 a A	3.743
5	45 P + 00K	45 P + 50 K[1]	3.629 A	3.859 a A	4.050 a A	3.846
6	45 P + 25 K	45 P + 25 K[1]	3.578 A	3.687 a A	4.020 a A	3.762
7	45 P + 50 K	45 P + 00 K[1]	3.527 A	3.889 a A	4.016 a A	3.811
8	90 P + 00 K	00 P + 50 K[1]	3.599 A	3.802 a A	3.927 a A	3.776
9	90 P + 25 K	00 P + 25 K[1]	3.493 A	3.845 a A	4.013 a A	3.783
10	90 P + 50 K	00 P + 00 K [1]	3.403 B	3.783 a AB	4.022 a A	3.736
11	90 P + 50 K[1]	00 P + 00 K	3.500 A	3.871 a A	3.987 a A	3.786
12	00 P + 00 K[1]	90 P + 50 K	3.632 A	3.589 a A	3.869 a A	3.696
Mean			3.516	3.717	3.924	3.719
F-test			n.s.[2]	*	*	
CV (%)			4.73	6.44	2.30	4.74

[1]Leaf fertilization with micronutrients: cobalt, molybdenum, boron, copper, manganese, and zinc; [2] Not significant by analysis of variance; [3] Means followed by different lowercase letters in the column differ from each other by Tukey's test at 5%; [4] Means followed by different uppercase letters in the row differ from each other by Tukey's test at 5%.

Moreover, Palhano et al. (1983) studied phosphate and potassium fertilization on soybean grain yield in the state of Paraná and did not obtain a response to phosphorus application in old (eight out of nine study sites) and newly cultivated soils (five out of eight sites). Old cultivation soils presented no response to potassium fertilization in eight out of nine studied sites, with contents above 1.1 $mmol_c\ dm^{-3}$. Seven out of eight studied sites in newly cultivated soils, reaching contents higher than 1.5 $mmol_c\ dm^{-3}$, had no response to potassium application; one of these seven sites showed a trend of negative soybean yield response with potassium addition. The site that responded had a potassium content of only 1.0 $mmol_c\ dm^{-3}$ in the soil.

Mascarenhas et al. (2000) studied limestone and potassium for soybean and also verified an absence of yield response to potassium fertilization. Moreover, the soybean only responded to potassium application when liming was conducted. According to Oliveira, Carmello, and Mascarenhas (2001), the best (Ca + Mg)/K ratios for soybean fertilization are between 22 and 31, regardless of the type of soil and cultivar.

Foloni and Rosolem (2008) conducted an experiment in Botucatu, SP, Brazil, on the early potassium fertilization of soybean conducted on millet over three consecutive years and concluded that the fertilization can be fully anticipated at the millet sowing without compromising the commercial crop yield.

Long-term experiments aiming to obtain soybean yield responses under the residual effect of these nutrients can also be found in the bibliography.

Borkert et al. (1997) conducted experiments lasting ten years to study the response of soybean to potassium fertilization and the residual effect of this fertilization on soybean grain yield and verified that yield in the control treatment (without fertilization) decreased only from the eighth consecutive growing season without fertilization due to a decrease of the nutrient in the soil below the critical levels.

Understanding the mechanism of nutrients in the soil is a difficult and highly important task, as the nutrient addition to the soil does not always imply an increase in yield. Furthermore, there is a natural decrease in soil nutrients over the years due to their export by the seeds if there is no fertilization, in addition to leaching losses in the case of potassium and erosion or fixation for phosphorus. These dynamics of nutrient import and export from the soil by the crop occur with greater security the higher the soil fertility level.

This complex knowledge is a key factor for rationalizing the use of these nutrients, allowing treating the soil as a financial application by adding reasonable amounts of nutrients to it when the production cost is favorable and using them at times when the production cost shows an unfavorable trend, which are factors that are very common in agriculture. The understanding of this rationalization is even more important when facing the reality that the source of these nutrients may become scarce, as the current concerns on the phosphorus sources.

Only treatment 1 (control) differed statistically from the others in the second and third years, with lower yield. The soil analysis (Table 2) shows that this soil had low phosphorus and medium potassium contents at the time of the experiment setup, being no longer quantified during the experiment.

Soybean cultivation under these fertility conditions showed no difference in yield between treatments in the first year, as already discussed.

However, yield reduced from the second year onwards, probably due to the depletion of reserves of these nutrients in the soil (Table 7).

Studies about the early fertilization on the soybean crop under no-tillage are scarce both in the national and international literature, but some of their results stand out.

Broch and Chueiri (2005) studied the effect of the mode of fertilizer application on the soybean yield in a no-tillage system in soil with a low phosphorus content during the growing seasons from 2001/2002 to 2003/04 and verified that the highest yields obtained in the first year occurred when only up to 50% of the fertilization was anticipated, with no difference in yield in the second agricultural year due to the early fertilization. However, a yield loss was observed in the third year when 100% of the fertilization was applied early, which, according to the authors, was attributed to the late sowing time or the occurrence of droughts, which would have harmed the vegetative soybean development, making it difficult to absorb nutrients applied early due to the low water content in the surface soil layer.

However, Broch and Chueiri (2005) also reported positive results. These authors conducted a series of field tests in commercial soybean areas in several locations in Brazil in the 1997/1998 growing season, comparing the traditional farmer fertilization with the early fertilization. The results showed no difference regarding soybean yield due to the early fertilization under the no-tillage system from the north of São Paulo to the Cerrado region. In addition, 28 fields under the no-tillage system were evaluated from the south of São Paulo to Rio Grande do Sul, showing that soybean benefited from the early fertilization. Also, some fields in these areas with early fertilization showed higher root depths and more vigorous plants and higher uniformity in germination and a better stand, which, according to the authors, was a consequence of the absence of high salt concentrations close to the seeds or region of initial root development.

Broch and Chueiri (2005) conducted experiments during seven agricultural seasons (1997/1998 to 2003/2004) to evaluate the effect of early fertilization (broadcast and in-furrow at pre-sowing) on the yield of soybean under a no-tillage system grown in a soil with a phosphorus content of 19.8 mg dm^{-3} (resin method) and potassium of 2.7 $mmol_c$ dm^{-3}. No statistical difference was observed in the mean soybean yield over the seven agricultural years as a result of early fertilization, whether conducted by broadcasting or furrowing. Moreover, the control treatment (without fertilization) also showed a decrease in yield from the second to the seventh agricultural year, differing statistically from the others. These results regarding the control treatment are similar to those obtained in the present study, which showed a decrease in soybean yield from the second agricultural year compared to that obtained in the first year.

Broch and Chueiri (2005) conducted another experiment during three agricultural seasons (2001/02 to 2003/04) to evaluate the effect of the mode of fertilizer application on soybean yield in the implementation of the no-tillage system in soil with an average phosphorus content of 13 mg dm^{-3}. In this case, no significant difference was found for soybean yield regarding the early broadcast fertilization applied immediately before soybean sowing compared to the in-furrow fertilization. Furthermore, a lower yield was obtained in the treatment without fertilization in the three crops, corroborating with the results obtained regarding the early fertilization.

Carvalho et al. (2004) also obtained undifferentiated yield data using soybean succession with different green manures (velvet bean, pigeon pea, sunn hemp, and millet) under the no-tillage system in the Cerrado region.

The overall evaluation of soybean yield obtained in this study over the three years of experimentation shows that the early phosphate and potassium soybean fertilization conducted on finger millet did not harm soybean yield, showing the feasibility of this technique.

Regarding the sustainability of the agroecosystem, Matos, Salvi, and Milan (2006) studied the operational feasibility of this practice in the field and found that the early fertilization allows a rationalization in the dimensioning of the machines for sowing, reducing the number of sets (tractors and seed drills), increasing the net income with the crop, and promoting the no-tillage system, a practice proven to be beneficial to soil conservation and the environment as a whole. This finding is important for soybean producers, as it allows sowing soybean with a smaller number of machines at the best recommended time, with soil conservation (WEYERS et al., 2021) and a better net income.

CONCLUSION

The early soybean sowing fertilization with phosphorus and potassium carried out during finger millet sowing does not interfere with the thousand-seed weight and soybean yield and may be recommended for sustainable soil use, preserving this resource for future generations.

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