DOI: 10.5433/1679-0359.2023v44n2p755

Soybean fertilization with filter cake and its effects on soil chemical attributes

Adubação da soja com torta de filtro e seus efeitos nos atributos químicos do solo

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Highlights

Using filter cake is a viable and sustainable practice in soybean cultivation.
Applying filter cake to soybean positively impacted plant height.
Soil chemical attributes were not altered by the use of filter cake.

Abstract

Correct waste disposal from the agro-industrial sector represents one of the premises for sustainable agriculture. This work aimed to analyze the use of sugarcane filter cake in soybean fertilization and its effects on soil chemical attributes. The experiment was conducted in a randomized block design with 6 treatments and 4 replications: T1 - Control; T2 - Mineral fertilization (300 kg ha^{-1} of the formulated 00-30-10); and the following percentages of the recommended dose of filter cake: T3 - 50% (17 ton ha^{-1}), T4 - 100% (34 ton ha^{-1}), T5 - 150% (51 ton ha^{-1}), and T6 - 200% (68 ton ha^{-1}). The soil chemical attributes were evaluated, and soybean was assessed for germination, number of pods per plant, number of seeds per pod, plant height, height of the first pod insertion, and yield. The treatments promoted no differences in soybean germination or height of the first pod insertion, while the use of filter cake positively influenced plant height. Moreover, no differences among treatments were found for pods per plant, seeds per pod, thousand-seed weight, and yield. Therefore, using organic filter cake residue in soybean cultivation is feasible, representing an alternative to chemical fertilization for soybean cultivation.

Key words: Fertilizers. *Glycine max.* Waste. Sustainability.

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Received: Mar. 13, 2023 Approved: June 07, 2023

Resumo

A destinação correta de resíduos do setor agroindustrial é uma das premissas para agricultura sustentável. O objetivo do trabalho foi analisar a utilização de torta de filtro, resíduo da indústria sucroalcooleira, na adubação da soja e seus efeitos sobre os atributos químicos do solo. A unidade experimental foi delineada em blocos casualizados com 6 tratamentos e 4 repetições: T1 – Testemunha; T2 – Adubação mineral (300 kg ha^{-1} do formulado 00-30-10); T3 – 50% da dose recomendada de torta de filtro (17 ton ha^{-1}); T4 – 100% da dose recomendada de torta de filtro (34 ton ha^{-1}); T5 – 150% da dose recomendada de torta de filtro (51 ton ha^{-1}); T6 – 200% da dose recomendada de torta de filtro (61 ton ha^{-1}). Foram avaliados os atributos químicos do solo e na cultura da soja a germinação, produtividade, número de vagens por planta, número de sementes por vagem, altura de plantas e a inserção da primeira vagem. Os tratamentos não promoveram diferenças na germinação da soja. Para a altura das plantas, o uso da torta de filtro influenciou de forma positiva. A altura da inserção da primeira vagem não apresentou diferenças entre os tratamentos. Para os parâmetros vagens por planta, sementes por vagem, peso de mil sementes e produtividade não houve diferenças entre os tratamentos. Para os atributos químicos do solo, foram observadas diferenças para os teores de matéria orgânica e carbono. O emprego do resíduo orgânico torta de filtro na cultura da soja é viável, pois apresentou-se como uma alternativa para adubação química na cultura da soja.

Palavras-chave: Fertilizantes. *Glycine max.* Resíduos. Sustentabilidade.

Introduction

Organic waste generated by agricultural and agro-industrial activities has increased due to higher production in recent years. Taking advantage of materials from these sectors and avoiding the accumulation of waste in the environment helps reduce dependence on imported chemical fertilizers and reinforces the sustainability of agricultural production (Camargo & Oliveira, 2018; Silva et al., 2021).

Many residues can be reused by soybean producers, varying according to availability and price in a given region. Among these by-products is the filter cake. It is a material from the sugar and alcohol sector derived from the mixture of ground bagasse and sludge from decantation during sugar clarification (Fravet et al., 2010). In this process, the hot broth undergoes sulfitation and receives a calcium hydroxide solution, which increases pH, allowing the flocculation of colloidal organic substances (Bernardino et al., 2018).

Cake production reaches 30 to 40 kg per ton of processed sugarcane. It has essential minerals, such as calcium, phosphorus, potassium, and nitrogen, with variable concentrations depending on sugarcane variety, maturation period, clarification process, and soil type (Fravet et al., 2010). Furthermore, as a residue with high levels of organic matter, it serves as food for microorganisms, favoring the transformation of natural phosphates into stable and labile

organic and inorganic forms in the soil (Fontenele, 2019). These characteristics make filter cake a good alternative for organic crop fertilization.

Soybean [*Glycine max* (L.) Merrill] occupies a prominent position in the Brazilian economy, justifying the need for research to improve its cultivation. The yield potential of this crop is genetically determined; however, cultural practices and environmental factors interfere with the production capacity, limiting its development at some point during the cycle (Dall'agnol, 2016). Among these cultural techniques is the correct use of fertilizers.

According to Associação Nacional para Difusão de Adubos [ANDA] (2022), Brazil imported 34,606,843 tons of fertilizers in 2022, showing a significant dependence of Brazilian agriculture on inputs from outside the country, especially KCl. To reduce this dependency and optimize the use of fertilizers, attention must be paid to alternatives for soil fertilization. For instance, adding organic matter by using animal, vegetable, and industrial residues, such as the filter cake that is produced on a large scale by sugarcane mills.

Thus, this study aimed to analyze the effect of using filter cake as an alternative fertilizer on soil chemical attributes and soybean development and yield.

Material and Methods

The experiment was carried out in the municipality of Maringá (23°20'30.86"S and 51°52'30.73"W, with an altitude of 483 m above sea level). The experimental area has a Eutrophic Red Latosol, according to the Paraná soil classification map (Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA], 2007).

Table 1 shows the soil chemical attributes of the experimental area before the treatments were implemented. Soil samples were collected at a depth of 00,20 m.

Table 1
Values referring to the chemical analysis of the soil(*) from the experimental area before implementing the filter cake experiment

Attributes	Abbreviations	Units	Results
pH in CaCl			5,1
Organic matter	MO	g dm-3	30,36
Carbon	(C)	g dm-3	17,61
Phosphorous	(P)	mgP dm-3	11,09
Potassium	(K+)	cmolc dm-3	0,92
Calcium + Magnesium	(Ca^{2+}+Mg^{2+})		10,4
Calcium	(Ca^{2+})		8,67
Magnesium	(Mg^{2+})		1,73
Hidrogen + Alumminum	(H^{+}+Al^{3+})		5,76
Total acidity	(H+)		5,76
Alumminum	(Al^{3+})		0
Sum of bases	(SB)		11,32
CEC			17,08
Saturation of bases	V%	%	66,27
Copper	Cu		-
		4.3	
mg dm^{-3}	66,58	21.4	
Zinc	Zn		27,05
Iron	Fe		55,85
Manganese	Mn		116,1
Sodium	Na+		17,39

(*)Performed at the Rural Laboratory of Maringá in 2017. Ca, Mg, Al: extractor potassium chloride N; P, K, Cu, Zn, Fe, Mn, Na: Mehlich extractor.

The waste used was the filter cake obtained in a sugar-alcohol plant located in the district of Iguatemi, Maringá-PR. The characteristics of the residue are described in Table 2.

Table 2
Characteristics of the filter cake applied in the soil in the present work

Residues	Characteristics									
	U %	OM %	N	P	K	Ca	Mg	C	C/N	pH (H_2O)
			g kg^{-1}							
Filter cake[1]	71	69,76	14,33	16,90	1,48	23,07	3,40	405,60	28,30	6,63

[1]Analysis carried out at the Agrochemical Laboratory of the State University of Maringá.

The experiment was carried out in a randomized block design with 6 treatments and 4 replications: T1 - Control; T2 - Mineral fertilization (300 kg ha^{-1} of formulated 00-30-10); and the following percentages of the recommended dose of filter cake: T3 - 50% (17 ton ha^{-1}), T4 - 100% (34 ton ha^{-1}), T5 - 150% (51 ton ha^{-1}), and T6 - 200% (68 ton ha^{-1}). The plots had an area of 16 m² (4 m x 4 m), with a 1-meter corridor between each block.

The filter cake doses were determined by interpreting the soil analysis according to the "Manual of Fertilization and Liming for Paraná State " ed. 2017. Taking into account the potassium levels present in the soil analysis and the filter cake along with soybean requirements, 50 kg ha-1 of potassium was needed, thus defining the dose of 34 ton ha^{-1} of filter cake. Therefore, according to the area of the plots (16 m²) and the treatments, 27.20, 54.40, 81.60, and 108.80 kg of filter cake were applied for T3, T4, T5, and T6, respectively.

Mineral fertilizer (NPK; 00-30-10) was applied at 300 kg ha^{-1}, according to the soil analysis (Table 1) and soybean nutritional requirements.

The soybean cultivar Baup 5400 Intacta RR was used. The seeds were treated with a commercial product composed of fipronil + pyraclostrobin + methyl thiophanate at a dose of 2 mL kg^{-1} of seeds. The seeds were inoculated with peat inoculant at 1 g kg^{-1} of seeds. The row spacing used was 0.45 m, with a density of 13 plants per linear meter, totaling a population of 288,888 plants ha^{-1}.

Mineral fertilization was carried out during soybean sowing using a trailed seeder, while the filter cake was applied manually. The soil samples were collected for chemical evaluation after soybean harvest using a Dutch auger at 00-0.20 m depth.

The variables evaluated in the soybean crop were the following:

- Germination: To evaluate soybean germination, all the plants that emerged from each plot 20 days after sowing were counted. Using the simple rule of three, the proportion between the seeds distributed in the soil and the emerged plants was estimated, thus achieving the germination percentage of each plot.

- Plant height: 10 plants were randomly selected per plot and measured (in cm) from the ground to the highest part of the plant using a measuring tape.

- First pod insertion: 10 plants were randomly selected per plot and measured (in cm) from the ground to the first pod insertion using a measuring tape.

- Yield: to evaluate soybean yield, 2 m² of each plot was harvested. The evaluated area was determined in the center of each plot, discarding the edges to avoid alterations in the results. Soybean was harvested manually and threshed with the aid of a tractor thresher. The threshed samples were cataloged according to each treatment and weighed using a precision scale. Productivity per hectare was estimated using a simple rule of three.

- Number of pods per plant: To evaluate the number of pods per plant, 10 plants were harvested from each plot, and the number of pods in each plant was counted; with these values, the average number of pods per plant was stipulated.

- Number of seeds per pod: 10 plants were harvested from each plot, and the number of seeds per plant was counted to estimate the number of seeds per pod.

The experimental data were subjected to analysis of variance using SASM-Agri software (Canteri et al., 2001). Means were compared using Tukey's test (5%) at a 5% probability level. The fertilization levels (0, 50, 100, 150, and 200%) were subjected to regression analysis (significant regression: p <0.005) using the Statistica 7.0 program.

Results and Discussion

Germination was evaluated 20 days after sowing, and no difference among treatments was found (P>0.05) (Table 3). The mean germination was 89.74%, ranging from 80.77% for T1 to 96.15% for T6. This result may have been influenced by the existing straw in the soil resulting from the cultivation of previous crops (soybean, maize, and wheat) in the no-tillage system running for 6 harvesting cycles. The cover residues favor soil moisture retention, promoting better conditions for crop germination and emergence (Cortez et al., 2019).

Table 3
Values referring to germination (%), plant height (cm), and pod insertion (cm) of soybean plants subjected to different treatments

Treatments[1]	Germination (%)	Plant height (cm)	Pod insertion (cm)
T1	80,77 a	69,7 b	14,5 a
T2	88,46 a	70,1 b	14,2 a
T3	88,46 a	74,7 ab	15,1 a
T4	90,38 a	76,3 ab	15,1 a
T5	94,23 a	82,0 a	15,9 a
T6	96,15 a	77,2 ab	14,0 a
C.V. (%)	11,34	6,52	8,17

[1]Averages followed by the same letter in the columns do not differ, according to Tukey's test (5%).
Treatments: T1 - Control; T2 - Mineral fertilization with 300 kg ha^{-1} of formulated 00-30-10; T3 - 27.20 kg of filter cake; T4 - 54.40 kg of filter cake; T5 - 81.60 kg of filter cake; T6 - 108.80 kg of filter cake.

For plant height (Table 3), filter cake positively influenced plant growth, with T5 having the highest plants (82 cm), followed by the treatments T6, T4, T3, T2, and T1. The height of the first pod insertion did not differ among treatments (P>0.05), ranging from 14.0 cm in T6 to 15.9 cm in T5.

Regarding yield and its parameters (Table 4), no differences were observed among treatments (P>0.05). This result is positive since the filter cake yield was equivalent to mineral fertilizer productivity. It is also noteworthy that the benefits of using organic sources in crop fertilization may go beyond the application in a given cultivation season due to its residual effect in later seasons, as Ghosh et al. (2009) reported.

Table 4
Values referring to the number of pods per plant, seeds per pod, thousand-seed weight (g), and yield (bags ha^{-1}) of soybean plants subjected to different treatments

Treatments[1]	Pods/ plants	Seeds /plants	Thousand-seed weight	Yield (bags ha^{-1})
T1	51,125 a	109 a	143,0 a	61,0 a
T2	58,675 a	121 a	143,5 a	74,9 a
T3	56,975 a	117 a	141,5 a	71,0 a
T4	56,675 a	117 a	143,5 a	71,4 a
T5	58,750 a	126 a	147,2 a	84,8 a
T6	58,525 a	121 a	143,0 a	80,3 a
C.V.	19,10%	18,39%	2,62%	22,50%

[1]Averages followed by the same letter in the columns do not differ, according to the Scott-Knott test (5%).
Treatments: T1 - Control; T2 - Mineral fertilization with 300 kg ha^{-1} of formulated 00-30-10; T3 - 27.20 kg of filter cake; T4 - 54.40 kg of filter cake; T5 - 81.60 kg of filter cake; T6 - 108.80 kg of filter cake.

Bettiol et al. (2023) stated that organic fertilization has its effect maximized in the long term, corroborating Liu et al. (2009), who also indicated that developing effective practices, especially manipulating different amounts and types of organic waste, can improve the sustainability of ecosystems in the long term.

Figure 1A shows the percentage of plant germination at 20 days after sowing. The maximum value occurred in treatment T6, with 96.15% ($p = 0.0759$). The regression analysis between the filter cake doses and the height of soybean plants (Figure 1B) showed a positive correlation ($p = 0.0191$ - $p<0.05$) and maximum correlation for the 150% dose.

Regarding the height of the first pod insertion and yield, there was no correlation (Figure 1C and Figure 1D). They presented values of $p = 0.1811$ and $p = 0.1176$, respectively, indicating that under the conditions of this experiment, the evaluated doses did not influence soybean yield.

An important point to be highlighted is that none of the treatments with filter cake had a negative influence on germination, plant growth, or yield.

For soil chemical attributes, prior to experiment implementation (Table 1), the values of macronutrients, micronutrients, and CEC were classified as high for soybean, according to EMBRAPA (2020). After the treatments were applied (Table 5), the pH values in calcium chloride did not differ among treatments ($P>0.05$), but they were below the indicated values for soybean. The ideal pH range in calcium chloride varies between 5.4 and 5.9, where the best availability of nutrients such as N, P, K, Ca, Mg, and S occurs, also avoiding the toxicity of some elements such as Al (EMBRAPA, 2020).

According to González et al. (2014), it is common for filter cake to have 9.1 g kg^{-1} of Ca.

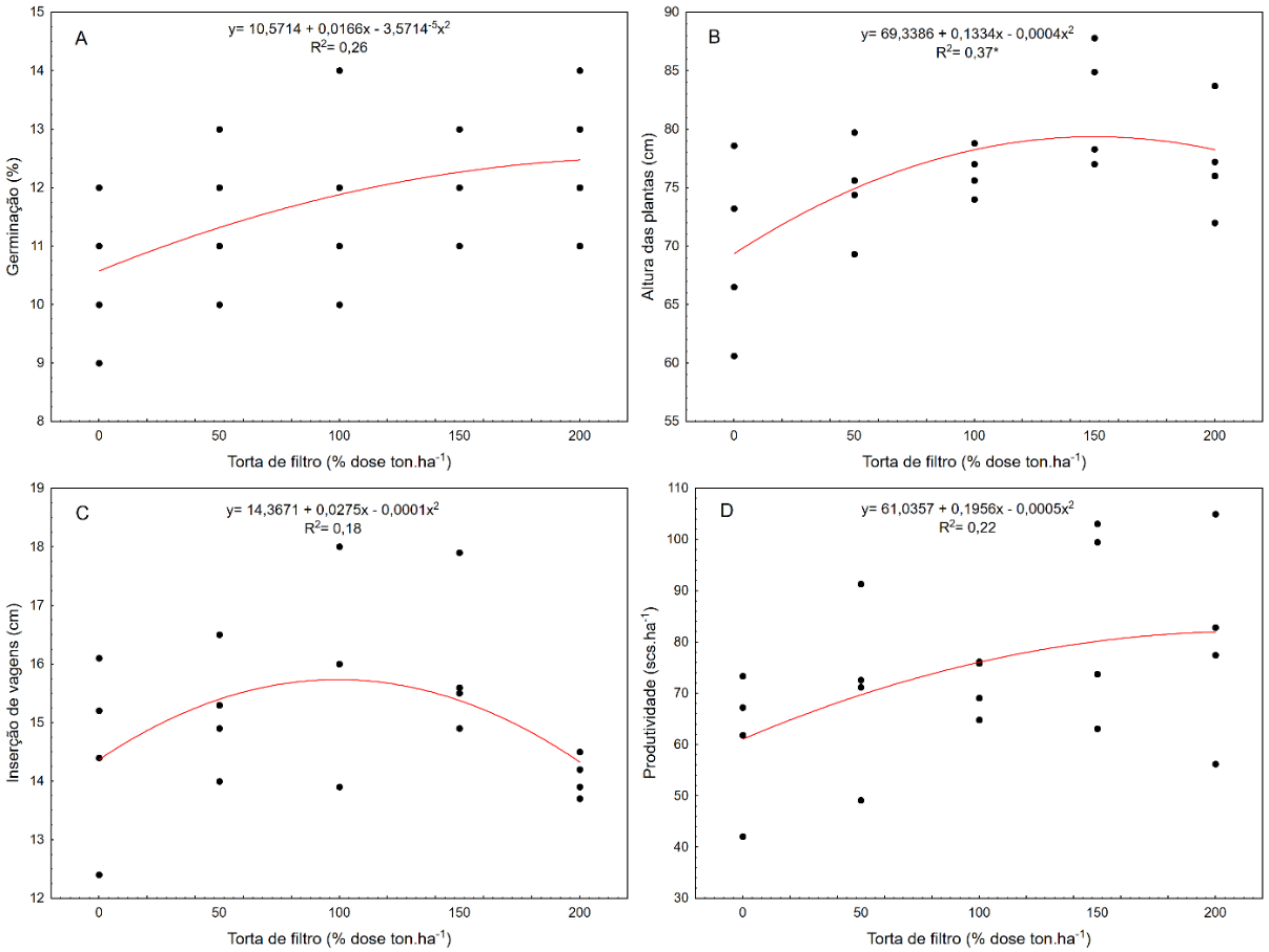

Figure 1. Graphic representation of the regression analyses for A) germination, B) plant height, C) insertion of pods, and D) yield according to the applied filter cake doses. Asterisks represent statistical significance ($p<0.05$).

However, despite the filter cake used in this experiment having 23.07 g kg^{-1} of Ca, its application did not lead to differences the content of this nutrient between treatments, probably due to the initial high Ca values in the soil (Table 1) (EMBRAPA, 2020).

The equality between the treatments for base saturation (V%) and CEC may be related to the soil characteristics in the experimental area, as the soil under study already presented good values for these parameters even before the experiment installation (Table 1). Soils with V% between 50 and 80 are generally ideal for most crops to develop properly (Ronquim, 2010), a fact observed in this work, in which the non-differentiation between treatments for V% was also linked to yield.

Table 5
Values of pH, V%, CEC, sum of bases, organic matter, and carbon of soil samples subjected to different treatments with filter cake organic waste

Treatment	pH (CaCl)[1]	V%[1]	CEC[1]	Sum of bases [1]	Organic matter[1]	Carbon[1]
			$Cmol_c\ dm^{-3}$		$g\ dm^{-3}$	
T1	5,05 a	66,36 a	17,81 a	11,82 a	31,17 a	18,08 a
T2	4,92 a	61,92 a	16,89 a	10,45 a	30,85 a	17,89 a
T3	4,95 a	63,97 a	17,45 a	11,16 a	29,92 a	17,35 a
T4	4,95 a	63,95 a	17,30 a	11,07 a	26,36 c	15,29 c
T5	4,92 a	62,10 a	17,02 a	10,56 a	28,02 b	16,25 b
T6	5,02 a	65,34 a	17,26 a	11,28 a	28,22 b	16,37 b
CV (%)	2,84	4,52	2,83	5,34	3,83	3,82

[1]Averages followed by the same letter do not differ according to the Scott-Knott test (5%).
Treatments: T1 - Control; T2 - Mineral fertilization with 300 kg ha^{-1} of formulated 00-30-10; T3 - 27.20 kg of filter cake; T4 - 54.40 kg of filter cake; T5 - 81.60 kg of filter cake; T6 - 108.80 kg of filter cake.

The amount of organic matter was higher in treatments T1, T2, and T3 without significant differences among them. Nevertheless, they differed from the other treatments (T4, T5, and T6), which showed lower amounts of organic matter.

Table 6 shows the values of macronutrients in the soil samples in each treatment, and among the evaluated nutrients; none showed significant differences among treatments.

Regarding the macronutrients in Table 6, the similarity between the values probably occurred due to the levels of these elements that were already present in the soil. Counterintuitively, applying different doses of the filter cake did not change the macronutrient levels in the soil. Nevertheless, Arruda et al. (2019) observed that using filter cake influences the mineralization of P in the soil, possibly due to its residual N that serves as food for P-mineralizing microorganisms.

The results obtained from the macronutrients once again corroborate the environmental viability of using this organic residue in the soil as a nutrient source for crops, including soybean. Mota et al. (2019) worked with filter cake and soybean and concluded that this residue can be used for crop fertilization and can even entirely replace mineral fertilization. In this way, the environmental impacts due to the inappropriate destination of this waste can be suppressed, promoting greater sustainability in agricultural production (Cordeiro et al., 2020).

Table 6
Macronutrient values in soil samples under different treatments

Treatment	P[1]	K[1]	Ca[1]	Mg[1]
	mgP dm-³		Cmolc dm-³	
T1	13,79 a	0,88 a	8,91 a	2,01 a
T2	17,19 a	0,88 a	7,61 a	1,95 a
T3	11,95 a	0,83 a	8,30 a	2,02 a
T4	11,93 a	0,79 a	8,22 a	2,05 a
T5	9,69 a	0,8 a	7,65 a	2,11 a
T6	12,71 a	0,85 a	8,22 a	2,21 a
CV (%)	43,01	11,55	6,73	10,36

[1]Averages followed by the same letter in the columns do not differ, according to the Scott-Knott test (5%).
Treatments: T1 - Control; T2 - Mineral fertilization with 300 kg ha^{-1} of formulated 00-30-10; T3 - 27.20 kg of filter cake; T4 - 54.40 kg of filter cake; T5 - 81.60 kg of filter cake; T6 - 108.80 kg of filter cake.

Conclusion

Filter cake did not influence soybean germination, insertion of pods, number of pods per plant, seeds per plant, thousand-seed weight, or yield.

Plant height was positively influenced by filter cake, and treatment T5 (150% of the recommended dose of filter cake) led to higher average plant height.

For soil chemical attributes, filter cake resulted in no changes since between T1 (Control) and T3 (50% of the recommended dose of filter cake), no differences were found for carbon, organic matter, pH, V%, CEC, and SB.

Using organic filter cake waste in soybean cultivation is feasible for the sustainable management of this legume, as it is presented as an alternative to chemical fertilization.

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