ISSN 1807-1929
Revista Brasileira de Engenharia Agrícola e Ambiental
Brazilian Journal of Agricultural and Environmental Engineering
v.27, n.12, p.927-933, 2023
Campina Grande, PB – http://www.agriambi.com.br – http://www.scielo.br/rbeaa

DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v27n12p927-933

Organic and mineral fertilization determining the agronomic performance of sunflower cultivars and soil chemical attributes[1]

Adubação orgânica e mineral determina o desempenho agronômico de cultivares de girassol e atributos químicos do solo

Weslian V. da Silva[2], José H. da S. Taveira[3], Patrick B. Fernandes[4*], Patrícia C. Silva[5], Ana B. G. da Costa[6], Carolina M. Costa[7], Pedro R. Giongo[5], Níbia S. D. Corioletti[2] & Antonio L. C. Gurgel[8]

[1] Research developed at Universidade Estadual de Goiás, Santa Helena de Goiás, GO, Brasil
[2] Universidade Estadual de Goiás, Campus de São Luís de Montes Belos, São Luís de Montes Belos, GO, Brazil
[3] Universidade Estadual de Goiás, Quirinópolis, Goiás, Brazil
[4] Instituto Federal de Educação, Ciência e Tecnologia Goiano, Rio Verde, GO, Brazil
[5] Universidade Estadual de Goiás, Santa Helena de Goiás, GO, Brazil
[6] Universidade Federal do Vale do São Francisco, Petrolina, PE, Brazil
[7] Universidade Federal de Viçosa, Viçosa, MG, Brazil
[8] Universidade Federal do Piauí/Campus Professora Cinobelina Elvas, Bom Jesus, PI, Brazil

HIGHLIGHTS:

Oil concentration increased in the achenes of the Sany 66 cultivar when filter cake was applied.
The short-term filter cake application enhances phosphorus availability in the 0-0.20 m soil layer.
In the nutritional management of sunflower cultivation, the application of 42 t ha^{-1} of filter cake can be recommended.

ABSTRACT: This study aimed to verify the effect of the application of filter cake, via soil and in association with mineral fertilization, on sunflower cultivars (*Helianthus annuus* L.) and the chemical properties of the soil. The experimental design used was randomized blocks in a 3 × 2 factorial scheme with six replicates, totaling 36 experimental units. Three sunflower cultivars (Sany 66, Nusol 4140, and Nusol 4170) and two fertilization strategies (mineral fertilization with and without filter cake) were used. Resorting to the filter cake increased the oil concentration in Sany 66. Mineral fertilization did not significantly affect achene production, with mean values being 2561.58 kg ha^{-1}. However, including filter cake resulted in a 21% increase in phosphorus (P) content in the 0-0.20 m soil layer in sunflower crops of the Nusol 4140 variety. Therefore, fertilization with filter cake, in combination with chemical fertilizers or alone, can be an effective strategy to increase soil P content and oil concentration in sunflower cultivation.

Key words: *Helianthus annuus* L., organic fertilizer, phosphorus, second crop

RESUMO: Este estudo teve como objetivo verificar o efeito da aplicação de torta de filtro, via solo e em associação com a fertilização mineral, em cultivares de girassol (*Helianthus annuus* L.) e nas propriedades químicas do solo. O delineamento experimental utilizado foi em blocos casualizados, em esquema fatorial 3 × 2, com seis repetições, totalizando 36 unidades experimentais. Foram utilizadas três cultivares de girassol (Sany 66, Nusol 4140 e Nusol 4170) e duas estratégias de fertilização (fertilização mineral com e sem torta de filtro). O uso da torta de filtro aumentou a concentração de óleo na cultivar Sany 66. A fertilização mineral não afetou a produção de aquênios, sendo obtido valores médios de 2561,58 kg ha^{-1}. No entanto, a inclusão da torta de filtro resultou em um aumento de 21% no teor de fósforo (P) na camada de solo de 0-0,20 m em cultivos de girassol da variedade Nusol 4140. Portanto, a fertilização com torta de filtro, em combinação com fertilizantes químicos ou isoladamente, pode ser uma estratégia eficaz para aumentar o teor de P no solo e a concentração de óleo no cultivo de girassol.

Palavras-chave: *Helianthus annuus* L., fertilizante orgânico, fósforo, segunda safra

• Ref. 270988 – Received 09 Jan, 2023
* Corresponding author - E-mail: zoo.patrick@hotmail.com
• Accepted 18 Jul, 2023 • Published 25 Jul, 2023
Editors: Geovani Soares de Lima & Hans Raj Gheyi

Introduction

Sunflower (*Helianthus annuus* L.) is versatile and is used in human and animal diets (Polviset et al., 2020; Grasso et al., 2021; Oliveira Filho & Egea, 2021). However, sunflower production in the Brazilian Cerrado faces challenges due to soil acidity and limited phosphorus availability (Alovisi et al., 2020). To achieve high yields, the application of 80 kg ha^{-1} P_2O_5 and 60 kg ha^{-1} K_2O as fertilizers is recommended (Sousa & Lobato, 2004). However, purchasing chemical fertilizers can increase production costs (Rezende et al., 2022; Leal et al., 2023).

Co-products from the sugar and ethanol industries are promising organic fertilizers because of their nutrient content and large-scale production (Carpanez et al., 2022). In 2021, sugarcane production was approximately 716 million tons (IBGE, 2021), resulting in an estimated 21.48 million tons of filter cake, which could provide phosphorus (P) up to 30 kg per ton. Filter cake effectively increases the soil's available P levels and promotes plant development (Soltangheisi et al., 2019).

Using filter cake as organic manure has multiple benefits, including improved soil quality and enhanced nutritional content of sunflowers, leading to increased oil production (Alzamel et al., 2022). This sustainable practice reduces the dependency on chemical fertilizers, emphasizing its importance in promoting environmental responsibility and resource efficiency.

This study hypothesized that applying filter cake in conjunction with mineral fertilizer can enhance achene production and improve soil chemical properties, aiming to enhance the practicality of using co-products as organic fertilizers in sunflower production.

This study aimed to examine the impact of filter cake application and mineral fertilization on sunflower cultivars and the chemical properties of Oxisols in the Cerrado.

Material and Methods

The study was carried out in the experimental area of the Universidade Estadual de Goiás – Campus Sudoeste –Santa Helena de Goiás, located in the southwest of the state of Goiás, Brazil (17° 49' 34.3" S, 50° 36' 24.4" W and 570 m of altitude); it was implemented in February 2019 and conducted until June 2019.

According to the Köppen classification, the climate in the region is of the Aw type, with an average temperature of 23.5 °C, ranging from 20.7 °C (June) to 25.0 °C (December) (Figure 1); the average annual rainfall is 1,785 mm, of which, 87% is concentrated between October and March. The region has an average yearly rainfall deficit of four months (Alvares et al., 2014).

The experimental design was composed of randomized blocks in a factorial scheme (3 × 2), with six replicates, totaling 36 experimental units. Three sunflower cultivars (Sany 66, Nusol 4140, and Nusol 4170) were grown under two fertilization strategies (mineral fertilization with and without filter cake).

The total area of the experiment was 916.2 m², where each unit contained seven cultivation lines (0.50 m apart) measuring 6.3 m in length (density of 2.22 plants per linear meter), totaling 98 plants per unit. The observation area for the experiment consisted of five central lines.

The sunflower cultivars used in the experiment presented the following production characteristics: hybrid cultivar Sany 66 flowers between 58 and 62 days after sowing, has potential for silage production, good health, and productivity in the second crop; cultivar Nusol 4140 starts flowering at 70 days after sowing, presents resistance to diseases, and intermediate production of achenes; and cultivar Nusol 4170 flowers at 65 days after sowing and is a hybrid with high oil content.

Before the experiment, the experimental area was used to cultivate *Brachiaria brizantha* as a cover crop. Therefore, the soil was prepared conventionally (plowing and light harrowing). Subsequently, the cultivars were sown in the second crop season (February/2019: this sowing time was chosen because the commercial company that provided the seeds recommended this cultivation strategy for the region where the experiment was implemented, with manual sowing, using 0.45 m in between plants, totaling 44,444 plants ha^{-1}. At

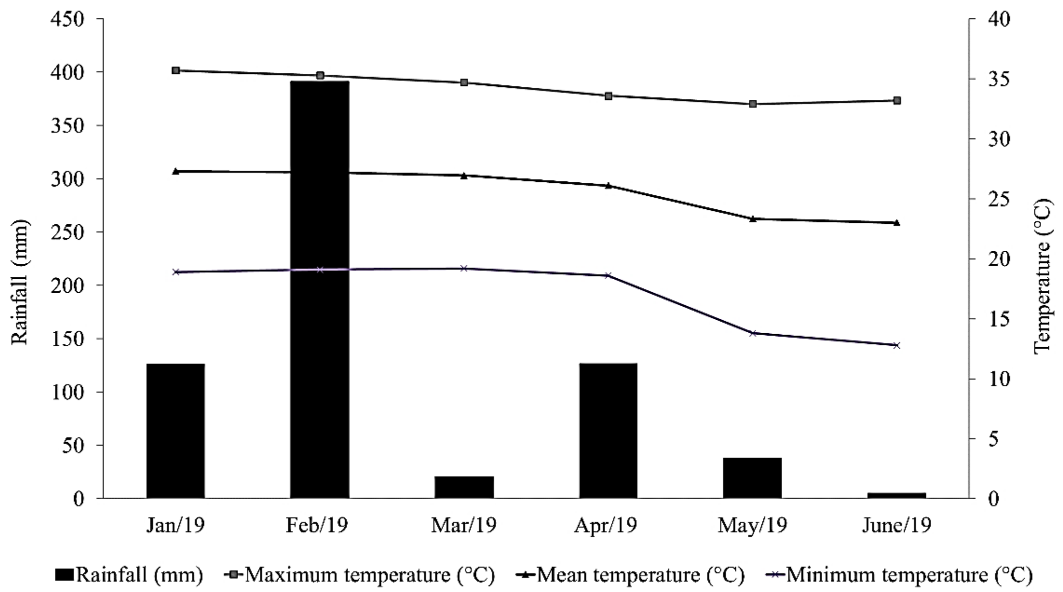

Figure 1. Rainfall, temperature (maximum, minimum, and average) from January 2019 to June 2019

the time of sowing, three seeds were placed per hole. Thinning was performed 15 days after seedling emergence, leaving only one plant per hole.

Before the experiment, the soil was chemically and physically characterized, and 20 samples were collected from the 0-0.20 m layer. Subsequently, a composite sample was formed and analyzed (Teixeira et al., 2017).

The soil was classified as eutrophic, such as an Oxisol (United States, 2014), with medium texture (480, 240, and 280 g kg^{-1} of sand, silt, and clay, respectively), as shown in Table 1.

The filter cakes used in the experiment were obtained from private companies in Santa Helena, Brazil. To verify the chemical composition of the vinasse, an analysis was performed following EMBRAPA (2009) to obtain the following values for the filter cake: 0.730 g kg^{-1} nitrogen (N), 1.97 g kg^{-1} P, and 0.350 g kg^{-1} K.

Based on soil analysis, an attempt was made 60 days before sowing to raise the base saturation to 70% by applying 2.55 t ha^{-1} of limestone filler. Fertilization management followed the recommendations of Sousa & Lobato (2004), using urea as a source of N, single superphosphate as a source of P, and potassium chloride to meet the K requirements in proportions of 40, 60, and 20 kg ha^{-1}, respectively. A total of 42 t ha^{-1} of filter cake associated with mineral fertilization was used.

Crop management techniques were carried out when necessary: manual weeding and application of insecticide (Curyom 500) from the chemical group Bezoylurea + Organophosphate at a proportion of 200 mL ha^{-1}, and PRIORI XTRA fungicide from the chemical group Strobilurin + triazole at a rate of 250 mL ha^{-1}. Boric acid (0.5 kg ha^{-1}) or glyphosate (6.55 L ha^{-1}) was applied (site-specific application) to provide B to the crop.

In June 2019, when the crop completed its cycle, 113 days after sowing (DAS), the capitula were manually harvested when the achenes had a moisture content of approximately 7%. The capitula was removed using pruning shears for subsequent manual threshing and laboratory analysis.

The achene yield was obtained from the material collected from 20 plants in the observation area of the plot, with conversion per hectare. One thousand achenes were weighed using a digital precision scale.

Oil was extracted at the Post-Harvest of Plant Products Laboratory located at the Goiás Instituto Federal de Educação, Ciência e Tecnologia Goiano, Rio Verde Campus in the municipality of Rio Verde, Goiás. For oil extraction, the seeds were first crushed, 50 g of the seed sample and 300 mL of hexane were added to the beaker and left for 24 hours to extract the oil. After 24 hours, the mixture was strained with filter paper to separate the oil and hexane mixture from the residue. To completely separate the oil/hexane mixture, firstly, the scale was tared with a volumetric flask, where the mixture was placed to evaporate, thus separating the oil from the hexane; after that, it was taken to an oven at 60 °C, to remove traces of hexane in the oil, which was weighed at room temperature. Subsequently, the obtained oil fraction was converted into a percentage (%) for each kilogram of achene produced.

Table 1. Chemical composition of the soil in the 0-0.20 m layer

Item	0-0.20
Active acidity (pH in $CaCl_2$)	5.30
Base saturation (%)	57.02
Organic matter (g dm^{-3})	33.00
[1]Phosphorus (mg dm^{-3})	7.60
Potassium (mg dm^{-3})	43.00
Sulfur (mg dm^{-3})	3.40
Calcium ($cmol_c$ dm^{-3})	3.30
Magnesium ($cmol_c$ dm^{-3})	1.10
Potential acidity ($cmol_c$ dm^{-3})	3.40
Cation exchange capacity ($cmol_c$ dm^{-3})	7.91
Zinc (mg dm^{-3})	0.50
Iron (mg dm^{-3})	34.60
Manganese (mg dm^{-3})	29.80
Copper (mg dm^{-3})	2.60
Boron (mg dm^{-3})	0.33

[1] Mehlich

The leaves of the plants were removed at the beginning of flowering (50 DAS) using the methodology of Ranjith et al. (1995), which consisted of collecting the 5th or 6th leaf below the capitulum from 30 plants from each plot. The collected leaves were sent to the laboratory at Universidade Federal de Goiás. Leaf analysis was conducted for P and K following the nitric, perchloric digestion method (EMBRAPA et al., 2009).

In June 2019, after harvesting, soil analysis was performed between rows. Thus, the following chemical parameters were verified: active acidity - pH (in $CaCl_2$); organic matter - OM (g dm^{-3}); phosphorus - P (mg dm^{-3}); potassium - K (mg dm^{-3}); calcium - Ca ($cmol_c$ dm^{-3}); magnesium - Mg ($cmol_c$ dm^{-3}); potential acidity - H+Al ($cmol_c$ dm^{-3}), cation exchange capacity - CEC ($cmol_c$ dm^{-3}); base saturation - V%; iron - Fe (mg dm^{-3}); copper - Cu (mg dm^{-3}); manganese - Mn (mg dm^{-3}); zinc - Zn (mg dm^{-3}); following methodologies recommended by Teixeira et al. (2017).

Before conducting the analysis, the obtained data were subjected to the Shapiro-Wilk normality test. Subsequently, the following procedures were carried out: Data were analyzed following a randomized-block model in a factorial scheme ($Yijk = \mu + Ai + Bk + Cj + [Ai \times Cij] + \varepsilon ijk$), in which: Yijk: observed value; μ: general constant; Ai: fertilization strategy effect (i = mineral fertilization with filter cake, and mineral fertilization without filter cake); Bk: block effect (k = I, II, II, IV, V, and VI); Cj: cultivar effect (j = Nusol 4170, Sany 66, and Nusol 4140); Ai × Cij: effect of the interaction between fertilization strategies and cultivar; εijk: random error, associated with each observed value. Subsequently, Tukey's mean test was applied at a probability of 0.05. The ExpDes package in R software, version 4.2.1, was used (R Development Core Team, 2022).

Results and Discussion

The interaction between mineral fertilization and cultivar significantly impacted oil concentration. However, no interaction was observed between mineral fertilization and cultivar regarding achene yield. Additionally, no interaction was found between the K and P concentrations in the leaves (Table 2). We hypothesized that this could be because of the cultivation season, as climatic factors may affect the absorption of these nutrients and achene yield.

Mineral fertilization with filter cake increased the oil concentration in the Sany 66 cultivar. Without the filter cake,

Table 2. Summary of the analysis of variance for the percentage of oil (O), achene yield (A), and potassium (K) and phosphorus (P) concentration in the leaf of sunflower cultivars (C) subjected to mineral fertilization (M), with and without filter cake

Item	DF	Mean squares			
		O	A	K	P
B	5	3.63^{ns}	1196309^{ns}	0.610^{ns}	0.022^{ns}
C	1	3.92^{ns}	10782297**	0.201^{ns}	0.015^{ns}
M	2	8.46^{ns}	926451^{ns}	0.656^{ns}	0.001^{ns}
C × M	2	27.97*	1798828^{ns}	0.204^{ns}	0.006^{ns}
R	25	5.32	593248	0.321	0.008
T	35	6.38	1203320	0.229	0.010
CV		18.78	20.30	21.40	20.47

ns, *, **, - respectively not significant, significant at a $p \leq 0.05$ and ≤ 0.01 by F test; DF - Degrees of freedom; CV - Coefficient of variation. B: Block; R: Residual; T: Total

the sunflower cultivars had an oil concentration of 11.80% (Table 3). Although sunflower plants can have oil levels of up to 38.90% (Dantas et al., 2019), three sunflower cultivars (Nusol 4170, Sany 66, and Nusol 4140) produced oil levels lower than 15% (Table 3). According to Thomaz et al. (2012), when sunflowers are sown as a second crop (February or March), flowering begins during the low rainfall period, which compromises the filling of achenes and oil accumulation (Mostafa & Afify, 2022).

Mineral fertilization had no influence, with an estimated mean value of 2561.58 kg ha^{-1}. However, there was a difference among the cultivars, with the Sany 66 cultivar showing a higher production of achenes (Table 4). These results indicate that this cultivar performed better in the second crop. However, to maximize the use of this cultivar in low rainfall scenarios, it is necessary to associate it with other cultivation strategies.

Table 3. Oil production (%) for sunflower cultivars subjected to mineral fertilization, with and without filter cake

Mineral fertilization	Cultivar		
	Nusol 4170	Sany 66	Nusol 4140
With cake	11.09 Ab	14.82 Aa	11.91 Ab
Without cake	12.38 Aa	10.62 Ba	12.40 Aa

Means followed by the same uppercase letters in columns and lowercase letters in rows do not differ from each other according to Tukey's test ($p > 0.05$)

No effect of mineral fertilization or cultivar was observed on K concentrations of 1.83 and 1.87 g kg^{-1} in the leaves, respectively. No differences were observed between mineral fertilization and cultivars in terms of P concentration, which was 0.463 g kg^{-1} in the fertilization treatments and 0.445 g kg^{-1} in the cultivars (Table 4).

Regarding the chemical composition of sunflower leaves, Ribeirinho et al. (2012) and Soares et al. (2020) found that a sufficient level of P in the leaves should be between 3 and 5 g kg^{-1}. In contrast, values between 30 and 45 g kg^{-1} should be quantified for K. Lower values of these macronutrients indicate that the plants did not receive an adequate supply of P and K during the production cycle. Furthermore, during this period, there is a reduction in soil moisture, which leads to a decrease in nutrient solubility, compromising the plants' absorption capacity (Giannini et al., 2022).

For the chemical components of the soil (pH, OM, V%, H + Al, CEC, Ca, Mg, and K), no interaction effect ($p > 0.05$) was observed between mineral fertilization and cultivars. However, an interaction effect between cultivar and fertilization was observed for P fractions in the soil (Table 5). However, the observed interaction effect between cultivar and fertilization for P fractions indicated that the soil's response to these nutrients was influenced by the specific cultivar used and the type of fertilization applied. This finding suggests that different cultivars may have varying abilities to take up and utilize P, depending on the fertilization strategy employed.

No interaction effect was observed between cultivar and fertilization for Cu, Mn, or Zn. However, a fertilization effect was observed on Zn concentrations in the soil. An interaction effect was also observed for the Fe fractions (Table 6). On the one hand, the impact of fertilizer application on Zn concentrations in the soil indicates that the choice of fertilization strategy can significantly affect the availability and accumulation of Zn, influencing soil health. However, the observed interaction effect for the Fe fractions suggests

Table 4. Achene yield and potassium and phosphorus concentration in the leaves of the sunflower cultivars subjected to mineral fertilization, with and without filter cake

Item	Mineral fertilization		Cultivar		
	With cake	Without cake	Nusol 4170	Sany 66	Nusol 4140
Achene yield (kg ha^{-1})	2722.00 a	2401.16 a	2070.65 b	3578.20 a	1895.67 b
Potassium (g kg^{-1})	1.96 a	1.69 a	1.98 a	1.75 a	1.76 a
Phosphorus (g kg^{-1})	0.465 a	0.461 a	0.440 a	0.449 a	0.505 a

Means followed by the same lowercase letters in rows do not differ from each other according to Tukey's test ($p > 0.05$)

Table 5. Summary of the analysis of variance for active acidity (pH in CaCl2), organic matter (OM), base saturation (V%), potential acidity (H+Al), cation exchange capacity (CEC), calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), in the 0-0.20 m soil layer managed with sunflower cultivars (C) subjected to mineral fertilization (M) with and without filter cake

Item	DF	Mean squares								
		pH	OM	V%	H+Al	CEC	Ca	Mg	P	K
B	5	0.135^{ns}	0.298^{ns}	52.39^{ns}	0.315^{ns}	0.411^{ns}	0.314^{ns}	0.040^{ns}	12.02^{ns}	618.38^{ns}
C	1	0.110^{ns}	0.340^{ns}	83.12^{ns}	0.314^{ns}	0.350	0.902^{ns}	0.017^{ns}	3.61^{ns}	13.86^{ns}
M	2	0.027^{ns}	0.163^{ns}	52.32^{ns}	0.160	0.017^{ns}	0.040^{ns}	0.100^{ns}	0.047**	40.11^{ns}
C × M	2	0.006^{ns}	0.111^{ns}	3.72^{ns}	0.023^{ns}	0.258^{ns}	0.315^{ns}	0.025^{ns}	39.66**	76.36^{ns}
R	25	0.075	0.230	74.17^{ns}	0.213	0.326	0.666	0.031	9.32*	198.59
T	35	0,081	0.231	66,92	0,221	11.46	0,592	0,034	10,86	236,49
CV		4.79	11.15	12.96	19.04	7.79	22.90	14.60	24.83	25.60

^{ns}, *, **, - respectively not significant, significant at $p \leq 0.05$ and $p \leq 0.01$ by F test; DF - Degrees of freedom; CV - Coefficient of variation. B - Block; R - Residual; T - Total

Table 6. Summary of the analysis of variance for copper (Cu), manganese (Mn), zinc (Zn), iron (Fe), and boron (B) in the 0-0.20 m soil layer managed with sunflower cultivars (C) subjected to mineral fertilization (M) with and without filter cake

Item	DF	Mean squares			
		Cu	Mn	Zn	Fe
B	5	0.079^{ns}	616.39^{ns}	0.071^{ns}	34.73^{ns}
C	1	0.096^{ns}	220.62^{ns}	0.003^{ns}	8.70^{ns}
M	2	0.013^{ns}	93.44^{ns}	0.173**	126.56**
C × M	2	0.045^{ns}	241.83^{ns}	0.027^{ns}	64.82
R	25	0.051	114.98^{ns}	0.017^{ns}	10.39
T	35	0.056	199.28	0.029	7.43
CV		13.56	16.36	22.32	11.99

^{ns}, *, **, - respectively not significant, significant at $p \leq 0.05$ and $p \leq 0.01$ by F test; DF - Degrees of freedom; CV - Coefficient of variation. B - Block; R - Residual; T - Total

that both the cultivar and fertilization practices play a role in the distribution and availability of Fe in the soil. This finding highlights the importance of selecting an appropriate combination of cultivar and fertilizer to maintain optimal Fe levels in the soil, which ultimately affects nutrient uptake and plant growth during sunflower cultivation.

There was no effect of mineral fertilization on pH, OM, V%, H+Al, CEC, Ca, Mg, K, Cu, and Mn, with the following mean values obtained: 5.74±0.047 (pH in $CaCl_2$), 4.31±0.080 g dm^{-3}, 66.48%±1.36, 2.43±0.095 cmol$_c$ dm^{-3}, 7.33±0.030 cmol$_c$ dm^{-3}, 3.57±0.128 cmol$_c$ dm^{-3}, 1.22±0.030 cmol$_c$ dm^{-3}, 45.28±2.56 mg dm^{-3}, 1.67±0.039 mg dm^{-3}, 65.55±2.35 mg dm^{-3}, respectively. Using filter cake combined with mineral fertilization did not significantly change soil chemical composition in the 0-0.20 m layer. However, there are some observations regarding soil acidity values, as pH values are lower than 6.0, which impair the availability of essential macronutrients (Oliveira et al., 2022; Tomazello et al., 2023). Additionally, the observed acidity level increased the accessibility of toxic nutrients, such as Fe and Al.

In the short term, filter cake did not influence OM deposition in the 0-0.20 m soil layers. Therefore, long-term studies are recommended to verify the effects of filter cakes on medium-textured soils. Additionally, it should be noted that soils located in the Cerrado, when managed under monoculture with annual crops, are more exposed to elements such as solar radiation, which reduces the accumulation and efficiency of OM mineralization (Almeida et al., 2021).

Although the filter cake did not influence most of the chemical components of the soil, this finding implies that adding this type of organic fertilizer does not cause significant changes in nutrient levels or the overall balance in the soil. These findings are highly relevant to agricultural practices, particularly for promoting sustainable and environmentally friendly approaches to soil management. Using filter cake as a fertilizer can be considered an alternative to synthetic mineral fertilizers, reducing dependence on chemical inputs and promoting organic farming practices (Fatokun et al., 2022; Almeida et al., 2023).

However, fertilization affected the Zn concentration, with a 26.6% increase observed when mineral fertilization with filter cake was used (Table 7). Zn is an essential micronutrient for plants. However, at elevated concentrations, this metal can

Table 7. Chemical properties of the 0-0.20 m soil layer cultivated with sunflower cultivars subjected to mineral fertilization, with and without filter cake

Item	Mineral fertilization	
	With cake	Without cake
Active acidity (in $CaCl_2$)	5.71 a	5.76 a
Organic matter (g dm^{-3})	4.21 a	4.40 a
Base saturation (V%)	65.27 a	67.68 a
Potential acidity (cmol$_c$ dm^{-3})	2.49 a	2.36 a
Cation exchange capacity (cmo$_{lc}$ dm^{-3})	7.31 a	7.35 a
Calcium (cmol$_c$ dm^{-3})	3.53 a	3.60 a
Magnesium (cmol$_c$ dm^{-3})	1.17 a	1.27 a
Potassium (mg dm^{-3})	46.33 a	44.22 a
Copper (mg dm^{-3})	1.65 a	1.68 a
Manganese (mg dm^{-3})	67.16 a	63.93 a
Zinc (mg dm^{-3})	0.661 a	0.522 b

Means followed by the same lowercase letters in rows do not differ from each other according to Tukey's test ($p > 0.05$)

reach toxic levels in the environment, affecting the growth and metabolism of plants (Kaur & Garg, 2021). Therefore, when consistently using a filter cake, it is advisable to monitor the levels of this element in the soil.

There was no significant difference among the cultivars in terms of pH, OM, V%, H+Al, CEC, Ca, Mg, K, Cu, Mn, and Zn, with the following means obtained:5.74 (pH in $CaCl_2$), 4.30 g dm^{-3}, 66.47%, 2.42 cmol$_c$ dm^{-3}, 7.33 cmol$_c$ dm^{-3}, 3.56 cmol$_c$ dm^{-3}, 1.22 cmol$_c$ dm^{-3}, 45.27 mg dm^{-3}, 1.66 mg dm^{-3}, 65.55 mg dm^{-3}, 0.591 mg dm^{-3}, respectively (Table 7). The cultivars used in this study may have had similar tolerance and nutrient absorption capacity characteristics during the second crop season, resulting in similar nutrient levels and soil properties.

The interaction between mineral fertilization and cultivar with respect to P and Fe levels (Table 8) was influenced by multiple factors. The genetic characteristics of cultivars play a crucial role in determining their responses to fertilization. Additionally, complex interactions between the nutrients present in the soil affect the availability and absorption of these elements by plants. Plant absorption capacity and soil conditions such as pH and organic matter content also influence this interaction. It is important to emphasize that these results are specific to the experimental conditions of this study and may not be directly applicable to other regions or cultivation practices (Gmach et al., 2019).

These results suggest a notable influence of the interaction between mineral fertilization and cultivar on sunflower crops' oil concentration and achene yield. However, it is essential to note that the effects differed depending on the specific nutrients and cultivars under consideration. Additionally, using filter

Table 8. Phosphorus and iron contents in the 0-0.20 m soil layer cultivated with sunflower cultivars subjected to mineral fertilization, with and without filter cake

Mineral fertilization	Cultivar		
	Nusol 4170	Sany 66	Nusol 4140
	Phosphorus (mg dm^{-3})		
With cake	7.95 Aa	7.16 Aa	11.06 Aa
Without cake	8.35 Aa	10.7 Aa	7.35 Ba
	Iron (mg dm^{-3})		
With cake	27.05 Ab	32.16 Aa	27.06 Ab
Without cake	26.95 Aa	23.18 Ba	24.9 Aa

Means followed by the same uppercase letters in columns and lowercase letters in rows do not differ from each other, according to Tukey's test ($p > 0.05$)

cake as a mineral fertilizer may impact various soil properties and levels of nutrients (Soltangheisi et al., 2019), such as Zn concentration (Table 7).

These findings emphasize the these interactions to enhance agricultural practices and support sustainable crop production. Nevertheless, further research is required to investigate filter cake application's long-term consequences and assess its efficacy across different agricultural systems and environmental conditions. This contributed to a more comprehensive understanding of the subject.

Conclusions

1. Using filter cake in conjunction with mineral fertilization while cultivating second-crop sunflowers enhanced oil content in the Sany 66 cultivar.

2. Conversely, in the initial stages of the productive cycle, the application of cake-based fertilization did not affect the chemical composition of the medium-textured Oxisol of Cerrado.

Literature Cited

Almeida, L. L. S.; Frazão L. A.; Lessa, T. A. M.; Fernandes, L. A.; Veloso, Á. L. C.; Lana, A. M. Q.; Souza, I. A.; Pegoraroa, R. F.; Ferreira, E. A. Soil carbon and nitrogen stocks and the quality of soil organic matter under silvopastoral systems in the Brazilian Cerrado. Soil and Tillage Research, v.205, p.1-10, 2021. https://doi.org/10.1016/j.still.2020.104785

Almeida, V.; Carneiro, G.; Almeida, R.; Souza, B.; Teixeira, I.; Vieira, J.; Leandro, W. Development and yield of common bean in response to organomineral fertilization based on filter cake. Journal of Plant Nutrition, v.46, p. 1-20, 2023. https://doi.org/10.1080/01904167.2023.2194904

Alovisi, A. M. T.; Cassol, C. J.; Nascimento, J. S.; Soares, N. B.; Silva Junior, I. R.; Silva, R. S.; Silva, J. A. M. Soil factors affecting phosphorus adsorption in soils of the Cerrado, Brazil. Geoderma Regional, v.22, p.1-7, 2020. https://doi.org/10.1016/j.geodrs.2020.e00298

Alvares, C. A.; Stape, J. L.; Sentelhas, P. C.; Gonçalves, J. D. M.; Sparovek, G. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift, v.22, p.711-728, 2014. https://doi.org/10.1127/0941-2948/2013/0507

Alzamel, N. M.; Taha, E. M.; Bakr, A. A.; Loutfy, N. Effect of organic and inorganic fertilizers on soil properties, growth yield, and physiochemical properties of sunflower seeds and oils. Sustainability, v.14, p.1-18, 2022. https://doi.org/10.3390/su141912928

Carpanez, T. G.; Moreira, V. R.; Assis, I. R.; Amaral, M. C. S. Sugarcane vinasse as organo-mineral fertilizers feedstock: Opportunities and environmental risks. Science of the Total Environment, v.37, p.1-14, 2022. https://doi.org/10.1016/j.scitotenv.2022.154998

Dantas, D. C.; Silva, Ê. F.; Rolim, M. M.; Silva, M. M.; Morais, J. E. F.; Lira, R. M. Production components of sunflower plants irrigated with treated domestic wastewater and drinking water in semiarid region. Revista Ceres, v.66, p.34–40, 2019. https://doi.org/10.1590/0034-737X201966010005

EMBRAPA – Empresa Brasileira de Pesquisa Agropecuária. Manual de análises químicas de solos, plantas e fertilizantes 2.ed. Brasília: EMBRAPA, 2009. 627p.

Fatokun, K.; Motsa, N.M.; Modi, A.T. Orange fleshed sweet potato response to filter cake and macadamia husk compost in two agroecologies of KwaZulu-Natal Province, South Africa. Agronomy, v.12, p.1-19, 2022. https://doi.org/10.3390/agronomy12123091

Giannini, V.; Maucieri, C.; Vamerali, T.; Zanin, G.; Schiavon, S.; Pettenella, D. M.; Bona, S.; Borin, M. Sunflower: From Cortuso's description (1585) to current agronomy, Uses and perspectives. Agriculture, v.12, p.1-16, 2022. https://doi.org/10.3390/agriculture12121978

Gmach, M. R.; Cherubin, M. R.; Kaiser, K.; Cerri, C. E. P. Processes that influence dissolved organic matter in the soil: a review. Scientia Agricola, v.77, p.1-10, 2019. https://doi.org/10.1590/1678-992X-2018-0164

Grasso, S.; Pintado, T.; Pérez-Jiménez, J.; Ruiz-Capillas, C.; Herrero, A. M. Characterisation of muffins with upcycled sunflower flour. Foods, v.10, p.1-7, 2021. https://doi.org/10.3390/foods10020426

IBGE - Instituto Brasileiro de Geografia e Estatística. Produção de cana-de-açúcar. 2021. Available on: <https:// https://www.ibge.gov.br/explica/producao-agropecuaria/cana-de-acucar/br>. Accessed on: Oct. 2022.

Kaur, H.; Garg, N. Zinc toxicity in plants: A review. Planta, v.253, p.1-28, 2021. https://doi.org/10.1007/s00425-021-03642-z

Leal, V. N.; Santos, D. C.; Paim, T. P.; Santos, L. P.; Alves, E. M.; Claudio, F. L.; Calgaro Júnior, G.; Fernandes, P. B.; Salviano, P. A. P. Economic results of forage species choice in crop–livestock integrated systems. Agriculture, v.13, p.1-11, 2023. https://doi.org/10.3390/agriculture13030637

Mostafa, H.; Afify, M. T. Influence of water stress on engineering characteristics and oil content of sunflower seeds. Scientific Reports, v.12, p.1-7, 2022. https://doi.org/10.1038/s41598-022-16271-7

Oliveira, L.Q.; Taveira, J.H.S.; Fernandes, P.B.; Backes, C.; Costa, C.M.; Santos, A.J. M.; Gurgel, A.L.C.; Ribeiro, A. P. P.; Rodrigues, L. M. Teodoro, A.G. Use of blood residue as alternative source of phosphorus in sunflower (*Helianthus annuus* L.) cultivation. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, v.74, p.153-159, 2022. https://doi.org/10.1590/1678-4162-12448

Oliveira Filho, J. G.; Egea, M. B. Sunflower seed byproduct and its fractions for food application: An attempt to improve the sustainability of the oil process. Journal of Food Science, v.86, p.1497-1510, 2021. https://doi.org/10.1111/1750-3841.15719

Polviset, W.; Prakobsaeng, N.; Wetchakama, N. Effect of supplementation of several edible plant oils on nutrient utilization and blood profile of beef cattle. Asian Journal of Dairy & Food Research, v.39, p.245-250, 2020. https://doi.org/10.18805/ajdfr.DR-167

R Development Core Team. The R Project for Statistical Computing. 2022. Available on: <https://www.r-project.org>. Accessed on: May 2022.

Ranjith, S. A.; Meinzer, F. C.; Perry, M. H.; Thom, M. Partitioning of carboxylase activity in nitrogen-stressed sugarcane and its relationship to bundle sheath leakiness to CO_2, photosynthesis and carbon isotope discrimination. Functional Plant Biology, v.22, p.903-911, 1995. https://doi.org/10.1071/PP9950903

Rezende, P. R.; Rodrigues, L. M.; Backes, C.; Santos, A. J. M.; Fernandes, P. B.; Giongo, P. R.; Ribon, A. A.; Bessa, S. V. Productivity and nutrient extraction by Paiaguás palisadegrass submitted to doses of nitrogen in single cultivation and intercropped with pigeon pea. Arquivo Brasileiro de Medicina Veterinária e Zootecnia, v.74, p.1151-1160, 2022. https://doi.org/10.1590/1678-4162-12827

Ribeirinho, V. S.; Melo, J. W.; Silva, D. H.; Figueiredo, L. A.; Melo, G. M. P. Fertilidade do solo, estado nutricional e produtividade de girassol, em função da aplicação de lodo de esgoto. Pesquisa Agropecuária Tropical, v.42, p.166-173, 2012. https://doi.org/10.1590/S1983-40632012000200002

Soares E. B.; Barros Júnior, A. P.; Albuquerque, J. R. T. de; Santos, M. G. dos; Lins, H. A.; Bezerra Neto F. Sunflower performance as a function of phosphate fertilization in semiarid conditions. Acta Scientiarum. Agronomy, v.42, p.1-9, 2020. https://doi.org/10.4025/actasciagron.v42i1.42960

Soltangheisi, A.; Santos, V. R. dos.; Franco, H. C. J.; Kolln, O.; Vitti, A. C.; Dias, C. T. dos. S.; Herrera, W. F. B.; Rodrigues, M.; Soares, T. de M.; Withers, P. J. A.; Pavinato, P. S. Phosphate sources and filter cake amendment affecting sugarcane yield and soil phosphorus fractions. Revista Brasileira de Ciência do Solo, v.43, p.1-17, 2019. https://doi.org/10.1590/18069657rbcs20180227

Sousa, D. M. G. de; Lobato, E. Calagem e adubação para culturas anuais e semiperenes. Cerrado: correção do solo e adubação. 2.ed. Brasília: Embrapa Informação Tecnológica, 2004. 416p.

Teixeira, P. C.; Donagemma, G. K.; Fontana, A.; Teixeira, W. G. Manual de métodos de análise de solo. 3.ed. Brasília: Embrapa, 2017. 573p.

Thomaz, G. L.; Zagonel, J.; Colasante, L. O.; Nogueira, R. R. Produção do girassol e teor de óleo nas sementes em diferentes épocas de semeadura no Centro-Sul do Paraná. Ciência Rural, v.42, p.203-208, 2012. https://doi.org/10.1590/S0103-84782012005000010

Tomazello, D. A.; Melo, E. M. F.; Santos, A. J. M.; Backes, C.; Teodoro, A. G.; Fernandes, P. B.; Rodrigues, L. M.; Belizario, D. S.; Ribon, A. A. Agronomic performance and soil chemical composition when using poultry litter as organic fertilizer in Mombasa Guinea grass production. New Zealand Journal of Agricultural Research, v.66, p.1-16, 2023. https://doi.org/10.1080/00288233.2023.2228735

United States. Soil Survey Staff. Keys to soil taxonomy. 12.ed. Lincoln: USDA NRCS. 2014. Available on: <http://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/>. Accessed on: Jun. 2023.