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ORIGINAL RESEARCH

Biosolid and sugarcane filter cake in the composition of organomineral fertilizer on soybean responses

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Abstract

Purpose Organomineral fertilizers formulated from different organic sources have been studied for the fertilization of several crops. Filter cake is currently one of the most used sources of organic matter; however, sewage sludge also presents characteristics of agronomic interest, being one of the major environmental problems in Brazil. In this sense, the efficiency of pelletized organomineral fertilizers produced with both sources were evaluated for the development of soybean under different fertilization levels.

Methods The experiment was carried out in greenhouse conditions. The soil was characterized as Red Eutrophic Oxisol. The experimental design was randomized block design in a $2 \times 4 + 2$ factorial scheme, corresponding to two sources of organic matter (sugarcane filter cake and treated sewage sludge), in four doses (50, 75, 100 and 125% of recommendation for soybean cultivation), as well as a mineral fertilization and no-fertilization treatments. The plant development was evaluated (stem diameter, plant height and chlorophylls *a* and *b*) at 30, 60 and 90 days after sowing.

Results Organomineral fertilizers formulated from sanitized sewage sludge or sugarcane filter cake promote a higher soybean plant height in relation to mineral fertilizer, especially after the middle of the crop cycle. The level of fertilization referring to 75% of the recommended dose for soybean, when made with sanitized sewage sludge or filter cake, resulted in large stem diameter in relation to mineral fertilization.

Conclusion Organomineral fertilizers based on sanitized sewage sludge or filter cake promote increases in soybean characteristics up to 90 days.

Keywords Sewage sludge · Sugarcane mill filter cake · *Glycine max* · Chlorophylls

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Introduction

The dependence upon and need for fertilizer importation are becoming greater with the expansion of cultivated areas and the constant growth of Brazilian exports of agricultural products. Imports of primary materials for fertilizers composition reached about 24,500 thousand tons in 2016, indicating an increase of 16.1% compared to the preceding year. In the same period, nitrogen, phosphorus and potassium fertilizers were recorded to increase their prices by 32.9, 14.4 and 6%, respectively (ANDA 2016).Therefore, the research for fertilizers that are economically viable, agronomically efficient and that take environmental liabilities in their composition must be stimulated.

An organomineral fertilizer is defined as the product from the physical combination of mineral fertilizers and organic products such as environmental liabilities. Among these, environmental liabilities are organic sources from sanitized, or treated, sewage sludge, which is one of the most promising materials to be an organomineral fertilizer component. There are other organic sources such as filter cakes, peat and poultry bed that can also be used in the formulations of biofertilizers (Tandon 1999; Binder et al. 2002; Amuda et al. 2008).

The sewage sludge must be first treated for agricultural use as a fertilizer, named biosolid, which means that it is ready to be used as a crop fertilizer (Andreoli and Pegorini 1998; Pires and Mattiazzo 2008). The use of hydrated lime (30% on dry basis), followed by solarisation (7 days),is an easy and cheap method to reduce the contamination levels of sewage sludge to a safe point, so it can be released to be used as fertilizer (Alves Filho et al. 2016). Soil fertilization with biosolids increases its organic matter, bases availability (Ca^{++}, Mg^{++} and K^{+}), sum of bases, CEC and soil pH, especially when the biosolid is treated with lime ($CaCO_3$) (Binder et al. 2002; Ferrer et al. 2011).

Filter cakes are one of the most common organic sources to produce organomineral fertilizer, mostly due to their wide availability, low costs and physical and chemical uniformity (Chen 1993). The sugarcane-processing mills produce big amounts of filter cake that are usually rich in P, N and organic matter which can improve soil chemical and physical properties (Valdes and Armas 2001). These characteristics set sugarcane filter cakes as good sources for crop biofertilizers composition (Prado et al. 2013; Wongkoon et al. 2014).

Currently, soybean is the most important oilseed crop under extensive cultivation in Brazil, which is the second largest world producer of this grain (USDA 2016). The soybean crop fertilization with organomineral fertilizer can increase crop production, improve fertilization efficiency and make a rational use of environmental liabilities. Therefore, the objective of this study was to evaluate environmental liabilities as sugarcane filter cake and treated sewage sludge at different levels on soybean crop responses during its development.

Materials and methods

The experiment was conducted in a glasshouse at the Federal University of Uberlândia (UFU), in Uberlândia city, Brazil, between January and April 2016. The experimental site was located at 843 m altitude, latitude 18° 54′S and longitude 48°15′W. The predominant climate of the region is subtropical type Cwa, according to Köppen (1948) classification. The glasshouse average temperature during the experiment period was 26.4 °C, varying from 17.5 to 28.5 °C.

A red Eutrophic Oxisol was used as classified by EMBRAPA (2018), with the following chemical characteristics at 0–20 cm soil depth (Table 1). Soil correction with lime was not necessary due to soil acidity (pH = 6.2) within the ideal range for growing crops and to the lack of toxic Al^{+3} ($m = 0$).

The sewage sludge (SS)used in this study was derived from the Municipal Department of Water and Sewage Sludge (DMAE) of Uberlândia and treated according Alves Filho (2014) to become a biosolid. The filter cake (FC) used was from Delta Sugarcane Mill Ltd at Uberaba city, Brazil. The chemical characteristics of the sewage sludge and filter cake used in this study were determined at the Laboratory of Soil Analysis (LABAS-UFU) (Table 2). The sewage sludge and filter cake present distinct P stocks, respectively, 2.23 and 0.95% P_2O_5 (Table 2), and therefore, different quantities of organic material were necessary to balance the P added in soil (Table 3).

The experimental design was a randomized complete block design with four replicates in a 2 × 4 + 2 factorial scheme, corresponding to two sources of organic matter for

Table 1 Chemical characterization of the red Eutrophic Oxisol

PH H_2O	P (mg dm^{-3})	K^{+} (cmoldm^{-3})	Ca^{++}	Mg^{++}	Al^{+3}	H + Al	BS	T	T	V (%)	M	O.M. (dag kg^{-1})	O.C.
6.2	2.3	0.31	2.3	0.8	0	2.8	3.41	3.41	6.21	55	0	2.7	1.6

pH in H_2O; P, K: Mehlich^{-1} extrator; Ca, Mg, Al: KCl 1 mol L^{-1} extractor; H + Al: SMP at pH 7,5; BS: base sum; t: effective CEC; T: CEC at pH 7; V: base saturation; m: aluminum saturation. O.M.: organic matter, O.C.: organic carbon. Methodologies based on EMBRAPA (2017)

Table 2 Chemical properties of the sewage sludge biosolid and the sugarcane filter cake

Sources	PH[a]	O.C.[a] (%)	N[a]	$P_2O_5^a$	K_2O^a	C/N[a]
Sewage sludge	7.60	19.80	0.79	2.23	0.24	25
Filter cake	6.81	23.49	0.61	0.95	0.30	38

[a]Evaluations proposed by EMBRAPA (2017)

the production of pelletized organomineral fertilizers (SS and FC), four levels of fertilization (50, 75, 100 and 125%) of the recommendation for the cultivation by the Soil Fertility Commission of the State of Minas Gerais (CFSEMG 1999) and two additional treatments: fertilization exclusively via mineral sources (MF) and a control without fertilization (NF). The organomineral fertilizers were produced by Geociclo Company in the formulation 3-17-10 plus B (0.2%), Zn (0.3%) and Mn (0.3%), one being a sewage sludge base and another filter cake.

The rates were based in P available in soil (2.3 mg dm^{-3}) and clay content (60%), which in our experiment P contents in soil was low with high clay contents, therefore needing a dose of 120 kg ha^{-1} to supply the P needed. In this way, P rate of 150 kg ha^{-1} (125%) was performed to check if there is P fixing in soil. In addition, according to Withers et al. (2018), for new areas, an initial single input of 35 kg P ha^{-1} is required to overcome soil P fixation, following a constant input of 25.2 kg ha^{-1}, the average annual fertilizer P use on crop land over the past 10 years. Therefore, a rate of P of 140 kg ha^{-1} P_2O_5 is commonly recommended in tropical soils. The mineral fertilizer used as one of the additional treatments had the same formulation 3-17-10 plus B (0.2%), Zn (0.3%) and Mn (0.3%). All treatments are specified in the Table 3.

Five seeds were sown per pot with a volume of 3 L of soil at a depth of 2 cm, with subsequent thinning at 14 days after sowing, maintaining one plant per pot. The cultivar UFUS Carajás was used, with determined growth habit, recommended for low latitudes and early flowering, which has a cycle between 100 and 110 days.

At 30, 60 and 90 days after sowing (DAS), stem diameter (mm) was measured using a digital caliper at 1 cm above ground level. The plant height (m) was measured using a ruler, considering the level of the soil to the apical meristem. The chlorophylls *a* and *b* were evaluated as the Falker index (FI) on the first fully expanded soybean leaf using a ClorofiLOG® (FALKER 2008).

The data were tested for assumptions of normality of residues by the Smirnov–Kolmogorov test ($p < 0.01$), for homogeneity of variances by the Levene test ($p < 0.01$) and for the additivity of the blocks by the test of Tukey ($p < 0.01$), before ANOVA (F test, $p < 0.01$). When ANOVA indicated significant differences between treatments, all were compared by the Dunnet test ($p < 0.05$) for each additional treatment (MN or NF). The sources of organic matter (SS or FC) were compared by the Tukey's test ($p < 0.05$) and the fertilization levels (0, 50, 75, 100 and 125%) were submitted to regression analysis (significant regression: $p < 0.05$ and $R^2 > 70\%$). The statistical programs used were ASSISTAT (Silva and Azevedo 2009) and SISVAR (Ferreira 2011).

Results and discussion

No differences were observed between the sewage sludge and the sugarcane filter cake sources related to the soybean biometric characteristics or chlorophylls (Table 4). This shows that both organic sources (SS or FC) used to produce the organomineral fertilizers generate similar results for the development of soybean plants. However, the sugarcane filter cake source has some advantages in relation to treated sewage sludge, since filter cakes from sugarcane mills are more available in many regions of Brazil. In contrast, there is less volume available of treated sewage sludge. The production of a biofertilizer based on treated sewage sludge could considerably contribute to reduce soil and water contamination, rationally discharging an environmental liability and making human living more sustainable (Tadon 1999; Usman et al. 2012).

Regarding the study of fertilization rates or levels, it was verified that there was a highly significant effect on stem

Table 3 Treatments specifications

Source of organic matter	Relative dose	P_2O_5 (ha^{-1})	Applied per (ha^{-1})	Applied per (pot^{-1})	Nomenclature
Treated sewage sludge	50% P_2O_5	60 kg	32.287 kg	0.048 g	SS50
	75% P_2O_5	90 kg	48.431 kg	0.073 g	SS75
	100% $P_2O_5^a$	120 kg	64.574 kg	0.097 g	SS100
	125% P_2O_5	150 kg	80.718 kg	0.121 g	SS125
Sugarcane filter cake	50% P_2O_5	60 kg	75.790 kg	0.114 g	FC50
	75% P_2O_5	90 kg	113.685 kg	0.171 g	FC75
	100% $P_2O_5^a$	120 kg	151.579 kg	0.227 g	FC100
	125% P_2O_5	150 kg	189.475 kg	0.284 g	FC125
Mineral fertilizer	705 kg ha^{-1} 3-17-10	120 kg	120 kg	0.180 g	MF
No fertilizer	0	0	0	0	NF

[a]For the calculation of fertilization levels of 50, 75, 100 and 125% of the P_2O_5, the recommendation proposed by the Commission of Soil Fertility of Minas Gerais State (CFSEMG 1999) was considered

Table 4 ANOVA for soybean stem diameter (D—mm), plant height (H—m) and chlorophylls *a* and *b* to compare sources (without additional treatments) and doses

Source of Variation	*df*	30 DAS[a]				60 DAS				90 DAS		
		D	H	*a*	*B*	D	H	*A*	*b*	D	*a*	*b*
Source (S)	1	0.186	< 0.000	4.493	3.677	3.015	0.114	1.422	0.555	0.003	0.088	1.529
Dose (D)	4	5.233**[b]	12.626**	14.308**	7.064**	6.636**	9.792**	1.793	1.887	6.625**	1.020	0.962
S x D	4	2.732	0.848	3.639	2.038	1.118	0.549	0.481	1.164	2.048	0.339	0.243
block	3	1.561	9.706	6.971	2.157	7.683	4.670	2.341	2.418	6.623	0.296	3.774
CV (%)		3.83	11.31	3.73	7.41	4.67	17.03	7.99	12.16	8.97	5.05	9.16

[a]DAS: days after sowing

[b]*F* test values with two asterisks (**) indicate differences at 1% significance

diameter at 30, 60 and 90 DAS and plant height at 30 and 60 DAS. However, a significant effect of fertilization levels (doses) for chlorophyll *a* and *b* (Table 4) occurs only at 30 DAS.

Soybean biometrics (stem diameter and plant height) and chlorophyll contents comparing the organomineral fertilizer treatments (SS and FC) to the additional treatments (MF and NF)are presented in Table 5.

Organomineral fertilizers formulated from sanitized sewage sludge or sugarcane filter cake promote higher soybean plant height in relation to mineral fertilizer, especially from the middle of the crop cycle. The level of fertilization referring to 75% of the recommendation for soybean, when made with organomineral fertilizer based on treated sewage sludge or filter cake, results in larger stem diameters at 90 DAS in relation to mineral fertilization. There is no evidence that organomineral fertilizers formulated from sanitized sewage sludge or sugarcane filter cake promote changes in chlorophylls *a* and *b* in soybean plants up to 90 DAS.

Stem diameter differs from the additional treatments (MF or NF) at 30 and 90 DAS; however, at 60 DAS, there were no differences between the treatments. These results indicated that approximately at the soybean flowering stage (60 DAS), the soybean stem diameter is similar among the fertilized treatments (SS, FC and MF), and at this period, stem diameter is not a biometric characteristic largely influenced by fertilizers variation. In the evaluation performed at 90 DAS, the 75% dose was among the most adequate for both organomineral fertilizers, resulting in a larger diameter in relation to the mineral fertilizer.

In spite of the greater reactive chemical potential of mineral fertilizer compared to organomineral, this characteristic is compensated by presenting a gradual release of its nutrients during the development of the crop, thus having a greater agronomic efficiency (Kiehl 2008). It seems that the gradual release of nutrients promoted by mineral fertilizers has not necessarily been characterized with a problem in the early stages of plant development, as reported by Oliveira

Table 5 Dunnet's test for soybean stem diameter (D—mm), plant height (H—m) and chlorophylls (*a* and *b*—Falker index) to compare biofertilizer treatments with the additional treatments

Treatments	30 DAS[a]				60 DAS				90 DAS		
	D	H	*a*	*b*	D	H	*a*	*b*	D	*a*	*b*
SS50	2.85	0.38	25.75	4.76	3.60	0.72	28.43	4.76	3.65	33.46	10.23
SS75	2.86*[b]	0.42*	27.88*	5.21	3.96	0.86*	29.71	5.21	4.06*	31.84	9.65
SS100	2.83*	0.39	28.11*	5.32	3.79	0.72	26.88	5.32*	3.91	33.03	10.64
SS125	2.92*+	0.46*	29.71*+	5.76+	4.40	0.92*+	27.03	5.76*	4.33*+	33.20	10.28
FC50	2.93*+	0.38	26.44	4.89	3.53	0.78*	28.51	4.89	3.89	32.78	9.44
FC75	2.67	0.39	27.81*	5.17	3.75	0.82*	27.38	5.17	4.42*+	32.74	9.44
FC100	2.76	0.44*	26.83	4.88	3.75	0.82*	26.58	4.88	3.83	32.19	10.06
FC125	2.67	0.45*	26.98	4.99	3.73	0.87*	25.43	4.99	3.78	33.04	10.06
MF	2.46	0.32	25.86	4.78	3.39	0.63	26.78	4.78	3.43	32.36	9.78
NF	2.41	0.31	25.08	4.48	3.24	0.52	27.83	4.48	3.40	33.85	10.15
CV (%)	3.79	4.63	4.44	7.21	4.63	16.03	7.35	11.94	8.27	5.11	9.34

[a]DAS: days after sowing

[b]Values with asterisks (*) and plus sign (+) indicate differences by Dunnet's test ($p < 0.05$) from the additional treatments MF (mineral fertilization) and NF (no fertilization), respectively

(2016). Other factors need to be better studied, such as the effects of release of organic acids from organic matter.

The plant height was always higher for the SS75, SS125 and FC125 treatments when compared to the mineral fertilization. At 60 DAS, all levels of the organomineral fertilizer from sugarcane filter cake presented taller plants than the MN treatment. Organomineral fertilizers in equivalent doses, or even when lower than the recommended mineral dose (100%), resulted in stem diameter and plant height equivalent, or superior, to the mineral fertilizer treatment (Table 4). Similar results were observed by Alane (2015), who evaluated an organomineral fertilizer pellets in the formulation 3-15-15 in soybean cultivation, where, comparatively, 200 kg ha^{-1} of an organomineral fertilizer resulted in the same productivity obtained when using 400 kg ha^{-1} of exclusive mineral fertilizer. Also, the soybean treated with the organomineral fertilizer presented higher foliar nitrogen and about 17% more grain production than the soybean fertilized with the mineral fertilizer.

Atere and Olayinka (2012) also report that soybean plants fertilized with organomineral fertilizer from aqueous compound of *Hyacinthus orientalis* enriched with N (25 kg ha^{-1} urea) and P (26 kg ha^{-1} single superphosphate - SSP) obtained gains significant in height and dry mass weight. The association of organic and mineral sources to produce biofertilizers allows a better use of nutrients by the plants. The organic fraction of an organomineral fertilizer minimizes the nutrient losses, since it promotes their slow release over the crop development period (Antille et al. 2013; Nakayama et al. 2013). In this study, the association of an organic source (SS or FC) with a naturally fertile soil increases the efficiency of the nutrients available in the system soil–plant, promoting a higher development of the plants treated with organomineral fertilizer.

It was found that at 30 DAS, the dose that provided the greatest stem diameter (2.81 cm) was equivalent to 99.3% of the recommended dose (Fig. 1a), regardless of the sources of organic matter used in the organomineral fertilizer formulation, sugarcane filter cake or treated sewage sludge (Table 5). There was no significant polynomial model adequate in using the data of soybean stem diameter at 60 and 90 DAS, and the maximum stem diameter observed at these periods was about 2.8 mm and 4.2 mm, respectively, for the 125 and 75% dose.

The graph of soybean plant height and organomineral fertilizer doses was better described by a positive linear regression for 30 DAS (Fig. 1b), indicating that the soybean plant height increased 0.0011 m for each percent increase in the organomineral fertilizer applied. No significant polynomial model is adequate when using the data of soybean plant height at 60 DAS, and the maximum plant height observed at the dose of 125% was about 0.90 m and 0.45 m, respectively.

In sorghum plants cultivated in pots, Oliveira (2016) observed increased stem diameter, plant height, leaf area, dry biomass and chlorophylls *a* and *b*, in plants treated with organomineral fertilizer (filter cake, peat or biosolids) compared to plants treated solely with mineral fertilizer. It was also observed that low doses of organomineral fertilizer performed equivalent results to the highest dose of mineral fertilizer (450 kg ha^{-1} of NPK 5-17-10). In the present study, organomineral fertilizer doses such as 75% of the recommended dose obtained good results for the soybean variables evaluated, indicating a good potential of this kind of fertilizer for soybean crop production.

No significant differences in chlorophylls levels were observed between fertilization with organomineral fertilizer and with mineral fertilization (Table 5). Similar results were observed by Magela (2017) when evaluating the effects of organomineral fertilizer and mineral fertilizers in corn,

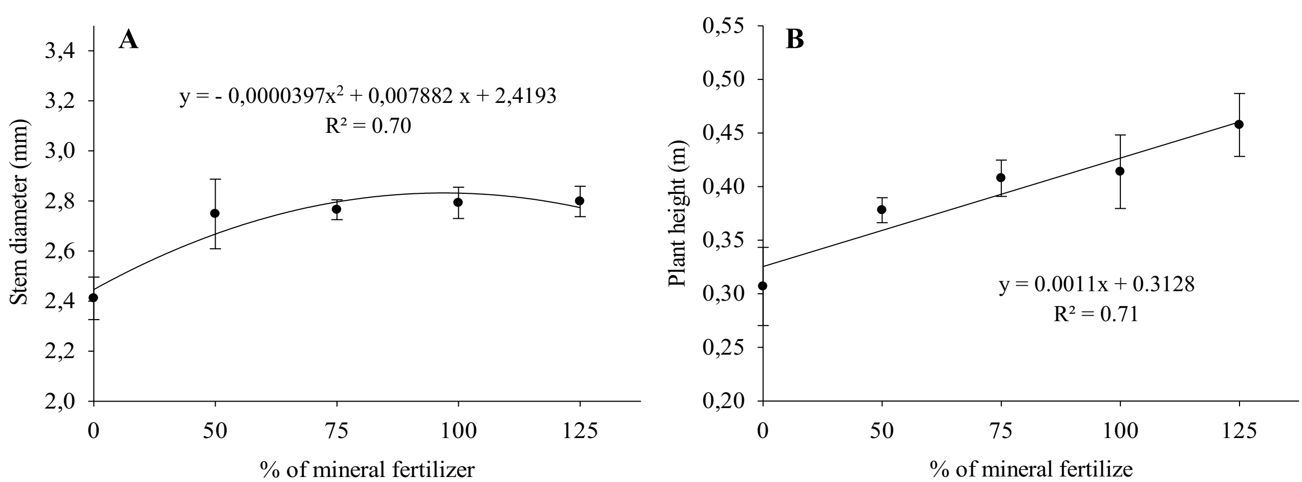

Fig. 1 Soybean stem diameter (**a**) and plant height (**b**)at 30 days after sowing

where no differences were observed for the contents of chlorophylls *a*, *b* and total (*a* + *b*) at 35 DAS. The soybean chlorophyll varies significantly only at 30 DAS, but no differences were observed for their contents in the other periods (Table 5).The chlorophylls content (*a* and *b*) at 30 DAS are presented as linear regressions in Fig. 2. For each percent of organomineral fertilizer increased, an increase of about 0.0265 and 0.0069 IF for chlorophylls *a* and *b*, is expected, respectively.

Chlorophylls are characterized as the main plant pigments for light energy capture in the process of photosynthesis (Hopkins 1999). This makes chlorophylls important to photosynthetic efficiency, to plant growth and adaptability to different environments (Engel and Poggiani 1991). However, in this study, no improvement in chlorophylls contents was observed after 30 DAS, and even so, the continuous application of organomineral fertilizer might improve soil nutrient availability, as a consequence of are is dual effect, and favors cropping stability in relation to the exclusive mineral fertilization (Galvão et al. 1999).

Fertilizers usually account for about 35% of the total crop production costs (Broch and Pedroso 2012), and organomineral fertilizer can reduce costs and improve crop productivity. Ferreira (2015) found that the production of potato (Ágata cultivar) was similar between mineral fertilizer and doses of organomineral fertilizer greater than 50% of the mineral fertilizer dose. In sugarcane, Sousa (2014) found yield increments of up to 24% when using biofertilizer in replacement of mineral fertilization. Our results show organomineral fertilizer benefits to soybean crop development, presenting similar soybean evaluations among mineral and organomineral fertilizations, even at low organomineral fertilizer doses.

Organomineral fertilizers are proved to be a viable alternative and interesting for total or partial substitution of mineral fertilization. Usually, they provided similar or superior results for plant growth characteristics, and have none to low potential for soil contamination with heavy metals such as nickel, cadmium, cobalt, chromium, molybdenum and lead (Magela 2017). However, Teixeira (2013) highlighted the lack of studies on the dynamics of the organomineral fertilizer reactions in soils related to nutrient release and their availability to plants or how organomineral fertilizer impacts crops development.

This study was conducted in a glasshouse under conditions less variable than on field and these primary results support the knowledge that organomineral fertilizer cover a series of attributes that can increase crop productivity and reduce its production costs with mineral nutrients.

Conclusions

Organomineral fertilizer doses equal or superior to 50% of the mineral fertilization recommended dose resulted in increased soybean stem diameter and plant height, but no great effects were observed for chlorophylls (*a* and *b*) contents later than 30 days after soybean sowing; Sugarcane filter cake and treated sewage sludge (biosolid) can be used to compound organomineral fertilizer that can replace exclusive mineral fertilization for soybean crop production.

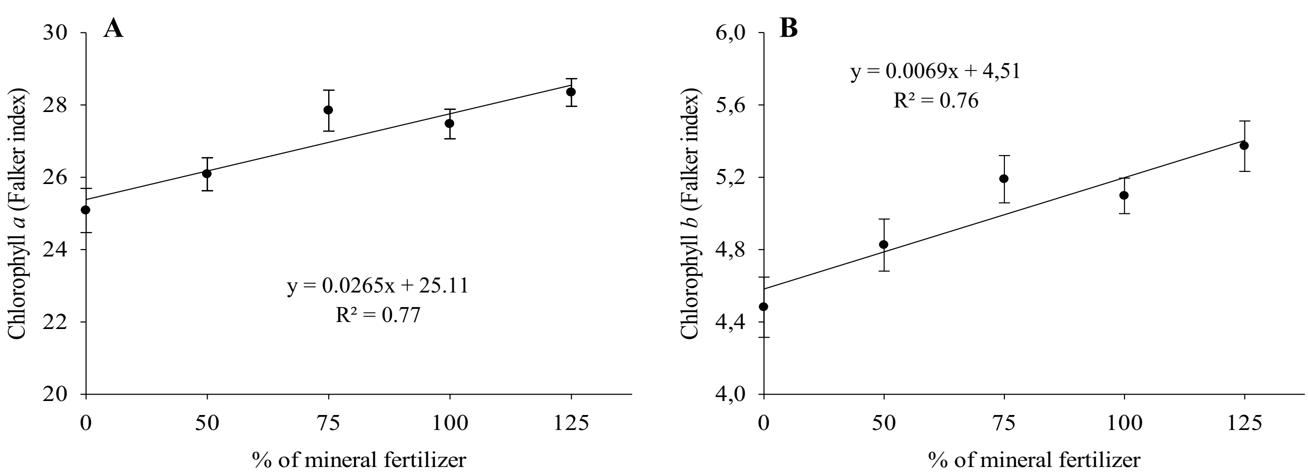

Fig. 2 Soybean leaf levels of chlorophyll *a* (**a**) and *b* (**b**) at 30 days after sowing

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