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Research Article

Potassium fertilization and bioactivators on the soybean yield and soil microbiota[1]

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ABSTRACT

Soil microorganisms are of paramount importance for crop yield. This study aimed to evaluate the effect of potassium chloride doses associated with two bioactivation sources on soybean yield and soil microbial activity. The experimental design was randomized blocks, arranged in a 5 x 2 factorial scheme, with four replications, being the first factor potassium doses (0, 30, 60, 90 and 120 kg ha^{-1} of K_2O), using potassium chloride as a source, and the second factor soil bioactivation products: Penergetic (250 g ha^{-1}) and Efficient Microorganisms (EM) (1:250), with 250 L ha^{-1} of spray volume. The KCl doses affected the soil microbial activity, while the soil bioactivating sources with the potassium chloride doses did not show significance for the leaf potassium content and soybean yield. K_2O doses higher than the maintenance dose for the soybean crop with EM negatively influenced the soil microbial biomass. The EM bioactivator associated with the maintenance dose of K for the soybean crop (60 kg ha^{-1}) is the most appropriate treatment for soil microbial activity, as it is the condition that presents the most stable environment and the highest microbial efficiency.

KEYWORDS: Soil activators, Penergetic, microbial biomass.

RESUMO

Adubação potássica e bioativadores na produtividade de soja e microbiota do solo

Os micro-organismos do solo são de suma importância para a produtividade das culturas. Objetivou-se avaliar o efeito de doses de cloreto de potássio associadas a duas fontes bioativadoras na produtividade de soja e atividade microbiana do solo. Utilizou-se delineamento experimental em blocos casualizados, em esquema fatorial 5 x 2, com quatro repetições, sendo o primeiro fator constituído por doses de potássio (0, 30, 60, 90 e 120 kg ha^{-1} de K_2O), utilizando-se cloreto de potássio como fonte, e o segundo por produtos bioativadores de solo: Penergetic (250 g ha^{-1}) e Micro-organismos Eficientes (ME) (1:250), com 250 L ha^{-1} de calda. As doses de KCl influenciaram na atividade microbiana do solo, enquanto as fontes bioativadoras de solo com as doses de cloreto de potássio não apresentaram significância para o teor de potássio foliar e produtividade da soja. Doses de K_2O superiores à de manutenção para a cultura da soja com ME influenciaram negativamente na biomassa microbiana do solo. O bioativador ME associado à dose de manutenção de K para a cultura da soja (60 kg ha^{-1}) é o tratamento mais apropriado para a atividade microbiana do solo, por tratar-se da condição que apresenta ambiente mais estável e maior eficiência microbiana.

PALAVRAS-CHAVE: Ativadores de solo, Penergetic, biomassa microbiana.

INTRODUCTION

Brazilian agriculture develops tending toward grain yield. One of the most economically important crops in the world and a protagonist in the increase in areas and grain production in Brazil is soybean (*Glycine max* L. Merrill), due to its different forms of use and the increase in global demand for food. Despite not being known worldwide as a staple food, it is an essential source of vegetable oil and protein (Bazzo et al. 2021, Silva et al. 2022). This oilseed yield is increasing in the country due to a set of technologies, but its progressive geographic expansion is a decisive factor, since the growth rate of the planted area is higher than that of yield (Escher & Wilkinson 2019). Even with the large increase in production costs, the soybean cultivation area has reached 42,892.6 thousand hectares, the largest ever recorded (Conab 2022).

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The introduction of inputs is a determining factor for increasing production; therefore, to achieve a maximum production, it is necessary to use appropriate agricultural practices (Costa et al. 2018, Giovanini et al. 2019). Proper fertilizer management is considered an essential strategy for establishing sustainable agriculture, with higher yields and profitability (Bazzo et al. 2021). Thus, scientific advances are needed to assess the possible interactions between management practices/ production technologies and their influence on the various productive factors.

Potassium is the second element most absorbed and exported by the soybean crop, being an essential nutrient in almost all processes necessary for the life of the plant, performing vital functions such as regulating the stomata opening and closing, synthesis of proteins and carbohydrates, and tolerance to abiotic stresses (Korber et al. 2017, Esper Neto et al. 2018). Potassium readily available to plants accounts at most for 2 % of the total soil K, being the remaining bound up with other minerals. Thus, soil bioactivators can be an efficient and sustainable alternative to accelerate the K release and meet the crop demand (Soumare et al. 2022).

The development of new research and innovations has been encouraged by the need for more sustainable, efficient and profitable agricultural production (Santos & Ribeiro 2019), which also collaborates with the reduction of the expansion of cultivated areas. Some technologies aim to bioactivate soil life among the practices or techniques that support the sustainable agricultural production system. In this sense, natural bioactivation aims to accelerate the decomposition of organic matter, increase and balance microbiological activities in the soil, trigger soil biomass metabolism and facilitate the interaction between plants and beneficial microorganisms (Cobucci et al. 2015). A commercially accessible solution of natural soil microbes with beneficial properties is Efficient Microorganisms (EM), also known as Bokashi, which means fermented organic material composed of aerobic and anaerobic microbes. Yet another source reported as a soil and plant bioactivator is Penergetic, which, according to the manufacturer, increases the photosynthetic efficiency of plants (Penergetic-P) and improves the performance of organic matter in decomposing soil organisms (Penergetic-K) (Hata et al. 2021, Lima et al. 2022).

Among the soil biological characteristics, the microbial biomass is defined as a living component, acting in the decomposition process, nutrient cycling and energy flow. Changes in its community and activity interfere with soil biochemical processes, agricultural yield and ecosystem sustainability (Agostinho et al. 2017), since the microbial biomass is fundamental for plant nutrition, as it acts in the release of enzymes and secondary compounds that act on the soil pH and thus help in the availability of nutrients, in soil enzymatic processes and decomposition of organic matter.

The activation of microorganisms through biological stimulators can help in several microbiological processes capable of influencing the availability and absorption of nutrients and crop yields. Thus, considering the importance of microorganisms and crop yields, it is essential to evaluate the association of potassium chloride with soil bioactivation sources, its influence on soil microbiota and crop yield. Therefore, the present study aimed to evaluate the effect of potassium chloride doses associated with bioactivation sources on soil microbial activity and soybean yield.

MATERIAL AND METHODS

The experiment was conducted at the experimental field of the Universidade Estadual de Goiás, in Ipameri, Goiás state, Brazil (17º43’04”S, 48º08’43”W and altitude of 794 m), during the 2020/2021 cropping season. The region has a semi-humid tropical climate (Aw type), with annual average temperature between 20 and 24 ºC and 1,300-1,700 mm of rainfall, with rains in the summer and drought in the winter (Alvares et al. 2013).

The soil in the area is classified as Dystrophic Red Yellow Latosol with a clayey texture (Santos et al. 2018), equivalent to Ferralsols (FAO 1998), and had already been cultivated for 15 years. The soil collection for chemical analysis was performed at a depth of 0-20 cm, showing the following results: 370, 90 and 540 g kg^{-1} for clay, silt and sand, respectively; pH = 5.2; H + Al = 1.8 $cmol_c$ dm^{-3}; Ca = 1.9 $cmol_c$ dm^{-3}; Mg = 0.6 $cmol_c$ dm^{-3}; Al = 0.0 $cmol_c$ dm^{-3}; P ($Mehlich^{-1}$) = 10.4; K ($Mehlich^{-1}$) = 52.3 mg dm^{-3}; organic matter = 20.0 g dm^{-3}; base saturation = 59.37 %; Zn = 1.5 mg dm^{-3}.

The experimental design was randomized blocks, arranged in a 5 x 2 factorial scheme, with four replications. The first factor consisted of potassium doses (0, 30, 60, 90 and 120 kg ha^{-1} of K_2O), using potassium chloride as a source. The second factor comprised the following soil bioactivation products: Penergetic (molasses and bentonite clay subjected to the application of electric and magnetic fields) and Effective Microorganisms (EM) technology (yeasts, lactic acid bacteria, photosynthetic bacteria, actinobacteria and fermenting fungi).

After demarcating the plots of the experimental area, potassium chloride was applied in the treatments delimited with the doses. Also, 250 g ha^{-1} of Penergetic-K and 250 L ha^{-1} of EM mixture (1:250) were applied to the soil in the delimited plots. The Monsoy 98Y21 IPRO soybean cultivar was sown with only phosphate fertilization (120 kg ha^{-1} of P_2O_5) using simple superphosphate as the source. At the R1 stage, the bioactivators were applied again via foliar at the same dose, and, for Penergetic, the foliar application was performed with Penergetic-P. The experimental plots consisted of seven rows with 0.50 m spacing between rows and 4 m in length, considering the three central rows for the evaluations and discarding 0.5 m at each end.

At the soybean full bloom, soil samples were collected from each experimental unit, in the 0-10 cm layer, to analyze the microbiological variables, being the microbial respiration obtained by incubating the samples with CO_2 capture in NaOH, for seven days, by adapting the fumigation-incubation method proposed by Anderson & Domsch (1990); the carbon from microbial biomass was obtained by the irradiation-extraction method, which consists of using electromagnetic energy, causing an effect on the transfer of energy and temperature, leading to cell disruption with the release of intracellular compounds (Mendonça & Matos 2005); and the metabolic quotient was obtained by dividing the basal respiration by the carbon from microbial biomass (Anderson & Domsch 1993).

Also, the electrical conductivity was evaluated at full bloom to estimate the amount of salt present in the soil solution, using the soil/water ratio of 1:2 (10 cm^3 of dry soil: 20 mL of water) for determination. The soil-water mixture was stirred for 30 min on a shaking table, kept at rest for 30 min and stirred for 30 s, then proceeded to the reading, determined by a bench conductivity meter. For leaf potassium (CK) content, ten leaves were randomly collected in each experimental unit; subsequently, the material was placed to dry in an oven with forced air circulation at a temperature of 65 ºC until it reached a constant mass. After drying, the material was ground in a Willey-type mill and packed in bags, after which it was analyzed by reading using the atomic emission spectrometry technique. At the time of physiological maturation (R9), the crop yield was evaluated by manually harvesting the useful area of each experimental plot, which was mechanically threshed and subsequently weighed. Then, the obtained data were transformed into kg ha^{-1}, and this yield was corrected for a moisture content of 13 %.

The obtained data were submitted to analysis of variance and the F test. The effect of the treatments on the analyzed variables was studied and, when significant, the Scott-Knott clustering algorithm was applied at 5 % of probability. For the doses, regression analysis was performed and, for data processing, the Sisvar 5.6 statistical analysis software was used (Ferreira 2019). Using the R software, the relationship between microbiological variables and electrical conductivity was determined by the Pearson's correlation analysis at 5 % of probability.

RESULTS AND DISCUSSION

According to the F test, the leaf potassium content and soybean yield were not influenced by the increasing potassium doses, soil bioactivation sources and the interaction between both factors. The interaction between factors influenced the electrical conductivity and microbiological variables (Table 1).

The leaf potassium contents found in the present study (average of 19.91 g kg^{-1}) were within the limits considered adequate for soybean (between 17 and 25 g kg^{-1}) according to Malavolta et al. (1997). Statistically equal levels, particularly in the absence of potassium fertilization, are associated with the presence of potassium in the soil in sufficient concentration to supply the crop needs. Positive responses to potassium fertilization are not expected when levels of the element in the soil are adequate or high, but it is necessary to replace what is extracted by the crops, considering the expected yield (20 kg ha^{-1} of K_2O for each ton of grains). In a study of the residual effect of potassium, Cavalli & Lange (2018) found that soybean uses soil K reserves and/or crop residue reserves to meet its physiological needs. It is noteworthy that the K content identified in the soil of the present study was 52.3 mg dm^{-3}.

Table 1. Summary of Anova for leaf potassium content, grain yield, soil electrical conductivity, microbial respiration, microbial biomass carbon and metabolic quotient.

Source of variation	DF	Mean squares					
		Leaf potassium content	Grain yield	Electric conductivity	Microbial respiration	Microbial biomass carbon	Metabolic quotient
K_2O doses (D)	4	1.974204^{ns}	0.227405^{ns}	2,822.557125^{ns}	17.93335^{ns}	19,925.4625**	0.030166**
Bioactivators (B)	1	1.764000^{ns}	0.018749^{ns}	2,043.470250^{ns}	2.751003^{ns}	2,220.10000^{ns}	0.015210*
D x B	4	1.989969^{ns}	0.393311^{ns}	3,818.064625*	30.64791*	34,560.4125**	0.031379**
Residue	27	1.2917	0.1562	1,147.1645	9.56550	716.6444	0.0008
CV (%)	-	5.71	11.81	27.95	17.70	14.42	24.83

*, ** and ^{ns}: significant at 5 % and 1 % of probability and not significant, respectively, by the F test.

Despite not showing a significant difference under different potassium doses, the grain yield presented an average yield of 3,345 kg ha^{-1}, a result considered satisfactory, since the national average for soybean yield is 3,029 kg ha^{-1}, and the average yield for the Goiás state is 3,714 kg ha^{-1} (Conab 2022). In similar studies, Souza et al. (2017) concluded that using Penergetic brings positive results and benefits in soybean production, increasing the grain yield by adding only NPK + micronutrients. Lima et al. (2022) suggest the incorporation of additional organic matter to evaluate the effects of Penergetic throughout cultivations, and Franco et al. (2018) point out that effective bioactivators require an adequate level of organic matter. In the present study, the organic matter content is considered medium (20 g dm^{-3}).

The results of the soil electrical conductivity (Figure 1A) fit the fourth-order regression curve only for Effective Microorganisms (EM), and Penergetic did not present a significant adjustment. It is observed that, despite the soil electrical conductivity not showing influence on the soybean development and yield, it was noted that 90 kg ha^{-1} of potassium chloride associated with the application of EM presented the highest value for electrical conductivity. In the literature, no studies that negatively related EM with the electrical conductivity of the soil were found. Corroborating this, Silva et al. (2022) discuss that the bioactivator restores the soil physicochemical properties. Pereira (1998) points out that the behavior of plants is different concerning salinity and that tolerance varies not only with saline concentration but also with management practices, climate and relative proportions of the various ions in the soil solution. Furthermore, soybean yield is reduced under a soil electrical conductivity between 4.0 and 8.0 dS m^{-1}. In the present study, the treatments showed averages below the referred range, with 0.1745 dS m^{-1} (174.50 uS cm^{-1}), being the highest soil electrical conductivity observed.

For the microbiological variables, the respiratory rate (Figure 1B) and microbial biomass carbon (Figure 1C) showed a quadratic adjustment to the addition of K_2O doses associated with the EM bioactivator, where the intermediate doses (30 and 60 kg ha^{-1}, respectively) showed the highest values of these indicators, being 20.44 mg C-CO_2 kg^{-1} of soil day^{-1} for respiratory rate and 344.50 mg C kg^{-1} of soil for microbial biomass carbon. Furthermore, the regression analysis indicated that the increase in K_2O tends to reduce the respiratory rate and the carbon in the microbial biomass at higher doses than the intermediate doses cited. The Penergetic bioactivator presented a decreasing quadratic response to the addition of K_2O doses, obtaining the opposite result to the EM and reaching the lowest respiratory rate with 60 kg ha^{-1}. High respiration rates can indicate both an adverse condition and adequate levels of microbial activity in the soil, and the more CO_2 released into the environment, the greater the microbial activity.

For the metabolic quotient, only the EM bioactivator was significant, showing a decreasing quadratic adjustment, where the lowest metabolic quotient index (0.05 mg C-CO_2 kg^{-1} Cmic day^{-1}) was obtained associated with a dose of 60 kg ha^{-1} of potassium chloride (Figure 1D), an interaction that demonstrated stimulation of the respiratory rate and a higher rate of incorporated carbon; therefore, it is considered that the treatment resulted in savings in the use of energy by the microorganisms. Cunha et al. (2011) point out that, as the microbial biomass becomes more efficient in the use of ecosystem resources, less CO_2 is lost through respiration, and a greater proportion of carbon is incorporated into the

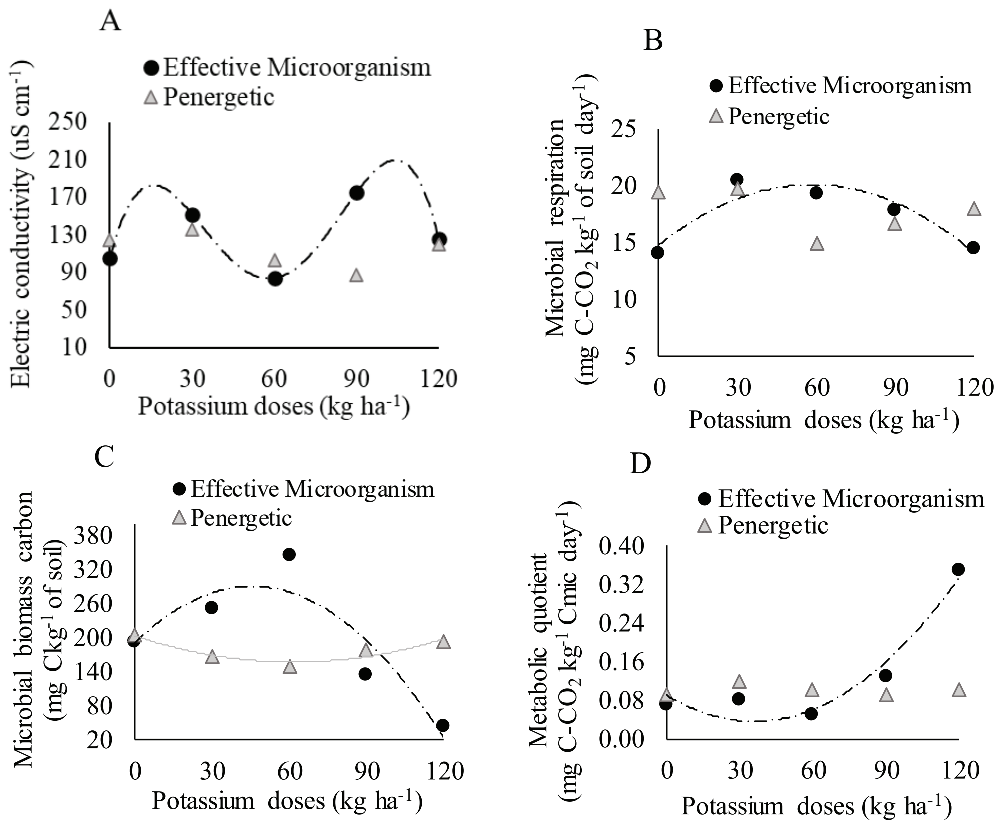

Figure 1. Regression equations for: A) electric conductivity associated with Effective Microorganisms ($y = -3E - 05x^4 + 0.007x^3 - 0.5081x^2 + 11.274x + 105.72$**; $R^2 = 1$); B) microbial respiration with Effective Microorganisms ($y = 0.0016x^2 + 0.1838x + 14.699$*; $R^2 = 0.8665$); C) microbial biomass carbon with Effective Microorganisms ($y = -0.0481x^2 + 4.3782x + 190.01$**; $R^2 = 0.8303$) and Penergetic ($y = 0.0121x^2 - 1.4974x + 202.69$*; $R^2 = 0.8611$); D) metabolic quotient associated with Effective Microorganisms ($y = 4E - 05x^2 - 0.003x + 0.0897$**; $R^2 = 0.9433$), as a function of potassium doses (0, 30, 60, 90 and 120 kg ha^{-1} of K_2O). **, * significant at 1 % and 5 % of probability, respectively.

microbial tissues, what results in a decrease in qCO_2, and, consequently, more stable agroecosystems.

The highest metabolic quotient value (0.35 mg C-CO_2 kg^{-1} Cmic day^{-1}) demonstrates that the highest dose associated with EM favored a greater carbon loss in the form of C-CO_2 to the atmosphere, expressing a low microbial efficiency. Anderson & Domsch (1993) and Guimarães et al. (2017) reported that the metabolic quotient is an important indicator of the efficiency of microorganisms in incorporating C into their biomass, corresponding to basal respiration per unit of microbial biomass. High metabolic quotient values are associated with less stable ecosystems due to stress or disturbance, possibly determined by intensive soil management and the frequent use of pesticides. It indicates that there may be a greater expenditure of energy and increased respiration for the maintenance of the microbial community, implying in a lower efficiency of the SMB-C. Thus, the EM bioactivator associated with a dose of 60 kg ha^{-1} is the condition that presents the most regular environment, being the most appropriate treatment for soil microbial activity.

The results of the Person's correlation analysis between soil microbiological attributes and electrical conductivity showed significant associations, with the increased respiration causing higher carbon contents in the soil microbial biomass ($r = 0.41$; $p < 0.01$); consequently, this increase reduced the metabolic quotient index, demonstrating a high negative relationship ($r = -0.74$; $p < 0.05$) (Figures 2A and 2B, respectively). In addition, it can be noted that the highest metabolic quotient index was obtained at the dose of 120 kg ha^{-1} of potassium chloride and the lowest value of carbon in the microbial biomass. Therefore, the correlation between biomass carbon and soil electrical conductivity was low, but with a higher significance level ($r = -0.33$;

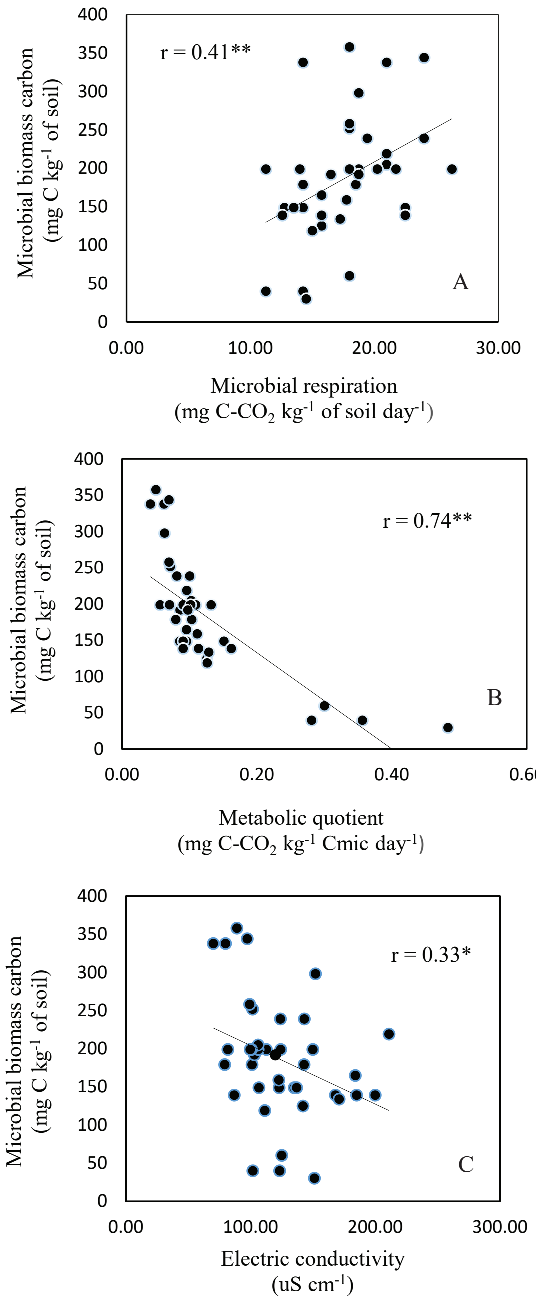

Figure 2. Pearson's correlation between microbial biomass carbon and the variables microbial respiration, metabolic quotient and electrical conductivity, according to the potassium doses and soil bioactivators sources.

$p < 0.05$), demonstrating that the higher the electrical conductivity, the lower the carbon in the microbial biomass (Figure 2C).

Morais et al. (2015) showed that the carbon of the microbial community is a sensitive indicator of increased salinity. Pereira et al. (2019) concluded that the excess of Cl^-, when added to the soil through potassium fertilization with KCl, has a biocidal effect, reducing the soil microbial activity. The salinity impairs the activity of microorganisms, reducing their basal respiration due to the low capacity of extracting organic matter and its direct negative effect on it (Rath & Rousk 2015, Soumare et al. 2022). The soil electrical conductivity indicates the concentration of salts providing an estimate of the salinity. Thus, based on the observed results, it is presumable that the increase in the KCl doses has interfered with the soil salinity and, concomitantly, affected the microorganisms, reducing the soil microbial activity.

CONCLUSIONS

1. Soil bioactivation sources with potassium chloride doses do not show significance for leaf potassium content and soybean yield;
2. K_2O doses higher than the maintenance dose for soybean with Efficient Microorganisms (EM) negatively influence the soil microbial biomass, as it increases the metabolic quotient and reduces the incorporated CO_2, consequently increasing the energy expenditure for maintaining the microbiota;
3. The EM bioactivator associated with the maintenance dose for soybean cultivation (60 kg ha^{-1}) is the most appropriate treatment for soil microbial activity, being the condition that presents a more stable environment, as it presented a higher respiratory rate, more carbon was incorporated into the microbial tissues and exhibited lower metabolic quotient values, thus indicating a greater microbial efficiency.

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