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RESEARCH ARTICLE

Edaphic respiration in bell pepper cultivation under biological fertilizers, doses and application times

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ABSTRACT

Biological fertilizers promote several benefits to the soil, and one of the ways to evaluate their quality is to determine the edaphic respiration. The present study aimed to evaluate edaphic respiration in bell pepper cultivation under doses and times of application of biological fertilizers. Two experiments were performed with applications of biological fertilizers prepared from manure and enriched organic compost, one using bovine manure (BM) and the other, sheep manure (SM). The experimental design used was in randomized blocks, in a 4 x 3 + 1 factorial scheme, with three replications, referring to the doses of biological fertilizers (100, 200, 300 and 400 dm³ ha^{-1}), application times (0, 30 and 60 days after transplanting – DAT) and the absolute control. The following variables were evaluated during the night and day: soil surface temperature (Tsurf) and 10 cm deep (T_{10}), soil moisture (M) and edaphic respiration (ER). SM provided the highest ER in the two shifts evaluated. The use of 400 and 300 dm³ ha^{-1} of SM, at times of 0 and 30 DAT, respectively, provided greater edaphic respiration in relation to the absence of manure during the day.

Keywords: Basal respiration; *Capsicum annuum*; Microbial activity; Soil quality

INTRODUCTION

Bell pepper (*Capsicum annuum* L.) is grown throughout the national territory. It is in the ranking of the ten vegetables of the greatest economic importance in Brazil, being the third most produced solanaceous, after tomatoes and potatoes. The main factors that stimulate its production are the fast economic return, the short period between harvests (usually weekly) and the great demand of the consumer market (Lopes et al., 2019; Santos et al., 2019).

Considering that the harvests are continuous and in short intervals, the quality of the soil is indispensable to express the productive potential of the bell pepper. In the face of anthropic degradation in agricultural crops, a viable alternative is the use of biological fertilizers, such as manure-based biofertilizers, which improve the physical, chemical and biological attributes of the soil, considering that they are rich in organic matter and living microorganisms, considered bioindicators of soil quality (González et al., 2019).

The biofertilizer is the product of aerobic or anaerobic fermentation of the mixture of organic materials and water, and nutrients, minerals and enriched organic compounds can be added. It is commonly used as a soil conditioner, acting as a fertilizer, concealer and microbiological inoculant. The microorganisms in its composition increase the availability of nutrients, optimizing the development and productivity of crops, being one of the most used nutritive sources in organic crops (Matos et al., 2018; Suddarth et al., 2019).

The increase in the availability of nutrients for plants is the result of the increased activity of microorganisms in decomposing organic matter. This activity can be determined by edaphic respiration, also known as basal respiration, which quantifies the carbon dioxide produced by microorganisms, resulting from the metabolic processes

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of the decomposition of organic matter. Thus, the greater the edaphic respiration, the greater the decomposition and mineralization of soil organic matter and the availability of nutrients for plants (Dehsheikh et al., 2020).

The rate of release of carbon dioxide varies according to biotic (soil microorganisms) and abiotics factors (humidity and temperature). Thus, any factor that changes the microclimate conditions of the soil and its interface with the atmosphere, can affect the rate of respiration (Valentini et al., 2015).

Bertollo (2015), evaluating the edaphic respiration in soils cultivated with black oats and corn under the application of biological manure based on bovine manure, verified a decreasing effect as the doses increased, possibly due to the greater efficiency of microorganisms in incorporating C into biomass. While, Medeiros et al. (2019) observed an increase in basal soil respiration with increased application of doses of bovine manure in radish cultivation. In another study with different organic sources (bovine, swine and poultry manure), no differences were observed between the compounds involved in edaphic respiration, only the increase between them (Müller, 2012).

Therefore, the organic source used as a biological fertilizer, as well as the time and the quantity applied, interfere in the chemical, physical and biological properties of the soil, and consequently, in the productive performance of the crops, and in this context, the present work aimed to evaluate the effect of doses and application times of biological fertilizers on edaphic breathing in bell pepper cultivation.

MATERIALS AND METHODS

Two experiments were performed simultaneously in an area of commercial cultivation in the Perimeter Irrigated Apolônio Sales, city of Petrolândia, Pernambuco. Located between the 38º 13 'and 38º 18' W meridians and the 8º 53 'and 9º 00' S meridians in the semiarid region of Pernambuco, on the banks of the São Francisco River. The climate according to the Köppen and Geiger classification is of the BSh type, characterized as a hot semiarid (Embrapa, 2004; Alvares et al., 2013).

The soil was classified as Neossol Quartzarenic Latosolic ortic (Embrapa, 2006). Even though the experiments were being installed in parallel, a sample composed of soil from each area was collected. The analysis was performed at the Soil Laboratory of UFPB, Campus III, Bananeiras-PB and the results can be seen in Table 1. The total organic carbon was also determined, with values of 8.60 and 6.23 g kg^{-1} for the biological fertilizer (SM) and biological fertilizer (BM), respectively.

In the experimental area, a digital thermohygrometer model TH-500 and a rain gauge model TFA 4760 were installed to obtain daily temperature, relative humidity and rainfall data (Fig. 1).

Table 1: Chemical analysis of the soils in the bell pepper cultivation areas

Soil sample	pH	P	K^+	Na^+	H^++Al^{+3}	Al^{+3}	Ca^{+2}	Mg^{+2}	SB	CTC	V	m	O.M.
	H_2O (1:2,5)	mg dm^{-3}		cmol$_c$ dm^{-3}							%		g kg^{-1}
BM	6.95	388.01	152.88	0.12	3.47	-	3.50	1.50	5.51	8.98	61.40	-	10.73
SM	6.81	497.50	155.22	0.10	3.14	-	3.50	1.10	5.10	8.23	61.92	-	14.83

H^++Al^{+3}: Potential acidity; SB: Sum of bases; CTC: Cation exchange capacity; V: Base saturation; m: Saturation by aluminum; O.M: Organic matter

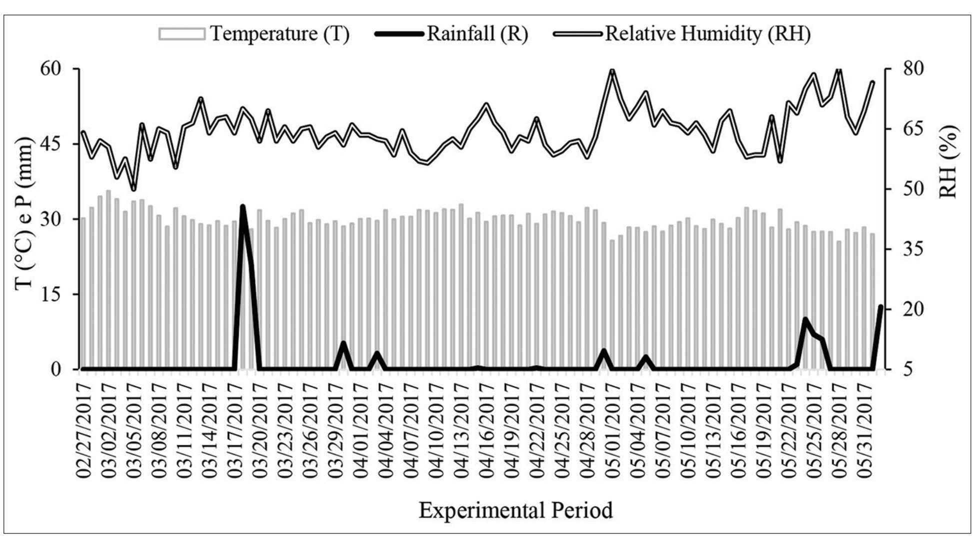

Fig 1. Temperature (T), rainfall (R) and relative humidity (RH) of the bell pepper cultivation area in the experimental period.

In both experiments, biological fertilizers were prepared, prepared from manure and enriched organic compost, one using bovine manure (BM) and the other, sheep manure (SM). The experimental design used was in randomized blocks, in a factorial scheme ((4 x 3) + 1), with three replications, referring to doses of biological fertilizers (100, 200, 300 and 400 dm³ ha^{-1}), application times (0, 30 and 60 days after transplanting – DAT) and the absolute control, referring to the absence of fertilization, totaling 13 treatments.

As for the application times, in treatments 1 to 4, the doses of biological fertilizers were applied in full on the day of transplanting (0 DAT), in treatments from 5 to 8 the doses were divided into two times, at 0 and 30 DAT, and in treatments from 9 to 12 the doses were divided into three times, with applications at 0, 30 and 60 DAT (Table 2).

The variety of bell pepper used was the hybrid Solário from Clause Vegetable Seeds. The seedlings were produced in trays of 128 cells, using commercial substrate, Bioplant®. After 32 days of sowing, the transplant was performed with a 1.5 x 0.5 m spacing 80 mg ha^{-1} of urea were applied to the five DAT (days after transplant), 130 mg ha^{-1} of the 06-24-12 formulation and seven DAT and 260 mg ha^{-1} of the 20-10-20 formulation to the 37 DAT. The experimental plot consisted of four rows of four meters, corresponding to an area of 24 m², with 32 plants (Fig. 2). The useful area was 6 m², consisting of the two central rows, eliminating two plants at the ends of each row, totaling 8 plants.

The preparation of biological fertilizers was performed according to the manufacturer's recommendations, using two bio-factories (polyethylene water tanks) with a capacity of 100 liters. The enriched organic compound consisted of recalcitrant substances, biodynamic preparations, pentoses, minerals and bran (Microgeo, 2019).

Each biofactory was filled with five kilograms of enriched organic compost, 15 liters of manure (bovine or sheep) and the remaining volume completed with untreated water, corresponding to the proportions of 5 and 15% of enriched organic compost and manure, respectively. Every three days the biological fertilizer was stirred, ready for use after 15 days of preparation (Microgeo, 2019).

The application of biological fertilizers was performed on the soil surface, using a hand-held sprayer with a capacity of five liters, and the pre-filtration of the organic input was performed through a sieve with a 2 mm diameter mesh. Chemical analyzes of biological fertilizers were performed at the Plant Tissue Analysis Laboratory at UFPB, Campus II, Areia-PB. The results can be seen in Table 3.

Table 2: Details of treatments regarding the times and doses of application of biological fertilizers

Treatments	Application times (DAT)	0	30	60
		Doses in dm³ ha^{-1}		
1	0.00	100.00		
2	0.00	200.00		
3	0.00	300.00		
4	0.00	400.00		
5	30.00	50.00	50.00	
6	30.00	100.00	100.00	
7	30.00	150.00	150.00	
8	30.00	200.00	200.00	
9	60.00	33.33	33.33	33.33
10	60.00	66.66	66.66	66.66
11	60.00	100.00	100.00	100.00
12	60.00	133.33	133.33	133.33
13	Absolute witness	0.00	0.00	0.00

Fig 2. Experimental plots of bell pepper cultivation under doses and times of application of biological fertilizers.

Irrigation was performed by dripping, adopting irrigation depth according to the methodology proposed by Bernardo et al. (2009), to determine the total irrigation required and the application time, with the aid of electronic sensors for determining soil moisture model Hidrofarm, model (HMF2030 / Falker®). The water came from the São Francisco River and the average daily-applied layer was 9.12 mm per plant, divided into two 4.56 mm applications, in the early morning and late afternoon. On days when there was enough rain, irrigation was suspended, completing when necessary. The water analysis was performed at the Soil Analysis Laboratory of UFPB, Campus II, Areia-PB. The results can be seen in Table 4.

The variables evaluated were: soil surface temperature (Tsurf) and 10 cm deep (T_{10}), soil moisture (M) and edaphic respiration (ER). To measure the temperature, a digital thermometer with stem, model TH 1300 was used. The humidity readings were performed using the HidroFarm model HFM, through a sensor that emits electromagnetic waves in the soil.

The temperatures, humidity and edaphic respiration were determined in each experiment after the daytime (6 AM to

Table 3: Chemical analysis of biological fertilizers applied to bell pepper cultivation

Biological fertilizer	U	CO	N	P	K	Ca	Mg	S	Na	Cu	Zn	Fe	Mn	B
	%		g L^{-1}							mg L^{-1}				
BM	98.7	10.4	0.1	0.08	30.9	0.22	0.58	0.05	-	0.43	0.61	5.12	0.62	2.22
SM	98.8	11.1	0.11	0.07	24.3	0.15	0.27	0.07	-	0.46	0.54	10.6	0.51	2.13

BM: Biological fertilizer prepared with bovine manure; SM: Biological fertilizer prepared with sheep manure; U: Moisture; CO: Dichromate oxidation method; N, P, K, Ca and Mg: Digestion with H_2O_2 and H_2SO_4; S, Fe, Cu, Mn, Zn and Na: HNO_3 digestion $HCLO_4$; B: Dry combustion extraction

Table 4: Chemical analysis of irrigation water used in the cultivation of bell peppers

pH	C.E.	SO_4^{-2}	Mg^{2+}	Na^+	K^+	Ca^{2+}	CO_3^{-2}	HCO_3^{-2}	Cl	SAR	PST	Classification
	dS m^{-1}	mg L^{-1}	mmol$_c$ L^{-1}									
6.7	0.09	0.0	0.18	0.2	0.1	0.1	0.0	1.2	0.3	0.6	0.0	C1S1

E.C: Electrical conductivity at 25°C; SAR: Sodium adsorption ratio; PST: Percentage of exchangeable sodium. C_1S_1: Richards (1954)

6 PM) and night (6 PM to 6 AM) periods, on consecutive days, using the method described by Grisi (1978). Each experimental plot had a vase (plastic buckets with a capacity of eight liters) and inside, containers with a capacity of 100 cm^3, containing 10 cm^3 of 0.5 N KOH to capture CO_2 released from the soil, within 12 hours.

After placing the solution, a container remained closed, being used as a control. The remaining containers were opened only when placing them in the hoods. The edges of these were covered with soil, preventing gas exchange with the environment. After 12 hours, the containers were collected and closed immediately after opening the bells.

The CO_2 released from the soil was quantified by the KOH titration of the containers using 0.1 N HCl, observing the spent volume of this acid solution between two turning points. In the first, after adding two drops of 1% phenolphthalein, the solution turns pink and then the HCl is added until it is clear. At the second turning point, after the addition of two drops of 1% methyl orange, the solution gains an orange color and then titration with HCl is performed until it reaches the pink color again.

Edaphic respiration was calculated according to the following equation (Grisi, 1978):

$$ER = \frac{352\,.(\Delta V_A - \Delta V_C)\,.N_B\,.N_A}{3\,.P\,.A_B} 10^4$$

Where, ER is the mass of CO_2 (mg m^{-2} h^{-1}), ΔVA is the difference in the volume of HCl spent on the first and second turning of the sample titration (cm^3), ΔVC is the difference in the volume of HCl spent in the first and second turning of the control titration (cm^3), NA is the concentration of HCl (n-eq L^{-1}), NB is the concentration of KOH (n-eq L^{-1}), P is the period the sample remains in the container (hours) and AB is the bucket opening area (cm^2).

The data collected in the experiments were subjected to the test of normality (Shapiro-Wilk) and homogeneity (Bartlett), and then subjected to analysis of variance. When they showed significant differences by the F test, the average Tukey test at 5% probability was performed for qualitative factors and regression analysis for quantitative ones. To compare the combinations of factors with the additional treatment, Dunnet's test at 5% probability was performed. The statistical program used was the R (R Core Team, 2018) and the ExpDes (Ferreira et al., 2018) and multcomp (Hothorn et al., 2008) packages.

RESULTS AND DISCUSSION

According to the analysis of variance (Table 5), there was a significant difference between biological fertilizers in the two shifts evaluated, for the variables soil surface temperature (Tsurf), soil temperature 10 cm deep (T_{10}), and edaphic respiration (ER). While the soil moisture variable (M), showed a difference only in the night shift.

The bovine biological fertilizer (BM) provided higher values of Tsurf and T_{10} at night (Table 5), which can be explained by the rain event (12.5 mm) that occurred before the evaluation of the area under application of the biological fertilizer (SM), which possibly led to a reduction in Tsurf and T_{10}, presenting a superiority of 15.90 and 18.11%, respectively. As for soil moisture, there was a difference between the biological fertilizers tested only at night, where SM showed superiority of 20.61%. Can be associated with the rain event that occurred before the evaluation.

Regarding edaphic respiration both at night and during the day (Table 5), higher averages are observed with the use of SM equivalent to the superiority of 25.39 and 32.67%, respectively when compared with BM. Edaphic respiration is influenced by several factors such as humidity, temperature, structure, texture and amount of organic matter in the soil (Silva et al., 2010), considering the organic carbon content of the inputs (Table 3), SM had a higher content (11.1%) while BM had 10.4%, which may have

Table 5: Summary of analysis of variance of soil surface temperature (Tsurf), soil temperature at 10 cm depth (T_{10}) and edaphic respiration (RE), in the night and day periods, in soil cultivated with pepper under biological fertilizers, doses and application seasons

	NIGHT			
SV	T surface	T 10 cm	M	ER
		P		
Season (S)	0.7877^{ns}	0.7359^{ns}	0.6275^{ns}	0.4837^{ns}
Dose (D)	0.7421^{ns}	0.7795^{ns}	0.7359^{ns}	0.897^{ns}
Fertilizers (F)	0**	0**	0.0013**	< 0.001**
S×D	0.2665^{ns}	0.3925^{ns}	0.5982^{ns}	0.9408^{ns}
S×F	0.6635^{ns}	0.6302^{ns}	0.2942^{ns}	0.8196^{ns}
D×F	0.5151^{ns}	0.5563^{ns}	0.2276^{ns}	0.9151^{ns}
S×D×F	0.2181^{ns}	0.2994^{ns}	0.8652^{ns}	0.6573^{ns}
CV (%)	33.85	33.88	12.22	0.72
BM	7.86^{a}	7.95^{a}	17.75^{b}	264.30^{b}
SM	6.61^{b}	6.51^{b}	22.36^{a}	354.25^{a}
	DAY			
SV	T surface	T 10 cm	U	RE
		P		
Season (S)	0.8754^{ns}	0.7803^{ns}	0.5143^{ns}	0.564^{ns}
Dose (D)	0.7442^{ns}	0.7107^{ns}	0.3823^{ns}	0.3163^{ns}
Fertilizers (F)	0**	0**	0.1148^{ns}	0**
S×D	0.4931^{ns}	0.584^{ns}	0.647^{ns}	0.8192^{ns}
S×F	0.5114^{ns}	0.2779^{ns}	0.5045^{ns}	0.9918^{ns}
D×F	0.9856^{ns}	0.971^{ns}	0.6888^{ns}	0.5376^{ns}
S×D×F	0.5394^{ns}	0.4115^{ns}	0.6355^{ns}	0.4272^{ns}
CV (%)	24.71	20.14	15.19	0.95
BM	10.86^{b}	11.50^{b}	-	223.51^{b}
SM	12.04^{a}	12.82^{a}	-	331.99^{a}

BM and SM: Biological fertilizer for cattle and sheep, respectively; SV: Source of variation; P: probability of the difference between treatments and interactions; **, * significant at the level of 1 and 5% probability ($p<0.01$ and $p \geq 0.05$), respectively; ns: Not significant. Values followed by the same letter in the column do not differ statistically. T: °C, M: % and ER: mg CO_2 m^{-2} h^{-1}

influenced the superiority of SM's edaphic respiration, because a greater amount of substrate for microbial activity, emits a greater amount of CO_2 into the atmosphere as the organic material was decomposed (Novak et al., 2018).

In the short term, the greater microbial activity promotes an increase in the availability of nutrients for plants, due to the greater decomposition of soil organic matter and mineralization, causing immediate effects on crops. In the long run, there is a reduction in the incorporation of C in the cell tissue, losing it to the atmosphere in the form of CO_2 (Souza et al., 2010; Santos et el., 2015).

In the daytime, the plots treated with SM obtained higher values Tsurf and T_{10} corresponding to increases of 9.80 and 10.29% in relation to those that were treated with BM (Table 5). The superiority of the variables analyzed with the use of SM provides an alternative for cultivation with this input in the bell pepper culture, which is explained by the fact that sheep manure presents faster degradation and with a shorter decomposition period than bovine manure (Medeiros et al., 2015).

Furthermore, goat manure is considered to be one of the most active and concentrated fertilizers, since 250 kg of sheep manure produce the same effect as 500 kg of cattle manure, it has good levels of nitrogen, phosphorus and potassium and its structure is soft, more solid and much less watery than cattle manure, providing aeration and therefore faster fermentation (Alves and Pinheiro, 2008).

When analyzing the times and doses of application of biological fertilizers at night (Fig. 3) and day (Fig. 4), it is noted that both fertilizers did not show significant differences in applications and dosages, for the soil surface temperature variables (Tsurf), soil temperature 10 cm deep (T_{10}), humidity and soil edaphic respiration (ER). Probably, because the bell pepper culture has a relatively short cycle, the application intervals, as well as, the quantities have not shown significant responses in the evaluated components.

There is only an increase in Tsurf and T_{10} in the 30-day application using BM, while there are reductions in SM treatments due to the increase in the application period during the night shift (Fig. 3). At the same time, the increase for manure caused a decrease in Tsurf and T_{10} in both biological fertilizers (Fig. 3).

Simultaneously, there was an increase in humidity with the addition of manure and application periods in both fertilizers, consequently, the edaphic respiration decreased because of this increase (Fig. 3), with the same behavior in humidity and edaphic respiration observed during the day (Fig. 4).

Zagatto (2018) observed a positive correlation between soil moisture and edaphic respiration, were in the dry season, when soil moisture was lower, there was a reduction in microbial activity, that is, less edaphic respiration. Soil temperature and humidity showed a negative correlation in a study by Valentini et al. (2015), evaluating edaphic respiration in two degraded areas (forest and anthropized area), obtaining average values of 130.6 and 86.7 mg CO_2 m^{-2} h^{-1}, respectively. Souto et al. (2009) performing the same type of assessment in an area cultivated with jurema-preta and a degraded area with a bare area, observed a maximum edaphic respiration value of 73.04 mg CO_2 m^{-2} h^{-1}.

The results obtained by the aforementioned authors are considerably lower than those of the present study (354.25 and 331.99 mg CO_2 m^{-2} h^{-1} in the night and day periods with SM) (Figs. 3 and 4), emphasizing that they did not perform any type of addition of microorganisms, relying only on the natural microbial community of the soils. Thus, it is important to emphasize that the application of biological

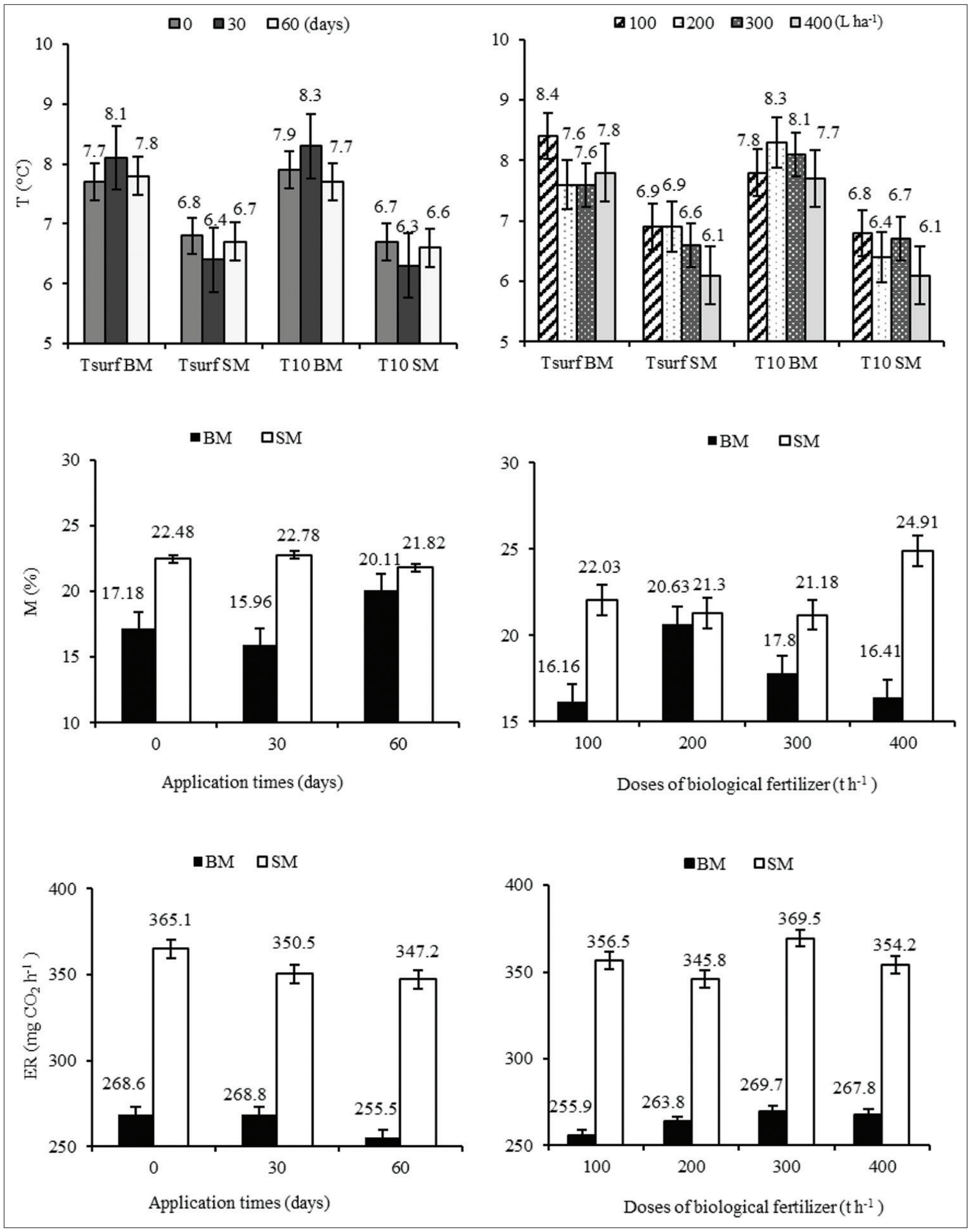

Fig 3. Averages of soil surface temperature (Tsurf), and 10 cm deep (T_{10}), soil moisture (M) and edaphic respiration (ER) cultivated with bell pepper under biological fertilizers, doses and application times in the night evaluation period. BM and SM: Bovine and Sheep Biological Fertilizer, respectively.

fertilizer provides an increase in edaphic respiration, and further studies should be performed that demonstrate differences in the microbiological composition and ease of degradation of the organic matter of each organic input, justifying these results.

Toniazzo et al. (2018) verified the increase of soil edaphic respiration in soil under application of swine manure treated in dung, biodigester and in natural form, observing high peaks in microbial activity due to the applied organic matter being easily decomposed.

In the period of determination of edaphic respiration in the present study, high temperature and relative humidity of the air were observed, which may justify the high values obtained, because, according to Valentini et al. (2015) the hot and humid climate accelerates the decomposition of soil organic matter by increasing microbial activity, consequently causing greater production of CO_2.

When comparing all treatments (sources of variation) with the additional treatment by the Dunnet test at 5% probability, a difference for RE was observed in the

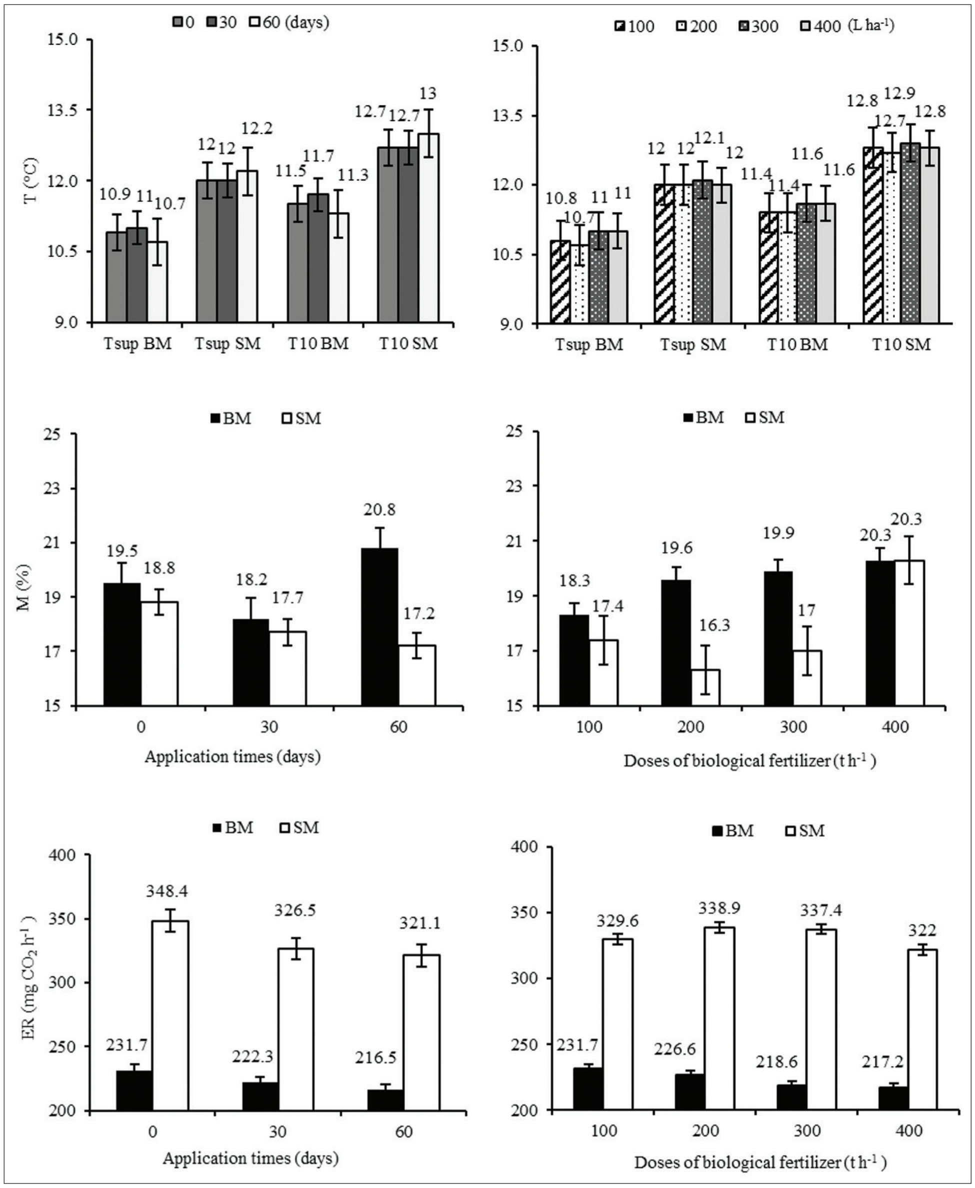

Fig 4. Averages of soil surface temperature (Tsurf) and 10 cm deep (T_{10}), soil moisture (M) and edaphic respiration (ER) cultivated with bell pepper under biological fertilizers, doses and application times in the daytime evaluation period. BM and SM: Bovine and Sheep Biological Fertilizer, respectively.

two periods evaluated, where SM was higher (Fig. 5 A). At night, all treatments showed higher values than the additional treatment, which can be explained by the lack of application of biological fertilizers, not obtaining the benefits caused by them.

A similar result was found by Holanda Neto (2011), evaluating the microbiological attributes of a constructed soil, vegetated with grasses after coal mining, where the values of the edaphic respiration referring to the treatments did not differ from the control.

During the day, treatments 4 (time 0 days and dose 400 $dm^3 ha^{-1}$) and 7 (time 30 days and dose 300 $dm^3 ha^{-1}$) obtained higher values than the additional treatment, probably because edaphic respiration showed lower values during the day, reducing the contrasts with the value of the additional treatment (Fig. 5 B).

These results can assist in the assessment of the adopted crop management, considering that this is a quality parameter that has a direct influence on soil fertility and on crop development (Novak et al., 2018).

SM provided the highest ER in the two shifts evaluated. For nighttime assessments, all treatments using SM showed greater edaphic respiration compared to additional treatment. In addition, during the day, only the treatments

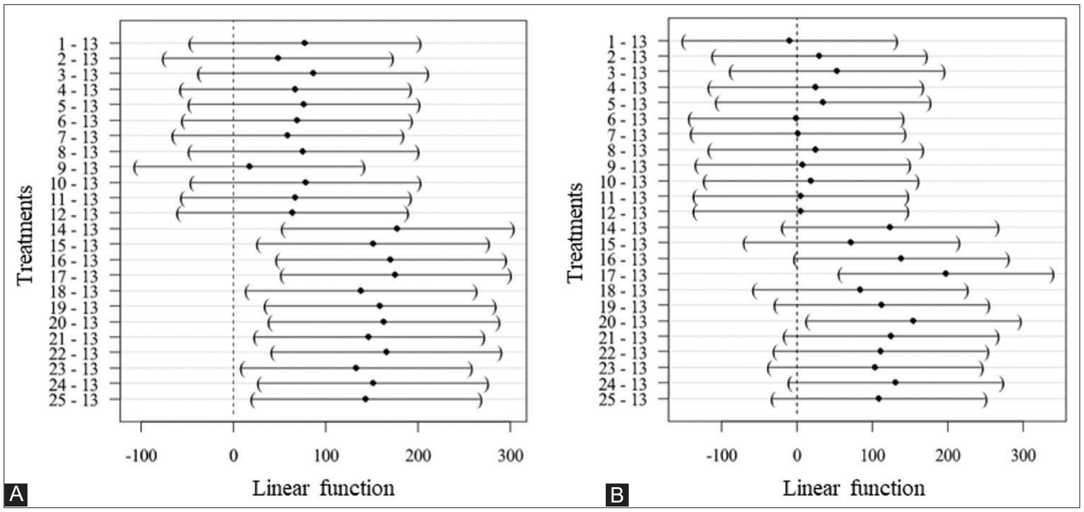

Fig 5. Dunnet test at 5% probability for edaphic respiration in the night (A) and day (B) periods. Treatments 1 to 12: referring to the experiment with bovine biological fertilizer; Treatments 14 to 25: referring to the sheep biological fertilizer experiment; 13: additional treatment.

in which 400 and 300 $dm^3\ ha^{-1}$ of SM were applied, at times of 0 and 30 DAT, respectively.

CONCLUSIONS

The biological fertilization based on sheep manure (SM) provides higher values of edaphic respiration in the two shifts evaluated, as well as higher values of temperature on the soil surface at 10 cm depth, during the day.

The use of 400 and 300 $dm^3\ ha^{-1}$ of SM, at times of 0 and 30 DAT, respectively, provided greater edaphic respiration in relation to the absence of manure during the day.

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Author's contributions

All authors contributed to the work presented here, read and approved the final manuscript. Ygor Henrique Leal and Thiago Jardelino Dias conceived, designed the experiments, analyzed the data and wrote the paper. Márcia Paloma da Silva Leal, Toshik Iarley da Silva, Marcos Fabricio Ribeiro de Lucena and Lucas Soares Rodrigues helped out the experiments in field, collected and tabulated the data. The authors Valéria Fernandes de Oliveira Sousa, Aline das Graças Souza and Oscar José Smiderle contributed to the review of the work.

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