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Gas exchange and leaf contents in bell pepper under energized water and biofertilizer doses

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Key words:
Capsicum annuum L.
organic fertilization
photosynthesis

A B S T R A C T

The objective of this study was to evaluate the effect of energized water and bovine biofertilizer doses on the gas exchange and NPK contents in leaves of yellow bell pepper plants. The experiment was conducted at the experimental area of the Federal University of Ceará, in Fortaleza-CE, Brazil, from June to November 2011. The experiment was set in a randomized block design, in a split-plot scheme; the plots were composed of treatments with energized and non-energized water and the subplots of five doses of liquid biofertilizer (0, 250, 500, 750 and 1000 mL plant^{-1} week^{-1}). The following variables were analyzed: transpiration, stomatal conductance, photosynthesis and leaf contents of nitrogen (N), phosphorus (P) and potassium (K). Water energization did not allow significant increases in the analyzed variables. The use of biofertilizer as the only source of fertilization was sufficient to provide the nutrients N, P and K at appropriate levels for the bell pepper crop.

Palavras-chave:
Capsicum annuum L.
fertilização orgânica
fotossíntese

Trocas gasosas e teores foliares no pimentão sob água energizada e doses de biofertilizante

R E S U M O

Objetivou-se, neste trabalho, avaliar o efeito da aplicação de água energizada e doses de biofertilizante bovino, nas trocas gasosas e nos teores foliares de NPK em plantas de pimentão amarelo. O experimento foi realizado na área experimental da Universidade Federal do Ceará, em Fortaleza–CE, no período de junho a novembro de 2011. O delineamento experimental foi em blocos casualizados no esquema de parcelas subdivididas, constituídas pelos tratamentos água energizada e não energizada e as subparcelas por cinco doses de biofertilizante líquido (0, 250, 500, 750 e 1000 mL planta^{-1} semana^{-1}). Foram analisadas as seguintes variáveis: transpiração, condutância estomática, fotossíntese e teores foliares de nitrogênio (N), fósforo (P) e potássio (K). A energização da água não possibilitou elevações significativas nas variáveis analisadas. O uso do biofertilizante como única fonte de adubação foi suficiente para disponibilizar os nutrientes NPK em níveis adequados para a cultura do pimentão.

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Introduction

Water is an essential factor in agriculture and there is the need for searching new technologies aiming its better use (Charlo et al., 2009). After an energization treatment using Aquatron®, water can become more available to plants, since, when pumped to the device, it receives an energy charge that makes its molecules freer, promoting higher absorption (Aquatron, 2015).

Evaluating the production of yellow pepper irrigated with energized water and biofertilizer doses, Borges et al. (2014) concluded that this water treatment did not promote significant alterations in the cultivation under ideal water conditions.

Organic fertilizers, such biofertilizers, have been studied in vegetables (Sediyama et al., 2014) and constitute strategic alternatives for yield increment and reduction in production costs, contributing to the balanced supply of macro and micronutrients (Rodrigues et al., 2009; Patil, 2010). Menezes Junior et al. (2008) reported that the addition of biofertilizer met the nutritional requirements of papaya in micronutrients. Melo et al. (2013) observed that this input increased the yields of bean and corn.

There is information in the literature evidencing the benefits of using organic sources in agriculture; however, studies involving the effects of organic fertilization on gas exchanges are still scarce. Thus, this study aimed to evaluate the effect of the application of energized water and biofertilizer doses on gas exchanges and leaf contents of N, P and K of bell pepper (*Capsicum annum* L.).

Material and Methods

The experiment was carried out at the experimental area of the Agrometeorological Station, at the Federal University of Ceará (UFC), in the municipality of Fortaleza-CE, Brazil, and started in May 2011. According to Köppen's classification, the climate of the region is Aw', rainy tropical, with high temperatures and rainy season predominantly from January to May, annual means in the period from 1981 to 2011 of: rainfall, 1,606.3 mm; temperature, 27.0 °C and evapotranspiration, 1,832.7 mm.

The experiment used the bell pepper cultivar 'Sunny F1', with cycle of 173 days after transplantation (DAT). Plants were cultivated in 40-L pots (plastic buckets), filled with a 5-cm layer of crushed stone and the rest of its volume completed with a mixture of sand and soil, classified as Red Yellow Argisol (EMBRAPA, 2006), at the proportion of 1:1. A substrate sample collected at the depth of 0.2 m was homogenized and sent to the laboratory for the determination of the chemical attributes shown in Table 1, according to EMBRAPA (1997).

The treatments were distributed in randomized blocks in a split-plot scheme, with four replicates. Plots were represented by two water treatments (energized and non-energized) and subplots by five doses of liquid bovine biofertilizer (0, 250, 500, 750 and 1000 mL plant^{-1} week^{-1}), considering three plants for evaluation, in a total of 120 experimental units.

Water energization was performed using the device Aquatron® Green Machine, which consists of two parts: an electronic control panel and an energy chamber. The controller sends electromagnetic signals to the electrodes installed inside the energy chamber, through which the water passes and is subjected to energization. These signals are converted to ultra-low-frequency (ULF) waves and, according to the manufacturer, they modify the arrangement of the water molecule (from polygonal to a more linear structure), breaking its surface tension and thus facilitating its absorption by the root system. Water chemical analyses are shown in Table 2.

Irrigation was performed using a drip system, which had one line of emitters per plant row and one emitter per plant, with mean flow rate of 8 L h^{-1}. Water was daily supplied and the irrigation time was calculated based on the evaporation measured in a Class A pan. As to the biofertilizer, the doses were divided into two applications per week.

The aerobic biofertilizer was produced in a 760-L polyethylene container with a mechanical agitator using bovine manure, water, cow milk, PT-4-O (accelerator of composting of organic residues), bone flour, MB4 stone powder, brown sugar and milk. Samples of the biofertilizer were collected and chemically analyzed according to EMBRAPA (2009), showing the following results: N, P, K, Ca and Mg (g L^{-1}): 0.2, 0.1, 0.8, 4.3 and 0.7, respectively, pH = 7.23 and EC = 4.10 dS m^{-1}.

At 67 and 173 DAT, five recently-developed leaves were collected per treatment for the determination of N, P and K contents, through the methods of micro-Kjeldahl, colorimetry and flame photometry, respectively (Malavolta, 1997). Gas

Table 1. Chemical analyses of the substrate (soil + sand)

Chemical characteristics												
C	OM	pH	P	K	Ca	Mg	Na	H+Al	SB	CEC	V	SSP
g kg^{-1}			mg dm^{-3}	mmol$_c$ dm^{-3}							%	
12.83	22.12	7.0	1.064	3.68	41.5	33.5	5.61	5.8	84.3	90.1	94	0

Source: Laboratory of Soils and Water for Irrigation/IFCE of Limoeiro do Norte. C – Carbon; OM – Organic matter; SB – Sum of exchangeable bases; CEC – Cation exchange capacity; V – Base saturation; SSP – Sodium saturation percentage

Table 2. Chemical analysis of the waters used for bell pepper irrigation

Cations (m mol$_c$ L^{-1})					Anions (m mol$_c$ L^{-1})					pH	SAR	EC (dS m^{-1})	Classification
Ca^{2+}	Mg^{2+}	Na^+	K^+	Σ	Cl^-	SO_4^{2-}	HCO_3^-	CO_3^{2-}	Σ				
Non-energized water													
1.00	1.7	4.3	0.2	7.2	3.8	-	3.6	-	7.4	7.9	3.81	0.73	C_2S_1: Water with intermediate salinity and low sodium concentration
Energized water													
0.7	1.8	5.1	0.3	7.9	4.2	-	3.6	-	7.8	7.8	4.61	0.79	C_3S_1: Water with high salinity and low sodium concentration

Source: Laboratory of Soils and Water for Irrigation/IFCE of Limoeiro do Norte. ∑ = sum; SAR – Sodium adsorption rate; EC – Electrical conductivity exchanges (photosynthesis, transpiration and stomatal conductance) were measured at 100 DAT (plants were still in the reproductive stage) using an infrared gas analyzer (IRGA - LI 6400 XT, LICOR), in an open system, with air flow of 300 mL min^{-1} and measurements between 9 and 12 h, in fully expanded leaves.

The results were subjected to analysis of variance and, when significant, to regression analysis. Means referring to water energization were compared by Tukey test, when applicable, with $P < 0.05$, using the computer program Assistat (Silva & Azevedo, 2002). Biofertilizer doses were evaluated through regression and the equations that best fitted to the data were selected based on the significance of the regression coefficients at the significance levels of 0.01 and 0.05 by F test and on the highest coefficient of determination (R^2).

Results and Discussion

According to the summary of the analysis of variance (Table 3), water energization did not promote significant effect on the studied variables, except for the leaf contents of K at 67 DAT. Biofertilizer doses had effect on the leaf contents of N and P at 67 DAT and N, P and K at 173 DAT. There was significant interaction of Water energization x Biofertilizer doses for the variables transpiration, N at 67 DAT and K at 173 DAT.

The comparative analysis of the means by Tukey test for K contents at 67 DAT, as a function of water energization, is shown in Figure 1. According to the results, under the conditions of this experiment, non-energized water caused a 4.6% lower K content in the sampled bell pepper leaves.

The observed K contents are within the range considered as adequate for the crop, according to Trani & Raij (1996). The mean K content of 48.9 g kg^{-1} was higher than that reported by Araújo et al. (2007), 42.98 g kg^{-1} in bell pepper treated with biofertilizer.

Interactions between nutrients can facilitate or hamper their absorption by plants. These processes of antagonism or synergism between nutrients may have affected the effect of water energization, since the process increases the efficiency of application of biofertilizers and the absorption of some nutrients, such as N and K (Aquatron, 2015).

P contents linearly decreased with the increase in biofertilizer doses (Figure 2).

This tendency can be explained by the source-sink relationship based on the number of fruits obtained at each dose. In the control and at the lowest dose, the mean number

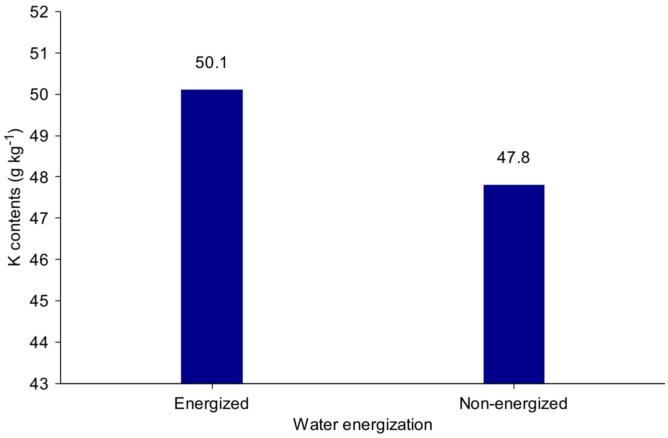

Figure 1. Potassium (K) contents in bell pepper leaves at 67 days after transplantation, as a function of irrigation with energized and non-energized water

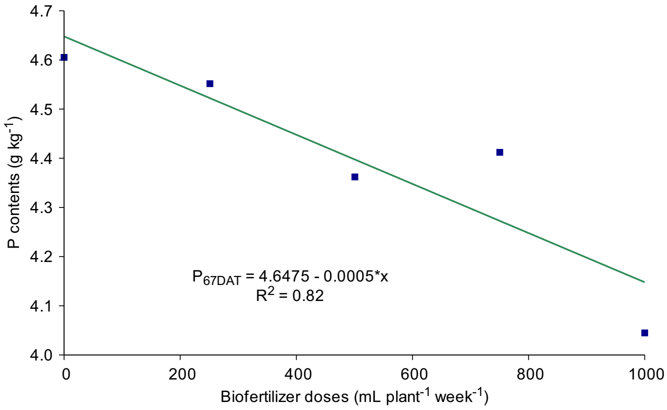

Figure 2. Phosphorus (P) contents in bell pepper leaves at 67 days after transplantation (DAT), as a function of different doses of biofertilizer

of fruits per plant was 7, which is surpassed by the doses of 750 and 1000 mL $plant^{-1}$ $week^{-1}$, which showed mean of 10 fruits per plant. At 67 DAT, the plant was already producing fruits and the contents of P were possibly being transferred to the sink (fruits).

At all biofertilizer doses, the mean P contents remained within the range considered as adequate for the crop, varying from 2 to 8 g kg^{-1} (Trani & Raij, 1996). The highest P content (4.6 g kg^{-1}) was observed at the dose zero and is higher than that reported by Santoro et al. (2013), 2.4 g kg^{-1}.

Leaf N contents in bell pepper at 173 DAT as a function of biofertilizer doses best fitted to a quadratic polynomial regression model (Figure 3). The N content reached its

Table 3. Summary of the analysis of variance for the values of photosynthesis (A), stomatal conductance (gs), transpiration (E) and leaf contents of N, P and K as a function of the application of energized and non-energized water and different doses of biofertilizer in bell pepper

Source of variation	DF	Mean square								
		A	gs	E	N (67 DAT)	P (67 DAT)	K (67 DAT)	N (173)	P (173)	K (173)
Water energization (En)	1	4.290^{ns}	0.003^{ns}	7.009^{ns}	0.056^{ns}	0.011^{ns}	37.969*	0.023^{ns}	0.036^{ns}	15.769^{ns}
Residue (a)	4	50.205	0.016	1.832	1.409	0.088	1.981	3.454	0.994	7.881
Biofertilizer (Bio)	4	12.666^{ns}	0.007^{ns}	1.402^{ns}	14.602*	0.289*	4.378^{ns}	6.548*	0.857**	46.050*
Interaction En x Bio	4	15.272^{ns}	0.009^{ns}	2.995*	14.790*	0.107^{ns}	9.891^{ns}	4.027^{ns}	0.232^{ns}	46.050*
Residue (b)	16	6.601	0.004	0.737	3.583	0.065	5.059	1.767	0.085	10.444
CV – a (%)	-	49.73	49.07	22.39	3.74	6.77	2.87	9.18	14.32	6.38
CV – b (%)	-	18.03	24.00	14.20	5.97	5.82	4.59	6.57	4.19	7.34

*Significant F test at 0.05; **Significant by F at 0.01; ^{ns}Not significant, CV – Coefficient of variation; DF – Degrees of freedom; DAT – Days after transplantation

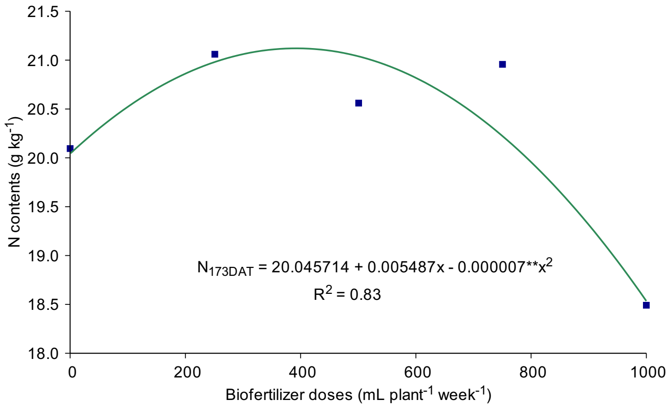

Figure 3. Nitrogen (N) contents in leaves of bell pepper at 173 days after transplantation (DAT), as a function of different doses of biofertilizer

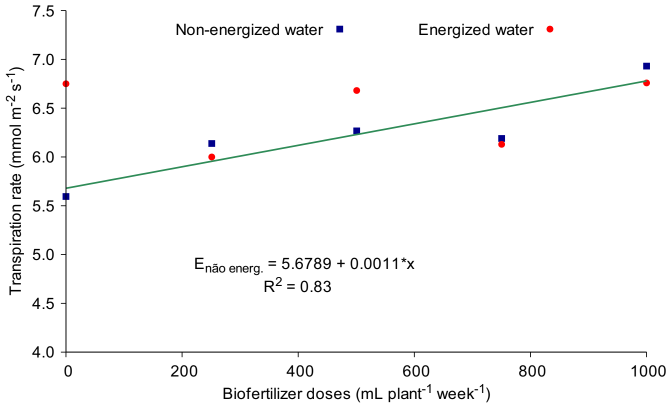

Figure 4. Transpiration rate of bell pepper plants at 100 days after transplantation, as a function of irrigation with energized and non-energized water and doses of liquid biofertilizer

maximum value of 20.80 g kg^{-1} at the dose of 275 mL $plant^{-1}$ $week^{-1}$; in this period, N contents remained below the recommended range (Trani & Raij, 1996), but the crop was in the fruiting stage and, probably, the nutrients of the leaves might have been exported to the fruits.

Considering the P contents in the same period and the biofertilizer doses, the data best fitted to an increasing linear function, with R^2 of 0.59. P contents ranged from 6.81 to 7.26 g kg^{-1}. Under these conditions, the following equation was generated: $P_{173DAT} = 6.596 + 0.0007^{**}x$. Therefore, there was an inversion of the tendency, compared with the analysis performed at 67 DAT. This positive influence of biofertilizer doses observed at the end of the harvests probably occurred because of the accumulation of nutrients for a new cultivation cycle. These results corroborate those of Menezes Júnior et al. (2014), who observed P accumulations increasing linearly with the increment in biofertilizer doses, but are different from those of Alves et al. (2009), who reported increase in P contents with the biofertilizer doses, which, when high, reduced these contents.

At 100 DAT, the transpiration rate of bell pepper as a function of biofertilizer doses, when plants were irrigated with energized water, best fitted to a quadratic polynomial model, with coefficient of determination of 0.31, generating the following equation: $E_{energ.} = 6.6503 - 0.0017x + 0.000002^{*}x^2$. Plants showed transpiration rate of 6.29 mmol m^{-2} s^{-1} with the estimated dose of 425 mL $plant^{-1}$ $week^{-1}$. The transpiration rate data obtained with the application of non-energized water at 100 DAT, as a function of biofertilizer doses, fitted to an increasing linear model (Figure 4). The values of transpiration rate varied from 5.59 to 6.93 mmol m^{-2} s^{-1}.

The application of biofertilizer at different doses with evident increase in the application of organic matter and nutrients and daily irrigation interval may have caused improvement in soil and plant water conditions, leading to the maintenance of absorption of water and cell turgor, allowing gas exchanges between the plants and the environment (Taiz & Zeiger, 2009).

Silva et al. (2011) report that the beneficial effects of the application of bovine biofertilizer on transpiration are due to the stimulus to the action of proteins and organic solutes, resulting in better nutritional conditions in the soil and in the plants. Similar results were found by Freire et al. (2014), who observed an increment of 97.7% in the transpiration rate of yellow passion fruit under treatments with bovine biofertilizer and utilization of mulch. Sarmento et al. (2011), evaluating organic sources and times of incorporation in beet cultivation, observed that transpiration did not show significant variations as a function of the applied treatments.

The significant interaction of Water energization x Biofertilizer doses for the N contents at 67 DAT is shown in Figure 5.

For irrigation with non-energized water, there was an increasing linear tendency for the values obtained in the period, as the biofertilizer doses increased. The highest biofertilizer dose caused the highest N content; however, when plants were irrigated with energized water, the N content fitted to a quadratic polynomial model, reaching the lowest value of 30.41 g kg^{-1} at the biofertilizer dose equivalent to 507 mL $plant^{-1}$ $week^{-1}$.

The mean N contents in bell pepper leaves are within the range considered as adequate for the crop (Trani & Raij, 1996), except for the control treatment, irrigated with non-energized water, which showed N content of 27.78 g kg^{-1}; the other treatments showed variation from 30.33 to 35.53 g kg^{-1} of N.

Alves et al. (2009), evaluating the nutritional status of bell pepper (*Capsicum annuum* L.), observed N contents from

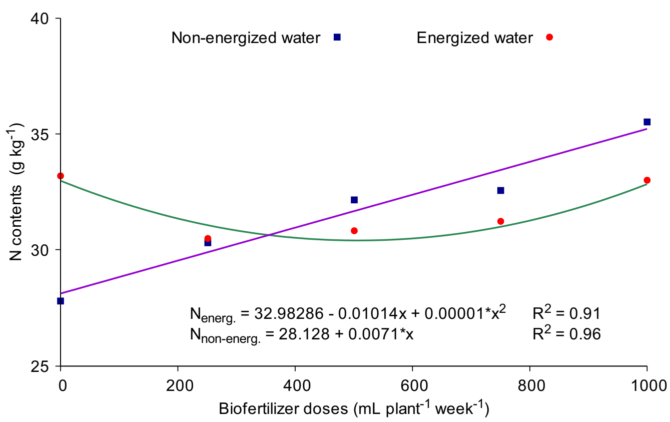

Figure 5. Nitrogen (N) contents in leaves of bell pepper at 67 days after transplantation, as a function of irrigation with energized and non-energized water and doses of liquid biofertilizer

30.88 to 33.50 g kg^{-1}, which are consistent with those found in the present study. Cavalcante et al. (2010) and Duarte et al. (2010), working under field conditions, observed increase in N contents in okra and watermelon plants fertilized with goat, cattle and chicken manure as organic sources, respectively.

At 173 DAT, only K contents were influenced by the interaction of Water energization x Biofertilizer doses (Figure 6). The highest K content for non-energized water with the increase in biofertilizer doses was equal to 48.59 g kg^{-1}, obtained at the dose of 800 mL $plant^{-1}$ $week^{-1}$. Considering the data for energized water as a function of the applied biofertilizer doses, there was a linear fit and the highest K content was equal to 47.7 g kg^{-1} at the highest dose of biofertilizer.

As observed in the present study, Sedyiama et al. (2014) evaluated the use of biofertilizers based on swine manure in colored pepper and found adequate values of nutrients in the leaves, thus indicating that the biofertilizer promoted adequate nutrition for the plants, probably because of its composition. These results differ from those obtained by Oliveira et al. (2014), who analyzed the nutritional status and characteristics related to the yield of pepper fruits in response to the application of liquid biofertilizers and observed that, except for calcium contents, the evaluated nutrients were below the range considered as adequate for the crop.

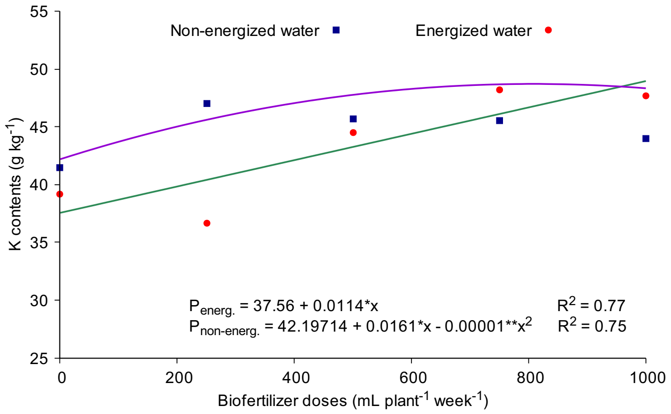

Figure 6. Potassium (K) contents in leaves of bell pepper at 173 days after transplantation, as a function of irrigation with energized and non-energized water and doses of liquid biofertilizer

Conclusions

1. Water energization allowed significant increase only in potassium contents.

2. The use of biofertilizer as the only source of fertilization was sufficient to provide the nutrients N, P and K at adequate levels for the bell pepper crop.

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