

Yield of strawberry crops under different irrigation levels and biofertilizer doses¹

Produção da cultura do morango sob diferentes lâminas de irrigação e doses de biofertilizante

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ABSTRACT - Strawberry is produced and appreciated in different regions of the world, due to its productive and commercial characteristics. Biofertilizer is an organic fertilizer that is easy to prepare and effective to nourish plants. The objective of this work was to assess the effect of different irrigation levels and anaerobically fermented bovine biofertilizer doses, on biomass accumulation and strawberry crop yield. The experiment was carried out in the experimental area of the UFC, in Fortaleza, Ceará, Brazil, from August to December 2012, under a screened environment. The experimental design was randomized blocks designed into subdivided plots, in which irrigation levels were applied via drip irrigation (equivalent to 33.3, 66.6, 100, 133.3 and 166.6% of the evaporation measured in the Class A tank - ECA), corresponding to the plots. The four doses of bovine biofertilizer (125, 250, 375 and 500 mL plant⁻¹ week⁻¹) were the subplots, with four replications. The assessed parameters were: biomass (root, shoot and total dry matter), fruit diameter, fruit length, number of fruits per plant, average fruit mass and yield. The biofertilizer and irrigation increased strawberry shoot biomass and total biomass. The interaction between irrigation and bovine biofertilizer raised the root matter to 3.7 g. The biofertilizer was nutritionally efficient for the strawberry regarding number of fruit, fruit diameter and yield. Irrigation increased strawberry length and average mass.

Key words: *Fragaria x ananassa Duch.* Organic input. Hydric stress.

RESUMO - O morango é produzido e apreciado nas mais variadas regiões do mundo, devido às suas características produtivas e comerciais. Já o biofertilizante é um adubo orgânico de fácil preparo e eficaz para nutrir as plantas agrícolas. O objetivo deste trabalho foi avaliar o efeito de diferentes lâminas de irrigação e doses de biofertilizante bovino de fermentação anaeróbica, sobre o acúmulo de biomassa e a produtividade da cultura do morango. O experimento foi realizado na área experimental da UFC, em Fortaleza-CE, no período de agosto a dezembro de 2012, sob ambiente protegido do tipo telado. O delineamento experimental foi em blocos casualizados em esquema de parcelas subdivididas, em que as lâminas de irrigação foram aplicadas via gotejamento (equivalentes a 33,3; 66,6; 100; 133,3 e 166,6% da evaporação medida no tanque classe A, ECA), constituindo as parcelas. As quatro doses de biofertilizante bovino (125; 250; 375 e 500 mL planta⁻¹ semana⁻¹) foram as subparcelas, com quatro repetições. Os parâmetros avaliados foram: biomassa (matéria seca da raiz, da parte aérea e total), diâmetro dos frutos, comprimento dos frutos, número de frutos por planta, massa média dos frutos e produtividade. O biofertilizante e a irrigação promoveram incrementos na biomassa da parte aérea e total do morangueiro. A interação entre irrigação e biofertilizante bovino eleva a matéria da raiz até 3,7 g. O biofertilizante apresenta eficiência nutricional para o desempenho do morangueiro quanto ao número de frutos, diâmetro do fruto e a produtividade. A irrigação elevou o comprimento e massa média de frutos do morangueiro.

Palavras-chave: *Fragaria x ananassa Duch.* Insumo orgânico. Estresse hídrico.

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INTRODUCTION

Strawberry is a herbaceous plant that belongs to the family Rosaceae and the genus *Fragaria*. It is cultivated in cold regions and also in tropical and subtropical climates. This wide geographic distribution occurs due to this fruit's high capacity for adaptation to the conditions of culture and of climate (MORALES *et al.*, 2012).

This crop is highly demanding in terms of water availability, hence the need for irrigation, mainly in regions where rainfall regimes are not enough or do not present an adequate distribution to supply the crop's water demand (STRASSBURGER *et al.*, 2009). It is worth noting that in irrigated agriculture, it is necessary to know the determinants of irrigation management (SOUSA *et al.*, 2014), soil moisture storage (PIRES *et al.*, 2007) and crop water needs.

Some research on water deficit has been developed and applied to strawberry crops by several researchers. Pires *et al.* (2007), analyzing the effect of different irrigation levels, observed higher yields of marketable fruits, number of fruits and average weight of fruits in a 10 and 35 kPa tension in protected environments. Teixeira *et al.* (2013) state that water tension around 15 kPa at a depth of 0.15m results in higher total fresh mass, number of fruits per plant and total yield.

Agricultural production generates different residues, which are mostly organic and can be reused as organic fertilizer. They are an important alternative to mineral fertilizers that come from scarce and expensive sources. Among these fertilizers are liquid biofertilizers, which are produced from the fermentation of organic matter with water, with or without air. In their composition they have almost all macro- and micronutrients necessary for plant nutrition, depending on the material used (VIANA *et al.*, 2013).

Several studies with biofertilizers in different crops show positive results. Among them, Mazaro *et al.* (2013) assessed strawberry yield and quality, and observed an increase in yield, average fruit mass and number of fruits due to higher concentrations of the *supermagro* biofertilizer. Dias *et al.* (2011) observed an increase in passion fruit yield due to the increased frequency of biofertilizer application. Chiconato *et al.* (2013), studying lettuce crops, observed that higher doses of biofertilizer resulted in more developed crops. However, excess nutrients can lead to stabilization and crop yield decline (DIAS *et al.*, 2015).

The objective of this work was to assess the effects of different irrigation levels and anaerobically fermented bovine biofertilizer doses, on the accumulation of biomass and yield of strawberry crops.

MATERIAL AND METHODS

The experiment was carried out at the Agrometeorological Station of the Department of Agricultural Engineering (DENA), at the Universidade Federal do Ceará - UFC, at Campus do Pici, Fortaleza, Ceará, Brazil, geographical coordinates: 3°44'45" S, 38°34'55" W and 19.5m altitude above sea level.

According to Köppen's classification, the climate of the region is type Aw', characterized as tropical rainforest, very hot, with rains predominant in summer and fall.

The experimental design was randomized blocks with subdivided plots, and the plots consisted of five irrigation levels (33.33, 66.66, 100, 133.33 and 166.66% of the evaporation measured in the Class "A" tank) and subplots by four doses of biofertilizer (125, 250, 375 and 500 mL per week⁻¹ plant⁻¹), with four replications.

The experiment was carried out under a screened environment consisting of anti-aphid screen, 12 m long by 6.4 m wide. To reduce radiation and temperature, an Aluminet® reflective screen was installed inside the environment, in addition to 6 lines of nebulizers at 1.60 m from the ground, with 3 nebulizers in each line.

The nebulizers were operated automatically through an electronic device (Timer). The Timer was programmed to power the system every 40 minutes and was shut down after 2 minutes of spraying, totaling 10 applications per day.

The pots were filled with a 2.5 L layer of gravel and 15 L of a substrate made of a mixture containing ariscus, coarse sand and organic compound, in the ratio of 4:3:3, respectively. The chemical analysis of the substrate is shown in Table 1.

'Oso Grande' seedlings were used, and two seedlings were transplanted in each pot. During the first week, the treatments received the same irrigation level, to standardize the initial development of the plants. The water content of the soil was taken to the condition of field capacity. After this period, the treatments were started. For monitoring soil moisture, ten tensiometers were installed at 20 cm depth in the different treatments.

The treatments used localized drip irrigation as the irrigation system. The evaporation was quantified by the Class "A" tank method, and it was installed at 30 m from the screen. The irrigation time was quantified by equation (1).

$$T_i = \frac{LLi * A_v * F_{aj}}{E_i * q_{vi}} \times 60 \quad (1)$$

Table 1 - Result of the chemical analysis of the substrate used in the strawberry before application of the treatments

Chemical Characteristics											
OM	N	Ca ²⁺	K ⁺	Mg ²⁺	Na ⁺	H ⁺ + Al ³⁺	BS	CEC	V	P	pH
(g kg ⁻¹)	----- (g kg ⁻¹) -----						(%)	(g kg ⁻¹)	-		
19.16	0.09	0.29	0.14	0.61	1.03	19	105.7	124.7	85	0.019	6.9

OM - Organic matter; BS - Base sum (Ca²⁺ + Mg²⁺ + Na⁺ + K⁺); CEC - Cation exchange capacity - [Ca²⁺ + Mg²⁺ + Na⁺ + K⁺ + (H⁺ + Al³⁺)]; V - Base Saturation - (Ca²⁺ + Mg²⁺ + Na⁺ + K⁺ / CTC) x 100; the pH was measured in aqueous extract (1: 2.5)

Where: *T_i* is the irrigation time (min); *LL_i* is the liquid irrigation level depending on the treatment (mm); *A_v* is the area of the pot (m²); *F_{aj}* is the adjustment factor (internal ECA/external ECA), 0.8 was used; *E_i* is the irrigation efficiency (0.90); *q_{vi}* is the flow per pot, depending on the treatment (L h⁻¹).

In order to meet the nutritional requirements of the plants during the strawberry cycle, the study adopted the maximum recommendation for chemical fertilization given by the Soil Chemistry and Fertility Commission (SOCIEDADE BRASILEIRA DE CIÊNCIA DO SOLO, 2004), corresponding to: 80 kg ha⁻¹ of N, 260 kg ha⁻¹ of P₂O₅ and 60 kg ha⁻¹ of K₂O. As a reference, for a stand with 50000 plants, the maximum dosage recommended per plant⁻¹ in the cycle was: 3.2 g N; 5.2 g P₂O₅ and 1.2 g K₂O.

According to Table 1, the substrate provided only 0.09; 0.019; 0.14 g kg⁻¹ of N, P and K, respectively. Multiplying the volume of the substrate in the pot (20 L) versus soil bulk density (1.4 g kg⁻¹), resulted in (28 g kg⁻¹). That is, the total N, P and K available for the plants before the application of the treatments was: 2.52; 0.53 and 3.92, respectively. Therefore, the nutritional complementation required was 0.68 of N, 4.67 of P and 2.72 of K (g plant⁻¹).

The simple bovine biofertilizer was prepared anaerobically using fresh bovine manure and water at a 1:1 ratio based on volume, for thirty days. To achieve the anaerobic system, the mixture was placed in 240-liters plastic bottles, leaving an empty space of 15 to 20 cm inside, and closed hermetically. A hose was fitted to the lid, with the other end dipped in a container with water at 20 cm, for exhaust gases (PENTEADO, 2007). The biofertilizer was supplied manually in 15 applications.

The nutrient contents (N, P, K, Ca, Mg, Fe, Cu, Zn and Mn) in the chemical composition of the biofertilizers dry matter are shown in Table 2. The analyses were performed using the methodology suggested by Malavolta, Vitti and Oliveira (1997).

At the end of the experiment (120 days after transplanting - DAT), the plants were harvested and separated into shoot (leaf + stem) and root. Afterwards, they were placed in paper bags, marked and placed in an oven at 60°C, until reaching a constant value of dry matter. The studied variables were shoot dry matter (SDM), root dry matter (RDM) and total dry matter (TDM = SDM + RDM).

The study also assessed the fruit diameter (FD) and fruit length (FL) in mm measured with a pachymeter, the number of fruits per plant (NF), the average fruit mass (FM) in g and yield (Y) in t ha⁻¹ through a precision scale.

The results were submitted to analysis of variance and according to the level of significance in the F test for the irrigation levels and biofertilizer, a regression analysis was performed at a significance level of 1% (***) and 5% (*) of probability, using the SAS program (SAS, 2000).

RESULTS AND DISCUSSIONS

According to the analysis of variance (Table 3), the interaction between irrigation levels and biofertilizer doses only influenced the root dry matter (RDM), while the shoot dry matter (SDM) and total dry matter (TDM), there was an isolated effect of the different irrigation levels and biofertilizers doses at a level of 1% of significance.

Table 2 - Composition of essential macro and micronutrients in the dry matter of the anaerobically fermented bovine biofertilizer

Biofertilizer	Mineral Elements										
	N	P	K	Ca	Mg	S	Na	Fe	Cu	Zn	Mn
----- g L ⁻¹ -----						----- mg L ⁻¹ -----					
	0.72	1.4	1	2.5	0.75	0.31	0.28	141.6	1.92	68.2	14.72

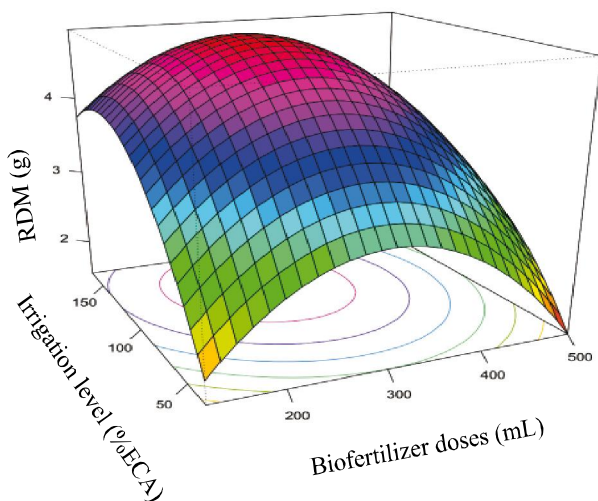
Table 3 - Summaries of the analyses of variance, by average square, referring to the average values of strawberry biomass

VS	DF	Average square		
		RDM	SDM	TDM
Block	3	0.04455 ^{ns}	1.61791 ^{ns}	1.62255 ^{ns}
Level (L)	4	1.32993**	90.20440**	105.19913**
Residue-(a)	12	0.06859	5.5217	5.48775
Biofertilizer (B)	3	3.53577**	49.00338**	70.95203**
L x B	12	0.17785**	10.78509 ^{ns}	12.41462 ^{ns}
Residue-(b)	45	0.06118	3.02856	3.13839
VC% - a		11.63	21.52	17.78
VC% - b		10.99	15.94	13.45

VS - Variation source; DF - Degrees of freedom; VC - Variation coefficient; RDM - Root Dry Matter (g); SDM - Shoot Dry Matter (g); TDM - Total Dry Matter (g); ^{ns} - Not significant, ** - Significant at 1% by the F test

Figure 1 - Root dry matter of the strawberry due to irrigation levels and bovine biofertilizer doses

$$\text{RDM} = -1.1 + 0.1318**L + 0.041**B - 0.00054**L^2 - 0.000078**B^2 + 0.000049L*B$$



The response surface presented in Figure 1 indicates that the dose of 410 mL of biofertilizer and 131.8% of ECA, interacted significantly to the maximum value of the studied variable, obtaining a polynomial behavior. This interaction provided higher values of RDM (3.7).

It is important to emphasize that the development of most crops is influenced by the conditions of the water content of the soil. Even in humid regions, water deficiency is a limiting factor for the development and accumulation of biomass. Silva *et al.* (2011), when assessing the response of carrot crops to the application of different irrigation levels, showed a similar tendency to what was found in this study.

The high decrease in root dry matter in the treatment with highest biofertilizer doses (Figure 1) can be explained by the accumulation of salts in the biofertilizer, which decreased root development even with a higher irrigation level.

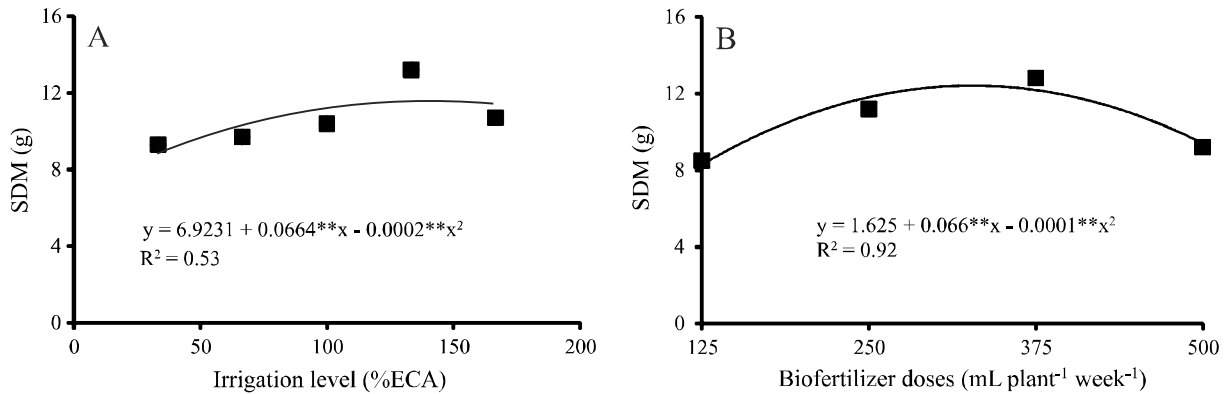
Portela, Peil and Rombaldi (2012) observed similar behavior of the strawberry RDM. According to the authors, the concentration of salts in the root environment, besides conditioning the absorption of essential nutrients, also influences the absorption of water for plant growth.

For the SDM, the quadratic polynomial model was the one that best suited the different irrigation levels, where the maximum production of SDM (12.43 g) occurred with a level equivalent to 166.5% of the ECA (Figure 2A), and for biofertilizer doses, the maximum estimate for SDM was 12.51 g, obtained at a dose of 330 mL plant⁻¹ week⁻¹ (Figure 2B).

Hydric stress affects the strawberry crop development and rate of CO₂ assimilation; thus, the plants present reduced leaf structures, independent of the biofertilizer dose. These results corroborate Chiconato *et al.* (2013) regarding lettuce crops, and Sousa *et al.* (2014) regarding peanut crops, where they observed SDM reduction at lower irrigation levels.

It should be noted that the use of organic sources in agricultural crops has already shown a positive effect on the SDM of several crops. Confirming this information, Viana *et al.* (2014) found increased dry matter in corn leaves, and Santos *et al.* (2017) in chunky banana, both fertilized with bovine biofertilizer.

Similar to this study, Santos and Trindade (2010), using goat manure as an organic source in watermelon crops, found results similar to that of this study for this variable and, similarly, Sousa *et al.* (2013), when fertilizing the cowpeas with bovine biofertilizer.

Figure 2 - Strawberry shoot dry matter due to irrigation levels (A) and biofertilizers doses (B)

Like the SDM results, polynomial equations best represent the TDM variable. The maximum estimated TDM was 15.35 g for an irrigation level of 96.56% of the ECA (Figure 3A), and 15.19 g for a biofertilizer dose of 407.5 ml plant⁻¹ week⁻¹ (Figure 3B).

This behavior reflects the proposal by Viana *et al.* (2012), in which all aspects of plant growth and development are affected by water deficit in tissues caused by excessive evaporative demand or limited water availability. Due to the water deficiency, there is a decrease in cell volume, an increase in solutes concentration and gradual dehydration of the protoplast (TAIZ; ZEIGER, 2013).

These results resemble those found by Gomes *et al.* (2005), when the authors found that in the presence of the bovine biofertilizer, 45 days after the emergence of sunflower plants, TDM was significantly higher when compared to the absence of the organic input. The results by Sousa *et al.* (2014) were also similar to the results found in this study on TDM of the strawberry crop in the coast of Ceará.

According to the analysis of variance (Table 4), the interaction between irrigation levels vs. biofertilizer doses influenced the number of fruits (NF) and yield (Y). At a level of 5% of significance, respectively. For the fruit diameter (FD), there was an isolated effect of the biofertilizer, whereas, for fruit length (FL) and fruit mass (FM), the levels were effective at 1% significance level.

Figure 4A shows the isolated effect of biofertilizer doses on fruit diameter; the polynomial model was the best fit for this variable. The bovine biofertilizer dose that most stimulated FD values was 500 mL per week⁻¹ plant⁻¹, with a diameter of 21.41 mm. While in Figure 4B, the irrigation level that most stimulated FL values was 122.5% ECA, obtaining a length of 25.23 mm with an R^2 of 0.91.

Studies that show the effect of organic sources with and without hydric stress were reported by Sousa *et al.* (2014). These authors evidenced that, when used as an organic source, bovine biofertilizer attenuated the effect of hydric stress on soil where sesame crops were grown. It is worth mentioning that the positive effect promoted by the bovine biofertilizer on yield has

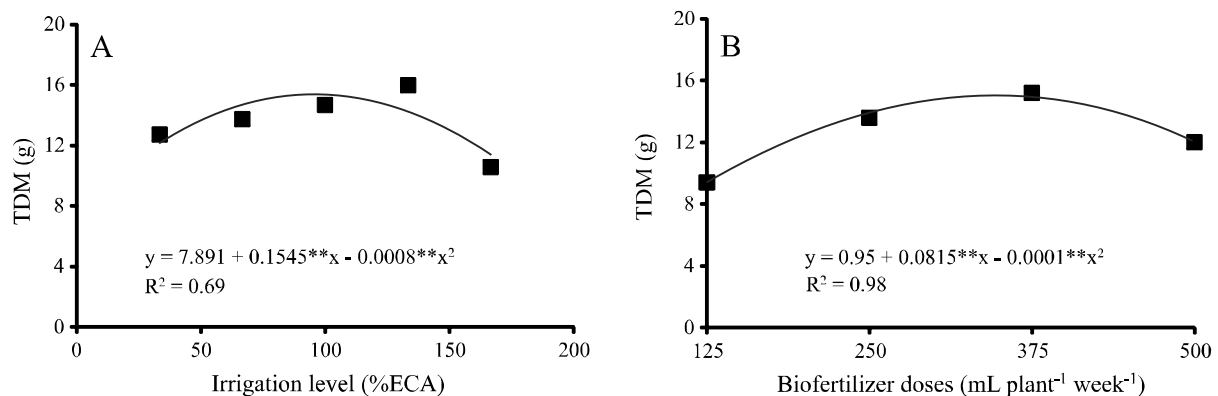
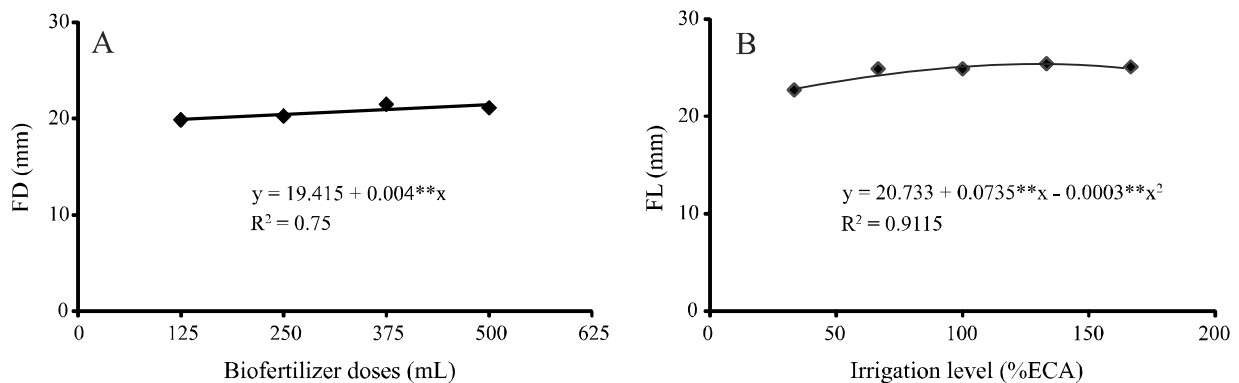
Figure 3 - Total dry matter of strawberry due to irrigation levels (A) and biofertilizers doses (B)

Table 4 - Summaries of the analyses of variance, by average square, referring to the average values of fruit diameter (FD); fruit length (FL); number of fruits per plant (NF), average fruit mass (FM) and yield (Y)

VS	DF	Average square				
		FD	FL	NF	FM	Y
Block	3	0.55063 ^{ns}	1.21185 ^{ns}	64.41250**	0.19288 ^{ns}	7.43328 ^{ns}
Level (L)	4	5.54894 ^{ns}	13.92315**	159.66875 ^{ns}	6.14859**	23.27436 ^{ns}
Residue-(a)	12	1.7821	1.3637	10.027	0.9764	2.9059
Biofertilizer (B)	3	6.51630**	7.85864 ^{ns}	180.54583**	0.80486 ^{ns}	16.82901**
LxB	12	1.81141 ^{ns}	6.30606 ^{ns}	39.78542 ^{ns}	0.83575 ^{ns}	3.58493 ^{ns}
Residue-(b)	45	0.9207	3.0313	17.849	0.7008	1.4377
VC% - a		6.44	4.75	27.87	17.24	43.98
VC% - b		4.63	7.09	37.18	14.61	30.93

VS - Variation source; DF - Degrees of freedom; VC - Variation coefficient; FD - Fruit diameter (mm); FL - Fruit length (mm); NF - Number of fruits per plant; FM - Average fruit mass (g); Y - Yield (t ha⁻¹); ^{ns}- Not significant, * - Significant at 5%, ** - Significant at 1% by the F test

Figure 4 - Fruit diameters due to fertilizer doses (A) and fruit length due to the irrigation levels (B)

already been verified by Viana *et al.* (2013) in melon crops.

It is important to emphasize that its application in agriculture is important due to the diversity of the chelated mineral nutrients available in the biological activity and as enzymatic activator of the plant metabolism (SANTOS *et al.*, 2017). This organic input also promotes a greater physical structuring of the soil, where it promotes a layer that prevents high water losses by evaporation (FREIRE *et al.*, 2011).

Guimarães *et al.* (2013), assessing the physical characteristics of the strawberry in the Vale do Jequitinhonha, report a diameter of 27 mm for the same biofertilizer ('Oso Grande'), higher than the result found in this work. On the other hand, Dias *et al.* (2015) did not obtain significant responses for this variable using the same biofertilizer ('Oso Grande').

Hydric stress can cause physiological damage to crops. It reduces the photosynthetic rate of the plants, resulting in closure of the stomata to decrease transpiration, thus affecting the absorption of CO₂; reduces leaf area, anticipates leaf senescence and compromises fruit quality (TAIZ; ZEIGER, 2013).

From the regression analysis for the number of fruits, according to the dosages of bovine biofertilizer, it was verified that the polynomial model was the most adequate, where the maximum number of fruits was 15.36 with a dose equivalent to 371 mL plant⁻¹ week⁻¹.

Possibly, the presence of salts may have had a negative influence on fruit production. Portela, Peil and Rombaldi (2012) state that salt stress reduces the absorption of essential nutrients, and consequently influences water absorption for the development of plants and more fruits.

Vignolo *et al.* (2011), assessing the production of strawberries from alternative fertilizers in pre-planting, report that 'Camarosa' biofertilizer produced 43.6 plant⁻¹ fruits and 'Camino Real' only 26.5 plant⁻¹ fruits. Rosa *et al.* (2013), studying strawberry production at different planting times, obtained 37.5 fruits plant⁻¹ for the biofertilizer 'Arazá' and 27.5 fruits plant⁻¹ for 'Yvapitá'.

Figure 6 shows the isolated effect of the irrigation levels on the average fruit mass. The linear model was the best fit for this variable. The highest irrigation level (166.66% of ECA) showed a higher average fruit mass (6.30 g), while the lowest level (33.3% of ECA) that resulted in fruit mass gain was equivalent to 20.16%.

For the yield variable (t ha⁻¹), after the regression analysis, the polynomial model was the best fit for the interaction of irrigation level and biofertilizer doses (Figure 7). The highest yield (4.65 t ha⁻¹) was obtained with the application of 327.2 mL plant⁻¹ week⁻¹ of biofertilizer.

Figure 5 - Number of strawberry fruits (g) due to irrigation levels and bovine biofertilizer doses

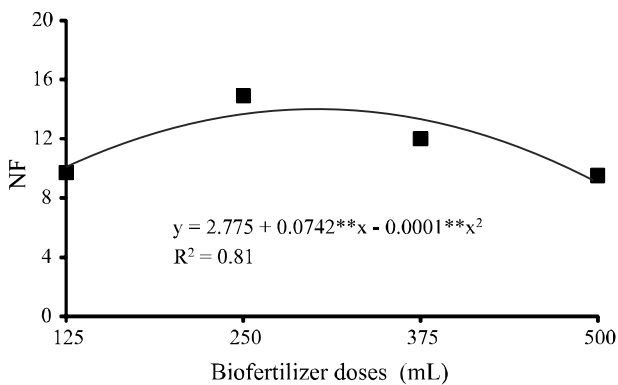


Figure 6 - Average mass of strawberry (g) due to irrigation levels

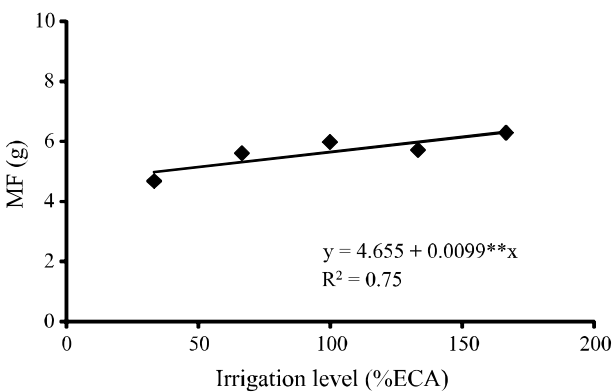
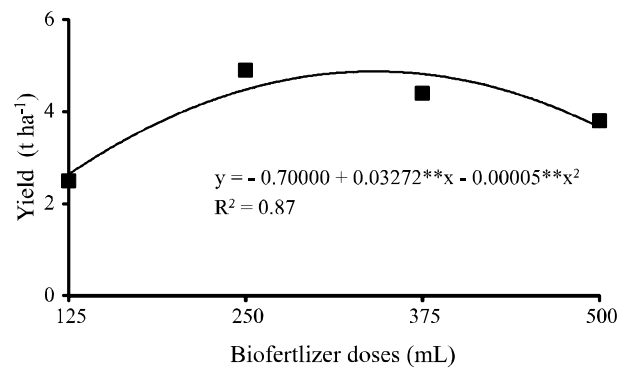


Figure 7 - Strawberry yield (t ha⁻¹) by irrigation level and bovine biofertilizer doses



This positive effect of the biofertilizer may be related to the presence of organic matter in this fertilizer, which provides direct positive effects on the soil, such as decreased compaction, increased water retention and better nutrient availability (SANTOS *et al.*, 2017).

The yield found in this study was lower than the results obtained by Dias *et al.* (2015), in the mountainous region of Maciço de Baturité. These authors obtained a yield of 10.5 t ha⁻¹ when using biofertilizer as an organic source.

Otto *et al.* (2009), when cultivating strawberry during the summer of Ponta Grossa, Paraná, Brazil, found responses of average commercial yield for the crop of Aromas 28.4 t ha⁻¹.

These changes in yield can be related to physiological and genetic factors that are altered by environmental conditions and that directly interfere with flowering and fruit development (MORALES *et al.*, 2011). Probably, the elevated temperatures may have led to a reduction in the yield of the strawberry (RESENDE *et al.*, 2010).

CONCLUSIONS

1. The biofertilizer and irrigation increased shoot biomass and total strawberry biomass;
2. The interaction between irrigation and bovine biofertilizer raised the root matter to 3.7 g;
3. The biofertilizer was nutritionally efficient for strawberry crops regarding fruit number, fruit diameter and yield;
4. Irrigation increased the length and average mass of strawberry fruits.

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