

Full Length Research Paper

Growth and efficiency of water use of papaya cultivars (*Carica papaya* L.) under doses of bovine biofertilizer in hydroponics cultivation

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Among the fruit plants cultivated in Brazil, papaya (*Carica papaya* L.) stands out by having high productivity of fruit quality. The seedling production system of this culture needs a technology that promotes the production of plants with high physiological and sanitary quality. Thus, we aimed to evaluate the growth, dry matter accumulation and the efficiency of water use of papaya cultivars under doses of bovine biofertilizer in hydroponic culture. We used a completely randomized design with eight treatments in a factorial scheme 4 x 2, with six replications, and a useful plant per repetition totalizing 48 useful plants. Four doses of biofertilizers (D = 10, 20, 30 and 40% v/v) were tested and applied in two varieties of papaya (Sunrise Solo (C1) and Tainung-01 (C2)). During the first 60 days after sowing, the papaya cultivars were evaluated for growth, dry matter accumulation and water use efficiency in accordance to their doses of biofertilizers. The cultivar Tainung-01 has a higher potential for growth, biomass accumulation and efficient use of water in comparison with the Sunrise Solo cultivar. The doses estimated of 25 and 35% (v/v) of bovine biofertilizer promoted the greater growth and dry matter accumulation for the cultivars Sunrise Solo and Tainung-01, respectively.

Key words: *Carica papaya* L., organic fertilization, hydroponics, seedling production.

INTRODUCTION

Among the fruit crops in Brazil, the papaya tree (*Carica papaya* L.) stands out for presenting high productivity of fruit quality. In the year of 2012, there was a national production of 1,517,696 tons, being the world's largest

producer and the third largest exporter of papaya, with the Northeast Region (902,000 tons) being the largest producer of this fruit, followed by the Southeast (549,000 tons), North (42,000 tons), Midwest (6,000 tons) and the

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Table 1. Chemical composition of biofertilizer solution enriched with bovine manure 60 days after the start of anaerobic fermentation.

pH	ECw (dS m ⁻¹ e)	Ca ⁺²	Mg ⁺²	Na ⁺	K ⁺	Cl ⁻	CO ₃ ²⁻	HCO ₃ ⁻	SO ₄ ²⁻	P (mg dm ⁻³)
6.34	8.08	3.71	2.40	3.27	1.69	4.59	0.43	2.03	1.02	56.00

South (4,000 tons), respectively (IBGE, 2014).

The culture has shown great economic and social expression, mainly in the states of Bahia, Espírito Santo, Rio Grande do Norte and Ceará. Regarding the exports, the state of Espírito Santo accounts for 50% of the total (Serrano and Catteano, 2010). Due to the expanded cultivated areas and the need to increase productivity and final product quality, efforts are made to always improve productivity levels and reduce production costs (Guimarães et al., 2012). Thus, new technologies have been introduced in the papaya culture aiming to raise productivity levels. As such, the use of biofertilizers and seedling production systems through hydroponics emerge as a promising alternative, considering that the phase of seedlings and their initial development interfere directly in the orchard productivity (Trinidad et al., 2000). Among the papaya cultivars most commonly grown in Brazil are those of Solo and Formosa groups. Cultivars from the 'Solo' group are intended mainly for the export market, for having smaller fruits. The main cultivars of the 'Formosa' group are imported hybrids that produce larger fruits that are intended mainly for the domestic market, being used in these conventional, integrated and organic crop practices (Hafle et al, 2009; Serrano and Cattenao, 2010).

The cultivation of papaya seedlings in a protected environment favors the production of high quality physiological and sanitary plants. According Fochesato et al. (2007), this needs to be done in containers where the seedlings produced alter their development complying with culture medium, when compared to the process in the field, with limited space for root growth. A good alternative for this is the optimization of propagation methods in hydroponics, which targets the time reduction to obtain seedlings, as well as a greater control of nutrition and phytosanitary conditions (Souza et al., 2013).

In most cases of hydroponic cultivation, the nutrient solutions are produced from a mixture of different fertilizer salts of high solubility in water (Resh, 1997), but they can also be produced from organic biofertilizers, a system known as "organoponics", or as part of the solution, as it occurs in organic-inorganic hydroponics (Martins, 2000).

Several studies have been reported in the literature with promising results of the use of biofertilizers in the seedling production from different cultures: Medeiros et al. (2008) with lettuce, Probst et al. (2008) in forage, Cocco et al. (2008) with tobacco and Dantas et al. (2014) with acerola. However, there are too few studies that enable the production of papaya seedlings using biofertilizers, especially when they are related to

hydroponic production.

Based on the above considerations, this study aimed to evaluate the growth, dry matter accumulation and efficiency of water use of papaya cultivars under doses of bovine biofertilizer in hydroponic cultivation.

MATERIALS AND METHODS

The experiment was carried out from February 3rd to April 3rd, 2012 in a seedling nursery at the Universidade Estadual of Paraíba (UEPB), Campus IV, Catolé do Rocha - PB, covered with a nylon shading screen for 50% brightness inside.

We used a completely randomized design with 8 treatments in a factorial 4 x 2, with six replications, and a useful plant per repetition, totaling 48 useful plants. Four doses of biofertilizers (D = 10, 20, 30 and 40% v/v) were tested and applied in two varieties of papaya (Sunrise Solo (C1) and Tainung-01 (C2)).

The plants were grown in a hydroponic system using modified Leonard jars, made with pet bottles according to the methodology of Santos et al. (2009). The bottles were cut 14 to 15 cm from the base and together with the caps they underwent a sterilization process at a 250 L water tank with sodium hypochlorite (10%) for one hour. After this period, all parts of the bottles were rinsed in tap water to remove excess sodium. To each vessel, it was added one liter of washed sand, which was sterilized by autoclaving at a temperature of 121°C for two consecutive days number of hours. After being filled, the pots were seeded (three seeds per pot) and covered with paper bags, in order to prevent algae growth in the solution.

The bovine biofertilizer was obtained by anaerobic fermentation, mixing equal parts of fresh cattle manure and slightly water win electrical conductivity - ECw = 0.8 dS m⁻¹, adding 2 kg of leaves and branches of the leguminous plant cowpea (*Vigna unguiculata* L.) (Table 1). For the preparation of the biofertilizer, plastics biodigesters with a capacity for 200 L were used, kept hermetically sealed for 45 days. To release the methane gas produced during fermentation, a thin hose was connected at the upper base and the other end was submerged in a water container to prevent the entrance of air and loss of quality of the organic feedstock (Santos, 1992). For being applied in liquid form, it was analyzed as if it were water for irrigation, as the data in Table 1, as a suggestion of Dantas et al. (2014). The total volume of the solution was 0.7 L, being replaced weekly based on culture evapotranspiration (ETc), as shown in Table 2.

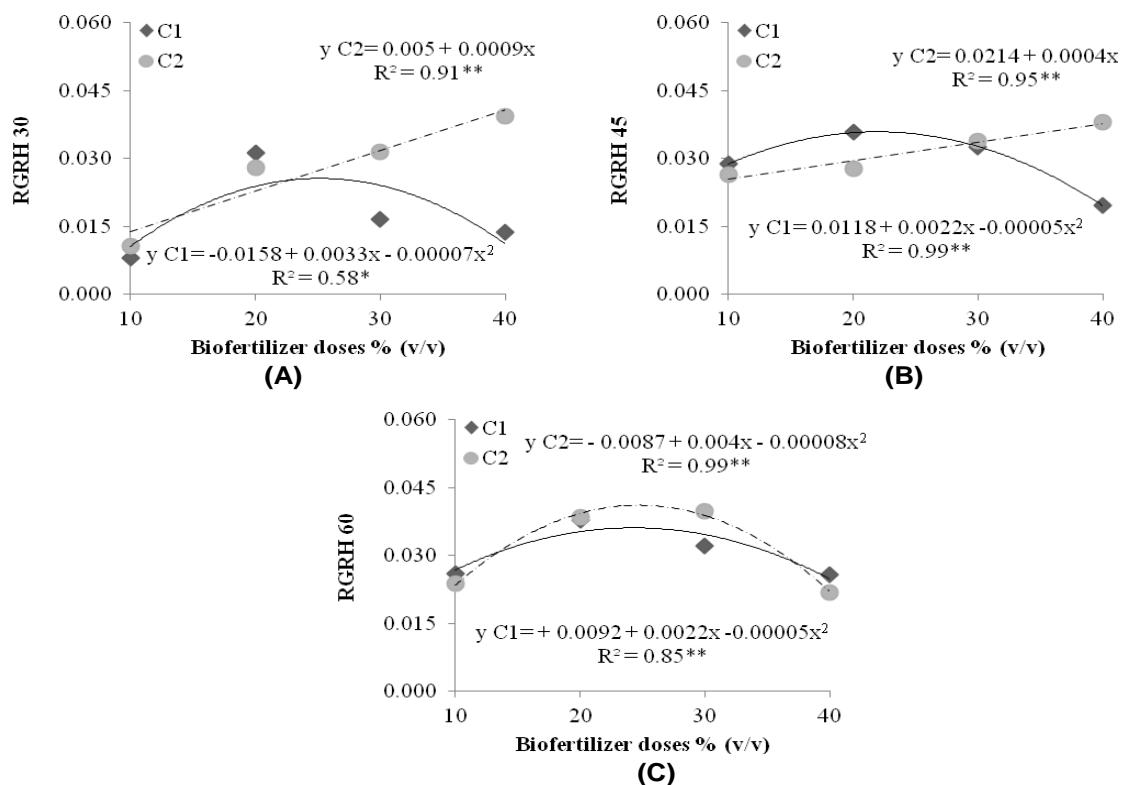
According to the methodology proposed by Benincasa (2003), relative growth rates in height (RGRH) were determined by equation 1 and in stem diameter (RGRSD) by equation 2. Based on the growth in stem diameter, and height the papaya seedlings reached in the end of the total emergency 15 after sowing in relation to the analyses performed at 30, 45 and 60 days after sowing (DAS).

$$RGRH = \frac{\ln H_2 - \ln H_1}{t_2 - t_1} \quad (1)$$

In which: RGRH = Relative growth rate in height of plants (cm cm⁻¹)

Table 2. Water and biofertilizer consumption for papaya (*Carica papaya* L.) seedlings during 60 days in organic hydroponic cultivation.

Biofertilizer doses (%)	Water volume	Biofertilizer volume	Total volume
	ml		
10	1485	165	1650
20	1320	330	1650
30	1015	435	1450
40	870	580	1450

**Figure 1.** Relative growth rates in height ($\text{cm cm}^{-1} \text{day}^{-1}$) of papaya cultivars (*Carica papaya* L.) (C1 = 'Sunrise Solo' and C2 = 'Tainung-01') at 30 (A), 45 (B) and 60 (C) days after sowing, in function of biofertilizer.

day^{-1}); H1 = plant height in time t1 (cm); H2 = plant height in time t2 (cm), and ln = logaritmo natural.

$$RGRSD = \frac{\ln SD2 - \ln SD1}{t2 - t1} \quad (2)$$

In which: RGRSD = Relative growth rate stem diameter ($\text{mm mm}^{-1} \text{day}^{-1}$); SD1 = plant stem diameter in the time t1 (mm); SD2 = plant stem diameter in the time t2 (mm), and ln = logaritmo natural.

Also at 60 (DAS) the plants were collected to obtain the leaf dry matter (LDM) (g), stem dry matter (SDM) (g) and root dry matter (RDM) (g), from the biomass partition of the collected material and packaging in an air circulating oven (DL-AF Dellta) at 65°C to dry the material for 72 h. After this period, the plants were weighed on an analytical balance (ABT 120-5DM Polimate). With the data of dry matter and water consumption by papaya, we determined the efficiency of water use (EWU) by the relationship between the produced dry matter and water consumed by the plant expressed in

g L^{-1} .

The results were submitted to analysis of variance (F test) and, when the parameters were significant, we used the Tukey mean comparison test (5%), for the cultivar factor and regression analysis, for the doses of biofertilizers with help from the SISVAR Software (Ferreira, 2011).

RESULTS AND DISCUSSION

To the relative growth in height of the cultivar C1 (Sunrise Solo), we verified a quadratic behavior at 30, 45 and 60 days after sowing, so that it reached the growth peak when cultivated under the doses of 24, 22 and 22% (v/v) of biofertilizer, respectively (Figure 1). Teixeira et al. (2009) also investigated reductions in height growth of papaya trees due to increasing doses of Lithothamnium.

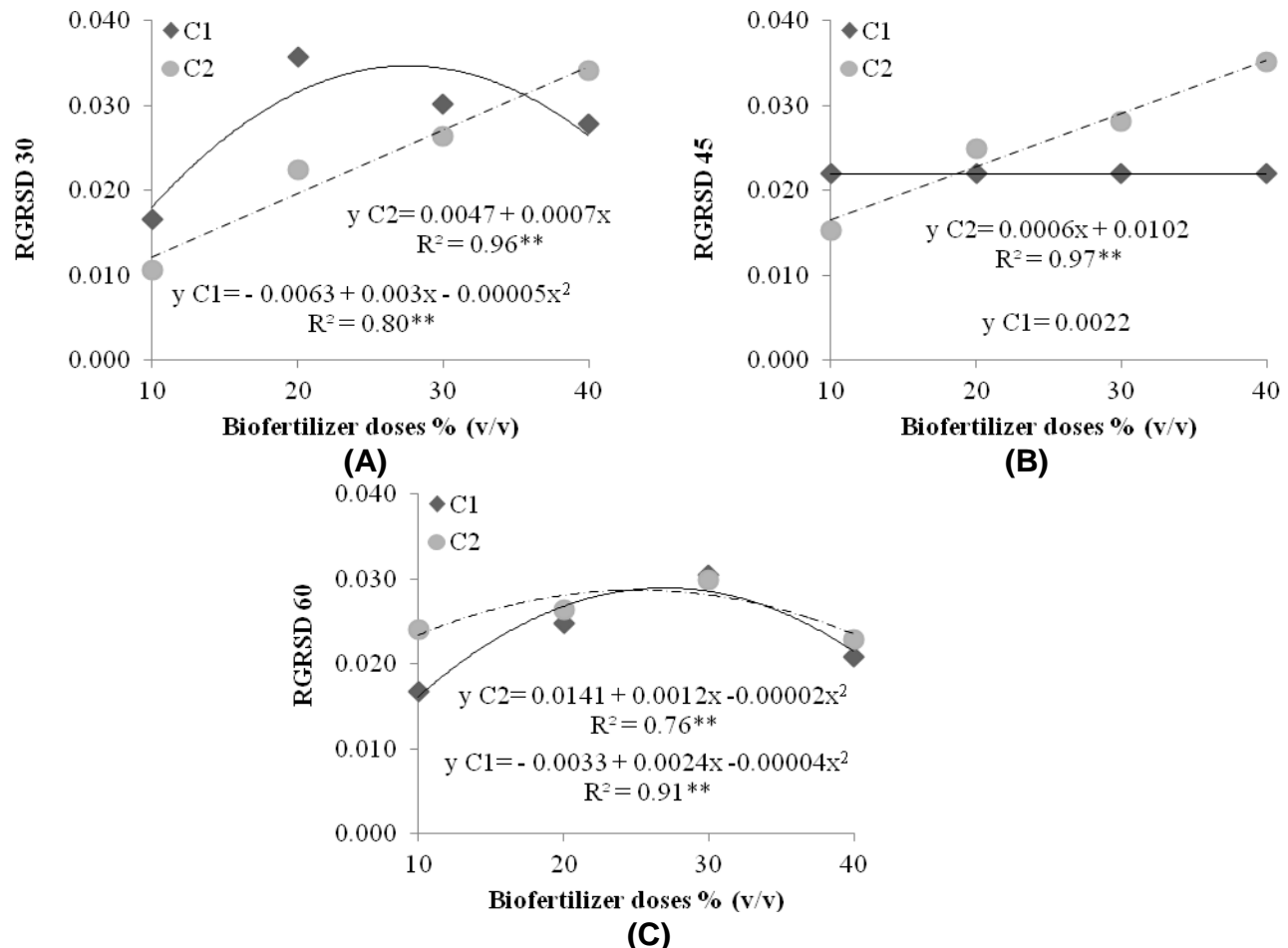


Figure 2. Relative growth rates stem diameter (RGRSD) ($\text{mm mm}^{-1} \text{day}^{-1}$) of the stem thickness of papaya cultivars (*C. papaya* L) (C1 = Sunrise Solo and C2 = Tainung-01) at 30 (A), 45 (B) and 60 (C) days after sowing, in function of biofertilizer.

A fact confirmed by Dantas et al. (2014) in acerola seedlings, where the height of the seedlings responded in a quadratic way to bovine biofertilizer doses. The authors believe that these results were influenced by the increase in substrate fertility providing toxic effects.

In order to cultivate C2 ('Tainung-01') a linear increase behavior was observed for the relative growth in height during the first 30 and 45 days after sowing due to the increase of biofertilizer doses up to the maximum level studied (40% v/v). It was also verified that at 60 days after sowing this behavior became quadratic, so that the higher relative growth rates in height were achieved at a 25% (v/v) dose of biofertilizer (Figure 1). Guimarães et al. (2012) also observed linear response of height growth in seedlings of *Carica papaya*. Tainung-01 in function of biofertilizer doses during the first 40 days after sowing. One can conclude from this that the need for larger doses of biofertilizer during the first 45 days after sowing may be related to lower efficiency of the plants' root system in this growth phase, so that at 60 days after sowing, when

the seedlings had a more developed root system, they were able to meet their nutritional needs in hydroponic solution containing lower biofertilizer doses.

For the growth in height, divergent behavior can be observed between the papaya (*C. papaya*) cultivars studied under biofertilizer doses at 30, 45 and 60 days after sowing (Figure 1). It was ascertained that the cultivar C1 ('Sunrise Solo') has lower nutritional requirements in relation to cultivar C2 ('Tainung-01'), thus demanding lower doses of biofertilizer to maximize its growth index. It was also observed that the cultivar C2 ('Tainung-01') holds the greatest potential for growth, especially under favorable nutritional conditions.

For the growth of stem diameter, it is found that C2 ('Tainung-01') was similar to that observed in height, so that the papaya plants obtained linear relative growth rates of stem diameter according to biofertilizer doses during the first 30 and 45 days after sowing, denoting the initial growth potential of the cultivar and biofertilizer efficiency in papaya plant nutrition (Figure 2).

However, at 60 days after sowing it was observed a quadratic behavior of the relative growth in stem diameter of C2 (Tainung-01), tending to reduce when cultivated in biofertilizer doses greater than 30% (v/v). Possibly after 45 days of sowing the papaya plants tend to reduce the growth in stem diameter due to the limitations of the container and a lower incidence of light in the nursery, reflecting the need for transplanting the seedlings. Thus, the reduction of growth limits nutrient and water absorption, such that larger doses of biofertilizer may have exerted a toxic effect on the papaya plants after this time.

Sunrise Solo (C1) showed a quadratic behavior to the relative stem diameter growth at 30 days after sowing, reaching the maximum growth under 30% (v/v) dose of biofertilizer (Figure 2A and B). It was also observed that at 45 days after sowing, there was no significant influence of the doses in the relative growth in stem diameter of papaya plants (Figure 2C and D). Such a fact may be related to the reduction of secondary growth activity of Sunrise Solo papaya plants, since at 45 days after sowing there was an increase in growth rates in height relative to the first 30 days after sowing, denoting the greater investment in primary growth.

However, at 60 days after sowing, a quadratic behavior was once again verified in the relative growth of papaya cultivars, so that the seedlings produced at doses of 30% (v/v) of biofertilizer obtained the highest growth rates of 0.04 (mm day⁻¹), similar to results obtained by cultivar Tainung-01, which also reached maximum growth at the respective dose. Lima et al. (2007) also found no differences in the relative growth of papaya plants Tainung-01 and Golden due to the evaluation period.

It is noteworthy that at 30 and 60 days after the sowing, both cultivars had similar growth rates, differing only in response to biofertilizer doses at 30 days, where cultivar Tainung-01 responds linearly to the doses, a fact that follows due to higher nutritional requirements of this cultivar in the first days after emergence, possibly due to having lower reserves from the seeds (cotyledons) compared to the cultivar Sunrise Solo who responded in a quadratic way to biofertilizer doses.

For the leaf dry matter, a quadratic response was observed in both cultivars in relation to doses of biofertilizer (Figure 3A), noting that the cultivar Tainung-01 had the highest leaf dry matter accumulation (0.71 g) under the dose of 34% (v/v) of biofertilizer. This value was 43.7% greater than the maximum leaf dry matter accumulation observed in cultivar Sunrise Solo (0.40 g), achieved at a dose of 21% (v/v) of biofertilizer.

Based on these results, it is possible to explain the greater growth potential of cultivar Tainung-01 in relation to cultivar Sunrise Solo, given that the leaves are the organs responsible for the plant's photosynthetic activity and with it, the greater accumulation of leaf dry matter denotes the largest investment in active photosynthetic area, favoring the higher photosynthetic potential,

encouraging further growth. This fact was observed in cultivar Tainung-01, that got high relative growth rates in stem diameter and height during the first 45 and 60 days after sowing respectively, in relation to cultivar Sunrise Solo (Figures 1 and 2).

Similar behavior was ascertained by Diniz et al. (2011) in passion fruit plants, on which the supply of more than 50% (v/v) of biofertilizer caused decline in leaves dry matter accumulation.

For stem dry matter, differing responses were verified between papaya cultivars depending on the increase of biofertilizer doses, and a quadratic response was found for cultivar Sunrise Solo with maximum accumulation of stem dry matter (0.27 g) in 26% (v/v) dose of biofertilizer (Figure 3B). For that, a linear and increasing behavior of cultivar Tainung-01 was examined based on the biofertilizer doses reaching the maximum accumulation of 0.49 g in a dose of 40% (v/v) of biofertilizer, being this accumulation 45% higher than the cultivar Sunrise Solo (Figure 3C).

These results are possibly related to higher growth rates in height and stem diameter observed in cultivar Tainung-01 in relation to Sunrise Solo. In addition to that, the behavior observed for dry matter accumulation in papaya plants with biofertilizer doses was similar to that seen in the growth, so that the best responses from cultivar Sunrise Solo were at doses estimated close to 25% (v/v) of soil biofertilizer, while the best performance of cultivar Tainung-01 occurred at levels close to 40% (v/v) of biofertilizer. This denotes the genetic variability among papaya cultivars belonging to the Solo and Formosa groups regarding nutritional needs.

As for the root dry matter, positive linear correlation was ascertained of cultivar Sunrise Solo to biofertilizer doses, obtaining increments of 0.007 g for each unit increase in the biofertilizer dose, reaching a maximum of 0.51 g in a dose of 40% (v/v) of biofertilizer (Figure 3C). The stimulation of root growth may be related to the need for greater selectivity of nutrient in cultivation solution by the plant, promoting with this the exclusion of ions at high concentrations, considering a reduction of growth and leaf biomass accumulation of cultivar Sunrise Solo under higher doses of biofertilizer (Figures 1, 2 and 3A).

For cultivar Tainung-01, a quadratic behavior was verified, a fact that confirms their stem and leaf dry matter accumulation. It was observed that in this cultivar the peak accumulation of root dry matter is reached in the dose of 34% (v/v) of biofertilizer, noticing a decrease thereafter (Figure 3C). This behavior can be related to the toxic effect of some nutrients with an increasing dose of biofertilizer, making the plant reduce its root system due to the increase of nutrient concentration (salts) in solution.

The divergence of the root system behavior of these cultivars due to the increase of biofertilizer doses may be related to its tolerance capacity to salt content in the solution. Sá et al. (2013) points out that the cultivar

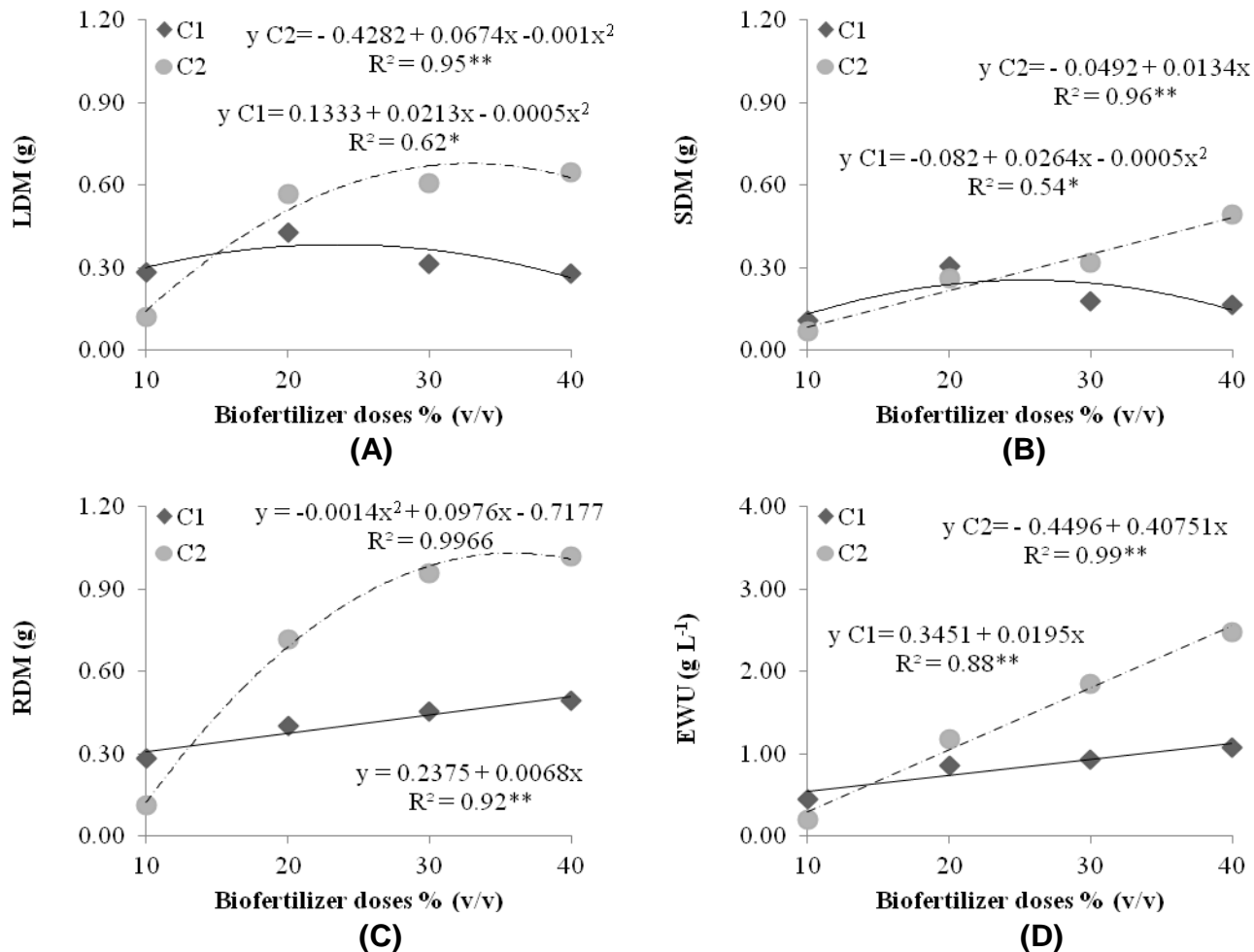


Figure 3. Leaf dry matter (LDM) (A), stem dry matter (SDM) (B), root dry matter (RDM) (C) and efficiency of water use (EWU) (D) of papaya cultivars (*Carica papaya* L) (C1 = Sunrise Solo and C2 = Tainung-01) at 60 days after sowing, in function of biofertilizer.

Sunrise Solo shows a higher potential of salt tolerance in relation to cultivar Tainung-01. This explains the root system growth capacity of cultivar Sunrise Solo even under the higher doses of biofertilizer, where there is a greater concentration of salts and nutrients in hydroponic solution.

It was observed that efficiency water use of both papaya cultivars increased linearly with the increase of bovine biofertilizer doses in the cultivation solution (Figure 3D). The efficiency water use is expressed by the relation between the biomass accumulation (CO_2 fixed during photosynthesis) and water consumption of the plant (sweating), so that the values denote the amount of carbon fixed by the plant by each unit of water lost (Taiz and Zeiger, 2013). It is believed that the higher doses of biofertilizer promoted an increase in the availability of nutrients in hydroponic solution, favoring root absorption, making it more efficient, and thereby promoting a reduction in the need of water uptake by the plants, since

along with it, the essential nutrients for their growth are absorbed, favoring the increase in water use efficiency.

It is noteworthy that cultivar Tainung-01 had the highest efficiency of water use in relation to cultivar Sunrise from doses greater than 15% (v/v) of biofertilizer, when compared under the same culture condition (Figure 3D). It was also verified that the cultivar Tainung-01 obtained unitary increments 75% higher than those observed for the cultivar Sunrise Solo with the increasing dose of biofertilizer. Thus, the greatest growth potential of cultivar Tainung-01 in relation to cultivar Sunrise Solo may be related to the first's higher efficiency in water use, denoting its greatest photosynthetic potential (CO_2 fixation) under increased nutrient availability.

Conclusions

The cultivar Tainung-01 has a higher growth potential,

biomass accumulation and efficient use of water in comparison to the cultivar Sunrise Solo. The doses estimated of 25 and 35% (v/v) of bovine biofertilizer promoted the greater growth and dry matter accumulation for the cultivars Sunrise Solo and Tainung-01, respectively. The cultivar Sunrise Solo has lower nutritional requirements to achieve its maximum growth in relation to cultivar Tainung-01.

Conflict of Interest

The authors declared that they have no conflict of interest.

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