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Efficiency of Water use for Strawberries Cultivated in different Semi-Hydroponic Substrates

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ABSTRACT

This study aimed to evaluate the efficiency of water use (WEU) and fruit yield (TMF) of strawberry cultivars grown in different substrates. The study used a randomized block design, in a factorial arrangement of 2x2x4 with two cultivars (Albion and Camarosa), two sources of seedlings (domestic and imported) and four substrates combinations: S1: milled sugar cane bagasse (70%) + organic compost (30%); S2: milled sugarcane bagasse (70%) + commercial substrate Carolina® (30%); S3: burnt rice husks (70%) + organic compost (30%) and S4: burnt rice husk (70%) + commercial substrate Carolina® (30%), arranged in four repetitions with each repetition consisting of 8 plants; 32 plants were evaluated in total. The cultivar Camarosa, of domestic origin, showed higher TMF and WEU (31521 kg ha^{-1} and 88,10 L g $fruit^{-1}$, respectively). The S3 provided greater TMF (37191 kg ha^{-1}); however both S3 and S4 had greater WUE (150,9 and 145, 9 L g $frut^{-1}$, respectively). The burnt rice husks mixed with organic compost is a renewable, low cost alternative that provides greater productivity and efficiency of water use for strawberries produced in semi-hydroponic systems.

INTRODUCTION

The fruit of the strawberry (*Fragaria ananassa*) is known for its strong flavor (Šamec *et al*., 2016), it can be eaten raw or processed (Xu *et al*., 2014), and also has pharmacological characteristics that may prevent chronic diseases such as cancer (Zhang *et al*., 2008). In 2012, land used in strawberry production around the world reached 241,000 ha, in recently years cultivation area has increased significantly, with principal producers being located China, The USA, Turkey, Mexico, and Spain (FAOSTAT, 2015). In Brazil the production in 2013 reached 3,200 tons of fruit, with an average productivity of 84.211 kg/ha (FAOSTAT, 2015).

The traditional method for strawberry cultivation is very laborious, and it results in increased pressure on producers to treat crops, due to a high prevalence of disease. Thus, arises the importance of adopting production systems which minimize the problems associated with traditional methods. Among possible systems, cultivation within a protected environment known as 'semi-hydroponics' stands out; in this system, a producer can manage environmental factors such as solar radiation, temperature, and water availability. This system can enable fresh fruit production all year, regardless of season. (Krüger *et al*., 2012; Šamec *et al*., 2016).

The use of substrates provides a favorable environment for the growth of the strawberry plants by, for example, promoting root growth and leading to an increase in the absorption of nutrients. Furthermore, drip

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irrigation is a very efficient method for providing water to the cultivars, this may be especially relevant to areas where water is a scarce commodity and the ground has light or loose texture (Kumar and Dey 2011)

In hydroponic strawberry production systems, an inert substrate with a balanced porosity that allows sufficient permeation of air and water is necessary; such a substrate results in the improved development of the root system and physical support of the culture. In addition to the total porosity, the substrate must have a high capacity for cation exchange (Vaughn *et al*., 2011).

One of the biggest obstacles for strawberry farming in semi-hydroponic systems is the availability of substrates, as these have a high cost to producer. Because of this, we have been seeking an agro-industrial waste option alternative that has ideal physical characteristics for the cultivation of the plants, a low cost, and widespread availability for producers.

Carbonized rice husks have been widely used as a substrate in semi-hydroponics; they present physical characteristics favorable for good plant growth, because they contribute to water retention, have good aeration and resistance to decomposition. They can also be reused when not contaminated by previous crops. (Mello *et al*., 2006).

The bagasse or residue from sugarcane production, from a physical point of view, shows good stability of particles which is a desirable feature of substrates for plants (Silva *et al*., 2008). In addition to this, it is often used in order to reduce production costs.

Similarly, the culture of strawberry plants requires large quantities of water during their production cycle; however the methods of irrigation and water management are not always efficient, and can result in a loss of water and therefore reduce the supply of water to the plants. (Martínez-Ferri *et al*., 2016).

The management of water irrigation is a practice of great importance for the profitability and environmental sustainability regarding strawberry production, and it has a strong influence on overall yield (Létourneau *et al*., 2015).

This study aims to evaluate the productivity and efficiency of water use for strawberry cultivars grown in a semi-hydroponic system with different substrates.

MATERIALS AND METHODS

The experiment was conducted at the Federal University of Santa Maria, Campus Frederico Westphalen, Rio Grande do Sul, Brazil, located at the coordinates 27º 23 S and 53º 25,74 W, at an altitude of 493 m. The climate is a temperate humid type with an annual average precipitation of 1735 mm and an average temperature of in the coldest month of the year being ≤ 13 ºC (Maluf, 2000).

The experiment was carried out in the period between May to December of 2015, inside of a greenhouse. The greenhouse had a metallic frame with an arched roof, measuring 20m long by 10m wide, and a ceiling height of 3.5m constructed in a north-south direction.

A randomized block experimental design was used, arranged in a factorial placement 4x2x2, four substrates, two cultivars (Albion and Camarosa). The plants were of two origins (domestic and imported), arranged in four repetitions, each consisting of eight plants totaling 32 evaluated plants. Each plot consisted of two rows of 1.0 m, spaced at 0.25 m.

Four plants in each row were planted spacing of 0.25 m. Domestic seedlings came from a nursery located in the town of Agudo / RS. Imported seedlings were grown in the nursery Patagonia Agrícola S.A., located in the municipality of El Maitén, Argentina, with the geographic coordinates of 42º3’S, 71º10’W and an altitude of 720 m above sea-level.

The substrates used in the experiment had an organic base and were made of organic material, S1: milled sugarcane bagasse (70%) + organic compost (30%), S2: milled sugarcane bagasse (70%) + commercial substrate Carolina® (30%), S3: burnt rice husks (70%) + organic compost (30%), and S4: burnt rice husks (70%) + commercial substrate Carolina® (30%). After being mixed in the aforementioned proportions, physical (Table 1) and chemical (table 2) analyses were conducted on the mixtures.

The different substrates packaged in heavy duty white tubular plastic bags with 150 µm 1.0 m long, by 0.3 m wide which were placed in stands approximately 0.8 m above the soil. The imported cultivar Camarosa was transplanted on May 25, 2015; the domestic cultivars Camarosa and Albion were transplanted on May 26, 2015, and the imported cultivar Albion was transplanted on June 8th, 2015, they were all grown until December 24, 2015.

Irrigation system and efficiency of water use:

Irrigation and fertigation was performed by a drip irrigation system located inside of the substrate bags, comprising drippers spaced 0.10 m apart. Each plot received the same regimen of irrigation throughout the experiment, according to the weather conditions.

We calculated the amount of water used in the entire duration of the experiment as Morillo *et al*., (2015), describes in the formula:

$$Q_{tag} = T_w + \sum_{i=1}^{n} WVI \qquad (1)$$

Table 1: Physical analysis of substrates for the semi-hydroponic cultivation of strawberries.

Substrate	Density (g/cm^3)	Total porosity (m^3/m^3)	Aeration space (m^3/m^3)	readily available water (m^3/m^3)	Buffering capacity (m^3/m^3)	Available water (m^3/m^3)	Remainder water (m^3/m^3)
S1	0.14	0.74	0.48	0.05	0.01	0.06	0.2
S2	0.09	0.75	0.46	0.09	0.02	0.11	0.18
S3	0.23	0.63	0.27	0.15	0.03	0.18	0.18
S4	0.13	0.67	0.29	0.24	0.08	0.32	0.05

Table 2: Chemical analysis of substrates for the semi-hydroponic cultivation of strawberries.

Substrates	Nitrogen (mm^{-1})	Phsphorus (mm^{-1})	Potassium (mm^{-1})	Calcium (mm^{-1})	Magnesium (mm^{-1})	Organic carbon (mm^{-1})	Hydrogenionical potential
S1	1.13	0.56	0.5	0.7	0.2	17.67	6.6
S2	0.35	0.08	0.64	0.3	0.6	12.25	5.6
S3	0.95	0.61	0.59	0.7	0.16	5.45	7.5
S4	0.24	0.1	0.69	0.2	0.6	5.75	7

Where: Q_{tag} = total quantity of water used over the entire period of the experiment; T_w = quantity of water used in different cultivation practices such as in preparation, planting, the initial washing of the substrate, etc.; WVI = quantity of water used during each irrigation period i= 1, 2, 224 (Moriollo *et al*., 2015). The amount of water used was the same for all treatments.

The efficiency of water usage for the production system was calculated as the ratio between the total amount of water used and the total production of fruit per plant (g) (Moriollo *et al*., 2015), described in the equation:

$$WEU = \frac{Q_{tag}}{TFP} \qquad (2)$$

Where: WEU = the efficiency of water use; Q_{tag} = Total amount of water used during the entirety of the experiment (liters); and TFP = total fruit production for each plant (grams).

Data analysis:

Initially, the data were analyzed for the presence of outliers; any extremes that did not belong to the sample were excluded. The outliers were categorized using SAS analyses. Later individual variance was analyzed in order to verify the homogeneity of variances. When the ratio between the highest and lowest mean square was below seven, an analysis of variance was used (Gomes 1990). The variables of efficiency of water use, and fruit yield that showed significant interaction (substrate x cultivar x origin) disrupted its simple effects. When the interaction was not significant, the principle effects were compared Tukey ($p \leq 0.05$). The analyses were conducted with use of the programs Microsoft Excel® and SAS (SAS institute Inc 2010).

RESULTS AND DISCUSSION

The analysis of variance showed a significant interaction ($p \leq 0.05$) between cultivar and origin, for fruit productivity and efficiency of water use, revealing that the response of cultivars to the studied variables differs according to the origin of the seedlings. It has been observed that the substrate influenced the response of the variables independently of cultivar and source, as the cultivar factor separately showed statistical significance ($p \leq 0.05$). Among the origins, no significant differences were found (Table 3).

For the variable of efficiency of water use, the cultivar Camarosa had significantly higher values (88.10±8.27) when compared to the cultivar Albion (139.42±17.11). For Camarosa, when compared by origin (domestic, imported), it was seen that the imported variant (122.24±16.70) used a greater volume of water in fruit production when compared to the domestic variant same species (88.10±8.27) ($p \leq 0.05$). An average of main effects showed that the cultivar Camarosa more had a higher water use efficiency.

The shallow root system, high leaf area, and a high water content within the fruit of strawberry plants are some factors which contribute to cultivars' high water requirement in order to maintain physiological homeostasis, though this requirement is known to differ from cultivar to cultivar (Martínez-Ferri *et al*., 2016). The results of this study revealed that the cultivar Camarosa showed the most satisfactory results when compared to cultivar Albion, and this fact is associated with the physiological and morphological characteristics of the cultivar (Martínez-Ferri *et al*., 2016; Grant *et al*., 2010).

Table 3: Summary of the analysis of variance for the variables fruit productivity and efficiency of water use.

Source	Degrees freedom	fruit yield (kg ha^{-1})	Efficiency of water use (l g fruit^{-1})
		Mean Square	
Substrate	3	216365.0985*	24080.2441*
Cultivar	1	111923.7025*	7279.5101*
Origin	1	5220.0625ns	274.5664 ns
Substrate*Cultivar	3	11989.8204 ns	662.5153 ns
Substrate*Origin	3	3728.7288 ns	1417.0097 ns
Cultivar*Origin	1	38956.8906*	14395.1896*
Substrate*Cultivar*Origin	3	9277.3085ns	4054.5078 ns
Coefficient of variation (%)		23.78	36.19

*significant at 5% probabililty
ns not significant

Table 4: Efficiency of water use strawberry for the imported and domestic cultivars.

Source	Water efficiency use		Average
	Albion	Camarosa	
Imported	113.57±8.60 aA	122.24±16.70 bA	117.91±9.27 a
Domestic	139.42±17.11 aB	88.10±8.27 aA	113.76±10.42 a
Average	126.50±9.70 A	105.17±9.66 B	

A b All means without a common superscript differ significantly between sources (p<0.05); A B: All means without a common superscript differ significantly between cultivars (p<0.05). Mean of four replicates ±SE.

In other studies, average results for water use efficiency were found at 113 and 102 m^3/t cultivation in soil, which calls attention to the high demand for water that the strawberry crop requires per hectare (Morillo *et al*., 2015). Concerns about the management and use of water has been widely discussed by environmentalists due to climate change scenarios, which often predict a general reduction in water availability for consumption and agricultural use. In agriculture, disasters caused by extreme weather conditions can cause damage to crops, with the potential to destabilize food systems threatening global food security (Lesk *et al*., 2016). Thus, it is of paramount importance to study how more food may be produced with lower quantities of water. To achieve this end, it is important to consider plant breeding and the selection of cultivars which best respond to water availability, and are able to produce more per liter of water used (Monaghan *et al*., 2013). For example, the strawberry plants use a significant amount of water to meet the water needs during the period of growth and development (Moriollo *et al*., 2015). It is therefore necessary to be aware of the principle strawberry cultivars and their water use efficiency, when considering how to achieve greatest efficiency values (Martínez-Ferri *et al*., 2014).

According to Grant *et al*., (2010), the responses to water stress were similar in multiple strawberry cultivars; while they had different leaf areas under favorable conditions, they all demonstrated a reduction in leaf area to a similar level, when water availability was limited. Strawberry crops, when subjected to a serious water deficit, experienced a reduction in weight and moisture after harvesting the fruit.

When strawberry plants are subjected to a severe drought, the fruit will exhibit a loss of mass and a low moisture content after the harvest. This results in a greater accumulation of anthocyanins in the fruits, and a premature red coloring which often presents itself earlier than the coloring of strawberries without water restrictions; the accumulation and biosynthesis of abscisic acid has also been observed (Chen *et al*., 2016).

Martinez-Ferri *et al*., (2016) observed differences in values for yield efficiency in early periods of production when using optimal amounts of water for production; the cultivars Benicia Splendor and fortune presented higher efficiency values when compared to the cultivars Antilhas, Sabrina, Camarosa, and Santa Clara. In addition, the same authors report that the size of the plants was different among the cultivars: Antilla, Camarosa, Sabrina and Santa Clara were significantly higher when compared to Fortuna, Benicia and Splendor. Grant *et al*., (2010), found significant differences between cultivars for water use efficiency, and this increased as the amount of water for each plant was limited; they found lower values for Delia , Emily, Totem and Cambridge Favourite cultivars and higher values in Elsanta and Symphony. Delia, Emily, Totem and Cambridge Favourite had greater values than Elsanta and Symphony.

The efficiency of water usage could be improved through the use of strawberry cultivars relatively tolerate to water stress and could result in increased productivity with greater sustainability (Martinez-Ferri *et al*., 2016). In the present scenario, a reduction of irrigation can reduce the production of fruit cultivars that would normally have high yield potentials (Grant *et al*., 2010). The results obtained in this study revealed that that the cultivars used in the study have a high efficiency of water use, thus indicating that they may be used for cultivation in areas where water availability is a limiting factor for production.

The low water availability affects the expansion of the fruit more, in some other cultivars than others, demonstrating that the yield of a cultivar is reduced when subjected to different water deficits. This further suggests that selection for high yield potential can indirectly lead to a high efficiency of water use and higher productivity yields when water is limited (Grant *et al*., 2010). Strawberry cultivars with greater efficiency of water use result in increased productivity, which may increase economic gains by reducing costs for water irrigation (Cattivelli *et al*., 2008). Gomes *et al*., (2015) reported that water use efficiency is directly related to the irrigation system and the frequency of application of water, regarding the production of strawberry plants.

Water use efficiency directly influences crop yield; the greater that the value for water use efficiency is, the greater the productivity will be. The productivity of this study's results have confirmed this hypothesis, i.e. the cultivar Camarosa showed higher productivity when compared to Albion when low amounts of water were applied to the two cultivars. This fact is related to the amount of available water, which was the same for both cultivars. When compared within the same cultivar, the one of domestic (Brazilian) origin Camarosa showed significantly better results when compared to imported variant (Table 5).

Table 5: Total fruit mass per hectare for imported and domestic strawberry cultivars.

Source	Fruit yield (kg/ha^{-1})		Average
	Albion	Camarosa	
Imported	23894.40±1577.51^{aA}	26466.90±3308.14^{bA}	25180.70±2570.27^{a}
Domestic	21548.70±2349.56^{aB}	31521.40±2281.97^{aA}	26535.10±2606.72^{a}
Average	22721.60±1990.99^{B}	28995.20±2868.30^{A}	

All means without a common superscript differ significantly between origin (p < 0.05); $^{A\ B}$All means without a common superscript differ significantly between cultivars (p < 0.05). Mean of four replicates ±SE.

The greater yield obtained by the cultivar Camarosa, was likely due to the fact that it is stronger and has a more robust root system than the Albion cultivar (Martinez-Ferri *et al*., 2016). These features allow for a better absorption of water in deeper soil layers, increasing the efficiency of water usage. Research also revealed that even when water availability was reduced, the Sabrina and Camarosa cultivars have shown relatively greater levels of production, demonstrating that water use efficiency is genotype-dependent (Martinez-Ferri *et al*., 2016).

Genetic improvement of strawberries is highly important in order to generate cultivars with unique morphological characteristics, in order to increase productivity in crops that may have limited access to water. The production of more efficient and sustainable agriculture is comprised of various approaches and technological innovations (Prety *et al*., 2010), such as semi-hydroponic or soil-less agriculture.

It has been observed that the efficiency of water usage on different substrates was best in S3 and S4. The S3 substrate was composed of burnt rice husks (70%) + organic compost (30%), and S4 of burnt rice husks (70%) + commercial substrate Carolina® (30%). The efficiency of water use was greater, because they provided better physical characteristics which benefitted the plants, such as a lower porosity (0.63 m^3/m^3 and 0.67 m^3/m^3, respectively), higher density (0.23 m^3/m^3 and 0.13 m^3/m^3, respectively), and lower aeration space (0.27 m^3/m^3 an 0.29 m^3/m^3, respectively), which are all features that assist in water retention for the plant (Figure 1A).

As the treatments all had the same amount of irrigation water applied to them, the obtained differences are due to the substrate used. This had a direct impact on water use efficiency and the overall productivity of the plant. The lower efficiency of water use observed for substrates S1 and S2 occurred due to excessive leaching, likely because these substrates present such high porosity. For fruit production, it was observed that the S3 mixture was significantly higher than the other substrates (Figure 1B).

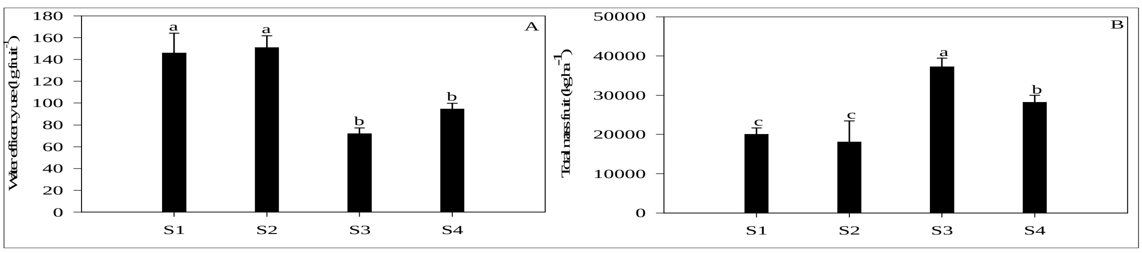

Fig. 1: (A) water use efficiency and (B) total fruit mass of strawberries cultivated in different substrates. T bar represent the standard deviation, calculated with four replicates.

According to the water retention properties, macro pores represent an important part of the soil and result in a high drainage capacity for the soil (Létourneau *et al*., 2015). Under these conditions, it is likely that the water supplied by irrigation in S1 and S2 substrates leached out rapidly due to larger aeration spaces. This is known to damage plants due to a lower amount of available water, and thus result in greater water stress for, in this case, strawberry plants. Thus, an increase in water use efficiency can be obtained by monitoring the matric potential in the root zone (Létourneau *et al*., 2015), which then can be used to determine the amount and frequency of irrigation for the particular type of substrate mixture used.

The results revealed that the S3 and S4 substrate blends have a better efficiency of water use and fruit productivity. These mixtures are composed of 70% burnt rice husks, a raw material easily and inexpensively purchased from producers. Thus, alternative, renewable, and low cost materials have demonstrated that they can effectively be used for strawberry cultivation in semi-hydroponic systems. Such substrates also reduce dependency on manufactured substrates.

Conclusion:

The domestic (Brazilian) cultivar Camarosa has greater water-use efficiency, as is reflected in its higher productivity of fruit when compared to the domestic cultivar Albion. However, within the same origin, the two imported cultivars showed no difference.

Among the combinations used as the substrate, the mixture of burnt rice husks (70%) + organic compost (30%) provides the best efficiency of water use and productivity for the semi-hydroponics strawberry crops; this substrate is made of cheap, renewable, and easy to obtain materials that may be used for semi-hydroponics strawberry cultivation.

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