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Water consumption of three ornamental species with the suction irrigation system

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ABSTRACT

Objective: To evaluate water consumption in ornamental plants (geranium, gazania and petunia) in two substrates with different particle sizes (fine and coarse) of tezontle and peat moss, through a suction irrigation system, which uses porous capsules as irrigation emitters.

Design/methodology/approach: The experimental design was in complete randomized blocks, with six treatments (three ornamental species and two substrates) with four repetitions (24 experimental units). The first mixture contains fine substrate (composed of tezontle with particle size less than 0.4 mm) and peat moss, in a 1:2 v/v ratio; the second mixture presents coarse substrate (composed of tezontle with particle size between 0.4-0.6 mm) and peat moss, 1:1 in v/v.

Results: In water consumption, there are significant differences by ornamental species and type of substrate, where the irrigation system has the ability to self-regulate. The highest water consumption was in petunia in the coarse substrate (which has a higher proportion of peat moss in its composition).

Limitations on study/implications: With use in protected agriculture, rural and urban orchards, gardens, walls and green roofs and research purposes.

Findings/Conclusions: The suction irrigation system through porous capsules has the capacity to continuously supply the water demanded by the plant-substrate-atmosphere system.

Keywords: Sustainable irrigation, irrigation, water efficiency.

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INTRODUCTION

Irrigation water is of best use when it is supplied to plants almost instantaneously (with constant moisture level in time) and in terms of amount, whatever is necessary (excess or deficiency have implications), which is associated with the form of water supply. There is a diversity of methods for water supply (irrigation) based on the agricultural system, intensive or extensive; for example, superficial gravity irrigation, pressurized irrigation, hydroponics and aeroponics. However, there is another irrigation option that works through suction,

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that is, by negative load. There is a close relationship between the amount of water used by a plant in normal growth conditions and the amount of plant material it produces (Lemaire *et al.*, 2005). Most of the studies on transpiration in plants are devoted to the study of crops (FAO, 2014) and there is scarce information about this topic in cutting flowers and potted plants (Montero *et al.*, 2001). For example, in "Freedom Red" poinsettia plants, their irrigation and Kc requirements were estimated by microlisimetric techniques in pots within a greenhouse, weekly. The consumption obtained in the first week was 0.24 mm·day^{-1} and increased until the tenth week to 0.9 mm·day^{-1} (Pacheco *et al.*, 2014). The use of ornamental plants in green spaces is very frequent, such as in parks, gardens, boulevards; in avenues, central reserves, roundabouts; cemeteries; even in green roofs and walls, among others (Salvador, 2003). The function of these green spaces, among other services, is to contribute to improve the air quality, regulate the environmental temperature, assimilate CO_2, generate oxygen, and prevent soil erosion; all of this, among other services, generates comfort and favors the spaces visually as ornamental components, and improves the quality of life (Rodríguez, 2002). In recent studies about climate change and particularly global warming with the increase in temperature, the increase in green areas in cities is an alternative to mitigate this process; from this the importance of ornamental plants (Herrera-Gómez *et al.*, 2017). With some exceptions, it is frequent for plant species planted in green areas not to prosper because of lack of knowledge about the species (adaptability to the weather) and of techniques for their management. In urban areas the problem of vegetation represents between 70 to 90% due to an inadequate selection of species (Lily, 1991; Fernández-Cañero *et al.*, 2014), and because of not having good management of irrigation water. The latter has greater relevance because it competes for this resource with the population, industry, agriculture and services, despite the advantages that green spaces offer. Presently, with the advances on the theme of evapotranspiration (ET) and on its calculation (FAO, 2014) to make a more efficient use of irrigation water, there is a need to improve in the estimation of the ET in zones with multiple microclimates (for example, green areas: gardens, parks, boulevards, etc.) where there is a diversity of plants and the measurement of ET is not representative when using traditional methods, which are inadequate (Snyder, 2014). Under this situation, estimating irrigation requirements (evapotranspiration estimation) in urban green landscapes is a challenge, especially in green walls (Pérez-Urrestarazu, 2018). Things to consider are biodiversity, size, geographic position of plants (which produce different microclimates), season of the year, different soils, water availability and even management of green spaces. Bainbridge (2002) suggested an alternative for irrigation for arid zones based on a bottle and intertwined nylon fabric that operates based on the absorption and liberation of water in the soil. A bottle (polyethylene terephthalate, PET) that is filled every time that it is emptied is necessary. Among the water supply systems for plants in a localized manner (at pressure) is drip irrigation, which is one of the most efficient, and is always operated adequately. The objective of this study was to evaluate the water consumption in three ornamental species that belong to the genera Geranium, Gazania and Petunia, through the suction irrigation system using porous capsules, in two substrates mixtures, under greenhouse conditions. Under the same management conditions and irrigation method in the ornamental species, two hypotheses have been suggested. *Ho*: there are no significant differences in water consumption between ornamental plants in the two types of substrate. *Ha*: there is at least one significant difference in water consumption in an ornamental plant for one of the substrates.

Emitters (capsules) for irrigation are spherical, made of ceramics, with constant wall thickness, pre-established surface-volume according to its size, and with a specific porosity (which depends on the manufacturing process). The ability to liberate or transfer water to the soil-plant-atmosphere system (SPAS) depends on the suction load, the hydraulic properties of the capsule, and the formulation and management of a nutritional solution applied in irrigation. It is considered that if there is an excess of water in the soil or low atmospheric demand, the irrigation system will not transfer water.

According to Filgueira *et al.* (2006), the infiltration process in the soil depends, among other factors, on the compacting, size and distribution of pores and the texture. There are several models that allow the simulation of the infiltration process (Philip, 1969, 1987 and Regalado, 2003).

$$I = S\sqrt{t} + Ct \tag{1}$$

Where: I, is the accumulated infiltration (mm); S, the capillary sorptivity ($mm \cdot h^{-1/2}$); C, the coefficient related to the hydraulic conductivity at saturation ($mm \cdot h^{-1/2}$); t, is time. The hydraulic conductivity represents the capacity of a porous medium to transmit water, where it is proportional to the soil moisture. If the pores are large, they are the first to lose water; one part of it is still retained in the pore walls, which results from a resistance to infiltration. Thus, two porous mediums with the same porosity can have different hydraulic conductivities, which depend on the distribution, size, continuity between pores, and characteristics of the liquid. In contrast, sorptivity represents the capacity or the speed of a porous material for absorption or desorption of liquids by capillarity, which is the function of the initial water content, uniformity and structure of the material, and the characteristics of the liquid (viscosity, density, superficial tension). Thus, for a surface (A) with a specific area, at a potential *ho*, where the capillarity force predominates:

$$\lim_{t \to 0}\left[\frac{Q(t)}{A}\right] = \frac{1}{2} S t^{-1/2} \tag{2}$$

Where: Q is the expenditure that happens in the area (A) in ($mm^3 \cdot s^{-1}$); t is time (s); A, contact surface (mm^2); S is the sorptivity that represents the water potential ($mm \cdot s^{-1/2}$). When integrating the equation (2), there is:

$$I = S t^{-1/2} \tag{3}$$

Where I, is the infiltration accumulated (mm). In the initial infiltration process in the soils and dry, there is sorptivity, where the effects of gravity and lateral capillarity are small, which is why they are not considered.

MATERIALS AND METHODS

The experiment was established in the greenhouse at the Water Sciences meteorological station, which is located in the coordinates: latitude 19° 27' 37.18" N and longitude 98° 54' 12.12" W, with altitude of 2240 masl. Three ornamental genera were selected: Petunia (Pe), Gazania (Ga) and Geranium (Ge); all of they are common in Estado de México, whether to grow them in the soil or in pots, in landscape design in California, there is a classification system of 3,546 plants (species, cultivars and hybrids) with different selection criteria (Costello *et al.*, 2014).

The substrates that were used are fine substrate (FS) – sieved tezontle (size of the mesh under 0.4 mm) plus peat moss, in a ratio 1:2 in v/v, respectively; and coarse substrate (CS) – sieved coarse tezontle (size of the mesh of 0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v, respectively. From each substrate, the water liberation curves were elaborated based on the methodology by Boodt *et al.* (1974) for organic substrates, with the aim of evaluating easily available water (EAW), among other factors. According to Burés S. (1997), in the EAW substrates, it is "the percentage of volume liberated is between 10 and 50 cm of tension in the water column on the substrate".

The porous capsules of clay were handcrafted with the casting technique (in molds) and firing in a ceramics kiln. The physical characteristics of the porous capsules allow using them as irrigation emitters that operate by suction, that is, at negative load. They were classified based on their sorptivity, where 24 capsules were selected from a group of 106. Each experimental unit (EU) was made up of one pot (of 23 cm superior diameter, 16 cm inferior diameter, 15 cm height, and exposure area of 415.48 cm); substrate (tezontle plus peat moss); ornamental plant (obtained by transplanting); and irrigation system. The irrigation system was integrated by a porous capsule (emitter) and the source of water supply at a suction height of −10 cm, with regards to the center of emitter (Figure 1). The capsules are connected to the water source through a polyethylene hose of 5 mm diameter.

Figure 1. Experimental unit with pot, substrate, plant, and irrigation system.

The water source was a precipitate glass (with capacity of 200 mL), covered in its superior part with aluminum paper, and thus to avoid evaporation. Nutrition was supplied through the irrigation water (fertigation), with Steiner's universal nutritional solution (Table 2) described for its management in Baca *et al.* (2016), with industrial-grade salts, with the same management for all the experimental units.

The experimental design was completely randomized blocks (CRB) with six treatments and four repetitions, with 24 experimental units (Table 1), which were distributed randomly in two blocks (Figure 2). The response variable was water consumption of three ornamental species (Ge, Pe and Ga) in two substrates under the same conditions of fertigation management by suction, through porous capsules in pots, inside a greenhouse. The water consumption was measured and recorded by experimental unit (mL day^{-1}) and it was replaced every day to maintain the suction load of -10 cm.

RESULTS AND DISCUSSION

The experimental phase took place from September 12 to November 30, 2017, with duration of 80 days.

Capsules (*emitters*). The porous emitters (capsules) were classified and selected based on the sorptivity (Table 3). It was calculated based on the change in weight of the capsules, from a dry to a wet state, when the sphere was put into contact with the water surface, in a dampening time of 10 minutes. For each type of substrate, 12 capsules were selected. The porous capsules (emitters) are very similar, with differences under 1% in terms in sorptivity, which allowed evaluating with greater certainty the effect of the substrate mixture and the ornamental species, in the water consumption.

Substrates. Table 4 shows the values of water retained (v/v) of each of the substrates, in four levels of suction (0, 10, 50 and 100 cm of water column), where the water content

Table 2. Chemical composition of Steiner Nutritional Solution.

Salt	**Anions**			**Cations**		
	(mmol$_c$ L^{-1})					
	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	K^+	Ca^{2+}	Mg^{2+}
Potassium nitrate	3			3		
Calcium nitrate	9				9	
Monopotassium phosphate (MKP)		1		1		
Potassium sulfate			3	3		
Magnesium sulfate			4			4
$\sum$	12.0	1.0	7.0	7.0	9.0	4.0
	$\sum$A=20.0			$\sum$C=20.0		
	mM					
	12.0	1.0	3.5	7.0	4.5	2.0
	PO=30*0.024=0.72 atm					

OP.-Osmotic Potential (atm.), Source: (Baca, Rodríguez, & Quevedo, 2016).

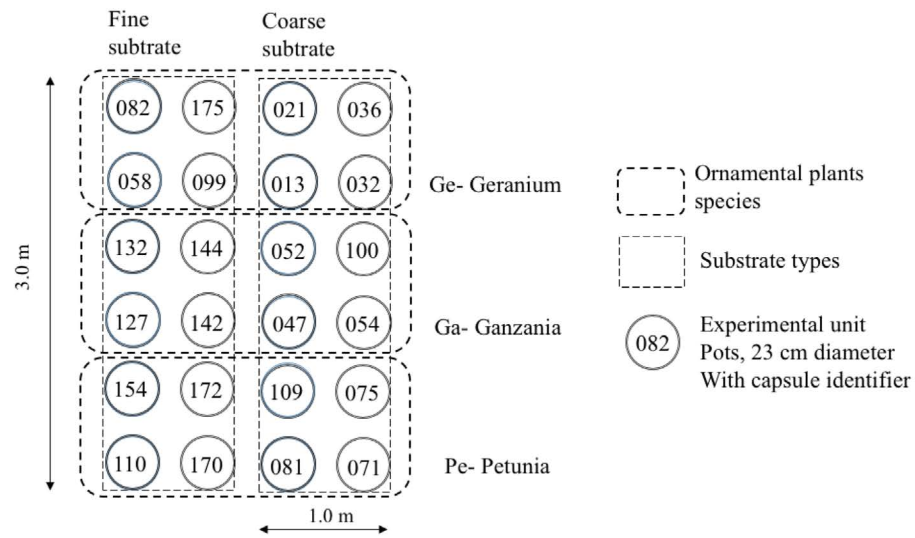

Figure 2. Distribution of experimental units in the greenhouse.

Table 1. Treatments to measure water consumption in three ornamental species (Geranium, Gazania and Petunia) in two substrates and irrigation system based on porous capsules in greenhouse.

Treatments	Substrate	Species	Notation
1	Fine Substrate	Geranium	SF-Ge
2	Coarse Substrate	Geranium	SG-Ge
3	Fine Substrate	Gazania	SF-Ga
4	Coarse Substrate	Gazania	SG-Ga
5	Fine Substrate	Petunia	SF-Pe
6	Coarse Substrate	Petunia	SG-Pe

* Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio 1:2 in v/v. Coarse Substrate (CS)=tezontle (0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v. Geranium (Ge), Gazania (Ga), Petunia (Pe).

Table 3. Statistics of sorptivity (mm $s^{-1/2}$) of the porous capsules for each substrate.

Estadistico	Fine Substrate	Coarse Substrate	Absolute difference
Maximum	0.524	0.569	0.045
Minimum	0.390	0.390	0.000
Media	0.444	0.474	0.030
Standard Deviation	0.038	0.049	0.011

that the substrates retain is different for each level. The coarse substrate presents a greater capacity for water retention at different forces of suction, despite having the largest particle size of tezontle (between 0.4-0.6 mm) due to the content of peat moss. When performing the water liberation curves of each substrate (Figure 3), a similar behavior is seen.

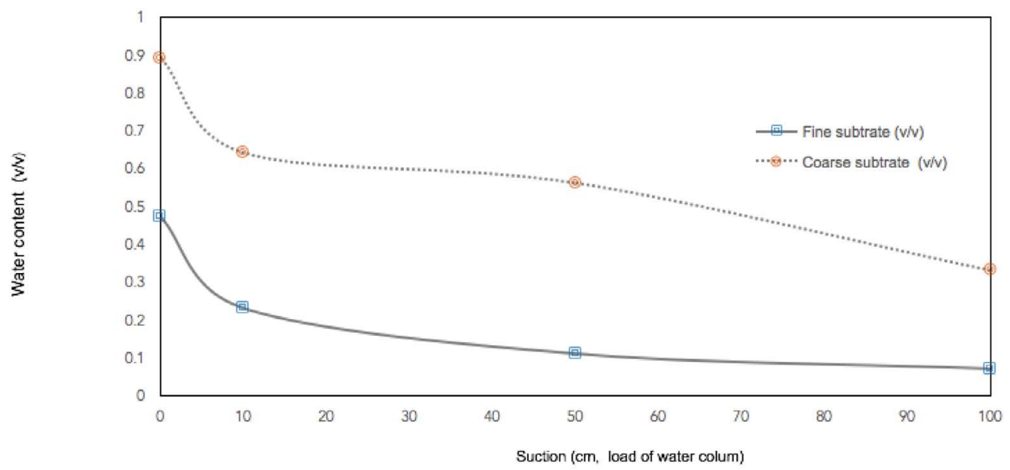

Figure 3. Curve of water retention of each of the substrates. *Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio 1:2 in v/v. Coarse Substrate (CS)=tezontle (0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v. Geranium (Ge), Gazania (Ga), Petunia (Pe).

Table 4. Volumetric water content at different tensions for each substrate.

Suction (cm) (c.c.a.*)	Fine Substrate **	Coarse Substrate ***
0	0.47	0.89
10	0.23	0.64
50	0.11	0.56
100	0.07	0.33

*c.c.a.- load of water column. **Ratio 1:2 v/v; Tezontle (<0.4 mm): peat moss). ***Ratio 1:1 v/v; Tezontle (0.4-0.6 mm): peat moss).

With the methodology by Boots *et al.* (1974), the results were evaluated and compared and interpreted based on these six variables (Table 5), given that it is a response in function of the type of material (organic, inorganic, synthetic, interaction between materials), size of the particles, and ratios of each mixture, which can even change the properties in time.

Table 5. Distribution of water, air and solids in substrates.

Variable	Fine Substrate (v/v)**	Coarse Substrate (v/v)**	Diferencia absoluta
Hardly available water (HAW)	0.07	0.33	0.26
Reserve Water(WR)	0.04	0.23	0.19
Easily available water (EAW)	0.12	0.08	0.04
Air capacity (AC)	0.24	0.25	0.01
Total pore spacel (TPE)	0.47	0.89	0.42
Solid Material (SM)	0.53	0.11	0.42

* Based on Boodt *et al.* (1974). ** v/v – Water content in v/v (volume of water /volume of substrate).

Fertigation. It is important to highlight the preparation of the nutritious solution, to avoid precipitations and with that, plugging of the internal surface of the capsules. It should be mentioned that the size of the pores in the capsules is measured in values of microns and ions at the level of angstrom.

Water consumption. For each experimental unit, the values are indicated in Table 6 (Fine Substrate) and Table 7 (Coarse Substrate), for each of the three ornamental species, where

Table 6. Water consumption by experimental unit of three ornamental species in Fine Substrate (FS) and irrigation system based on porous capsules, in greenhouse conditions.

EU*	Capsule Number	Irrigation sheet (cm)	Irrigation sheet (cm)	Irrigation sheet (cm)	Total (cm)
	Geranium				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12-Nov 21	-	-	
	DAS	1-80			
1	21	7.63	3.67	1.84	13.14
2	36	5.97	2.5	1.25	9.72
3	13	7.66	3.46	1.76	12.88
4	32	6.87	3.08	1.5	11.45
	Average	7.03	3.18	1.59	11.8
	S.D.	0.8	0.51	0.27	1.57
	Gazania				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12-Oct 30	Oct 31-Nov 20	Nov 21-Nov 30	
	DAS	1-50	51-70	71-80	
1	52	6.09	2.61	1.46	10.16
2	100	7.39	5.43	2.37	15.19
3	47	7.25	4.61	2.19	14.05
4	54	2.48	4.18	0.39	7.05
	Average.	5.8	4.21	1.6	11.61
	S.D.	2.29	1.18	0.9	3.73
	Petunia				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12- Oct 30	Oct 31-Nov 20	Nov 21-Nov 30	
	DAS	1-50	51-70	71-80	
1	109	7.91	3.34	1.8	13.05
2	75	5.89	1.88	1.03	8.8
3	81	8.21	5.41	2.64	16.26
4	71	10.57	6.03	3.22	19.82
	Average.	8.15	4.17	2.17	14.48
	S.D.	1.92	1.91	0.96	4.69

*E.U.-Experimental Unit. **DAS=Days after settling. ***S.D.-Standard Deviation. **** Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio of 1:2 in v/v.

the accumulated water consumption is indicated by phenological stage and the total. In terms of the total water consumption in the fine substrate, as it increased, it was 11.27, 14.23 and 18.23 mm for Geranium, Gazania and Petunia, respectively; similarly, for the coarse substrate, it was 11.61, 11.8 and 14.48 mm for Gazania, Geranium and Petunia, respectively.

Table 7. Water consumption in ornamental plants by experimental unit in Coarse Substrate (CS) and irrigation system based on porous capsules, in greenhouse conditions

EU*	Capsule Number	Irrigation sheet (cm)	Irrigation sheet (cm)	Irrigation sheet (cm)	Total (cm)
	Geranium				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12-Nov 21	-	-	
	DAS	1-80			
1	21	7.63	3.67	1.84	13.14
2	36	5.97	2.5	1.25	9.72
3	13	7.66	3.46	1.76	12.88
4	32	6.87	3.08	1.5	11.45
	Average.	7.03	3.18	1.59	11.8
	S.D.	0.8	0.51	0.27	1.57
	Gazania				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12-Oct 30	Oct 31-Nov 20	Nov 21-Nov 30	
	DAS	1-50	51-70	71-80	
1	52	6.09	2.61	1.46	10.16
2	100	7.39	5.43	2.37	15.19
3	47	7.25	4.61	2.19	14.05
4	54	2.48	4.18	0.39	7.05
	Prom.	5.8	4.21	1.6	11.61
	D.E.	2.29	1.18	0.9	3.73
	Petunia				
	Phenological stage	Vegetative	Flowering	Ripering	
	Date	Sep 12- Oct 30	Oct 31-Nov 20	Nov 21-Nov 30	
	DAS	1-50	51-70	71-80	
1	109	7.91	3.34	1.8	13.05
2	75	5.89	1.88	1.03	8.8
3	81	8.21	5.41	2.64	16.26
4	71	10.57	6.03	3.22	19.82
	Average.	8.15	4.17	2.17	14.48
	S.D.	1.92	1.91	0.96	4.69

*E.U.-Experimental Unit. **DAS= Days after settling. ***S.D.-Standard Deviation. **** Coarse Substrate (CS)=tezontle (between 0.4-0.6 mm) and peat moss in a ratio of 1:1 in v/v, respectively.

To test the hypotheses, the statistical analysis of the experimental design was carried out with statistical package SAS 9.4, with regards to the water consumption as a response variable, in the three ornamental genera (Geranium, Gazania and Petunia) and the two substrates (fine and coarse). Based on the results from the ANOVA and Tukey's means analysis, it can be seen that there are no significant differences in water consumption between the treatments (Tables 8, 9). This implies that the irrigation system by porous capsules is capable of supplying water to ornamental plants, regardless of the species and within the substrates studied.

However, not all the hypothesis tests have a total certainty, which is why for the selection of a treatment with the mean improvements, it is frequent to use Tukey's and Duncan's test to make multiple comparisons between pairs of means in agricultural research. In a study, they tested the Tukey, Duncan and Dunnett tests (multiple means comparison with a control) in contrast with the specific means selection tests by Bechhofer and Hsu; they found that Dunnett's test was better, after Duncan's, given that Tukey's test is very conservative (García-Villalpando *et al.*, 2001). Similarly, Wong-González (2010) mentions that in order to conduct analysis of variance, it is necessary to understand the theoretical bases of the tests, and recommends that the most convenient test should be determined based on the objective. Therefore, Duncan's multiple means analysis was carried out, given that the errors of the experimental model are large. Based on Duncan's multiple range

Table 8. ANOVA of water consumption in ornament plants (Geranium, Gazania and Petunia) (alfa=0.05), established in two types of substrates (Fine and Coarse) and irrigation system based on porous capsules, in greenhouse.

Source	D.F*	Suma of squares	Mean Square	Value of F	Pr > F
Model	5	156.8330833	31.3666167	2.82	0.0476
Error	18	200.53265	11.1407028		
Corrected total	23	357.3657333			

* D.F. Degrees of freedom.

Table 9. Group of means with Tukey's test, of water consumption of three species of ornamental plants (Geranium, Gazania and Petunia), in two types of substrate (Fine and Coarse), and irrigation system based on porous capsules, in greenhouse.

Tukey groups	Mean	n	Treatments
A	18.643	4	SF-Pe
A	14.483	4	SG-Pe
A	14.228	4	SF-Ga
A	11.798	4	SG-Ge
A	11.613	4	SG-Ga
A	11.268	4	SF-Ge

*Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio 1:2 in v/v. Coarse Substrate (CS)=tezontle (0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v. Geranium (Ge), Gazania (Ga), Petunia (Pe).
**Means with the same letter are not significantly different.

means test, which controls the rate of the comparison error (Type I error) but not the experimental errors (Tables 10, 11).

The variation in water consumption is higher in fine and coarse substrates in Petunia, and it is similar in Gazania in the coarse substrate. Water consumption in Geranium was similar in both substrates and slightly higher in Gazania with fine substrate (Figure 4).

Based on the results, it is observed that there are two groups with statistically significant differences, which implies that the null hypothesis (*Ho*) is rejected. This is where group A is the Petunia treatments in both substrates and Gazania with fine substrate, which are the ones that presented the highest water consumptions (between 14.22 and 18.64 cm), with the Petunia treatment with fine substrate being the highest. Group B is integrated by the treatments of Gazania and Geranium (in the two types of substrates), in addition to

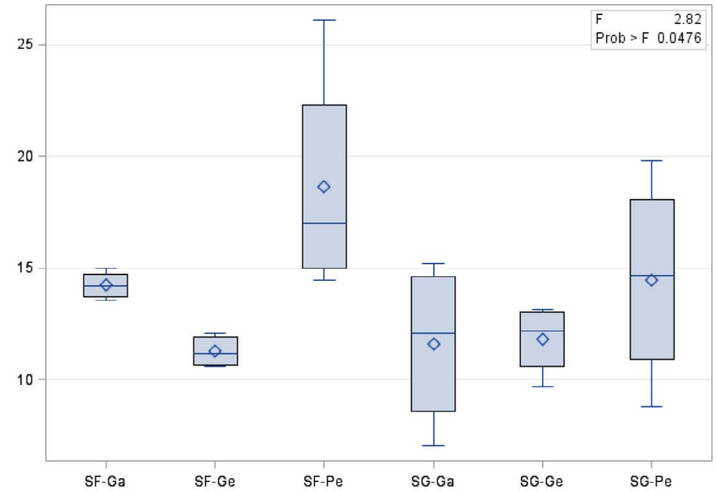

Figure 4. Box diagram of water consumption (cm) by treatment of three ornamental plant species (Geranium, Gazania and Petunia), in two types of substrate (Fine and Coarse) and an irrigation system based on porous capsules, in greenhouse.

Table 10. Groups of means (Duncan) of water consumption of three species of ornamental plants (Geranium, Gazania and Petunia), in two types of substrate (Fine and Coarse) and irrigation system based on porous capsules, in greenhouse.

Duncan Grouping		Mean	n	Treatments
	A	18.643	4	SF-Pe
B	A	14.483	4	SG-Pe
B	A	14.228	4	SF-Ga
B		11.798	4	SG-Ge
B		11.613	4	SG-Ga
B		11.268	4	SF-Ge

*Fine Substrate (FS)=tezontle (≤ than 0.4 mm) with peat moss, in a ratio 1:2 in v/v. Coarse Substrate (CS)=tezontle (0.4-0.6 mm) and peat moss in a ratio 1:1 in v/v. Geranium (Ge), Gazania (Ga), Petunia (Pe).
**Means with the same letter are not significantly different.

Table 11. Intervals of range for Duncan's means.

Number of Means	2	3	4	5	6
Critical Range	4.958	5.202	5.357	5.463	5.541

Petunia with coarse substrate, with water consumptions between 11.26 and 14.48 cm. The treatments that are in both groups are Petunia with coarse substrate and Gazania in fine substrate.

CONCLUSIONS

Significant differences in water consumption by ornamental plants and substrate type were present, where the irrigation system by porous capsules with suction have the capacity to supply continuously the water demand of the plant-substrate-atmosphere system of each of the species evaluated, based on the capacities for moisture retention of each substrate that was used.

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