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Pumice for Efficient Water Use in Greenhouse Tomato Production

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1. Introduction

The worldwide water demand is increasing (Yokwe, 2009). Although the type, magnitude and scope of the problems for water can vary from country to country (Biswas, 2010), the sector considered as the biggest user of water is agricultural (Hamdy et al., 2003). Therefore, water conservation through the efficient use of this resource in agriculture, is one of the most important firsts in the world (Díaz et al., 2004), especially in arid and semiarid regions (Forouzani & Karami, 2011). Different alternatives have been proposed to achieve sustainable water use in agriculture (Abad & Noguera, 2000; Díaz et al., 2004; Fuentes & García, 1999).

The food production in greenhouses is one of the alternatives to ensure efficient use of water (Abad & Noguera, 2000; Cadahia, 2000; Tahi et al., 2007). Greenhouses are structures that have a plastic cover, easy climate control systems, irrigation equipment and automated fertilization, elements that are used to increase productivity of horticultural and ornamentals crops (Cadahia, 2000; Cantliffe et al., 2003). In this production system, soil is often not used; instead other materials or mixtures of materials, known as substrate are used (Abad et al., 1996).

Substrates are mineral or organic materials, used for an anchor for plants and as a container of water they need (Dalton et al., 2006). To this end, substrates must have high storage capacity of water and keep it available to plants (Bender, 2008). However, these materials are often not native to the region where the activities of greenhouse production are taking place, which increases their cost (Cadahia, 2000). Therefore, natural materials and wastes are in a given region, have an important role in agricultural activities (Yaalon & Arnold, 2000) and in the preparation of substrates.

One of the naturally occurring mineral substrates, readily available and inexpensive is the sand, the material found in all environments (Moinereau et al., 1987). However, its moisture retention capacity is low, which implies the constant application of water to keep the plants grown on this substrate. Some industrial wastes such as rice husks, coconut fiber, coffee husks, rockwool, phenolic foams (Calderon & Cevallos, 2003), compost (López & Salinas, 2004) and pumice (Segura et al., 2008), also used as substrates.

Pome particles of 2-5 mm in diameter in natural conditions are responsible of the higher moisture holding capacity of sandy soils pomaceous origin (Segura, 2003), because they have a water storage capacity of 68%, of which 80% is readily available to plants (Segura et al., 2005). It is also suggested, that pumice can be used as promoter of retention of moisture in the soil or substrates for greenhouse, increasing efficiency in water use at low cost. In this regard, studies conducted without crop in sandy substrates of sedimentary origin with 30% of industrial pumice waste (2.38-3.35 mm in diameter) found increased water-holding capacity of the substrate 44%, of which, 56% was available (Segura et al., 2008). In this sense, the materials pomaceous discarded by blue jeans factories after the fabric softening and fuzz, become important in arid and semiarid regions of the world, where problems with water scarcity are found (Forouzani & Karami, 2011) and produces greenhouse vegetables to make an efficient water use. However, the behavior of moisture over time on this substrate with a horticultural crop has been rarely reported.

The tomato crop (*Lycopersicon esculentum* Mill) is one of the main vegetables grown throughout the world (Al-Omran et al., 2010; Bender, 2008), both in open ground and in greenhouse systems (Quintero, 2006). Water management in intensive production of tomato in greenhouse is of vital importance for this crop. Water performs a number of basic functions in the life of tomato plants, constituting 95% of its fresh weight (Castilla, 2005). In addition, the water needs of this plant are presented in three critical periods: in the emergence of the seedling, early flowering and during filling of fruit (González & Hernández, 2000).

In this context, it is likely that the amount of water used for development and production of tomato, decreases when using a sand-pumice substrate under greenhouse conditions; i.e. the growth and fruiting of tomato plants are not affected when applied different frequencies of irrigation due to capacity of moisture retention of sand-pumice substrate.

The objectives of this study were to evaluate the behaviour of moisture in a sandy-pumice substrate over time; assess the development of tomato plants until fruiting in this substrate in greenhouse and to establish the frequency of irrigation needed without affecting the development of plants in this substrate.

2. Materials and methods

2.1 Study area

The research was conducted in a greenhouse of Instituto Tecnológico de Torreón, located in the Región Lagunera, in Torreón, Coahuila México. This region is located between 25° 36′ 45′′ and 25° 36′ 47′′ north latitude and between 103° 22′ 19′′ and 103° 22′ 21′′ west longitude, at 1159 meters above sea level (Fig. 1). Climate is a dry desert with summer rainfall and cool winter [Bw (h′) hw (e)] (García, 1988). Total annual precipitation is 250 mm and evaporation is 2 400 mm. The average annual temperature is 21 °C, with annual maximum temperature of 29.5 °C and minimum of 14.8 °C; the warmest month is June (35.3 °C) and January is the coldest month with 6.6 °C (CNA, 2011).

2.2 Methodology

The work was divided in three stages: 1) Selection of experimental material, 2) Greenhouse work and 3) Laboratory work.

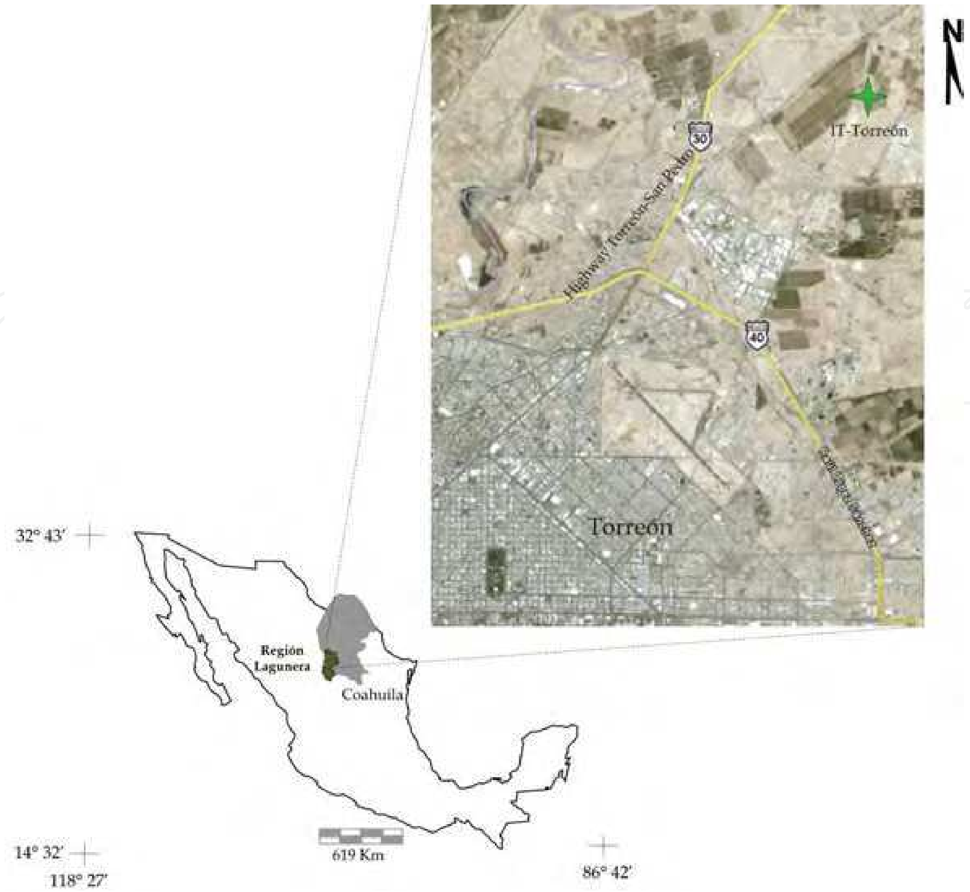

Fig. 1. Localization of study area

2.2.1 Selection of the experimental material

The substrate used was a mixture of sand with pumice. The sand was obtained by sieving coarse sediments of the Nazas river through two sieves (2 mm and 0.5 mm in diameter) to remove particles of the size of gravels, silts and clays, as established in the laboratory manual of Soil Survey Laboratory (SSI, 1996). The mineralogical composition of the sand was obtained by powder diffraction of X-ray (Melgarejo et al., 2010). The sand has quartz, pyroxene, biotite, mica, and calcium and sodium feldspar. The sand retains water easily available, but quickly lost its due to its low moisture retention capacity (Calderon & Cevallo, 2003; Porta et al., 1999). Carbonates were removed from sand (Resh, 1989). Pumice particles were obtained from wastes of a maquiladora company in the region. Pumice wastes were crushed and sieved to bring them to a diameter between 2.38 mm and 3.35 mm, size of the particles that retains a greater amount of water (60% in their pores) (Segura, 2003). Subsequently, particles of desired size were put through a wash, cool water first and then with hot water in order to eliminate industrial wastes (Sandoval & Brisuela, 2002); finally they left to dry in the shade at room temperature. Tomato plants (*Lycopersicon esculentum* Mill) cv. Río Grande, were used in this experiment. This variety has 90% germination, is of intermediate and semi-early cycle (Paez et al., 2000).

2.2.2 Greenhouse work

The sand-pumice substrate was elaborated according to methodology used by Segura et al. (2008), with the proportions of 30% pumice and 70% sand, based on volume. This substrate has a field capacity of 15.7% and a permanent wilting point of 4.9, with available moisture of 10.8% (Segura et al., 2008). The substrate was placed in black plastic pots (circular area of 283.53 cm^2) with a capacity of six litres and previously plugged holes. The weight of dry substrate in the pot was recorded in the balance, resulting in an average weight of five kilograms per pot. Also, before transplantation of tomato seedlings, the substrate in the pots was saturated with water for 48 hrs. When time went on, plugged holes of the pots were uncovered in order to drain excess water until the drip rate was one drop every ten seconds (Preciado et al., 2002) ensuring that the substrate was on field capacity (Segura et al., 2008). At this point, the weight of the wet pot was recorded, so that subtracting to this data the weight of the pot with dry substrate it is obtained the initial water weight or initial moisture content.

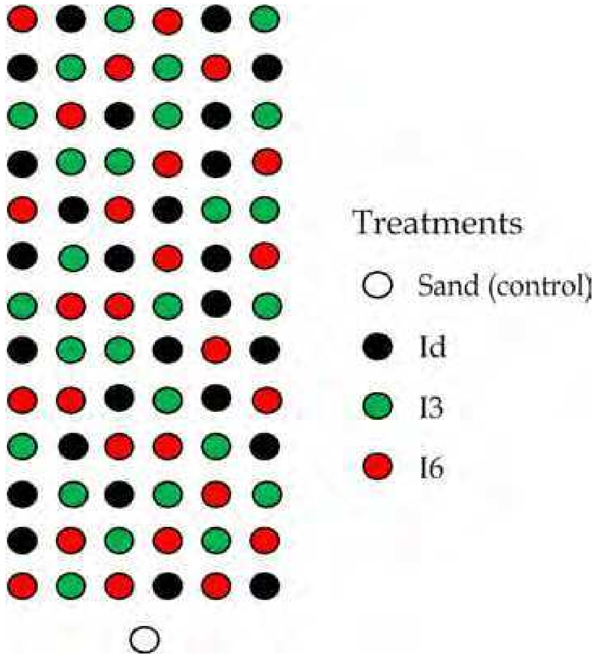

Fig. 2. Distribution of the treatment in the experiment

Tomato seeds were placed in a container whose cavities had substrate (peat moss) wet. Light irrigations with modified nutritious solution of Steiner (1961) whose components are N, P, K, Ca, Mg, Fe, Cu, Zn, Mn and B, with 550, 27, 514, 634, 122, 10, 0.5, 0.45, 1.23 and 0.29 $mg\cdot L^{-1}$, respectively (Magdaleno-Villar et al., 2006), was applied every three days until the seed germinated. The transplant was performed when the seedlings were 20 cm in height, measured from the cotyledons. The plants before being transplanted were weighed, with the aim of adding weights to the initial moisture and monitor the behaviour of moisture later.

The plants in the substrate were put through three different irrigation frequencies: daily, every three days and six days (I_d, I_3 and I_6, respectively), which for this experiment corresponded to the treatments. Each frequency had 26 repeats and a control with only sand and frequency of irrigation daily (control), so that the work consisted of 79 experimental units. The experimental design was completely random (Fig. 2).

The moisture content of each pot was recorded daily by the gravimetric method at twelve hours for eighty days. The lost water was replenished with nutritious solution according to the corresponding treatment; for example, the difference in moisture in the pot of I_d treatment was recovered at the time of the weighing. When the treatment was I_3, the moisture content was recorded only, and the solution was added until the fullness of the set time and so on.

At the same time, destructive sampling of plants in each treatment were carried out at 28, 40, 52 and 60 days after transplanting (dat) according to proposed by Segura et al. (2011). Five plants of each treatment were randomly selected in each set date. Plants were separated from the substrate to obtain the data of plant height, root length, number of flowers and number and weight of fruit. The average fresh weight of plants per treatment at each sampling was added to the rest of the corresponded pots, in order to have a total weight of each of them and continue with their gravimetric weight every day. Finally, at 80 dat six plants were evaluated leaving a potted plant to another process in the laboratory. The results were evaluated by analysis of variance and a Tukey's test at $p \leq 0.05$.

2.2.3 Laboratory work

At the end of the greenhouse stage, the substrate of the last pot with plant of each treatment was analyzed micromorphologically in order to observe its porosities and spatial distribution of the particles of pumice and sand. To achieve this, the pots were taken to the laboratory without disturbing the physical conditions of the substrate, i.e. without moving the substrate; only the aerial part of the plat was cut at the base (two centimetres above the surface of the substrate).

The four pots with substrate and plant roots were air-dried and in the shade. Once dried, they were impregnated with polyester resin and styrene monomer, at a ratio of 7:3, mixed with potassium fluoride. Subsequently, they were left in gelation in the shade for 20 days.

When they were hardened, it was proceed to cut them with a diamond blade and polished with different abrasives to a thickness of 30 μm, to obtain thin sections of 6×7.5 cm. The thin sections were analyzed with an Olympus petrographic microscope, with magnifications of 2.5× to 100×. The description of the thin sections and microconstituents was based on the manual developed by Bullock et al. (1985). The description of the porosity was performed on digital images obtained with a CCD Olympus camera of 4.1 Megapixel, getting close up of rectangular shape array of 86×64 mm (5504 mm^2) with a spatial resolution of 31 μm per pixel. The analysis of the image was performed with an analyzer Image Pro Plus v4.5 (Media Cybernetic, Maryland, U.S.A.).

In the other hand, the average leaf area for each treatment was obtained by cutting eight leaves per plant sampled; on the leaves the maximum length was measured from the base of the petiole up to the tip of the central leaflet and the maximum width of the leaves was measured perpendicular to maximum length (Astegiano et al., 2001). In addition, the leaves were photocopied to obtain leaf area by using a LICOR (LI-3000) leaf area meter.

Also, the efficiency of water use (EWU) of tomato plants was obtained by relating the gross weight of the fresh fruits in kilograms, until the last day of the experiment, with the total amount of water (in m^{-3}) used until then.

3. Results and discussion

3.1 Behaviour of moisture in the substrate

The amount of water used in each treatment was different (see Table 1). The water consumption presented when using sand-pumice substrate at different irrigation frequencies, was lower than the substrate of sand (98.82 L plant^{-1}). The above was due to the effect that the pumice particles had with sand and water. When moisture comes into contact with mineral particles create a potential difference matrix (Hillel, 1982; Miller & Gardner, 1962). In this sense, the sand-pumice substrate is a system composed of two subsystems, where the sandy substrate has greater potential than the pumice, which causes the water retained in the sand evaporates first and then the one in the pumice; i.e. the water in the pores of the sand, product of arrangement of its particles, evaporates first and subsequently the one found in the pores of the pumice (Segura et al., 2008).

Sample date (days)	Water applied (mm)							
	Sand substrate		Sand-pumice substrate					
			I_d		I_3		I_6	
	Total	Daily average water	Total	Daily average water	Total	Daily average water	Total	Daily average water
0	0	0	0	0	0	0	0	0
28	6.52	0.23	2.71	0.09	2.03	0.07	1.45	0.05
42	4.01	0.28	3.21	0.22	2.98	0.15	2.13	0.10
52	5.60	0.56	2.93	0.28	2.51	0.25	1.88	0.18
60	4.91	0.61	2.63	0.32	2.31	0.28	2.11	0.26
80	13.80	0.69	8.81	0.42	7.69	0.38	6.51	0.32
Total	34.85		20.29		17.55		14.10	

Table 1.Water applied to plants tomatoes in sand and sand-pumice substrates and different irrigation frequencies

Pomaceous material found in sand acts as little tightly sponges (Daniels & Hammer, 1992) with a high content of pores (60%) of which, 15% are driving pores and 45% are storing pores (Segura et al., 2003) or mesopores (30-70 µm in diameter) and micropores (<30 µm in diameter), respectively (Sumner, 2000).

Analyzing micromorphologically sand-pumice substrate, it was observed an apedal structure (without aggregates). In this context, porosity is defined as of compound packaging (Bullock et al. 1985; Stoops, 1993), because of presence of pomaceous particles with interconnected pores, which causes the existence of a greater number of pores of storage in sand substrate (Segura et al., 2003; Sumner, 2000). Figures 3 and 4 are examples of the above.

In Fig. 3 it shows the exposure of a pumice particle in 20×, where it can be seen a rough surface with pores of different diameter and a magnification at 100× of a thin section where it appears the porosity of pumice, place where water is stored. In Fig. 4, three photomicrographs (in greyscale, in ultraviolet light and binary format) show spatial distribution of particles of pumice and sand, in this case the clearer parts on the picture 4a and 4b belongs to porosity space; see as how the pore space is increased where the pumice is.

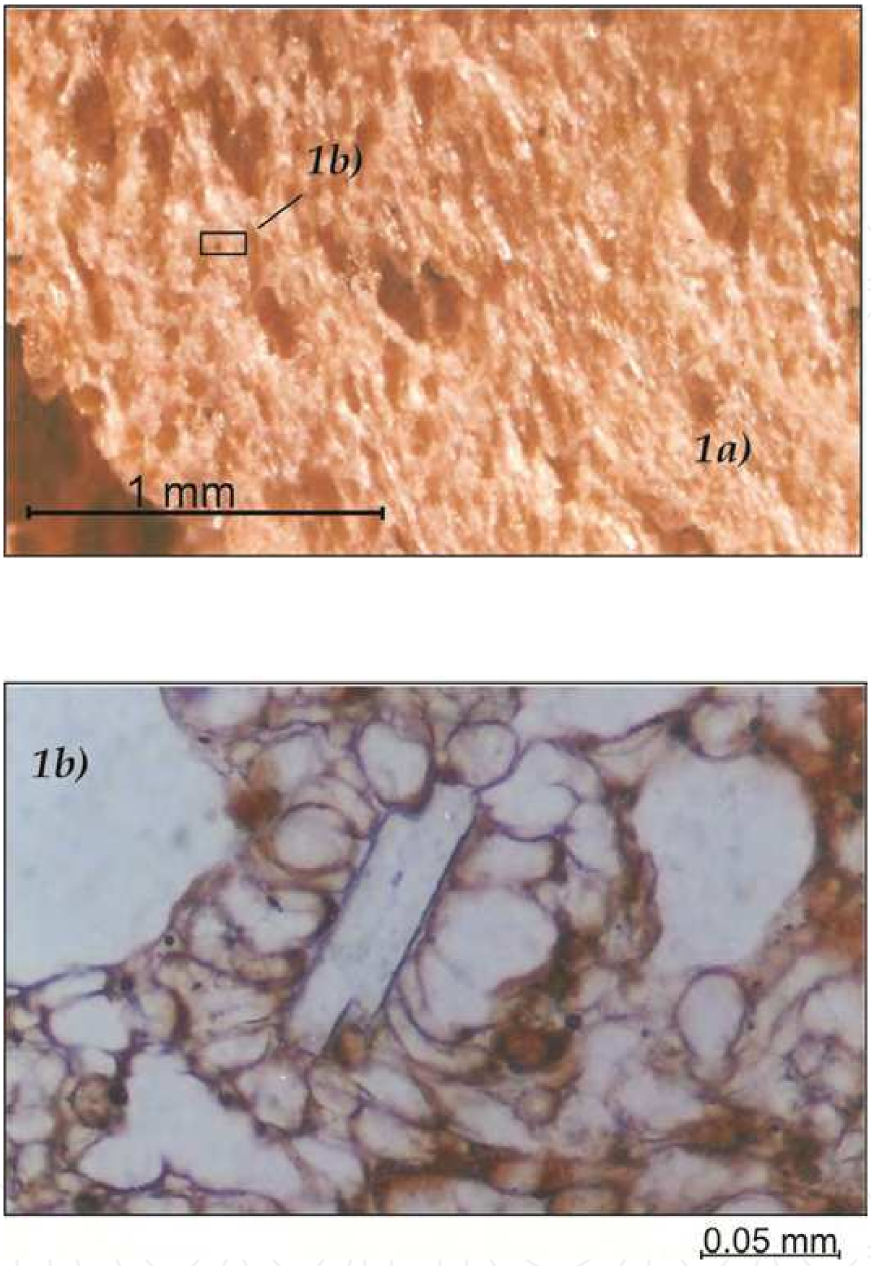

Fig. 3. Photomicrographs of a pumice particle: *1a*) pumice particle with incident light, *1b*) pumice porous in thin section with plane polarized light

Even when different treatments had the same substrate, in treatment I_d (sand-pumice substrate) was missed a greater amount of water (20.29 mm·plant^{-1}) than treatments in frequencies I_3 and I_6 (17.55 y 14.10 mm·plant^{-1}, respectively). Segura et al. (2008) indicate that the moisture in the sand-pumice substrate is lost at a rate of 2.46% per day. In our case, each treatment had higher ratios of percentages of loss than those reported in the literature. Considering that initial moisture was of 0.74 mm, I_d, I_3 and I_6 treatments had 11.43%, 10.00% and 9.06% of loss of water daily, respectively.

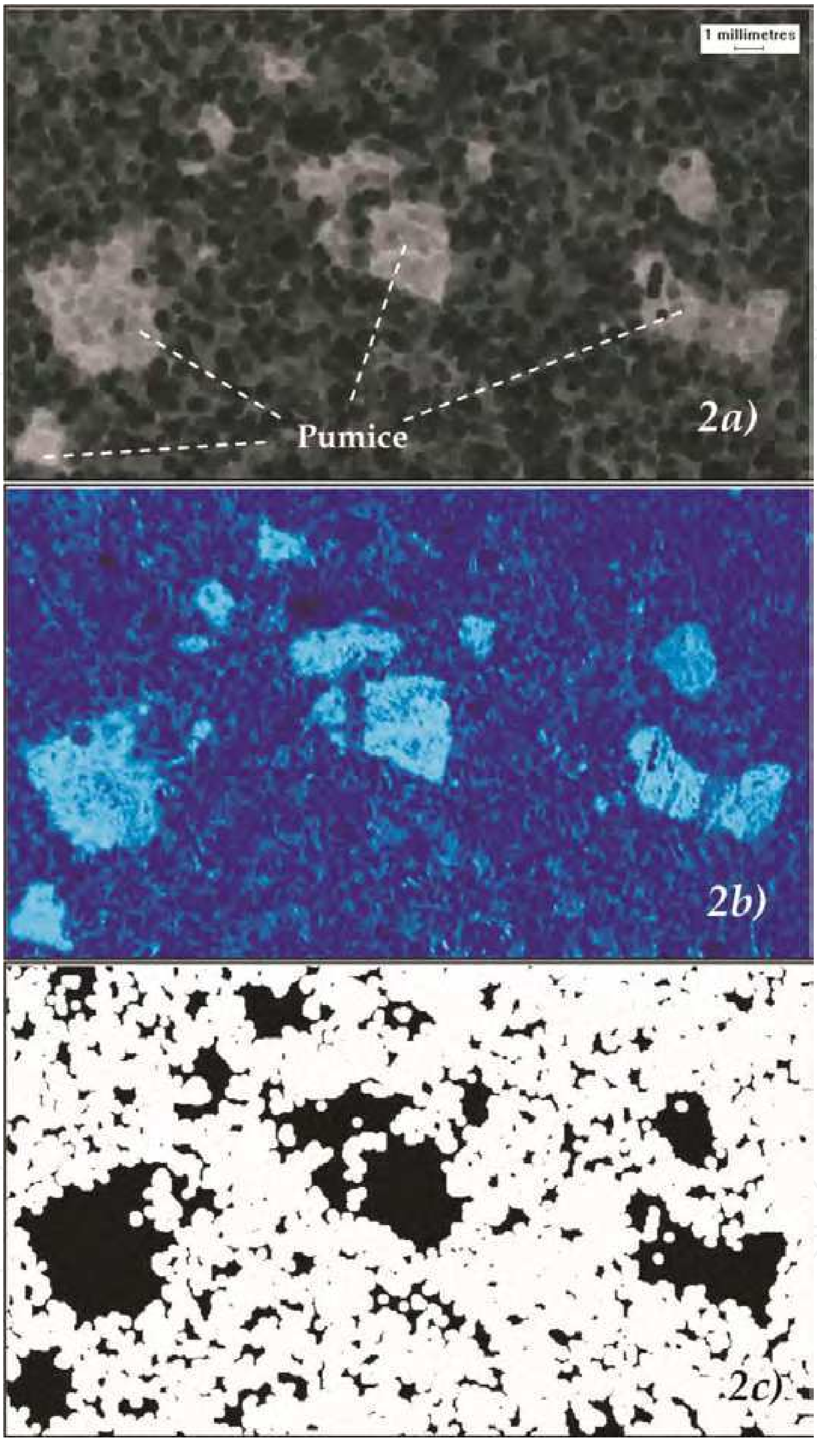

Fig. 4. Photomicrographs of sand-pumice substrate: 2*a*) greyscale; 2*b*) ultraviolet light and 2*c*) binary format. The pumice particles increase the porous space of sand

Although, it must be considered that the effect of plant factor used in this work, since in those reported in the literature all that was evaluated was the substrate. For this reason, the treatments had different loss rates (see Table 2), tending to reduce the average moisture as time went on in days. This behaviour was mainly due to the different times when irrigation was applied, where it could be observed the effect of pumice on the moisture retention capacity of sand and therefore, the amount of water to replenish (Fig. 5). In our case, the models of lineal regression between the moisture of substrate and I_d, I_3 and I_6 treatments (MI_d, MI_3 and MI_6, respectively) and time (t) show the effect of timing of irrigation in the substrate.

Treatment	$M = \beta t + c$	R^2	p^*
Sand	$Ms = -0.0625\,t + 0.2461$	0.7222	0.058
I_d	$M_{Id} = -0.0847\,t + 0.7212$	0.9749	0.048
I_3	$M_{I3} = -0.0741\,t + 0.7298$	0.9883	0.022
I_6	$M_{I6} = -0.0671\,t + 0.7521$	0.9949	0.035

*p: Rejection probability of the variance analysis regression.

Table 2. Simple lineal regression model between the H to each treatment and t

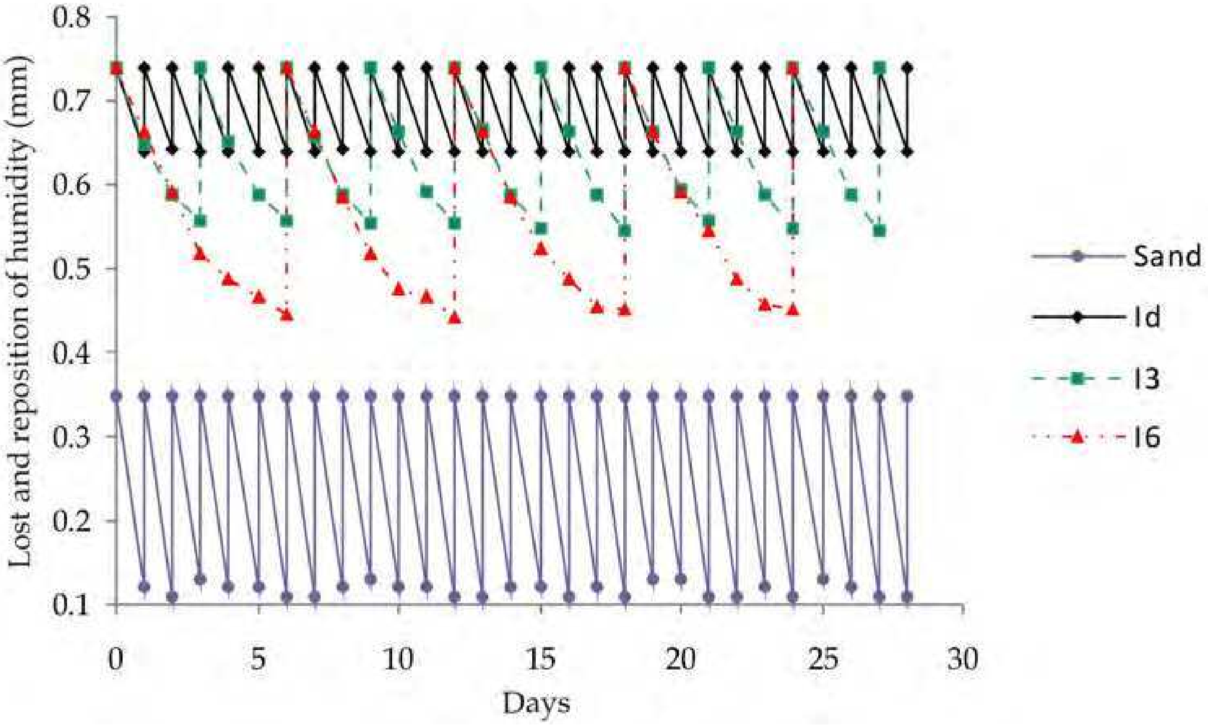

Fig. 5. Behaviour of moisture in each treatment over time

These models are significant at $p \leq 0.05$ level. The rejection probability value ($p = 0.022$) of the analysis of variance of the regression between H_{I3} and t was the most significant, with a negative trend and a $R^2 = 0.9883$. However, these results are averages per day and differ from those reported by other authors (Savvas et al., 2006; Tzortzakis & Economakis, 2007).
When analyzing the average amount of water applied by irrigation time over time, in I_6 treatment were applied larger volumes of water divided into a few times of application (see Table 3).

Treatment	Sample date (days)	Number of irrigation for each period	Average of water applied by irrigation (mm)
I_d	28	28	0.10
	42	14	0.22
	52	10	0.29
	60	8	0.32
	80	20	0.44
I_3	28	9	0.22
	42	5	0.59
	52	3	0.83
	60	2	1.15
	80	7	1.09
I_6	28	5	0.29
	42	2	1.06
	52	2	0.94
	60	1	2.11
	80	3	2.17

Table 3.Average amount of water applied to each irrigation time and the number of irrigation between sampling and sampling

This situation is contrasting with those in I_d, where volumes were lower, even though the total of volume in this treatment was higher than in other frequencies. As an example figure 3 is shown, where it can be seen that the lost of moisture in the treatments I_3 and I_6 were accumulating exponentially, making this the action of pumice, recovering the lack of water at time is was supposed to. In the I_d treatment the water was resting at the time of its weighted, so it was not observed the moisture loss exponentially as in other treatments. Segura et al. (2011) indicate that in daily irrigation is not given an opportunity to the functioning of the sand-pumice system, since moisture is replenished day after day; whereas when irrigation is every three days, the moisture is lost first in the sand remaining in the pumice. This situation goes so far when irrigation is every six days, since water is lost in the sand and in the pumice. This can result in problems in the development of plants (Tahi et al., 2007).

All the above indicates that the sand-pumice substrate has the ability to store water and not lose easily, but what happened to the tomato plants that were in the substrate? This topic will be addressed below.

3.2 Development of tomato plants

3.2.1 Water consumption

The different tomato plants during its development and fruiting, consumed different amounts of water at each sampling date (see Table 1). In the I_d treatment the amount of average water per pot with tomato plant in the first sampling (28 dat) was of 0.09 $mm \cdot day^{-1} \cdot plant^{-1}$ and 0.42

mm·day^{-1}·plant^{-1} from the 80 dat; these results have little difference to those reported in the literature. Flores et al. (2007) indicate that the tomato plant in the early days of development requires 0.200 L (0.07 mm) and during the period of greatest demand up to 1.500 L (0.52 mm). This contrasts with findings in the treatments I_3 and I_6. For example, the I_3 treatment in the period of greatest demand (from 60 to 80 dat) plants consumed 0.38 mm·day^{-1}·plant^{-1}, i.e. there was a water savings of 10% compared with I_d treatment. This can be explained by the moisture retention capacity of the substrate, as mentioned earlier.

The I_6 treatment had a lower increase due to water requirements by tomato plants as time passed. In this regard, when water stress is generated in tomato crop, the plant reacts by closing its stomata to avoid perspiration (Al-Omran et al., 2010; Asgharipour & Armin, 2010; Bender, 2008). However, if water stress is prolonged, the plant is able to transpire accumulating solutes and reducing the size of their cells to decrease the water potential; when this happens, the plant opens its stomata partially to continue with its vital functions (Reddy et al., 2005). In our case, the results in this treatment at 60 dat was of 73 cm, result similar to that report (75 cm) by Macua et al. (2003) in plants subjected to water stress.

Treatment	Sample date				
	28	42	52	60	80
	Leaf area (cm^2)				
Sand	250.23 a	1340.50 a	1453.61	1540.22	1534.25
I_d	252.03 a*	1345.08 a	1458.82 a	1542.13 a	1548.44 a
I_3	255.98 a	1221.11 a	1354.65 b	1469.42 b	1559.57 a
I_6	93.52 b	586.81 b	710.85 c	739.56 c	801.71 b
LSD	56.45	289.37	77.35	22.15	31.13
	Root lenght (cm)				
Sand	20 a	35 a	47 b	54 a	60 a
I_d	22 a	38 a	50 a	57 a	65 a
I_3	20 a	39 a	48 b	55 a	66 a
I_6	17 b	26 b	28 c	32 a	39 b
LSD	2.88	4.88	1.90	3.21	6.50

*Different letters in the same column indicate significant difference, Tukey´s test ($p \leq 0.05$). LSD: Lower significant difference

Table 4. Results of leaf area and root length of tomato plants in sand-pumice substrates at different sampling dates

In the case of leaf area (La) the trend of results was similar to plant height. The I_d treatment had the highest La at the end of the experiment (1548.44 cm^2); however, it did not present significant differences ($p \leq 0.05$) compared to I_3 treatment (see Table 4). The I_6 treatment presented the lowest La in the experiment. Orozco et al. (2008) indicated that the leaf area is a physical indicator that determines the magnitude of the photosynthetic machinery, used to meet the demand of photosynthate by the growing organs of the crop and for this; the plant requires the presence of water to carry out the process of photosynthesis. The absence of significant differences between the treatments of daily irrigation and every third day at the end of the experiment is an indication that despite not adding water daily in treatment I_3, tomato plants were not subjected to a water stress.

When tomato plant was not exposed to prolonged water stress, it can perform its physiological processes without any problems (León et al., 2005; Páez et al., 2000; Tahi et al., 2007). Instead, the I_6 treatment by presenting a lower La, reflects the water stress to which it was submitted. In general, the lack of water results in a poor development of leaf area since water reservoir that a plant has is used to stay alive and thus decrease its physiological processes (Macías et al., 2010; Sirvansa, 2000; Tahi et al., 2007).

Another physiological variable evaluated was the root. The length of this organ in the experiment was significant ($p \leq 0.05$). At first differences among the three treatments were presented, but after the 52 dat the I_d and the I_3 treatments had very similar root lengths unlike the I_6 treatment (see Table 4). Results closely related to the presence of water in the substrate, as explained above.

Fig. 6. Tomato plant roots in sand-pumice substrate

One of the interesting aspects that were observed was the presence of roots in the particles of pumice (see Fig. 6). Several authors have reported that plant roots may have access to the water that is found inside the pores of pumice (De León et al., 2007; Savvas et al., 2006). Event that occurs because the water in the pores of particles of pumice is held at a tension less than 0.0024 kPa, so the water is readily available (Segura et al., 2008).

3.2.2 Flowers and fruits

The flowers of tomato in this experiment appeared after the 28 dat (see Table 5). The number of flowers between I_d and I_3 treatments had not significant differences ($p \leq 0.05$) until eighty days. However, it can be observed that the amount decreases in accordance with the passing of time, this condition occurs because it began with fruiting. León et al. (2005) state that moderate water stress does not affect physiological process in tomato plants as flowering and fruiting (Tahi et al., 2007). The I_6 treatment introduced its first flowers after the sixty days. The absence of flowering plants in this treatment was due to water stress to which they were subjected. The tomato plants are sensitive to water stress and high temperatures, since they affect flowering and reduce fruit production (Shubang, 2002; Sirvansa, 2000).

Treatment	Sample date			
	42	52	60	80
	Flowers			
Sand	13 a	17 a	23 a	16 a
I_d	12 a*	16 a	22 a	17 a
I_3	13 a	18 a	20 b	16 a
I_6	-	-	-	9 b
LSD	2.0	5.1	2.0	3.3
	Fruits			
Sand	-	-	8 a	23 a
I_d	-	-	8 a	22 a
I_3	-	-	5 b	21 a
I_6	-	-	-	-
LSD	-	-	2.0	2.0

*Different letters in the same column indicate significant difference, Tuckey's test ($p \leq 0.05$).

LSD: Lower significant difference

Table 5. Results count flowers and fruits of tomato plants in sand-pumice substrates at different sampling dates

The appearance of the fruits started to sixty days. Between the I_d and I_3 treatments there were no significant difference at 80 dat. On average there were 22 and 21 fruits per plant unharvested, respectively (Table 5). The fruits harvested totalled 15 for the I_d treatment and 14 for the I_3 treatment per plant, with an average weight per fruit of 140 and 135 g, respectively.

3.3 Efficient water use (EWU)

The EWU of tomato plants showed significant differences between the control and the other treatments under study. The EWU of the plants in the sand substrate was 36.32 $g \cdot m^{-3}$ (Table 6), result in treatment less than in I_d and I_3 treatments (36.84 and 38.57 $g \cdot m^{-3}$, respectively). These results are greater than (12.1 $g \cdot m^{-3}$) reported by other authors (Al-Omran et al., 2010; Tahi et al., 2007). Even though the experiment lasted only eighty days, the results showed the usefulness of sand-pumice substrate; also demonstrate the utility of pumice for this purpose.

Substrate	Treatment	Tomato plant yield to 80 dat (g)	Total water applied (m^{-3})	EWU ($g \cdot m^{-3}$)
Sand	Daily	3.560	0.098	36.32 a*
Sand-pumice	I_d	2.100	0.057	36.84 a
	I_3	1.890	0.049	38.57 a
	LSD			3.36

*Different letters in the same column indicate significant difference, Tukey's test ($p \leq 0.05$).

LSD: Lower significant difference.

Table 6. Efficient water use of tomato plants in sand and sand-pumice substrates

4. Conclusions

The behaviour of moisture in the sand-pumice substrate with tomato plants is consumed at a rate of 10 to 11% per day with respect to its ability to retain moisture. This allows to space the time of application of water every three days to tomato plants on this substrate without its development is affected, so the flowering and fruiting stages are carried out without putting plants to a water stress. The use of pumice particles as an improver of moisture holding capacity of sandy substrate helps plants to make an efficient use of water in greenhouse. However, more research related to nutritional quality of fruits is needed to ensure the obtaining of a quality product making an efficient use of water.

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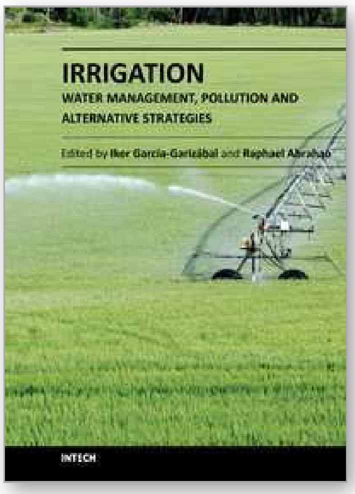

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Irrigated agriculture is the most significant user of fresh water in the world and, due to the large area occupied, is one of the major pollution sources for the water resources. This book comprises 12 chapters that cover different issues and problematics of irrigated agriculture: from water use in different irrigated systems to pollution generated by irrigated agriculture. Moreover, the book also includes chapters that deal with new possibilities of improving irrigation techniques through the reuse of drainage water and wastewater, helping to reduce freshwater extractions. A wide range of issues is herein presented, related to the evaluation of irrigated agriculture impacts and management practices to reduce these impacts on the environment.

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