ORIGINAL ARTICLE

Suction Irrigation Technology for the Production of Tomato (*Lycopersicon esculentum*) under Controlled Conditions

Tecnología del riego por succión para la producción de tomate (*Lycopersicon esculentum*)en condiciones controladas

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ABSTRACT. The experimental results under controlled conditions for the determination of the suction height appropriate for tomato cultivation, variety (F1-FA572), subjected to irrigation by suction with ceramic porous capsules are presented. The suction height (h = -15 cm) was found like the most appropriate for the capsules characteristics and soil used in the experiences. The selection criterion was the number of fruits observed. The vegetative growth of the crops (plants height), the daily water consumption and the number of fruits per plant were observed. Values approximately coincident of water consumption by the crop perspiration were found.

Keywords: sustainable agriculture, ceramic porous capsules, saving water, zero energy.

RESUMEN. Se presentan los resultados experimentales bajo condiciones controladas para la determinación de la altura de succión apropiada para el cultivo del tomate variedad F1-FA 572 sometido al riego por succión con cápsulas porosas de cerámica. Se encontró una altura de succión (h= -15 cm) como la más adecuada para las características de las cápsulas y el sustrato de cultivo empleados. El criterio de selección fue el número de frutos observados. Se realizaron observaciones sobre el crecimiento vegetativo del cultivo (altura de las plantas), el consumo de agua diario y el número de frutos por planta. Se encontraron valores de consumo de agua aproximadamente coincidentes con la transpiración del cultivo.

Palabras clave:agricultura sostenible, cápsulas porosas, ahorro de agua, energía cero.

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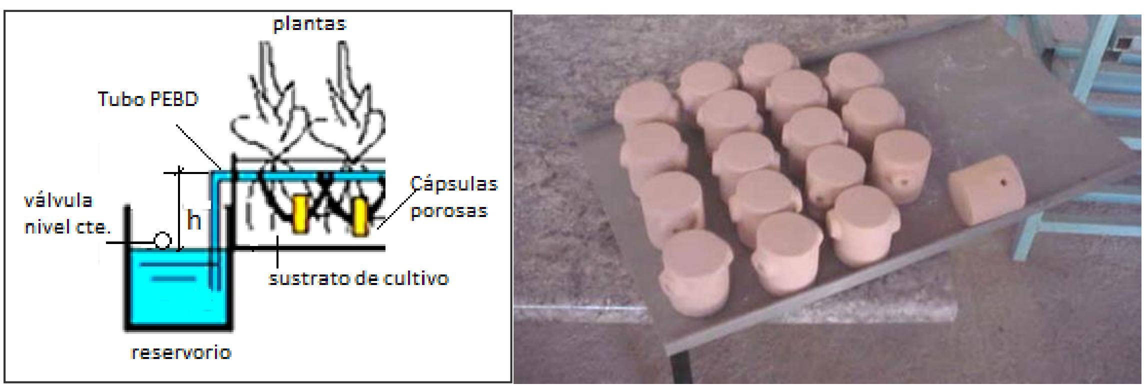
INTRODUCTION

The current problems associated to the prolongeddrought the country suffers, have generated the necessity to develop new techniques and irrigation methods to minimize the use of water and energy for agriculture, (Brown *et al.*, 2015). At present, some efforts are carried out for the scientific community at national and international level in order to develop goodpractices and conservationist technologies of soil, water and energy resourcesat local and regional level (López *et al.*, 2016). Other efforts in the socioeconomic and environmental order have been developed at regional level in Cubathat offer alternatives and ways for the conservation of natural resources (Barzev, 2008). The irrigation by suction technology with the use of ceramic porous capsules constitutes a promissory alternative for the production of vegetables to small scale in arid zones and with problems of drought and extreme drought. The technology for the production of porous capsules has been developed in the last years by Peña (2015). Other applications like the irrigation of small areas of gardens have been proposed and developed with success by Peña (2017), in tourist facilities in Ciego de Ávila and in the oriental provinces with other technological alternatives like the production of cocoa postures through the irrigation by suction with the utilization of several materials as wicks (Ochoa y Peña, 2012).

Amongthe main problems associated to the use of this irrigation technology, it is highlighted the requirement of their adaptation for different cultivations according to the physiologic characteristics of the plants Silva *et al.* (2012). These systems work in virtue of the Law of Energy Conservation. The water contained in the capsules (Figure 1B) passes to the soil through the capsules pores and they are recharged by effect of the suction exercised by the plant root system (water uptake) in the soil in a self-regulated way. The level of the water in the feeding reservoir to the system is placed below the cultivation soil to a height (h) known as suction height (Figure 1A).



(A) (B)

FIGURE 1. (A) Simplified scheme of irrigation by suction system: (B) ceramic porous capsules. Source: Ownelaborationbyauthors.

All vegetablescrops do not have same root system. Some are more profuse, deep and strong as the tomatoroots while others as lettuce rootsare weaker and deeper (Bainbridge, 2001). Even, the appropriate suction height can be different depending on the root system characteristic to each variety ofthe same plant. For this reason, the adaptation to irrigation by suction with porous capsules is one of the fundamental problems that needs attention and the main way for it is the experimentation with the purpose of knowing the most advisable suction height (h) among others,for each cultivation parameters (Peña, 2015). The suction height (h), does not only depend on the physiologic characteristics of the plants, there is also a strong influence of the physical composition of the cultivation soil and of the geometric dimensions, specific surface and total porosity of the capsules used according to reports by Dalzell (1991).

The objective of this work, is to find the suction (h) height for the tomato variety F1-FA 572 through the experimentation under controlled conditions.

The development of this research, will allow using the obtained criteria to adapt irrigation by suction systems with ceramic porous capsules for this variety under field conditions.

METHODS

The experiment was carried out in ceramic containers of 22 cm of height; diameter 27 cm and volume. 8943.9 cm^3. The experience was conducted in an open experimental area of the Hydraulic Research Center (CEH) of the University in Ciego de Ávila, Cuba. The selected tomato variety was F1. FA 572 of indeterminate growth according its high productive value. The geometric properties of the ceramic porous capsules utilized are shown in the Table 1.

The porous capsules were connected with reduced diameter pipes (4.5 mm) of PEBD using resistant to the humidity paste (Figure 2). The main components to build the ceramic porous capsules are: kaolin, moonstones, calcium carbonate, sand silica, powdered glass and water in different proportions. The total porosity of the capsules observed in tests carried out previously was 32.5% (Peña, 2015). The ceramic containers were filled manually with the cultivation soil composed by: 50 % of red compact soil and 50% of bovine manure, with the following properties: average real density =2.63 g/cm^3.; infiltration coefficient = 50 mm/h.; total porosity = 52.10 %.These properties were determined previously by Peña (2015). Neither any type of industrial fertilizer was used nor chemical products for pest control in this experience.

Four treatments (T) were evaluated with five replicas each one. A total 20 ceramic containers (five for each treatment) were used. Four different suction heights were evaluated: (T1 h=0 cm); (T2 h = -10 cm); (T3 h = -15 cm) and (T4 h = -20 cm). The height of suction h=0 means that the level of water in the constant level reservoir (Figure 1A) is the same as the level of the porous capsula center placed in the ceramic container. The negative values -10, -15 and -20 are the distances measured from the level of water in the constant level reservoir until the center of the capsules placed in the containers.

TABLE 1. Geometric Characteristic of the Porous Capsules Utilized (Peña, 2015)

External Diameter (cm)	Height (cm)	Wall Thickness (cm)	Bases Area (cm^2)	Lateral Area (cm^2)	Total Area (cm^2)	Volume (cm^3)
4.8	5.3	0.60	36.16	79.88	116.04	41.71

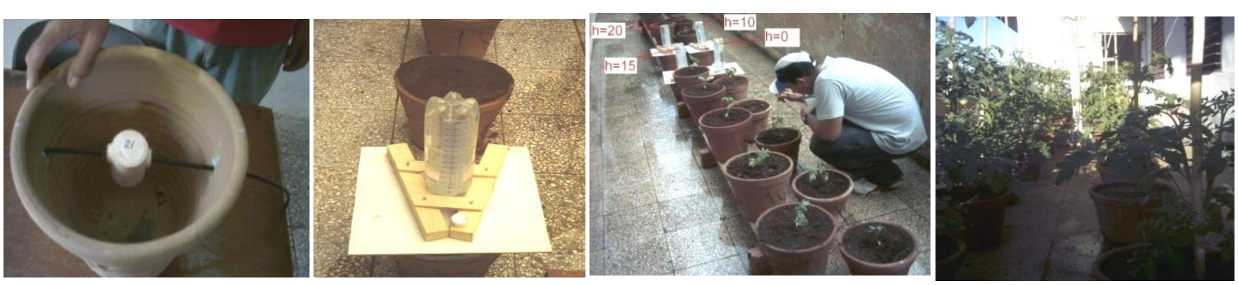


FIGURE 2. Step sequence of the experiment under controlled conditions: From left to right: porous capsules placement into the containers; device to measure the water volume. View of the experiment assembly and crop in growth phase. Source: own elaboration by authors.

The ceramic containers were drilled in two positions and the capsules were placed so that they were located in their centers to a depth of 10 cm from the container superior border (Figure 2). The soil mixture was improved using a sieve of 1 cm^2, to achieve a uniform composition and free of strange objects that can cause a faulty operation of the system according to Bainbridge (2001). For each treatment, the feeding reservoir was placed according to the suction height evaluated with regard to the center of the porous capsules. Devices were placed to control the water volume consumed by the plants (Figure 2). They were built with plastic containers of 10 liters, wooden lids and PET bottles graduated in cm with the purpose of maintaining the constant level of water in the feeding reservoir according to the protocols described by Peña (2015).

Water consumption in the different treatments was observed daily by measuring the volume consumed with the measuring devices. Data about the plants growth (plant height) were observed every ten days in order to obtain information of interest for future investigations about the adaptation of this irrigation method under field conditions. The experiment lasted 78 days.

The average number of fruits was quantified in each treatment during six weeks in the fructification stage like a selection parameter of the best suction height in the four treatments evaluated according to the methodology reported by Olguin (1997). The approach of using the production obtained under experimental conditions as pattern to define the suction height (h) for each cultivation and variety, has been well documented and accepted by the scientific community (Peña, 2015).

For the investigation data processing the software MS Excel was used. A variance analysis (ANOVA) of one factor was applied to a 5% level of significance for determining the differences among the treatments and for selecting the most convenient for this variety, based on the number of fruits observed in each one, during six weeks in the fructification stage.

RESULTS AND DISCUSSION

Water consumption in all the evaluated treatments was increased considerably during the fructification stage which is attributable to the increment of the physiologic requirements of the plants in this stage like it is appreciated in Table 2. A very similar behavior was observed in treatments T2 and T3 in water consumption for the development phases. However, in treatment T4, the consumption of water decreased drastically compared to the remaining ones. This behavior is because the suction height (h = -20 cm) is very high to the characteristics of the capsules and the soil mixture used. It is affirmed that plants were not able to exercise an enough suction force to create a hydrodynamic imbalance in the soil that propitiated the suction principle. Treatment (T1), manifested operative deficiencies in its operation because interferences in the free surface in the feeding reservoir caused air aspiration in the system.

Of singular interest is the precise knowledge of the daily consumption of plants that oscillates between 0.30 – 0.33 L/p/d (liter/plant/day). This value is approximately equivalent to the perspiration of the plants according to Olguin (1997) which reports that the suction irrigation method constitutes a good way to estimate the perspiration in several vegetables.

In Table 2 accumulated water consumption per development stage for each one of the evaluated treatment is shown. Some data of interest that can serve as reference for future investigation works in this thematic are also shown.

In treatments T1 and T3, average growth of the cultivation (plants height) was greater until approximately 40 days since planting from which a similar behavior was observed (Figure 3). This condition is attributable to that in T1, the suction height similar to 0 generates easier water uptake, however, in treatment T3 with suction height h = -15 cm, a hydrodynamic effective balance with the properties of the capsules and mixture soil used seems to be reached. These results differ from those reported by Daka (2001) in the same tomato variety that reports higher values of growth with h = -10 cm, which is probably consequence of the climatic differences, capsules with different dimensions and properties and the soil mixture utilized.

Treatment T4 definitively had a more unfavorable behavior due to the suction height inadequate for this cultivation and variety. Treatment T2 had an average growth near T3, but with slight differences.

Average number of fruits observed in the treatments starting from the six weeks after the flowering stage is shown up in Figure 4. Of all evaluated treatments, T3 was the most favorable with an increment sustained in this indicator. The results of the analysis carried out demonstrate the significant statistical differences shown in Table 3.

When formulating the nullity hypothesis (H0) and the alternative (H1); if the statistic F calculated is bigger than its critical value (Fc) or the probability (P) is smaller than the significance level (α) for 5%, the decision to reject Ho and to accept H1 is taken; being demonstrated that significant differences exist among the treatments.

TABLE 2. Water Consumption r for each Treatment during the Experiment (78 days) (L/p) Average Liters per Plant Accumulated in 78 days; (L/d) Average Liters per Day per Treatment; (L/p/d) Average Liters per Plant per Day

Development Phases	**Water Consumption per Treatment (L)**			
	T1	**T2**	**T3**	**T4**
Initial Stage	28.29	19.19	18.10	7.53
Flowering Stage	22,11	17.60	17.73	11.93
Fructification	64,23	70,93	67,62	49,09
Harvest Stage	13.74	11.51	10.63	9.01
Measure Unit	**Data of Interest**			
(L/p)	25.67	23.84	22.82	15.51
(L/d)	1.650	1.550	1.500	1.00
(L/p/d)	**0.330**	**0.310**	**0.30**	**0.200**

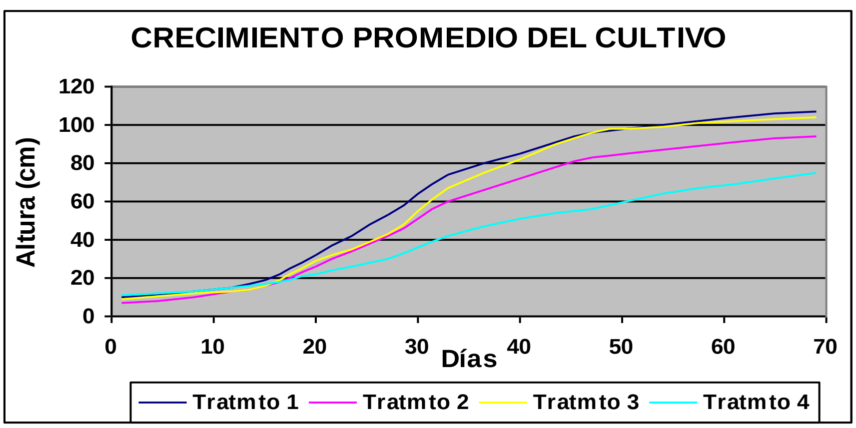


FIGURE 3. Average growth of tomato cultivation, variety F1- FA 572 with suction irrigation under experimental conditions

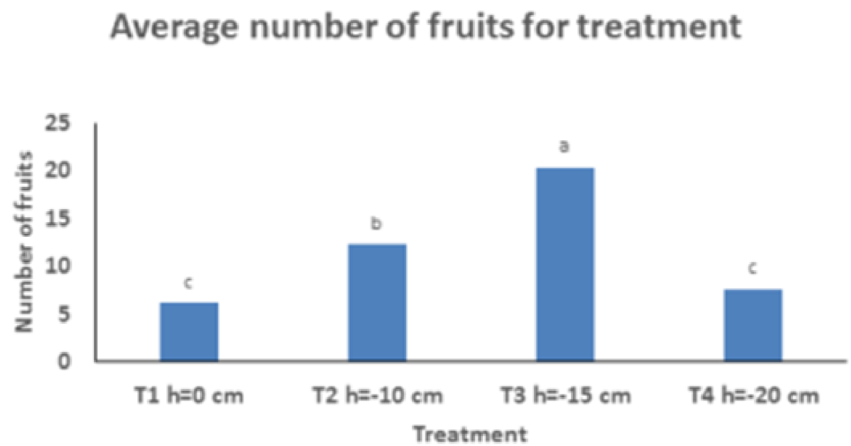


FIGURE 4. Average number of fruits in tomato cultivation, variety F1. FA 572 with suction irrigation under controlled conditions.

TABLE 3. Statistical Analysis Result: Variance Analysis of a Factor for the Variable Number of Fruits in the Evaluated Treatments

Groups	Count	Adds	Average	Variance	i
T1 h=0 cm	30	186	6.2	8.5100	c
T2 h=-10 cm	30	369	12.3	25.596	b
T3 h=-15 cm	30	612	20.4	90.524	a
T4 h=-20 cm	30	228	7.6	5.1448	c

Variation Origin	Adds of Squares	Grades of Freedom	Squares Averages	F	P	Fc
Among groups	3692.625	3	1230.875	37.93	3.68674E-17	2.682
Inside the groups	3763.5	116	32.44396552			
Total	7456.125	119				

An outstanding observed aspect is that, in the varieties of tomato of undetermined growth, under field conditions with drip irrigation, the flowering stage in the months October-November begins starting from the 65-75 days after sowing under the climatic conditions of Cuba (Peña, 2015). In this investigation it was observed the flowering beginning at the 55 days under controlled conditions. The most logical reason for this behavior is the fact that water consumption is self-regulated by the own plants. In these conditions the stress is not verified. In the interaction with the cultivation soil mixture and the easily available water, a phenomenon well-known as “biologically optimum irrigation regime” is verified and it reduces the productive cycle of the crop growing. This aspect has been reported by other investigators and in other vegetables under suction irrigation (Bainbridge, 2001).

It is important to point out that, in this irrigation method, any energy is not used for the water pumping because the suction energy of the roots plants “water uptake energy” is used. The water use is optimum and practically it is coincident with the crops perspiration according to criteria reported by Olguin (1997). Additionally, in this work, chemical products have not been used to fertilize. For this reason, irrigation by suction can be considered like an alternative for the sustainable production of organic vegetables to small scale.

CONCLUSIONS

- The most appropriate suction height to place the ceramic porous capsules in the soil mixture used for tomato cultivation variety F1. FA 572 were of h = -15 cm. With this value, a bigger quantity of average fruits was observed with a significant statistical difference regarding the remaining evaluated treatments.
- The irrigation by suction with porous capsules constitutes a viable alternative for the sustainable production of organic vegetables to small scale, however, it requires more study and research under the conditions of Cuba.

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