Hydrogel for improving water use efficiency of *Capsicum annuum* crops in Fluvisol soil

Eficiencia del agua de riego mediante la aplicación de hidrogel en *Capsicum annuum* en suelo Fluvisol

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Originales: *Recepción:* 01/12/2016 - *Aceptación:* 04/08/2017

Abstract

This study aimed at assessing the effect of hydrogel on irrigation water use efficiency and yield of *Capsicum annuum* crops. It was used the hybrid pepper variety El Salvador as the experimental material, with row widths of 1.0 m and a 0.5 m separation between plants. It was evaluated five pre-hydrated gel doses: 0.5, 1.0, 1.5, 2.0 and 2.5 g/plant. Treatments were arranged in a randomized complete block design. The variables under study were: water consumption, irrigation frequency and water use efficiency, plant height, fruit characteristics, and yield. Results showed that hydrogel, at doses ranging from 2 to 2.5 g/plant, reduced the depth of application from 388.6 mm to 197.6 and 196 mm, respectively. Water efficiency was correlated with hydrogel use producing up to 10.1 $kg.m^{-3}$, whereas the control treatment reached 5.1 $kg.m^{-3}$. Production variables did not show statistical significance. The conclusion is that hydrogel worked as a water retainer releasing water into the Fluvisol soil and making water use more efficient in pepper crops, without affecting plant development.

Keywords
water retainer • water consumption • irrigation frequency • yield of pepper crops

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Resumen

El objetivo fue evaluar la influencia de la dosis de hidrogel en la eficiencia de riego y en el rendimiento del cultivo de pimiento. Se utilizó como material experimental el híbrido Salvador el mismo que se estableció a un distanciamiento de 1,0 m entre hileras y 0,5 entre plantas. Se estudiaron cinco dosis: 0,5; 1,0; 1,5; 2,0 y 2,5 g/planta, el mismo que fue previamente hidratado. Los tratamientos se establecieron en un diseño de bloques completos al azar. Se midieron las variables relacionadas con el riego: consumo de agua, frecuencia de riego y eficiencia del uso del agua; además, la altura de planta, características del fruto y el rendimiento. Los resultados indican que la aplicación del hidrogel con una dosis entre 2 y 2,5 g/planta se obtiene una reducción de la lámina de aplicación de 388,6 mm a 197,6 y 196 mm respectivamente. La eficiencia del agua tiene relación con el hidrogel produciendo hasta 10,1 kg.m^{-3} a diferencia del testigo que alcanzó 5,1 kg.m^{-3}. Las variables productivas no presentaron influencia estadística. Se puede concluir que el uso de hidrogel actúa como un retenedor de agua que la libera fácilmente en un suelo Fluvisol haciendo eficiente el uso del agua en un cultivo de pimiento sin afectar su desarrollo.

Palabras clave

retención de agua • consumo de agua • frecuencia de riego • rendimiento del pimiento

Introduction

In Ecuador, there is a broad supply of water retainers or conditioners for increasing water retention in agricultural soils. However, they are generally used without a proper consideration of soil and crop types. This has perhaps limited the use of this technology among local farmers. The use of water retainers is still very sporadic despite their broad spectrum of benefits; probably due to the lack of scientific information from local research concerning its use. In the province of Manabí, and mainly in places where there is difficulty to access water, farmers use hydrogel on horticultural and perennial crops, but without considering any formal instructions on its application, dose and soil type.

Buck and Evans (2010) found that hydrogel could modify the physical properties of soils (*i.e.* apparent and real densities, pore spaces, and water retention capacity). The changes were mainly associated with hydrogel dose. The modifications also occurred after adding other soil improvers, for example peat, for this reason hydrogel is also known as a soil conditioner. Martyn and Szot (2001), after evaluating two commercially available hydrogel types, at different concentrations in soil, found variations, though without any clear trend. The same response was produced by other organic components such as peat and vermiculite. Rivera *et al*. (2015) indicate that hydrogel has an effect on the time the soil needs to dry up. On the other hand, when used in dry soil, hydrogel can moisten the soil in levels that vary depending on soil type. Arbona *et al.* (2005) reported an increase of 30% in soil moisture after using hydrogel. Authors such as Johnson and Leah (1990) and Nissen (1995) have commented on the importance of using hydrogel on forest trees, especially during the sowing period.

When water is scarce, it results in massive loss of crops. Thus, hydrogel can be used as a solution to prevent such losses. Save *et al.* (1995) recognize that hydrogel can decrease the frequency of irrigation and reduce water lixiviation. According to Santelices (2005), in *Eucalyptus goblulus,* harvested in the spring, hydrogel contributed to the survival of plants with less access to water. On this ground, the aim was to assess the effect of hydrogel on water use efficiency of *Capsicum annuum* crops in Fluvisol soil.

Materials and Methods

The study was conducted in the Carrizal river valley, in the municipality of Bolívar, Manabí, Ecuador. The valley is typically formed by Fluvisol soil as a consequence of previous floods. The area is geographically located between 0º 39' 34'', South Latitude; and 80º 02' 45.07'', West Longitude; at an altitude of 16 meters above sea level.

It was evaluated 5 doses of agricultural hydrogel, comprised of 1% potassium polyacrylamide, which were added to the soil at the base of each plant. The doses were: 0.5 (T1), 1.0 (T2), 1.5 (T3), 2.0 (T4) and 2.5 (T5) g/plant, plus a control treatment consisting of a plot without hydrogel.

Soil characteristics

The soil was primarily composed of Fluvisol, which is formed by sedimentation layers (5). Its corresponding texture was 70% sand, 8% silt and 22% clay. The field capacity was 0.23 cm^3 (H_2O)/cm^3 (soil), with a total tension of 10 centibars and an apparent density of 1.3 g/cm^3.

Plant material

The hybrid pepper variety El Salvador was used as the olant material, with row widths of 1.0 m and a 0.5 m separation between plants. Seeds were placed in germinating trays for transplant after 21 days.

Experimental design

A randomized complete block design. Was used with four replicates for each treatment. Each experimental unit consisted of a 24 m^2 plot, with 48 plants distributed along three drip irrigation tubes of a 1.0 m separation and 32 m long. Each treatment was replicated four times.

Hydration

Following the indications of Rivera *et al*. (2015), hydrogel was hydrated before being added to the soil, using 100 ml of water/g for one hour. It was then placed in the soil at a depth of 25 cm at each plant.

Irrigation

The drip irrigation system consisted of an irrigation head, a filter, a pressure gauge and a valve. The drip irrigation tubes had a valve for controlling the flow for each treatment. The lateral line had a diameter of 50 mm, and the drip tubing was of 16 mm in diameter, releasing a flow of 4 L/h.

Irrigation was programmed through tensiometers, which were used for each treatment. First, data on tension and soil moisture were collected, and then the values were adjusted to fit the equation by Van Genuchten (1980).

$$\theta = \theta r + \left(\frac{\theta s - \theta r}{[1 + (\alpha h) \wedge n] \wedge 1/n - 1} \right)$$

where:

θ = moisture content (at a specific tension)
θr = residual moisture content
θs = saturation moisture content
h = soil tension
α = optimized parameter
n = optimized parameter

Field capacity (FC) was 10 centibars. Irrigation time was programmed at 20 centibars or above. After data collection, it was used the replacement depth equation as follows:

$$Lb=(CC\text{-}HA)xdaxDxFai$$

where:
Lb = raw sheet replacement
CC = field capacity
HA = moisture content during irrigation
da = apparent soil density
D = soil stratum depth
Fai = adaptation factor

After calculating the depth of irrigation, it was calculated the irrigation time using the following equation:

Tr= raw volume/dripping flow rate

Analyzed parameters

Variables related to irrigation

It was considered water consumption (mm), taken from the sum of the irrigation depths used for each irrigation; the frequency, as the interval of days between irrigations; and the total number of irrigations. Water efficiency was obtained from the relationship between consumption in m^3 and kilograms of pepper produced.

Plant height

The height (cm) was measured from the base of the plant up to the terminal apex during days 7, 14, 21, 40, 60, 80 and 100 after transplant, using a measuring tape.

Fruit characteristics

Among these variables, was considered: length, weight and diameter. Length and diameter were measured in centimeters using a Vernier caliper. Fruit weight was measured in grams using an analytical laboratory scale.

Yield

As the sum of total harvest weight per unit of area, expressed as t/ha. The total number of fruits per plant was obtained from the sum of the fruits produced from the harvest divided by the number of plants.

Statistical Analysis

Using irrigation variable data, was created average frequency tables showing total water consumption for each treatment. The other variables were evaluated through analysis of variance and the Tukey test at the 5% level of probability.

Results and Discussion

Data regarding irrigation variables are presented in table 1 (page 27). Treatments showed big numerical differences mainly in water consumption. The differences were more notorious in T4 and T5, with values reaching total consumption of 197.6 y 196 mm, respectively.

The control treatment (without hydrogel) reached a consumption of 388.6 mm, showing that it was possible to save up to 40% water. With this respect, Agaba *et al.* (2011) found that hydrogel, at 0.4%, reduced at least half the water consumption of the control treatment in a sandy soil. In contrast to Montesano *et al.* (2015), who found that the application of hydrogel, at 2%, significantly increased moisture retention in sandy soil; in this type of soil, hydrogel tends to be more efficient than in clay soils. López *et al.* (2013), while evaluating a polyacrylamide hydrophilic polymer on Anaheim chili, found that it reduced the volume of water, though not down to the level shown in this study. This may be due to the fact that, in this research, the polymer was placed at the base of each plant, which proved to be more efficient.

Table 1. The six treatments and variables related to irrigation.
Tabla 1. Variables relacionadas con el riego en los tratamientos en estudio

Treatments	Water use (mm)	Irrigation frequency (days)	# of irrigations	Water efficiency (*Kg.m^{-3})
T1	376.1	2 y 3	44	5.5
T2	374.4	2 y 3	44	5.3
T3	301.6	2 y 4	36	6.7
T4	197.6	3 y 6	22	9.9
T5	196	3 y 6	22	10.1
Control	388.6	2 y 3	44	5.1

* Kilogram of pepper produced per cubic meter of water.
* Kilogramo de pimiento producido por metro cúbico de agua.

Previous research has used a mix of soil substrates in pots (5, 6, 10, 13), but when used in the field, during normal plant development, it may be possible to obtain different results.

Irrigation frequency varied from 2 to 6 days depending on the treatment. This happened because the frequency was not pre-established, but was subjected to soil tension, which was influenced by the effect of hydrogel. Treatments with more hydrogel (T4 and T5) reported up to a six-day irrigation interval. Treatment T1, T2 and Control had a frequency of 2 and 3 days, respectively. T3 had a frequency ranging from 2 to 4 days. This frequency increase made the number of irrigations smaller, thus less water was needed. Wadas *et al.* (2010), from experiments carried out in *Eucalyptus urograndis* plantations, argue that moderated stress symptoms, due to water deficit, can last up to ten days.

The obtained water use efficiency suggests that the application of hydrogel, at doses between 2.0 y 2.5 g/plant, can produce up to 10.1 kg.m-^{3} of *C. annum* showing higher values than other treatments. López *et al.* (2013), while evaluating a water-absorbing polymer, at a dose of 25 kg.ha^{-1} added to a sandy-loam soil, did not find any statistically significant differences. Hydrogel is considered to be an essential element for saving water in pepper crops, without affecting its productivity.

Hydrogel particles retain water, and then slowly release it into the soil when the plant needs it. Water encapsulation inside the hydrogel particle prevents losses due to evaporation, intensifying the effect when the particle is in the soil. However, the stress caused by dry soil makes hydrogel particles release the encapsulated water. On the other hand, Rivera Fernández *et al.* (2018) comment on the relationship between soil texture and water conveyance by hydrogel. Also, the specific soil particle surface has been found to affect water retention in soil (18). It is necessary to emphasize that the above-mentioned outcomes occurred when the doses of hydrogel ranged between 2.0 y 2.5 grams per plant; using it in lesser amounts did not produce any effect. Therefore, we can argue that an increase in hydrogel levels makes water retention more efficient, as stated by Idrobo *et al.* (2010), who studied hydrogel in sandy soils.

Plant height

Table 2 (page 28) shows plant height values on the different evaluation days.

Table 2. Average height values of the plants (cm) on different days.

Tabla 2. Valores promedios de la variable altura de planta (cm) en diferentes días.

Treatments	Plant height (days)						
	7	14	21	40	60	80	100
T1	11.63	20.7	30.8	50.68	70.05	81.8	86.15
T2	11.73	20.43	31.03	50.13	71.13	82.63	84.63
T3	11.5	20.8	31.18	50.98	70.3	79.95	85.58
T4	11.48	20.13	31.63	51.48	70.43	80.9	84.78
T5	11.05	19.88	31.15	49.3	70.95	81.48	84.6
Control	11.73	20.1	30.68	50.38	70.08	80.53	85.75
Probability	0.9	0.87	0.97	0.4	0.53	0.33	0.63
Standard error	0.55	0.61	0.84	0.73	0.49	0.86	0.8

According to the analysis of variance, there was no significant statistical difference (p>0.05), which suggests that hydrogel had no negative effect on crops. However, there are numerical differences in each one of the evaluations conducted.

The highest values on day 7 were obtained with the Control and T2, 11.73 cm; followed by T1, 11.63. The smallest value was obtained with T5, 11.05 cm. On day 14, all treatments showed an increase in height, as in the first evaluation. T5 showed the smallest value, 19.88 cm. The other treatments had values above 20 cm. On day 21, there was a similar increase to that of the first evaluations. Height, among treatments, did not show a trend that suggests a significant difference. The same situation remained until day 100.

Fruit characteristics

Table 3 shows the characteristics of C. *annum* fruits, with weight and length not presenting any statistically significant difference (p>0.05). However, as can be seen, there were differences in fruit diameter (p=0.002). With respect to weight, despite not showing statistical differences, it was observed that all treatments exceed 100 g, with T1 having the largest average value, 114.87 g, and T2 the smallest mean value, 106.98 g.

Table 3. Variables related to pepper fruit characteristics.

Tabla 3. Variables de las características del fruto de pimiento.

Treatments	Fruit variables		
	Fruit weight (g)	Length (cm)	Diameter (cm)
T1	114.87	12.13	5.93 ab
T2	106.98	10.15	5.45 bc
T3	107.93	12.53	6.08 a
T4	107.55	10.13	5.58 abc
T5	108.18	12.63	5.88 abc
Control	109.8	11.43	5.38 c
Probability	0.31	0.36	0.002
Standard error	2.56	1.04	0.11

Different letters in a column indicate statistical difference, Tukey at 0.05.

Letras diferentes en una columna indica diferencias estadísticas, Tukey 0,05.

In the initial harvests, pepper fruits had more weight than at the end of the experiment. Likewise, the variability in fruit characteristics, even from the same treatment, was high. The values presented here are the average results from all harvests, thus they give the impression of having less variability.

Fruit length and weight presented only numerical differences and not any statistical significance. Values ranged from 10.13 to 12.63 cm, T4 and T3, respectively. As with weight, there was a high variability among pepper fruits. Sometimes fruits were of 25 cm in diameter, but other times, they were only 5 cm.

Diameter was affected by the studied variable, showing statistical differences (p=0.002). T3 was different from the other treatments obtaining the first statistical category with an average value of 6.08 cm. The smallest diameter was that of the control treatment with 5.38 cm. Despite having statistical difference, variation among treatments is not as notorious as with the previously analyzed variables.

Fruit variables such as length and diameter are important when commercializing the product. Fruit must preferably be between 12-15 cm in size. However, in this study, most fruits were above or below this size, which made fruit classification more difficult. These variables are determined by the characteristics of the plant material. Other variables related to crop management, for example fertilization, irrigation and number of fruits per plant are also influential. There could be plant material with more length, such as Tikal, which was studied by Lesser (2004), reaching 17.88 cm in size. The other material evaluated by the same author ranged between 10.12 y 14.56 cm.

Yield

Yield variables did not show statistical differences (p>0.05). The number of fruits per plant ranged from 8.93 y 9.35, treatments T1 and T2, respectively. The values were obtained from the sum of all harvests.

Yield, in $t.ha^{-1}$, was not affected by hydrogel, presenting similar yield values. This may be due to the fact that all treatments received the required amount of water. Treatment T1 obtained the largest average value 20.53 $t.ha^{-1}$, followed by T3 with 20.3 $t.ha^{-1}$, and T4 with the smallest mean value of 19.48 $t.ha^{-1}$. After obtaining high differences between hybrid and traditional varieties, Lesser (2004) concluded that yield is dependent on plant material.

Table 4. Yield, expressed in number of fruits per plant and tons per hectare.

Tabla 4. Rendimiento en números de frutos por planta y toneladas por hectárea.

Treatments	# fruits/plant	$t.ha^{-1}$
T1	8.93	20.53
T2	9.35	20.03
T3	9.4	20.3
T4	9.05	19.48
T5	9.1	19.7
Control	9.08	19.95
Probability	0.54	0.91
Standard error	0.2	0.72

Conclusions

Hydrogel, at doses between 2 to 2.5 g/plant, reduced irrigation water consumption making water use more efficient by producing twice as many kilograms of pepper per cubic meter of water.

Hydrogel, when added to Fluvisol soil, increased the water retention capacity, and released water into the soil when needed, without affecting the yield because no difference was found when compared to yield values from the control treatment.

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