Article

Irrigation deficit and hydrogel application in olive productivity in desert regions

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Abstract

The over exploitation of the water table and the lack of water in the semi-desert region of northern Sonora represents a serious problem. For this reason, the objective of this work was to evaluate the effect of a 50% irrigation deficit (DR50%) and a hydrogel (H) on the yield and quality of the olive cultivation ‘Manzanilla de Sevilla’ in the semi-desert region of Caborca, Sonora, during the 2016 to 2017 cycle. The treatments evaluated were: DR50%, DR50%+H, R100% (control) and R100%+H. The results obtained indicate statistical differences in the moisture content of the soil between the DR50% and the control, with a reduction of 22.7% (2 880 m^3 h^{-1}) in the volume of water applied with the DR50% in relation to the control, without affecting the yield and quality of the fruit. The hydrogel addition showed no response in any of the parameters evaluated. The yield and quality of the fruit was statistically the same for all the treatments evaluated.

Keywords: *Olea europeae*, efficiency, irrigation, water.

Reception date: December 2018
Acceptance date: February 2019

Introduction

The establishment and development of crops in the semi-arid region of Caborca, Sonora, depends exclusively on irrigation water from deep wells that are extracted from the aquifer, being the only source of water for this area, which is located in the Sonoran desert, characterized by having low water recharge and during the last 10 years has been affected by marked depletion of the aquifers, in addition to the rains that normally occur in the region are less than 200 mm per year with an evaporation greater than 2 300 mm per year (Robles, 2001).

The low availability of water, the high costs of the energy required for its extraction, as well as the increase in demand for it by the agricultural sector, make it necessary to implement a more efficient technological management in the use and management of water. One of the strategies to contribute to the above and reduce over-exploitation of groundwater, as well as increase profitability in the production of crops in regions with low water availability such as the semi-desert zone of northern Sonora, is minimizing necessary the volumes applied to the production of crops, without affecting their quality and performance.

The irrigation deficit (DR) is carried out in a specific phenological stage and is commonly used in certain fruit species to reduce the amount of water without affecting the productive development (Behboudian, 1997). In the case of olive, it corresponds to the stage of hardening of the bone and after harvesting (Lavee and Woodner, 1991; Moriana *et al*., 2007). Some studies indicate that DR does not affect fruit yield or weight (Goldhamer, 1999; Vita *et al*., 2011). However, the DR reduces flowering the following year (Alegre *et al*., 2002) and accelerates fruit ripening (Alegre *et al*., 1999) and the response to DR varies according to the olive variety (Patumi *et al*., 1999).

Another alternative to make the use of water more efficient in agricultural production is the use of hydrophilic polymers (hydrogels, water retainers) highly absorbent and insoluble in water, which help reduce the loss of water caused by evaporation and percolation, reducing the costs of both inputs (fertilizers) by decreasing infiltration losses; as well as in the consumption of electrical energy by increasing the water retention capacity in the soil and consequently reducing the frequency of irrigation (López *et al*., 2016). Hydrogels, hydroretainers or super absorbers, are hydrophilic or water-absorbing polymers with three-dimensional structure, usually made up of long-chain, high-molecular-weight organic molecules joined by cross-links between the chains (Kazanskii and Dubroskii, 1991).

Some researchers indicate that the use of hydrophilic polymers improve the water retention capacity in the soil by making better use of rainwater or irrigation by losing less by percolation, as well as reducing the evaporation of water, reducing nutrient leaching. and improve the aeration and drainage of the soil, which allows to space the frequency of the irrigation, favor the development of the root system, the growth of the plant, improve the biological activity and increase the production (Baasiri *et al*., 1986; Henderson and Hensley, 1986; Lamont and O'Connell, 1987; Cotthem *et al*., 1991; Bres and Weston, 1993; Mikkelsen *et al*., 1993; Orzolek, 1993; Nissen, 1994; Mikkelsen *et al*., 1995; Ross *et al*., 2003; Rojas *et al*., 2004; Sojka *et al*., 2005; Baron *et al*., 2007; Orts *et al*., 2007; Rivera *et al*., 2007; Sojka *et al*., 2007). López *et al*. (2016) mentions that the polyacrylamide-based hydrophilic polymer (PAM), Lluvia solida®, is capable of absorbing the equivalent of 268 times its weight using distilled water.

Also, when the water has presence of salts, the polymer reduces the absorption capacity with water, the hydration capacity being lower as the salt content increases with a reduction in water absorption up to 116 times its weight.

The effect of hydrophilic polymers is more evident in soils with high drainage (Idrobo *et al*., 2010), sandy texture (Baasiri *et al*., 1986; Orzolek, 1993; Ross *et al*., 2003), as in arid climates (Baasiri *et al*., 1986; Katime, 2003; Rojas *et al*., 2004; Baron *et al*., 2007; Alburquerque *et al*., 2009). On the other hand, the stability of the polymer is also affected by the temperature, so that an increase in temperature reduces the capacity of water retention by the polymer, the effect being greater at temperatures above 60 °C (Baasiri *et al*., 1986; Katime, 2003), a situation which also occurs under low temperature conditions, being most noticeable around 15 °C (Fitzpatrick *et al*., 2004; Sojka *et al*., 2007).

Hydrophilic polymers, once applied to the soil, undergo a gradual degradation, influencing the ultraviolet rays coming from the sun in their degradation and the use of agricultural implements in their fractionation (Azzam, 1983; Sojka *et al*., 2006). The continuous process of wetting and drying through which the polymer crosses the soil brings significant changes in water absorption and retention capacity, reducing its effectiveness (Wang and Gregg, 1990; Choudhary *et al*., 1998).

In evaluations of the use of hydrophilic polymers in the production of different crops indicate that in the tomato crop was observed a positive effect on the germination and growth of plants in this crop (Rojas *et al*., 2004); likewise, the increase in dry root weight and dry fruit weight benefited, which was reflected in an increase in production (Rivera *et al*., 2007). In the production of coriander, it increased the efficiency of water use, the yield of green and dry matter, as well as the number of plants, depending on the volume of water applied and the growing season (Alburquerque *et al*., 2009). In radish cultivation, an increase in moisture retention was observed, also showing a better dosage of fertilizers Idrobo *et al*. (2010).

In bean production, under salinity conditions in arid and semi-arid climate, it has great potential for use to reduce saline stress in the plant (Kant and Turan, 2011) authors such as Rodríguez (2017) indicates that the combination of hydrogel with salicylic acid, they favored the growth of bean plants and significantly increased productivity under greenhouse conditions, in addition treated plants showed a greater tolerance to drought. López *et al*. (2013) mentions that in the cultivation of Anaheim pepper (*Capsicum anuum* L.) under greenhouse conditions, with the use of hydrophilic polymers, a 12% reduction in the volume of water applied in relation to the control was obtained, as well as a greater weight of fruit and a higher yield per m^2.

The objective of this study was to evaluate the feasibility of producing without affecting the yield and quality of the olive tree, reducing by 50% (irrigation deficit) in one stage of the crop the volume applied by the regional producer in combination with the use of a polymer hydrophilic (hydrogel).

Materials and methods

Description of the study area

The experiment was conducted in the olive region of the coast of Caborca, Sonora, in the Rural Production Society ‘Campo Aguilar’ located at 30° 48’ 49’’ North and 112° 54’ 18’’ West and an altitude of 44 m. The climate is desert with an average annual temperature of 22 °C, with January being the coldest month with 4.6 °C and July the hottest, with 40.2 C with a rainfall of less than 200 mm per year (Robles, 2001).

Characteristics of the soil

The soil properties of the orchard presented a sandy texture, an electrical conductivity of 7.9 dS m^{-1}, 1.4% of organic matter and a pH of 7.9, poor in nitrogen and medium in phosphorus and potassium content.

Agronomic management

The evaluation was carried out in the 2016-2017 cycle in an olive orchard of 17 years of age established with the cultivar ‘Manzanilla de Sevilla’, with a planting frame of 10 x 5 m (200 trees ha^{-1}). The experiment was established under drip irrigation, using an irrigation hose located on one side of the plantation line with five drippers per tree, the water used comes from deep wells that work with electricity. In general, the agronomic management was carried out by the cooperating producer which consisted in the application of the fertilization dose 80N-40P using urea (46-00-00) and phosphonitrate (33-03-00) as a source of nitrogen and phosphoric acid (00-52-00) as a source of phosphorus.

For the control of pests, especially for the control of the olive fly, two applications of insecticides were made: Malathion (1 L ha^{-1}) at the beginning of the cycle without the presence of fruit and later Spinosad (0.25 L ha^{-1}) with presence of fruit. The irrigation was applied in general to the whole garden with a total of 66 irrigations during the whole cycle.

Treatments evaluated

Four treatments formed by two irrigation levels at 100% (R100%) and 50% humidity (DR 50%), in combination with the application of 10 kg ha^{-1} of hydrogel (H), were evaluated. The hydrogel product used was the BountiGel^{TM} G whose active ingredient is Potassium polyacrylate, cross-linked potassium salt (2-propenoic acid homopolymer). The treatments evaluated were: Treatment 1). Control of the cooperating producer (R100%), the risks were applied throughout the year with drippers of an expense of 8 L h^{-1}, (traditional technology of olive producers in the region). Treatment 2). R100%+H, the control treatment was added 10 kg ha^{-1} of hydrogel (distributed in 50 g $tree^{-1}$). Treatment 3) DR50%, consisted in reducing 50% of the volume of water applied to the control treatment with the use of 4 L h^{-1} drippers. Treatment 4) R50%+H, to the treatment DR50% was added 10 kg ha^{-1} of hydrogel distributed in 50 g $tree^{-1}$.

All the treatments evaluated were applied a total of 66 irrigations throughout the year. To treatments 3 and 4 (DR50% and DR50%+H), of the total of 66 irrigations, to 30 of them, they were reduced by 50% the volume of water applied with respect to the control (R100%), during the period from December 02, 2016 to March 19, 2017. Irrigation water was applied by means of 5 drippers per tree with an average frequency of every six days between irrigations. The hydrogel was applied to the ground below the line of the irrigating hoses in doses of 10 kg ha^{-1} (50 g tree^{-1}) distributed in 5 holes per tree at a distance of 1 m between them and with a depth of 30 cm.

During the evaluation period, the moisture content of the soil in both treatments was measured at a depth of 40 and 80 cm by means of watermark soil moisture sensors which indicate the changes in soil moisture by expressed stress values in centibars or kilopascal (cb, or kPa). These sensors have a measurement range from zero to 200 kPa, where readings close to zero correspond to a soil completely saturated with water and those close to 40 kPa to a soil that requires irrigation (Payan *et al*., 2013). The sensors were placed on both sides of the dropper at a distance of approximately 35 cm (Figure 1 and 2).

Figure 1. Soil moisture readings at two depths.

Figure 2. Location of humidity sensors.

Characteristics evaluated and statistical analysis

The variables evaluated were: moisture content in the soil (kPa) at two depths of 40 cm and 80 cm, taken daily during the evaluation period, yield (kg tree^{-1}), fruit weight (g), fruit diameter (cm), length of the fruit (cm) and seed pulp ratio.

The harvest was made the last week of July and the yield was taken by harvesting three trees of each of the repetitions and the characteristics of the fruit was made by taking 100 random fruits of each tree of different treatments at the time of harvest. The evaluation was established in the field according to a random block design with four repetitions; however, the soil moisture content data was analyzed as a 2 x 4 factorial where the A factor corresponded to two soil depths (40 cm and 80 cm) and the B factor to the four irrigation treatments (R100%, R100%+H, DR50%, DR50%+H). The aforementioned variables were analyzed statistically using the experimental design program of FAUANL version 2.7 (Olivares, 2016). The separation of mean was made according to the Minimum Significant Difference (DMS) at 5%.

Results and discussion

Humidity of floor

Soil humidity recorded during the evaluation period was very uniform in the layer from 0 to 80 cm deep since no statistical differences were observed between the moisture contents at 40 cm and at 80 cm depth with values of 19.5 kPa and 19.2 kPa, respectively for both depths; which indicates that the frequency of irrigation and the volume of water applied in each one of them, did not allow the presence of moisture differences in the monitored soil layer (Table 1).

Table 1. Soil moisture values (kPa) corresponding to two depths in the cultivation of the olive cultivar 'Manzanilla de Sevilla'.

Depth (cm)	Soil moisture (kPa)
40	19.5 a^{z}
80	19.2 a

^{z}= means with the same letter are statistically equal (DSM 5%).

In relation to the application of the irrigation and hydrogel deficit, the statistical analysis detected significant statistical differences between irrigation treatments evaluated, separating them into two statistical groups. In the first group, treatments with DR50% recorded the lowest moisture content in the soil, with the highest tension readings, with values of 24.4 kPa and 24.3 kPa, respectively for the DR50% and DR50%+H treatments. In the second statistical group were located treatments where no irrigation deficit was applied, with a higher moisture content and lower stress values, with 14.6 kPa and 14.1 kPa, respectively for the R100% and R100%+H treatments (Table 2).

The results obtained show that the application of hydrogel did not present a positive response with respect to the moisture content in the soil, which contrasts with that indicated by (Ross *et al*., 2003; Rojas *et al*., 2004). The differences presented in the moisture content were due to the reduction in the volume of water applied (Table 2). Soil moisture values corresponding to the interaction between soil depth and irrigation treatments show the same response as the previous results as shown in Table 3.

Table 2. Soil moisture values (kPa) corresponding to four irrigation treatments in olive cultivar 'Manazanilla de Sevilla'.

Treatment	Soil moisture (kPa)
DR50%	24.4 a^z
DR50% + H	24.3 a
R100%	14.6 a
R100% + H	14.1 a

^{z}= means with the same letter are statistically equal (DSM 5%).

Table 3. Soil moisture values (kPa) corresponding to the soil depth interaction-irrigation treatments in olive cultivar 'Manzanilla de Sevilla'.

Treatment	Soil moisture (kPa)
80 cm-DR 50%	25 a^z
40 cm-DR 50% + H	24.9 a
40 cm-DR 50%	23.9 a
80 cm-DR 50% + H	23.7 a
40 cm-R 100%	14.9 b
40 cm-R 100% + H	14.5 b
80 cm-R 100%	14.4 b
80 cm-R 100% + H	13.7 b

^{z}= means with the same letter are statistically equal (DSM 5%).

It should be noted that treatments with 100% moisture, with and without hydrogel, had a higher moisture content, without fluctuations and more uniform throughout the evaluation period with readings around 15 kPa, while treatments with DR50% with and without hydrogel they presented lower humidity content with a greater fluctuation in the values of these, but all less than 40 kPa (Figure 3). In this regard, Payan *et al*. (2013), indicate that the value of 40 kPa is the indicated value to start the application of irrigation.

On the other hand, the instructions for installation and operation of the soil moisture meter Watermark (Irrometer) recommend that, according to the prevailing texture in the region, the normal range to apply the water is 30 to 60 kPa. According to the moisture values observed in Figure 3, it can be inferred that in the R100% treatment (treatment of the producer) with and without hydrogel, excess water was applied during the whole period, in addition to the olive, which is a culture that presents a high efficiency in the use of water (Grijalva *et al*., 2010).

All the evaluated treatments were applied a total of 66 irrigations during the whole crop cycle, corresponding a total sheet of 126.7 cm (12 760 m^3 ha^{-1}) to the control treatment R100% with and without hydrogel, while the treatments with the use of DR50% a total sheet of 97.9 cm was applied (9 790 m^3 ha^{-1}) which represents a reduction of 28.7 cm (2 870 m^3 ha^{-1}) with respect to the treatment of the regional producer, being 22.7% lower the volume of water applied with the irrigation deficit. In this regard, Grijalva *et al*. (2016) mentions that, in a similar evaluation, with the application of a DR50% on olive, it obtained a decrease in irrigation sheet of 21.6 cm.

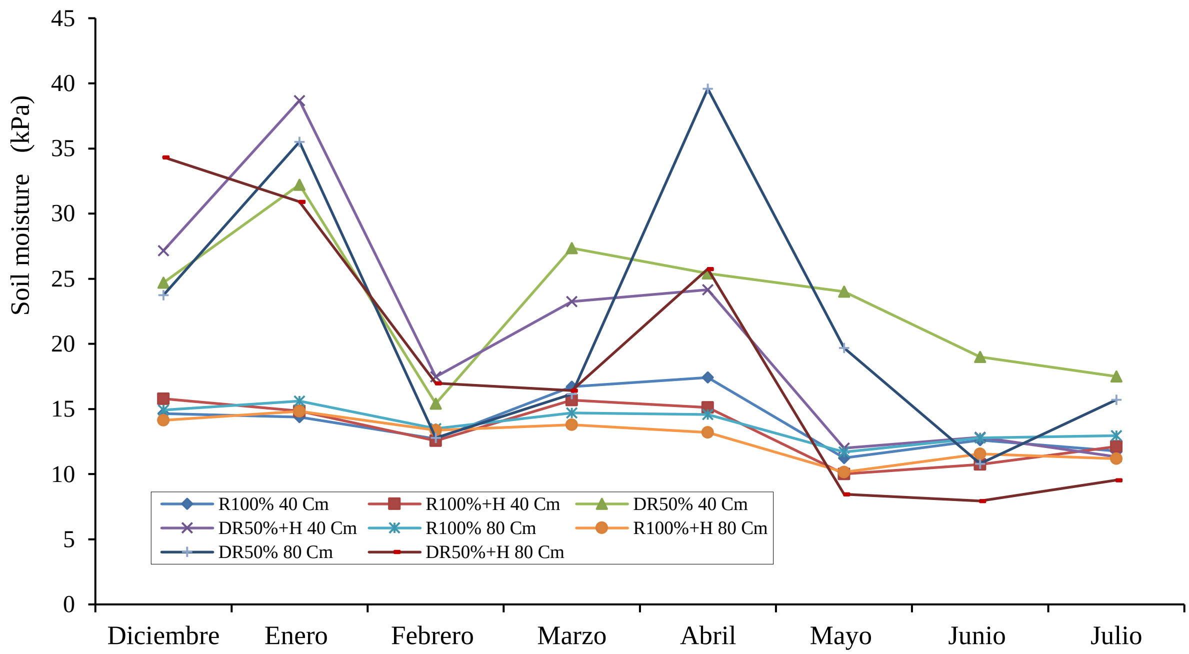

Figure 1. Monthly soil moisture of four irrigation treatments at two depths.

Considering that the region has established 1 589 hectares with the cultivation of olive trees (SIAP, 2014), which are irrigated with the traditional technology of the regional producer. In olive production in the region, it is feasible to reduce the extraction of water from the aquifer, with the use of the technology evaluated in the present work, in an approximate volume of 4 576 320 m^3 per year, which represents an important saving of water considering the scarcity conditions of this resource in this region.

Performance

With the application of the DR50% the reduction of humidity did not affect the yield with respect to the control, which agrees with what was mentioned by (Goldhamer, 1999, Vita *et al*., 2011). The yields were statistically the same for all the treatments, with a production of 72.2 kg ha^{-1} for the DR50% against 74.2 kg ha^{-1} for the control R100%. On the other hand, the addition of hydrogel did not present a positive effect in the increase of the yield since in both moisture levels no significant statistical differences were detected between the treatments with and without hydrogel application (Table 4), which does not agree with as indicated by Rivera *et al*. (2007); López *et al*. (2013); Rodríguez (2017) (Table 4).

Table 4. Yield and fruit weight corresponding to four treatments in olive cultivar 'Manzanilla de Sevilla'.

Treatment	Yield (kg tree^{-1})	Yield (t ha^{-1})
R100% + H	92.5 a^z	18.5 a^z
R100%	74.2 a	14.8 a
DR50% + H	73.2 a	14.6 a
DR50%	72.2 a	14.4 a

^{z}= means with the same letter are statistically equal (DSM 5%).

Quality

The weight, diameter, length of the fruit and the pulp-bone relationship were not affected by the application of the irrigation deficit, the statistical analysis did not detect differences between the treatments evaluated in each one of the measured parameters, which agrees with the mentioned by (Goldhamer, 1999; Vita *et al*., 2011). The same happened with the application of hydrogel to the soil. The application of this polymer did not improve the values of the four parameters and these did not present significant differences between treatments (Table 5), which does not agree with that mentioned by López *et al*. (2013).

Table 5. Fruit weight, fruit diameter, fruit length and bone pulp ratio corresponding to four irrigation treatments in the cultivation of the olive cultivar 'Manzanilla de Sevilla'.

Treatment	Fruit weight (g)	Diameter of fruit (cm)	Fruit length (cm)	Pulp/seed ratio
R100%+H	3.5 a^z	1.71 a^z	2.2 a^z	3.45 a^z
R100%	3.4 a	1.69 a	2.15 a	3.43 a
DR50%+ H	3.7 a	1.72 a	2.21 a	3.43 a
DR50%	3.4 a	1.7 a	2.14 a	3.4 a

^{z}= means with the same letter are statistically equal (DSM 5%).

Conclusions

The deficit of irrigation to 50% did not affect the yield and quality in the cultivation of the olive tree.

With the application of the irrigation deficit it is feasible to reduce the sheet applied by the producer by 28.8 cm (2 880 m^3 ha^{-1}).

The application of hydrogel did not affect the moisture content in the soil, nor the yield nor the quality of the olive tree.

Cited literature

Alburquerque, J. A. C.; De Lima, V. L. A.; Menezes, D.; Azevedo, C. A. V.; Dantas, J. and Da Silva, J. G. 2009. Características vegetativas do coentro submetido a doses do polímero hidroabsorvente e lâminas de irrigação. Rev. Bras. Engenharia Agríc. Amb. 13(6):671-679.

Alegre, S.; Girona, J.; Marsal, J.; Arbonés, A.; Mata, M.; Montagut, D.; Teixido, F.; Motilva, M. J. and Romero P. 1999. Regulated deficit irrigation in olive tree. Acta Hortic. 474:373-376.

Alegre, S.; Marsal, J.; Mata, M.; Arbonés, A.; Girona, J. and Tovar, M. J. 2002. Regulated deficit irrigation in olive trees (*Olea europaea* L. Cv. Arbequina) for oil production. Acta Hortic. 586:259-262.

Azzam, R. A. I. 1983. Polymeric conditioner gels for desert soils. Communication Soil Science Plant 14:739-760.

Baasiri, M.; Ryan, J.; Muckeih, M. and Harih, S. N. 1986. Soil application of a hydrophilic conditioner in relation to moisture, irrigation frequency and crop growth. Soil Sci.17:573-589.

Barón, A.; Barrera, I. X.; Boada, L. F. y Rodríguez, G. Evaluación de hidrogeles para aplicaciones agroforestales. Rev. Ing. Invest. 27(3):35-44.

Behboudian, M. H. 1997. Deficit irrigation in deciduos orchard. Horticultural Review. 21:105-131.

Bres, W. and Weston, L. A. 1993. Influence of gel additives on nitrate, ammonium, and water retention and tomato growth in a soilless medium. Hortic. Sci. 28(10):1005-1007.

Choudhary, M. I.; Al, O. A. M. and Shalaby, A. A. 1998. Physical properties of sandy soil affected by soil conditioner under wetting and drying cycles. Agric. Sci. 3(2):69-74.

Cotthem, V.; Lehtonen, H. S.; Rotter, R. P. and Kahiluoto, M. H. 1991. Hydrogel devices in agriculture. Soil Technol. 183-189 pp.

Fitzpatrick, C. S. B.; Fradin, E. and Gregory, J. 2004. Temperature effects on flocculation, using different coagulants. Water Sci. Technol. 50(12):171-175.

Goldhamer, 1999. Regulated deficit irrigation for California canning olives. 1999. Acta Hortic. 474:369-372.

Grijalva, C. R. L.; Navarro, A. J. A. C. y Fimbres, F. A. 2010. El cultivo del olivo bajo condiciones desérticas del Noroeste de Sonora. SAGARPA-INIFAP-CECH-CECAB. Folleto técnico núm. 41. 100 p.

Grijalva, C. R. L.; Aguilar, S. J. C.; Macías, D. R.; López, C. A.; Robles, C. F. y Valenzuela, R. M. J. 2016. Efecto del déficit de riego sobre la productividad, calidad y uso del agua en olivo (*Olea europea* L.) bajo ambiente cálido y árido de México. *In*: XIX Congreso Internacional de Ciencias Agrícolas. Mexicali, BC. 738-742 pp.

Henderson, J. C. and Hensley, D. L. 1986. Efficacy of a hydrophilic gel as a transplant aid. Hortic. Sci. 21(4):991-992.

Idrobo, H.; Rodríguez, A. M. y Díaz, J. E. 2010. Comportamiento del hidrogel en suelos arenosos. Ingeniería de Recursos Naturales y del Ambiente. 9:33-37.

Kant, A. C. and Turan, M. 2011. Hydrogel substrate alleviates salt stress with increase antioxidant enzymes activity of bean (*Phaseolus vulgaris* L.) under salinity stress. Afr. J. Agric. Res. 6(3):715-724.

Katime, I. A. 2003. Hidrogeles inteligentes. Rev. Iberoam. Polímeros. Bilbao, España. 42 p.

Kazanskii, K. and Dubroskii, S. 1991. Chemistry and physics of agricultural hidrogels. Adv. Polym. Sci. 104:97-133.

Lamont, G. P. and O'Connell, M. A. 1987. Shelf-life of bedding plants as influenced by potting media and hydrogels. Sci. Hortic. 31:141-149.

Lavee, S. and Woonder, M. 1991. Factor affecting the nature of oil accumulation in fruit of olive (*Olea europaea* L.) cultivars. J. Hortic. Sci. 66:583-591.

López, E. J.; Huez, L. M. A.; Rueda, P. E. O.; Jiménez, L. J.; Rodríguez, J. C.; Romero, E. L. K. and Dávila. F. X. 2013. Evaluación de un polímero hidrófilo en chile Anaheim (*Capsicum annum* L.) cultivado en invernadero. Terra Latinoam. 31(2):115-118.

López, E. J.; Garza, O. S.; Jiménez, L. J.; Huez, L. M. A. and Garrido, L. O. 2016. Uso de un polímero hidrófilo a base de poliacrilamida para mejorar la eficiencia en el uso del agua. Eur. Sci. J. 12(15):160-175.

Mikkelsen, R. L.; Behel, A. D. and Williams, H. M. 1993. Addition of gel-forming hydrophilic polymers to nitrogen fertilizer solutions. Fertilizer Res. 36:55-61.

Mikkelsen, R. L.; Behel, A. D. and Williams, H. M. 1995. Using hidrophilic polymers to improve uptake of manganese fertilizers by soybeans. Fertilizer Res. 41:87-92.

Moriana, A.; Pérez, L. D.; Gómez, R. A.; Salvador, M.; Olmedilla, N.; Ribas, F. and Fregapane G. 2007. Irrigation scheduling for traditional, low density orchard: water relation and influence on oil characteristics. Agric. Water Management. 87:171-179.

Nissen, J. 1994. Uso de hidrogeles en la producción de frambuesas (*Rubus idaeus*) del sur de Chile. Agro Sur. 22(2):160-164.

Olivares, S. E. 2016. Paquete de diseños experimentales FAUANL. Versión 2.7. Facultad de Agronomía UANL. Marín, NL, México.

Orts, W. J.; Roa, E, A.; Sojka, R. E.; Glenn, G. M.; Iman, S. H.; Erlacher, K. and Pedersen, J. S. 2007. Use of synthetic polymers and biopolymers for soil stabilization in agricultural, construction, and military applications. J. Materials Civil Eng. 19(1):58-66.

Orzolek, M. D. 1993. Use of hydrophylic polymers in horticulture. HortTechnol. 3(1):41-44.

Patumi, M.; Dandria, R.; Fontanazza, G.; Morelli, G.; Giori, P. and Sorentino, G. 1999. Yield and oil quality of intensive trained tres of three cultivars of olive (*Olea europaea* L.) under different irrigation regimens. J. Hortic. Sci. Biotechnol. 74:729-737.

Payan, O. S.; Morales, M. A.; Valdez, G. B.; Martín, R. M. H. and Ibarra, F. F. A. 2013. Programa de riego en vid (*Vitis vinifera* L.) de mesa 'Perlette' y 'Sugraone' con sensores de humedad. Rev. Chapingo Ser. Hortic. 19(2):163-172.

Rivera, C. A.; Baeza, C. A. y Chavarriaga, W. 2007. Efecto de un retenedor de agua y dosis crecientes de fertilizantes foliares sobre la producción de tomate chonto y larga vida bajo cubierta plástica agroclear. Agron.15(1):103-119.

Robles, C. F. 2001. Análisis climatológico de la región de Caborca, Sonora. Ciclo P-V 2001-2001. Reporte Técnico. INIFAP-CIRNO-CECAB. Caborca, Sonora, México. 7 p.

Rodríguez, M. A. G. 2017. Evaluación de un hidrogel y ácido salicílico durante el crecimiento, desarrollo y rendimiento de un cultivo de frijol (*Phaseolus vulgaris* L.) bajo invernadero. Tesis Universidad Autónoma Antonio Narro. División de Agronomía. Departamento de botánica. 61 p.

Rojas, B.; Aguilera, R.; Prin, J. L.; Cequea, H.; Cumana, J.; Rosales, E. y Ramírez, M. 2004. Estudio de la germinación de semillas de tomate en suelos áridos extraídos de la península de Araya (Venezuela) al utilizar polímeros de tipo hidrogeles. Rev. Iberoam. Polímeros. 5(1):17-27.

Ross, C. W.; Sojka, R. E. and Foerster, J. A. 2003. Scanning electron micrographs of polyacrylamide-treated soil in irrigation furrows. J. Soil Water Conservation. 58(5):327-331.

SIAP. 2014. Servicio de Información Agroalimentaria y Pesquera. Cierre de la producción agrícola por estado. htpp://www.siap.gob.mx.

Sojka, R. E.; Entry, J. A. and Fuhrmann, J. J. 2006.The influence of high application rates of polyacrylamide on microbial metabolic potential in an agricultural soil. Appl. Soil Ecol. 32(2):243-252.

Sojka, R. E.; Bjorneberg, D. L.; Entry, J. A.; Lentz, R. D. and Orts, W. J. 2007. Polyacrylamide in agriculture and environmental land management. Adv. Agron. 92:75-162.

Vita, S. F.; Pacheco, D.; Olguin, A.; Bueno, L.; Carelli, A. and Capraro, F. 2011. Effect of regulated déficit strategies on productivity quality and water use efficience in a high density 'Arbequina' olive orchard located in an arid región of Argentina. Acta Hortic. 888:81-88.

Wang, Y. T. and Gregg, L. L. 1990. Hydrophilic polymers- their response to soil amendments and effect on properties of a soilless potting mix. J. Amer. Soc. Hort. Sci. 115(6):943-948.