LA GRANJA:
REVISTA DE
CIENCIAS DE LA VIDA
pISSN:1390-3799; eISSN:1390-8596

Scientific paper/ Artículo científico

SOIL SCIENCE

EFFECTS OF HYDROGEL ON MOISTURE VOLUME IN SOILS WITH DIFFERENT TEXTURES

VOLUMEN DE HUMEDECIMIENTO POR LA APLICACIÓN DE HIDROGEL EN SUELOS DE DIFERENTES TEXTURAS

Rubén Darío Fernández[1]*, Carlos Mora Mueckay[2], Juan Ramón Moreira Salto[1] and Dídimo Alexander Mendoza Intriago[3]

[1] *Agricultural Career. Universidad Laica Eloy Alfaro de Manabí-Campus Chone, Av. Marcos Aray Dueñas, 130301, Chone, Ecuador.*
[2] *Universidad Técnica de Manabí, Av. Urbina, y Portoviejo, 130105, Portoviejo, Ecuador.*
[3] *Agricultural Career. Universidad Laica Eloy Alfaro de Manabí, Av. Circunvalacion 130804, Manta, Ecuador.*

*Corresponding author: ruben.rivera@uleam.edu.ec

Abstract

The objective of the study was to determine the wetting volume (wet bulb) of the hydrogel applied to three types of soil. Soils used were: a) clay (clay 52%; silt 32%; sand 16%); b) silty clay loam (36% clay; 56% silt; 6% sand) c) sandy loam (12% clay; 32% silt; 56% sand), to which 1% potassium hydrogel was applied. The application was made with previously hydrated hydrogel, in three diameters that were: 4.7, 7.0 and 10.5 cm with a length of 10 cm where the following initial volumes were obtained 173.5, 384.8 and 866 cm^3 occupied by the hydrogel. The wetting volume (cm^3), moisture percent, and the hydration of the hydrogel in the soil were measured. The results indicate that the humidification volume depends on the initial volume, so the higher the initial volume, the greater the humidification volume regardless of the type of soil; however, it presents a greater volume of humidification in the sandy loam soil, probably due to mobility of the water in it. The moistened area increases its humidity by 14% regardless of the type of soil. The hydration of the hydrogel in the soil only reaches 42% compared to hydrating it in free water. Determining the volume of wetting allows estimating the amount and location of hydrogel to be applied to a crop based on the bulb that needs to be formed in the soil.

Keywords: Soil hydration, wet bulb, increased humidity, sandy loam.

Resumen

El estudio tuvo como objetivo determinar el volumen de humedecimiento (bulbo húmedo) del hidrogel aplicado en tres tipos de suelo. Se utilizaron suelos: a) arcilloso (arcilla 52 %; limo 32 %; arena 16 %); b) franco arcilloso limoso (arcilla 36 %; limo 56 %; arena 6 %) c) franco arenoso (arcilla 12 %; limo 32 %; arena 56 %), a los cuales se aplicó hidrogel al 1 % de potasio. La aplicación se realizó con hidrogel previamente hidratado, en tres diámetros que fueron: 4.7, 7.0 y 10.5 cm con una longitud de 10 cm donde se obtuvieron los siguientes volúmenes iniciales 173.5, 384.8 y 866 cm^3 que ocupaba el hidrogel. Se midió el volumen de humedecimiento (cm^3), porcentaje de humedad y la hidratación del hidrogel en el suelo. Los resultados indican que el volumen de humedecimiento depende del volumen inicial, de manera que a mayor volumen inicial se tendrá mayor volumen de humedecimiento indiferente del tipo de suelo; sin embargo, el suelo franco arenoso presenta un mayor volumen de humedecimiento, seguramente por la movilidad del agua en el mismo. La zona humedecida incrementa su humedad en un 14 % indiferentemente del tipo de suelo. La hidratación del hidrogel en el suelo solo alcanza un 42 % en comparación con la hidratación en agua libre. La determinación del volumen de humedecimiento permite estimar la cantidad y ubicación de hidrogel que se debe aplicar en un cultivo en función del bulbo que se requiere formar en el suelo.

Palabras clave: Hidratación en suelo, bulbo húmedo, incremento de humedad, franco arenoso.

Orcid IDs:

Rubén Darío Rivera Fernández: http://orcid.org/0000-0003-2436-1321
Carlos Mora Mueckay: http://orcid.org/0000-0001-8714-4653
Juan Ramón Moreira Salto: http://orcid.org/0000-0003-4434-5986
Dídimo Alexander Mendoza Intriago: http://orcid.org/0000-0002-6524-3228

1 Introduction

In agriculture, hydrogel is used for economic and agronomic benefits (Cisneros et al., 2020), in vegetables (Pereira et al., 2019) and perennial crops (M'barki et al., 2019). Hydrogel is a hydrophilic, soft, elastic polymer that expands with water, increasing its weight but without losing its structure, and it looks like crystals when dehydrated (Ahmed, 2015). Its goodness has allowed hydrogel to be used in areas such as biomedicine (Nicolson and Vogt, 2001; Amin et al., 2009) and in agriculture it has been used as an element to avoid water stress in crops (Dragusin et al., 1996), since water retention is its main characteristic (Satriani et al., 2018). The first studies in this area date back to the 1970s in the germination and growth of seeds (Palacios et al., 2016).

At the moment, its application is known and its varies depending on the crop and substrate or soil to be used. Agaba et al. (2011) recommend 0.4 % of hydrogel in Agrostis stolonifera, and Montesano et al. (2015) recommend 2 % in sandy soils. Jankowski et al. (2011) applied 50 gm^2 to different substrates and cultures. Rivera et al. (2018) achieved the highest yields when applying from 2 to 2.5 g/plant in pepper. However, it is worth mentioning that studies that show a high influence of hydrogel on crops have used high amounts of hydrogel. Maldonado-Benitez et al. (2011) recommend $4gL^{-1}$ or higher, and Chirino et al. (2011) mention that a 1.5 % dose of hydrogel is effective.

On the other hand, the behavior of hydrogel is related to the physical characteristics of the soil, especially its texture (Rivera and Mesías, 2018), showing the dynamics of the behavior of the soil. Hydrogel has been widely used in soils with low water retention (Lopes et al., 2013; Rojas et al., 2004; Idrobo et al., 2010), and in agricultural areas with lack of rainfall or drought (Santelices, 2005), with several types of soil texture. In addition, most of the experiments carried out have been in pots and in mixed substrates or disturbed soil (Maldonado-Benitez et al., 2011; Idrobo et al., 2010; Najafi et al., 2013; Jankowski et al., 2011) which may have different behavior when applied in the field directly. Fonteno and Bilderback (1993) state that the effectiveness of hydrogel is determined by the type of soil or substrate, basically by its porosity. Barón et al. (2007) mention that hydrogel modifies the hydraulic dynamics of the soil. Orikiriza et al. (2013) identified that hydrogel caused increased survival of *Picea abies, Pinus syllivestris* and *Fagus sylvatica* in sandy soils.

Similarly, hydrogel is frequently associated with the management of water resources in crops, with regard to the irrigation interval (Wadas et al., 2010; Yazdani et al., 2007), particularly in forest crops (Hüttermann et al., 1999; Al-Humaid and Moftah, 2007; Agaba et al., 2010). However, studies also show that the presence of hydrogel does not have a significant influence. Wang (1989), studying the application of hydrogel in *Codiaeum variegatum*, found that the growth is the same compared to the control; however, it avoids its wilting. Geesing and Schmidhalter (2004) indicate that the application of hydrogel shows no benefit to the survival or growth of *Triticum aestivum*. This variation leads to the belief that there are aspects that are not considered at the moment of using hydrogel in crops. These include this area or volume of moistening (wet bulb) in the soil caused by hydrogel, which would be necessary to know the location of the product on the soil. Plant roots can expand their root system with a higher moisture content in the soil, allowing it to be more efficient even when the product is placed locally in the crops. Because of the latter, the aim of the research is to determine the volume of hydrogel moistening in different diameters and soil types.

2 Materials and Methods

2.1 Experimental material

The study was conducted at the Soil and Water Laboratory of the Lay University Eloy Alfaro de Manabí, Chone-Ecuador. NewGel G, distributed by Marketing of Ecuador and manufactured by Whidden Industrial Park was used as experimental material, which has the following composition: Potassium acrylamine polymer 99.9 % and potassium 0.01 %. Soils of fluvial origin (*Mollic Udifluvent.*) and coluvial origin (V*Vertic Hapluodoll*) were used. A texture analysis was performed by the pipetting method to separate the sand and clay particles, and the texture classification was done using the texture triangle (Moorberg and Crouse, 2017). Three textural classes were used for the study: A) clay (clay 52 %; silt 32 %; sand 16 %); b) clay, silty and loamy (clay 36 %; silt 56 %; sand 6 %) c) loamy sandy (clay 12 %; silt 32 %; sand 56 %).

Table 1. Averages of the final parameters of the hole where hydrogel was placed in the different soils.

Sandy loamy soils			
Final diameter (*cm*)*	9.3±0.9	12.8±1.1	17.5±1.6
Final lenght (*cm*)*	13.2±0.2	13.7±0.1	1.7±0.3
Moistened volume (cm^3)*	723.2±24.2	902±35.2	1539.4±56.3
Silty clay loam soil			
Final diameter (*cm*)*	9.02±0.8	13±0.7	14.22±1.1
Final lenght (*cm*)*	13±1.8	12.3±1.3	12.2±1.2
Moistened volume (cm^3)*	657.2±22.4	1247.8±54.2	1071.6±48.6
Clay soil			
Final diameter (*cm*)*	7.1±0.6	10.6±1.1	14.06±1.7
Final lenght (*cm*)*	12.4±1.8	12.3±2.0	12.5±1.9
Moistened volume (cm^3)*	317.4±23.6	700.6±31.1	1074.8±49.3

*Initial parameters: Diameter (*cm*): 4.7; 7; 10.5; Length: 10 *cm*.
Volume: 173.5; 384.8; 865.9 cm^3; values for each column respectively.

2.2 Experimental management

A transparent container (glass) was used to observe the moisture caused by hydrogel in the soil. It had a capacity of 0.027 m^3 with dimensions of 0.30 m on all sides, in which the samples of the different soil types were placed. Soil samples were taken and dried once they were placed in the containers.

2.3 Moistening volume

Previously hydrated hydrogel was used as recommended by Rivera and Mesías (2018), who suggest 100 mL of water per gram of hydrogel. It was then placed in holes with the following diameters 4.7; 7.0 and 10.5 cm at a depth of 15 cm of which 10 cm were occupied, leaving 5 cm of soil covering the product. It was set aside for 24 hours without any sun protection. Moistening was measured from the edges of the product to the changes of dark tone caused by the moisture of the hydrogel in the soil, obtaining the diameter (*cm*), length (*cm*) and volume (cm^3); it was calculated by adjusting the values to the equation of a cylinder (1), obtaining an initial volume of 173.5; 384.8 and 866 cm^3.

$$V = \pi * r^2 * h \tag{1}$$

Where, V is the volume in cm^3, r is the ratio of the hole (*cm*) and h is the lenght (*cm*) of the hole with hidrogel.

2.4 Soil moisture

The moisture percentage was measured before and after (24 hours) hydrogel was applied. The soil section moistened by hydrogel was sampled and the moisture percentage was determined by gravimetry. The increase in humidity was determined, taking into account the initial soil moisture and the final moisture. This procedure was performed on each soil type and by triplicate.

2.5 Moisture of the hydrogel in the soil

To estimate the hydrogel hydration in the soil, 2 g of unhydrated hydrogel was placed in a sieve #60, which was placed in dry soil of the different soil types under study. This procedure prevented hydrogel from spreading at the time of hydration in order to measure its hydration. Sufficient water was then applied simulating surface and drip irrigation, until the soil was achieved at field capacity. After one hour of irrigation, the strainer was removed with hydrogel and the hydrated hydrogel was separated from the soil, the percentage of hydration was weighed and was estimated compared to free water hydration.

3 Results and discussion

3.1 Volume of soil moistening

Table 1 shows the final parameters of the moistened area in the different soils. It is observed that the final diameter of moistening is related to the initial diameter, with some tendency to increase as the initial diameter increases. The length varied due to an increase in the moisture of the lower part of the initial bulb; there was no significant increase in the upper part. The increase in the lower part had less variation with respect to the diameter, increasing to 4.7 cm in sandy-loamy soil. These parameters show the movement of the vertical and horizontal water in the soil, which is directly related to the texture of the soil and was observed when evaluating this variable in the different soils.

On the other hand, the final volume had a significant increase according to the type of soil, being the sandy loamy soil the one with the highest moisture content as stated by Rivera and Mesías (2018), who relate the behavior of the hydrogel to the texture of the soil and in turn to the specified surface of the soil (Ruiz et al., 2016). Narjary et al. (2012), mentions that hydrogel is usually more efficient in sandy soils than in heavy soils.

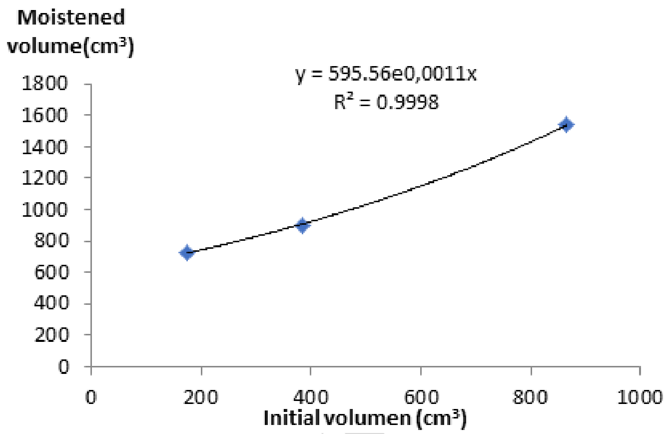

Figure 1. Ratio between initial volume and final moistening volume in sandy soil.

Sandy soils infiltrate a lot more water compared to heavy soils, so it can be deduced that water contained in the hydrogel capsule, when passing to the soil, has a similar behavior when applying irrigation water, with the only difference that the amount of water contained in the hydrogel is small compared to traditional irrigation, and this delivery of water to the soil occurs when the soil exerts a high matrix pressure and when the soil has less moisture content, which is consistent because the lower initial moisture content (sandy-loamy) was presented by the soil with higher moisture volume. However, the latter should be corroborated in experiments, since it was not studied in this research. On the other hand, the initial volume is directly proportional to the moistening volume, although this condition was only met in sandy, clay loamy soil (Figure 1 and 3), while the clay-loamy soil did not present any tendency (Figure 2). The determination of the wet bulb formed by hydrogel is important to decide where to place the product according to the root system, in order to estimate the amount of hydrogel to be applied and the diameter and depth of the hole where the hydrogel will be placed, so that the roots can catch water for their development.

3.2 Soil moisture

The moisture percentage of the soil moistening is shown in Table 2, where moisture has increased 14 % regardless the type of soil. These values are similar to those found by Rivera and Mesías (2018) although they differ in loamy soils, where the increase was 17.4 %. This could suggest a 14 % increase of soil moisture in dry soils. It is posible that the soil with low humidity present soil moisture because of hydrogel; therefore, it is necessay to conduct studies with different soil moisture levels.

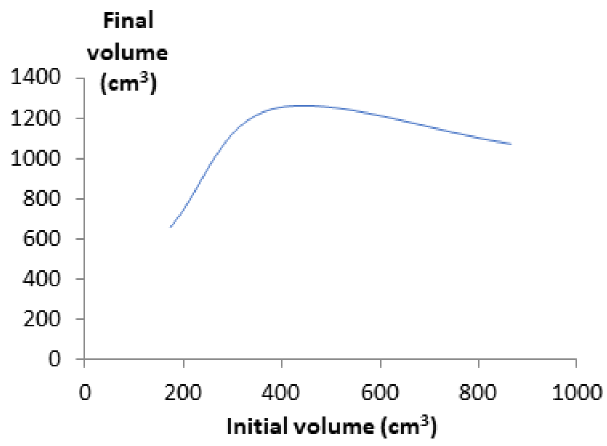

Figure 2. Initial and final volume in loamy soils.

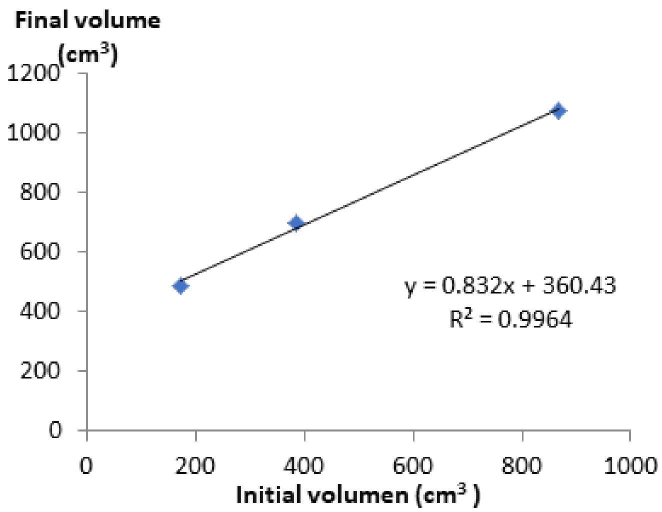

Figure 3. Relationship between the initial and final volume in clay soils.

3.3 Hydration of hydrogel in the soil

The hydration of the hydrogel in the soil is lower than the hydration percentage in water, only as high as 42 % with respect to the hydration in water (Figure 4). Hence, if using hydrogel on the soil without prior hydration, it must be taken into account its ability to hydrate the soil and thus the plant. Information on this hydrogel hydration in soil is not defined in the scientific literature, although it is widely recommended in crops, mainly in forestry crops. The fact that it is not hydrated in equal proportion to the hydration that occurs in free water may indicate the soil will resist and the hydrogel will not expand normally, and therefore will not absorb water fully.

4 Conclusions

The volume of hydrogel moistening occurs depending on the type of soil and the initial volume of hydrogel in the soil. Sandy-loamy soil finds it easier to form a larger wet bulb unlike other soils. The area moistened by the hydrogel has increased humidity in about 14 % with respect to the initial content and regardless the type of soil, with the possibility of preparing the soil to the field capacity.

Table 2. Increase of soil moisture applying hydrogel in all three soils.

Type of soil	Initial moisture % (Dry soil)	Moistening percentage (%)
Sandy	4.7	18.8±0.8
Loamy	6.5	20.8±1.2
Clayey	8.6	22.8±1.5

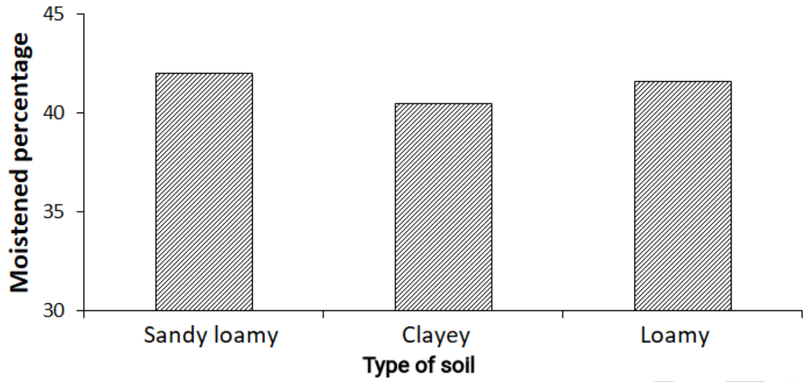

Figure 4. Percentage of hydrogel hydration in the soil with respect to hydration in free water.

When applying unhydrated hydrogel to the soil, it cannot be hydrated as equal as with free water, because the soil is pressurized and makes it difficult for the hydrogel particle to be hydrated normally. In all soils, 42 % of hydration was achieved with respect to free water hydration. It is important to consider that knowing the behavior of hydrogel in soil will optimize its use; therefore, studies should be conducted on its stability, rehydration and soil duration in crops under production.

References

Agaba, H., Orikiriza, L.and Obua, J., Kabasa, J., Worbes, M., and Hüttermann, A. (2011). Hydrogel amendment to sandy soil reduces irrigation frequency and improves the biomass of agrostis stolonifera. *Agricultural Sciences*, 2(04):544. Online:https://bit.ly/3m6MKZg.

Agaba, H.and Baguma Orikiriza, L., Osoto Esegu, J., Obua, J.and Kabasa, J., and Hüttermann, A. (2010). Effects of hydrogel amendment to different soils on plant available water and survival of trees under drought conditions. *Clean-Soil, Air, Water*, 38(4):328–335. Online:https://bit.ly/2J3KZ0U.

Ahmed, E. (2015). Hydrogel: Preparation, characterization, and applications: A review. *Journal of advanced research*, 6(2):105–121. Online:https://bit.ly/368Sdct.

Al-Humaid, A. and Moftah, A. (2007). Effects of hydrophilic polymer on the survival of buttonwood seedlings grown under drought stress. *Journal of Plant Nutrition*, 30(1):53–66. Online:https://bit.ly/3q0lLB7.

Amin, S., Rajabnezhad, S., and Kohli, K. (2009). Hydrogels as potential drug delivery systems. *Scientific Research and Essays*, 4(11):1175–1183. Online:https://bit.ly/37cxaFk.

Barón, A., Barrera, I., Boada, L., and Rodríguez, G. (2007). Evaluación de hidrogeles para aplicaciones agroforestales. *Ingeniería e Investigación*, 27(3):35–44. Online:https://bit.ly/2JfcnbQ.

Chirino, E., Vilagrosa, A., and Vallejo, V. R. (2011). Using hydrogel and clay to improve the water status of seedlings for dryland restoration. *Plant and Soil*, 344(1-2):99–110. Online:https://bit.ly/3mfboHk.

Cisneros, E., Cun, R., Herrera, J., González, R., Cun, S., and Sarmiento, O. (2020). Efecto de los polímeros en la economía del agua. *Revista Ingenie-*

ría Agrícola, 10(1):21–27. Online:http://opn.to/a/uApBC.

Dragusin, M., Martin, D., Radoiu, M., Moraru, R., Oproiu, C., Marghitu, S., and Dumitrica, T. (1996). Hydrogels used for medicine and agriculture. In *Gels*, pages 123–125. Online:https://bit.ly/3fFlVc8. Springer.

Fonteno, W. and Bilderback, T. (1993). Impact of hydrogel on physical properties of coarse-structured horticultural substrates. *Journal of the American Society for Horticultural Science*, 118(2):217–222. Online:https://bit.ly/3fFmR08.

Geesing, D. and Schmidhalter, U. (2004). Influence of sodium polyacrylate on the water-holding capacity of three different soils and effects on growth of wheat. *Soil use and management*, 20(2):207–209. Online:https://bit.ly/39kL4YB.

Hüttermann, A., Zommorodi, M., and Reise, K. (1999). Addition of hydrogels to soil for prolonging the survival of pinus halepensis seedlings subjected to drought. *Soil and tillage research*, 50(3-4):295–304, Online:https://bit.ly/2V8ltdh.

Idrobo, H., Rodríguez, A., and Díaz, J. (2010). Comportamiento del hidrogel en suelos arenosos. *Ingeniería de Recursos Naturales y del Ambiente*, (9):33–37. Online:https://bit.ly/33kSVS0.

Jankowski, K., Jankowska, J., and Sosnowski, J. (2011). Rooting properties of lawn grasses established on the basis of red fescue in the aspect of the applied hydrogel. *Acta Scientiarum Polonorum. Agricultura*, 10(4):69–78. Online:https://bit.ly/36dDFs1.

Lopes, J., Pinto, A., Campagnolo, M., Contro, U., de Matos M., and Guimarães, V. (2013). Sobrevivência e crescimento inicial de pinhão-manso em função da época de plantio e do uso de hidrogel. *Ciência Florestal*, 23(3):489–498. Online:https://bit.ly/3nZYUDS.

Maldonado-Benitez, K., Aldrete, A., López-Upton, J., Vaquera-Huerta, H., and Cetina-Alcalá, V. (2011). Producción de pinus greggii engelm. en mezclas de sustrato con hidrogel y riego, en vivero. *Agrociencia*, 45(3):389–398. Online:https://bit.ly/3mii2g2.

Moorberg, C. J. and Crouse, D. A. (2017). Soils laboratory manual, k-state edition. NPP eBooks.

M'barki, N., Aissaoui, F., Chehab, H., Dabbaghi, O., del Giudice, T., Boujnah, D., and Mechri, B. (2019). Cultivar dependent impact of soil amendment with water retaining polymer on olive (olea europaea l.) under two water regimes. *Agricultural Water Management*, 216:70–75. Online:https://bit.ly/2HMv06E.

Najafi, F., Golchin, A., and Mohebi, M. (2013). The effects of aquasorb water-absorbing polymer and irrigation frequency on yield, water use efficiency and growth indices of greenhouse cucumber. *J. Sci. & Technol. Greenhouse Culture*, 4(15):14–22. Online:https://bit.ly/3q8LqHB.

Narjary, B., Aggarwal, P., Singh, A., Chakraborty, D., and Singh, R. (2012). Water availability in different soils in relation to hydrogel application. *Geoderma*, 187:94–101. Online:https://bit.ly/2V87TX0.

Nicolson, P. and Vogt, J. (2001). Soft contact lens polymers: an evolution. *Biomaterials*, 22(24):3273–3283. Online:https://bit.ly/36aEMsD.

Orikiriza, L., Agaba, H., Eilu, G., Kabasa, J., Worbes, M., and Hüttermann, A. (2013). Effects of hydrogels on tree seedling performance in temperate soils before and after water stress. *Journal of Environmental Protection*, 4(07):713–721. Online:https://bit.ly/3o2FNZT.

Palacios, A., Rodríguez, R., Prieto, F., Meza, J., Razo, R., and Hernández, M. (2016). Hidrogel como mitigador de estrés hídrico: una revisión. *Revista Iberoamericana de Ciencias*, 3(5):80–90. Online:https://bit.ly/39nnk5Z.

Pereira, B., Araájo, G., Dos Santos, A., Dos Anjos, G., and Mediros, F. (2019). Watermelon initial growwth under diferent hydrogel concentrations and shading conditions. *Revista Caatinga*, 32(4):915–923. Online:https://bit.ly/3mdKvnb.

Rivera, R. and Mesías, F. (2018). Absorción de agua de hidrogel de uso agrícola y su humedecimiento de tres tipos de suelo. *Revista de la Facultad de Ciencias Agrarias*, 50(2):15–21. Online:https://bit.ly/39l9aCw.

Rivera, R., Rodriguéz, F., Mesías, F., and Mendoza, D. (2018). Hydrogel for improving water use efficiency of capsicum annun crops in fluvisol soil. *Revista de la Facultad de Ciencias Agrarias*, 50(2):23–31. Online:https://bit.ly/39l9aCw.

Rojas, B., Aguilar, R., Prin, J., Cequea, H., Cunana, J., Rosales, E., and Ramírez, M. (2004). Estudio de la germinación de semillas de tomate en suelos áridos extraidos de la peninsula de araya (venezuela) al utilizar polímeros de tipo hidrogeles. *Revista Iberoamericana de Polímeros*, 5(1):17–27. Online:https://bit.ly/3o1IYkr.

Ruiz, H. A., Sarli, G., Reynaud, C., Filgueira, R., and de Souza, F. (2016). La superficie específica de oxisoles y su relación con la retención hídrica. *Revista de la Facultad de Ciencias Agrarias. Universidad Nacional de Cuyo. Mendoza. Argentina.*, 48(2):95–105. Online:https://bit.ly/39s9EHf.

Santelices, R. (2005). Desarrollo de una plantación de eucalyptus globulus establecida en primavera con diferentes tratamientos de riego. *Bosque (Valdivia)*, 26(3):105–112. Online:https://bit.ly/3mg982n.

Satriani, A., Catalano, M., and Scalcione, E. (2018). The role of superabsorbent hydrogel in bean crop cultivation under deficit irrigation conditions: A case-study in southern italy. *Agricultural Water Management*, 195:114–119. Online:https://bit.ly/3o2h4EV.

Wadas, J., Ribeiro da Silva, M., Cury, J., and dos Santos, T. (2010). Uso de hidrogel na sobrevivência de mudas de eucalyptus urograndis produzidas com diferentes substratos e manejos hídricos. *Ciência Florestal*, 20(2):217–224. Online:https://bit.ly/3q90OE8.

Wang, Y. (1989). Medium and hydrogel affect production and wilting of tropical ornamental plants. *HortScience*, 24(6):941–944. Online:.

Yazdani, F., Allahdadi, I., and Akbari, G. A. (2007). Impact of superabsorbent polymer on yield and growth analysis of soybean (glycine max l.) under drought stress condition. *Pakistan journal of biological sciences: PJBS*, 10(23):4190–4196. Online:https://bit.ly/3fHKCol.