Emirates Journal of Food and Agriculture. 2022. 34(9): 800-805
doi: 10.9755/ejfa.2022.v34.i9.2933
http://www.ejfa.me/

RESEARCH ARTICLE

Nanotechnology for dryland agriculture water saving: Biodegradable hydrogel application in sweet corn (*Zea mays saccharate* Sturt) production

Radian Radian[1], Budiyati Ichwan[2], Islah Hayati[2]*, Addion Nizori[3], Marlina Marlina[4], Mapegau Mapegau[2], Efrizal Efrizal[5,6], Mohd Raznan Ramli[6], Aaronn Avit Ajeng[6]

[1]Department of Agricultural Cultivation, Faculty of Agriculture, Tanjung Pura University, Indonesia, [2]Department of Agro Eco-Technology Faculty of Agriculture, Jambi University 36361, Jambi-Sumatera, Indonesia, [3]Technology of Agricultural Product Department Faculty of Agriculture Jambi University 36361, Jambi-Sumatera, Indonesia, [4]Department of Plant Protection Faculty of Agriculture, Syiah Kuala University, Darussalam Banda Aceh, Indonesia, [5]Faculty of Agriculture, Jambi University 36361, Jambi-Sumatera, Indonesia. [6]Institute of Biological Sciences, Faculty of Science, University of Malaya 50603, Kuala Lumpur, Malaysia

ABSTRACT

This work aimed to determine the effect of biodegradable superabsorbent hydrogel based on cellulose derivatives on the growth and yield of sweet corn (*Zea mays saccharata* Sturt) on dry land. The design used was a completely randomized design (CRD). The applied treatments consisted of four levels of hydrogel: without hydrogel (control), 2, 4, and 6 g per plant, respectively. Each treatment was repeated six times in this experiment, yielding a total of 24 experimental pots. Each experiment pot contained 3 plants, thus all 72 plants. The results showed that the hydrogel would significantly increase soil moisture, relative water content, growth of the plant height, stem diameter, and ear cobs without corn husk. Likewise, on the length of the ear without ear cobs and wet ear weights without corn husk. As the hydrogel preserves soil moisture, allowing water to be available for the plant, it might also temporarily store soil from the water and gradually remove it into the soil. Further investigations should be performed to completely characterize the interaction between the superabsorbent hydrogel and the dry land soil.

Keywords: Soil moisture; Cellulose derivatives; Hydrogel; Nanotechnology; Sweet corn; Superabsorbent

INTRODUCTION

Sweet corn (*Zea mays saccharate* Sturt), is widely developed in Indonesia. Sweet corn is consumed because of the sweeter taste, more fragrant aroma contains sucrose sugar, and low fat so it is good for diabetics. In addition to the seeds, other parts of the sweet corn plant have economic value, including young stems and leaves for animal feed, old stems, and leaves (after harvest) for green fertilizer/compost, dried stems, and leaves as fuel to substitute firewood, young corn fruit for vegetables, cakes, and various other food processing products (Leblanc et al., 2006).

The policy of developing sweet corn cultivation is in line with the dry land empowerment program because dry land is an alternative for most farmers in rural areas. Because fertile land was very limited, the choice may fall on using sub-optimal dry land. The problem of dry land for crop cultivation are low fertility, high soil acidity, and relatively limited water availability because the water source only depends on rainfall. In the meantime, global warming is due to the production of excess greenhouse gases such as CH_4, CO_2, and N_2O, causing climate change that directly affects the distribution of water, which is uneven and difficult to predict. This can cause water scarcity, which causes drought on agricultural land.

In light of this situation, water management must be optimally pursued, which is on time, on the right amount of water, and the target, so that it is efficient in efforts to increase plant growth and production on dry land. In addition, the anticipation of crop drought due to an inadequate supply of rainwater needs to be addressed with various efforts, including providing hydrogels. Hydrogel has been applied in the agricultural system as either soil amendment or a seed coating material. Studies have shown

***Corresponding author:**
Islah Hayati, Department of Agro Eco-Technology Faculty of Agriculture. **E-mail:** islah.hayati@unja.ac.id. **Tel.:** +62-852-796-40586

Received: 11 May 2022; **Accepted:** 19 August 2022

that soil amendment with hydrogel can improve water and fertilizer retention in soil, improve soil aeration, reduce evapotranspiration, improve seedling emergence, and prolong water availability for plant use (Demitri et al., 2013; Guilherme et al., 2015; A Rakshit et al., 2017).

Furthermore, hydrogels can absorb and release water. When it comes in contact with water, the polar hydrophilic group in the hydrogel is the initial part that is hydrated by a water molecule that causes the formation of primary bonds. The formation of these primary bonds can occur due to the presence of nan cavity-sized cavity structures in the polymer hydrogel network, which enables the hydrogen bonding between water molecules and polar hydrogel groups (Ostrowska-Czubenko and Gierszewska-Druzyńska, 2009). This process causes structural hydrogels to swell, which allows hydrogel structures that are hydrophobic to have the ability to bind the water.

The hydrogel is a kind of temporary media that can store and supply water for plants. After the polymer absorbs water, the soil structure will get better and the soil's ability to retain water (water retention capacity) will increase also. This hydrogel is known in agriculture as a substance that can be used to improve soil physical properties, to increase water storage capacity, water use efficiency, permeability and infiltration speed of land, reduce irrigation frequency, the tendency of soil density, stop erosion and loss water, and increase crop productivity (Sampathkumar et al., 2020).

The hydrogel or superabsorbent polymers (SAP) are hydrophilic three-dimensional network polymers, the macromolecular network that can absorb and release water reversibly within their molecular matrix based on external stimulants (Guilherme et al., 2015; Rohindra et al., 2004; Zohuriaan-Mehr and Kabiri, 2008)

Unlike soil conditioners which only form a linear network so that it is water-soluble, hydrogels have a cross-linked network that, when exposed to water, will form a three-dimensional macromolecular network with the ability to absorb water that far exceeds its weight or volume (or commonly called superabsorbent material) and water-insoluble (Zohuriaan-Mehr and Kabiri, 2008). The application of hydrogels on agricultural land has been proven to be able to increase water retention in soils because water that is wasted outside the root zone can be absorbed by hydrogel material and can then be reused for up to 95% of the water stored in this material (Sampathkumar et al., 2020).

The application of nanotechnology in agriculture has been stated by (Amqam et al., 2020) that future packaging trends are bio-degradable and have antimicrobial capabilities. Thus, in agriculture, nanotechnology also requires further study related to its potential to be used in controlling disease in plants to increase crop productivity.

MATERIALS AND METHODS

This research was conducted at the Greenhouse of Agriculture Faculty, Jambi University, Muaro Jambi Regency (-1.6132, 103.5187), at an altitude of 35 meters above sea level. This study uses a Completely Randomized Design (CRD), with the treatments consisting of four levels of hydrogel, namely: without the addition of hydrogel as control, 2 g of hydrogel per plant, 4 g of hydrogel per plant, and 6 of hydrogel per plant. Each treatment was repeated 6 times so that there were 24 experimental pots. Each experiment pot contained 3 plants. Thus, the total number of plants was 72 plants. Each experiment pot was filled with 7 kg of soil as a planting medium in the condition of field capacity.

Hydrogel crystal was applied by the wet application method following procedure outline by Miller et al. (2019) with slight modifications. The hydrogel was immersed in water as much as 200 times the weight of each dose of hydrogel per the treatment and left for 2 hours until saturated, and then spread evenly into a pot containing 4/5 soil part of the specified planting medium (5.6 kg). Then followed by entering the remaining 1/5 part of the planting media into a pot, as much as 1.4 kg, which served as a ground cover in a pot so that the hydrogel was not damaged due to direct contact with ultraviolet light. The next was the wetting step of the soil surface in a pot to maintain moisture to promote seed germination. Variables observed were soil moisture (planting media), the relative water content of leaves (RWC), plant height, stem diameter, length of corn cobs, diameter, and fresh weight of corn cobs.

Measurement of soil moisture (planting media) was done two times, first at planting (initial soil moisture), and second when the plants were three weeks old. Measurements were made in the afternoon (16:00) using a hygrometer. The relative water content is calculated using the formula (Equation 1) (Soltys-Kalina et al., 2016):

$$RWC = (FW - ODW)/(TW - ODW) \times 100\% \ [10] \quad \text{(Eq. 1)}$$

where RWC = relative water content, FW = fresh weight, ODW = oven-dry weight, and TW = turgor weight. Leaf sampling for RWC measurements was conducted at noon when the plants were planted 3 and 6 weeks after planting (WAP). The data were subjected to analysis of variance (F-test). Means were compared using Duncan multiple range tests (DMRT). To see the relationship between RWC and growth and yield, correlation and regression analysis were performed using Minitab software version 18. Meanwhile, to determine the magnitude of the role of yield components, multiple additive linear regression analysis was performed using the test model (Equation 2):

$$Y = b_0 + b_1X_1 + b_2X_2 + \varepsilon \qquad \text{(Eq. 2)}$$

Where,
Y = Weight of fresh cobs without husks (g)
X1 = Length of fresh cobs without shells (cm)
X2 = Diameter of fresh cobs without shells (cm)

RESULTS

From a visual standpoint, it looked that plants treated with hydrogels, plants treated with hydrogels, and plants not treated with hydrogels had different leaf margin colours. Plants that weren't treated with hydrogel had delicate white edges to their leaves. The white tint discovered is an indication of mildew disease in maize plants caused by the fungus *Sclerosporamaydis* (Balan, 2022). These symptoms began to appear at 4 weeks after planting, with a relatively small percentage of 1.26% of the population of plants that were not treated with hydrogels. Even though plants showed symptoms with relatively small percentages, there were indications that the use of hydrogels in agriculture, especially those related to plant disease control, needs to be studied further because plants that were treated with hydrogels in research did not show symptoms as seen in plants received hydrogel treatment.

Soil moisture and relative water content (RWC) of growing media

Hydrogel significantly affected soil moisture and relative water content. The soil moisture and relative water content in the hydrogel of 6 g plant were significantly higher than the soil moisture in the hydrogel of 2 g per plant and without hydrogel. Likewise, the relative water content shown in Table 1, soil moisture measured at planting was relatively the same, both those that were given hydrogel and those not added with hydrogel, which ranged from 71.61 - 73.22%. Three weeks later, the soil moisture in all hydrogel treatments showed a decreasing trend.

Table 1: Soil moisture and relative water content (RWC) leaves of sweet corn plant at various hydrogel doses

Hydrogel doses (g per plant)	Soil moisture (%)		RWC (%)	
	At planting	3 WAP	3 WAP	6 WAP
6	73.22	71.64^a	75.53^a	73.50^a
4	73.08	71.57^a	75.14^a	73.45^a
2	71.55	60.73^b	67.44^b	58.52^b
0	71.61	50.54^c	62.08^b	49.43^c

The numbers followed by the same letter are not significantly different according to the Duncan test at the 5% level. WAP: Week after planting and RWC: Relative water content

Growth of sweet corn plants

This study showed that hydrogels were able to store water and release it back into the soil proportionally, plants always have a water supply for their growth (Ejeian et al., 2021). The results indicate that the hydrogels 4 and 6 g per plant was able to increase the height of sweet corn plants and stem diameter, This means that hydrogel can have a good influence on the growth of sweet corn plants. This influence is related to the function of hydrogels that can hold and release water and nutrients into the soil which plants can then absorb.

The yield of sweet corn plants

Hydrogel affected the length, diameter, and fresh weight of corn cob. The increase in hydrogel from 4 to 6 per plant significantly increased corn cob's length, diameter, and fresh weight, compared with hydrogel 2 g per plant, and without hydrogel. This can occur because hydrogels can provide water and nutrients for plants up to the period of generative growth to allow a high rate of photosynthesis during the flowering, seed formation, and seed filling phases. The high rate of photosynthesis during these phases due to hydrogels allows for allocating more photosynthates into the part of the plant to be harvested. Correspondingly, (Tenreiro et al., 2020) suggested that cereal crops are determined by photosynthesis after flowering.

Yield components (length and diameter of fresh cobs without husks) played a significant role in determining the yield of sweet corn, which in this study was the weight of fresh cobs without husks. The equation obtained is: Y = -25,214 + 1,393 X1 + 0,862 X2 (R2 = 0,87) with F_{count} regression 23,528* and F0.05 = 5.12. The diversity of weights of fresh, unhulled cobs per plant is determined jointly by the diversity of the length of fresh, unhulled

Table 2: Plant height and stem diameter of sweet corn plants at various hydrogel doses

Hydrogel doses (g per plant)	Plant height (cm)	Stem diameter (cm)
6	143.53^a	0.80^a
4	137.24^a	0.83^a
2	126.34^b	0.69^b
0	105.83^c	0.54^b

The numbers followed by the same letter are not significantly different according to the Duncan test at the 5% level.

Table 3: Length of corn cob, diameter, and fresh weight at various hydrogel doses

Hydrogel doses (g per plant)	Length of corn without cob (cm)	Diameter of corn without cob (cm)	Fresh weight of corn without cob (g)
6	10,53^b	1,77^b	19,35^b
4	10,17^b	1,75^b	17,62^b
2	9,18^a	1,38^a	12,80^a
0	7,62^a	1,08^a	12,13^a

The numbers followed by the same letter are not significantly different according to the Duncan test at the 5% level.

cobs (X1) and the diameter of fresh, unhulled cobs (X2). Furthermore, the variable selection results carried out by the backward step method showed that only the length of fresh cobs without husks significantly played a role in determining the amount of fresh weight of cobs without husks (Table 4). Meanwhile, the diameter of fresh cobs without husks had no significant role in determining the diversity of weights of fresh cobs without husks.

RWC correlation with growth and yield

The results of correlation analysis (Table 5) showed that RWC was positively correlated with the growth and yield of sweet corn, which included plant height (r = 0.9660), stem diameter (r = 0.7526), and fresh cob weight (r = 0.9544). This means that the RWC and sweetcorn yields change in the same direction. The greater the RWC value, the greater the average growth and yield, and vice versa. Based on the correlation analysis between RWC and growth and results, it can be stated that RWC is very closely correlated with the three variables.

The results of the regression analysis of plant height were expressed by the equation model Y = 109.3 + 6.198X (R2 = 0.9320) (Fig. 1). This model shows that with one unit in the hydrogel dose increase, the plant height will increase by 6,198. The coefficient of determination (R2) was 0.9320, indicating that the hydrogel dose caused 93.20% of the variation in plant height (Y).

Table 4: The results of the selection of variables X1 and X2 against Y using the step-back method

Paesial	FX (I)	F count	F0.05
Y	1	7.479*	5.12
	2	3.146	5.12

Y = Weight of fresh cobs without husks
X1 = Length of fresh cobs without shells
X2 = Diameter of fresh cobs without shells

Table 5: Analysis of linear correlation between RWC and growth variables and sweet corn yield

Growth and yield variables	r_{count}	r_{table}	Criteria
Plant height	0.9660	0.950	Very strong
Rod diameter	0.7526	0.950	Very strong
Fresh cob weight	0.9544	0.950	Very strong

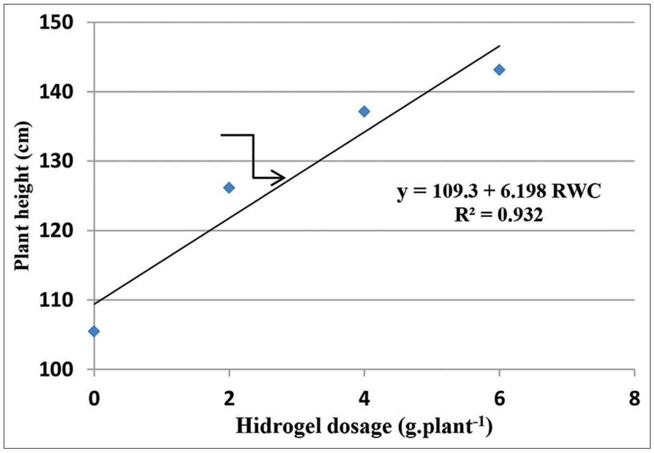

Fig 1. Regression between hydrogel dose and sweetcorn height.

Regression analysis for fresh cobs weight was expressed by the equation model Y= 11.550 + 1.304X (R2 = 0.9900) (Fig. 2). The model explains that an increase will follow every one-unit increase in the hydrogel dose in fresh cobs weight of 1,304 units. The coefficient of determination (R2) of 0.9890 indicates that 90.90% of the variation that occurs in the weight of fresh cobs is caused by the hydrogel.

Furthermore, the regression analysis results of soil moisture (KT) at the time of planting are expressed by the model equation Y = 52.62 + 3.685X (R2 = 0.8970). The model shows that every one-unit increase in the hydrogel dose causes an increase in soil moisture of 3,685 units. The coefficient of determination (R2) of 0.909 indicates that 90.9% of the variation in soil moisture is due to the hydrogel dose. Regression analysis of soil moisture at 3MST plant age was expressed by the equation Y= 71.43 + 0.341X (R2 = 0.863) (Fig. 3). This equation explains that every time there is an increase of one unit of hydrogel dose, it causes an increase in soil moisture of 0.341 units. The coefficient of determination (R2 = 0.863) showed that 86.3% of the variation in soil moisture at the age of 3 WAP was caused by the hydrogel dose.

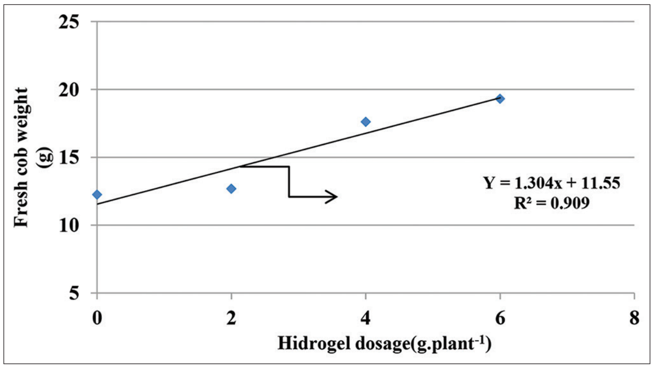

Fig 2. Fresh cob weight regression.

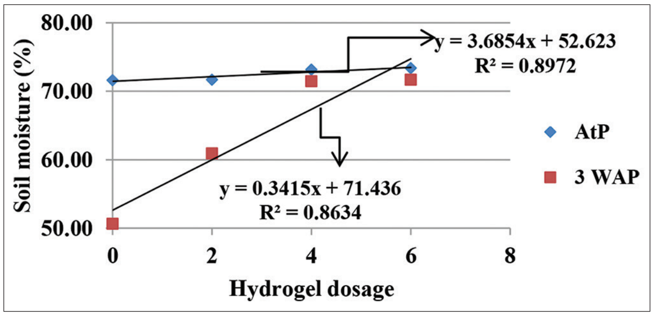

Fig 3. Regression of soil moisture at planting (AtP) and 3MST (WAP).

DISCUSSION

If referring to the soil moisture at planting, a decrease in soil moisture is higher in hydrogels 2 g per plant and 0 g per plant is 15.12% and 29.42%. The decrease in soil moisture at 6 g per plant and 4 g plan hydrogel were relatively small, 2.16% and 2.07%, respectively. The soil moisture measurement shows that hydrogels can hold water and release it into the ground. According to Ostrowska-Czubenko and Gierszewska-Druzyńska (2009), when there is contact with water, the hydrophilic group that is polar in the hydrogel is the initial part that is hydrated by water molecules that causes the formation of a primary bond. The formation of these primary bonds can occur due to nanocavity-sized cavity structures in the polymer hydrogel network, which enables hydrogen bonding between water molecules and polar hydrogel groups. This process causes structural hydrogels to swell, which allows hydrogel structures that are hydrophobic to have the ability to bind water. Wang and Gregg (1990) stated that hydrogels can absorb distilled water up to 500 times the weight of the dry volume. In certain conditions, the hydrogel can release stored water and then return it to its original media, the soil. Thus, soil moisture can be maintained.

The ability of hydrogels to store water and then release it back into the soil is also supported by observations of the relative water content in this study. The relative water content of 4 g plant and 6 g per plant hydrogel is significantly higher than the relative water of 2 g per plant hydrogel and without hydrogel, both 3 WAP and 6 WAP. Based on the relative water content of 3 WAP and 6 WAP, it can be seen that the reduction in relative water content in 3 weeks is relatively small in hydrogel 6 g per plant, and 4 g per plant, 2, 69%, and 2.25%, while in the provision of hydrogel 2 g per plant and without hydrogel, the relative decrease in water content was quite large, namely 13.23% and 20.38%, respectively. The WAP result demonstrates that hydrogels may hold water and then gently release it proportionately into the soil, where it can be absorbed by plant roots, as evidenced by the high relative water content.

The content in the hydrogel consists of a water release gel structure which in dry conditions can optimize the recovery/supply of stored water for plant needs. This can occur because hydrogels, known as water-absorbing polymers, are composed of polymers that, in a detailed framework called vacuoles, can store air and water connected by polygonal bridges (Johnson and Veltkamp, 1985; Mandal et al., 2020). A similar report from other researchers (Bellot and Ortiz de Urbina, 2008; Kramer, 1969) showed that the use of soil enhancers can increase plant height and stem diameter of sweet corn plants. Water is the most influential factor among the environmental factors that influence the growth and development of plants. This can be understood because more than 80% of the fresh weight of the plant consists of water, so if the water is available, it will encourage plant growth to be better because water is important for cell division and enlargement (Langensiepen et al., 2020).

According to Tenreiro et al. (2020), the availability of adequate water to meet plants' water needs is very important. Adequate water availability during periods of plant growth can drive high photosynthesis rates and high elements nutrient transport rates into plants. Similarly, photosynthate partitions into parts of plants that will be harvested, including cob, will also increase to produce a larger cob.

In plants that are given hydrogel, as much as 2 g per plant and without hydrogel begins to indicate the presence of disorders in its physiological function. It is distinguished by low soil moisture and relative water content as a water deficit in the rooting environment. Water scarcity slows photosynthesis by shutting stomata and raising mesophyll resistance, reducing photosynthesis efficiency (Ottaviani et al., 2020).

Closing all or part of the stomata reduces CO2 importation, lowering the CO2 content in the leaf's intercellular space. The amount of CO_2 that decreases in the leaves will reduce the amount of CO_2 that goes into the Calvin cycle and increase the O_2/CO_2 ratio. This increased ratio resulted in the enzyme ribulose bisphosphate carboxylase (RuBP carboxylase) delaying and adding O2 (instead of CO2)to the Calvin cycle. Its products are degraded, and a single-carbon compound molecule is sent out of the chloroplasts towards the mitochondria and peroxisomes, breaking down the molecule into CO2 without generating ATP or assimilate. This series of processes is called photorespiration. Without ATP or assimilate in photorespiration, maize growth and productivity are reduced to 2 g per plant, and growth and productivity are blocked or not ideal. It has an impact on the availability of generative growth as well as corn production.

CONCLUSION

Based on the findings, it is possible to conclude that adding hydrogel to dryland soil might enhance soil moisture, relative water content (RWC) on leaves, plant height growth, stem diameter, and ear cob diameter without corn husk. Similarly, on ear length without ear cobs and wet ear weights without cornhusk. The hydrogel can store water and remove it gently into the soil, to retain soil moisture that allows water to be available for plants. Future study on the use of hydrogel on dryland soil with various crop growing methods and management is required.

CONSENT OF PATIENT

This research was not using humans as objects.

CONSENT OF ETHICS

This research was not using endangered species of animals, instead, it has the purpose of helping farmers to solve the problem of drought land to reach maximum yield.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

FINANCIAL SUPPORT

This research was supported financially by the Directorate General of Higher Education, Ministry of Education and Culture of Indonesia.

Authors' contributions

All authors contributed equally to the research and discussion of the obtained data of the manuscript. Radian conducted the studies under the guidance of Dr. Islah Hayati, Dr. Budiyati Ichwan and Dr. Addion Nizori. Additionally, Marlina, Mapegau, Efrizal, Mohd Raznan and all authors further contributed to the writing of the different sections of the paper.

REFERENCES

Amqam, H., U. F. Achmadi, B. Haryanto, I. Yusuf and Kusharisupeni. 2020. Nutritional intake pattern of horticulture farmers in three ethnic populations in Indonesia and farmer susceptibility to chlorpyrifos insecticide. Enferm. Clín. 30: 196-200.

Balan, G. A. 2022. Diseases of Corn in the Black Sea Steppe of Ukraine. In: Proceedings of the Scientific Forum with International Participation "Ecology and Agrotechnologies-fundamental Science and Practical Realization. Vol. 3. Sofia, pp.141-147.

Bellot, J. and J. M. Ortiz de Urbina. 2008. Soil water content at the catchment level and plant water status relationships in a Mediterranean *Quercus ilex* forest. J. Hydrol. 357: 67-75.

Demitri, C., F. Scalera, M. Madaghiele, A. Sannino and A. Maffezzoli. 2013. Potential of cellulose-based superabsorbent hydrogels as water reservoir in agriculture. Int. J. Polym. Sci. 2013: 1-6.

Ejeian, M. and R. Z. Wang. 2021. Adsorption-based atmospheric water harvesting. Joule. 5: 1678-1703.

Guilherme, M. R., F. A. Aouada, A. R. Fajardo, A. F. Martins, A. T. Paulino, M. F. T. Davi, A. F. Rubira and E. C. Muniz. 2015. Superabsorbent hydrogels based on polysaccharides for application in agriculture as soil conditioner and nutrient carrier: A review. Eur. Polym. J. 72: 365-385.

Johnson, M. S. and C. J. Veltkamp. 1985. Structure and functioning of water-storing agricultural polyacrylamides. J. Sci. Food Agric. 36: 789-793.

Kramer, P. J. 1969. Plant and Soil Water Relationships: A Modern Synthesis. McGraw-Hill, New York, USA.

Langensiepen, M., M. A. K. Jansen, A. Wingler, B. Demmig-Adams, W. W. Adams, I. C. Dodd, V. Fotopoulos, R. Snowdon, E. Fenollosa, M. C. De Tullio, G. Buck-Sorlin and S. Munné-Bosch. 2020. Linking integrative plant physiology with agronomy to sustain future plant production. Environ. Exp. Bot. 178: 104125.

Leblanc, M. L., D. C. Cloutier and K. A. Stewart. 2006. Rotary hoe cultivation in sweet corn. HortTechnology. 16: 583-589.

Mandal, S., V. K. Vema, C. Kurian and K. P. Sudheer. 2020. Improving the crop productivity in rainfed areas with water harvesting structures and deficit irrigation strategies. J. Hydrol. 586: 124818.

Miller, V. S. and M. A. Naeth. 2019. Hydrogel and organic amendments to increase water retention in anthroposols for land reclamation. Appl. Environ. Soil Sci. 2019: 4768091.

Ostrowska-Czubenko, J. and M. Gierszewska-Druzyńska. 2009. Effect of ionic crosslinking on the water state in hydrogel chitosan membranes. Carbohydr. Polym. 77: 590-598.

Ottaviani, G., G. Keppel, L. Götzenberger, S. Harrison, O. H. Opedal, L. Conti, P. Liancourt, J. Klimešová, F. A. O. Silveira, B. Jiménez-Alfaro, L. Negoita, J. Doležal, M. Hájek, T. Ibanez, F. E. Méndez-Castro and M. Chytrý. 2020. Linking plant functional ecology to island biogeography. Trends Plant Sci. 25: 329-339.

Rakshit, A., P. C. Abhilash, H. B. Singh and S. Ghosh. 2017. Adaptive Soil Management : From Theory to Practices. In: Rakshit, P. C., H. B. Abhilash, S. Singh and. S. Ghosh., (eds.). Springer, Singapore.

Rohindra, D. R., A. V. Nand and J. R. Khurma. 2004. Swelling properties of chitosan hydrogels. South Pac. J. Nat. Appl. Sci. 22: 32-35.

Sampathkumar, K., K. X. Tan and S. C. J. Loo. 2020. Developing nano-delivery systems for agriculture and food applications with nature-derived polymers. Science. 23: 101055.

Soltys-Kalina, D., J. Plich, D. Strzelczyk-Żyta, J. Śliwka and W. Marczewski. 2016. The effect of drought stress on the leaf relative water content and tuber yield of a half-sib family of 'Katahdin'-derived potato cultivars. Breed. Sci. 66: 328-331.

Tenreiro, T. R., M. García-Vila, J. A. Gómez, J. A. Jimenez-Berni and E. Fereres. 2020. Water modeling approaches and opportunities to simulate spatial water variations at crop field level. Agric. Water Manage. 240: 106254.

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

Zohuriaan-Mehr, M. J. and K. Kabiri. 2008. Superabsorbent polymer materials: A review. Iran. Polym. J. 17: 451-477.