The Application of Hydrogel in Agriculture for Reducing High Pumping of Irrigation Water in Algeria

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Abstract

The application of hydrogel in agriculture has gained a wide interest in the last decades due to the great benefits that it has provided to this sector. In Algeria, agriculture suffers from two main issues: water shortage and climate change, especially in the south of the country (Sahara), which is classified within the arid and semi-arid regions, where irrigation is based exclusively on groundwater. This paper presents an experiment of hydrogel application in agricultural soil for reducing overexploitation of groundwater used for irrigation. Hydrogels are super absorbent polymers. They are biodegradable and have the ability to absorb and retain a large amount of water. The aim of this work is to evaluate the effect of hydrogel on the efficiency of soil moisture retention through treating sandy soil with different doses of hydrogel. The results indicate that the application of hydrogel can increase the water retaining capacity of sandy soil up to 40%.

Keywords: Agriculture, Ground water, Sandy soil, Hydrogel, Irrigation .

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1. Introduction

In recent years, the demand for water in many sectors including residential, industrial uses, and agricultural sector has substantially increased. On the other hand, water shortage has created a great challenge for several countries. In Algeria, the water stress index is poor with a water availability ratio of 411m3/capita/year and ranks the country in absolute water scarcity [1]. In addition, forecasts estimate that freshwater availability will be 332 and 300 m3/capita/year in 2025 and 2050 respectively [2]. Agriculture in Algeria is the second important factor economy after petroleum investments. Since the independence, the Algerian population has witnessed a rising demographic growth each year, which caused it one of the largest importer countries of agricultural products and food. Now the challenge of the country is to look for self- sufficiency and so, it has to deal with different issues such as lack of training for human resources, old-fashioned irrigation systems, low investment, management difficulties, etc. nevertheless, the major issues are climate change and lack of water.

In Algeria, agriculture is commonly based on rainfall for irrigation like many other countries and it is considered as the main source for irrigation. Recently, rainfall became an insecure source for irrigation because of rain fluctuation especially in arid and semi-arid areas like the Sahara (desert) of the country, leading to trend towards the exploitation of groundwater. The use of groundwater for irrigation has dramatically increased in different parts of the world [3]. It is presented as a way to increase food production and fight rural poverty [4]. In Algeria, the available groundwater reserves are evaluated to approximately

8.5 billion m^3, assessed as 2.5 billion m^3 in northern regions and 6 billion m^3 in the Sahara regions, which is deemed non-renewable [5]. Due to irregular rainfall and climate change, it has been observed that groundwater became more vulnerable to overuse and contamination [6]. Additionally, a previous study has been performed by Khezzani B and Bouchemal S, has indicated that the rate of decline of groundwater levels has increased by 0.29 m/year [7], as a result of overexploitation of groundwater and high pumping.

Algeria's main crops are cereals (mainly wheat and barley), citrus fruit, vegetables, grapes, and fresh dates [8]. The policy of the country is looking for sustainable agriculture (productive and profitable agriculture that protects the environment and that is socially equitable) [9]. For this purpose, many sustainable improvements in agricultural techniques are being studied in order to increase agriculture production andensure food security with less irrigation water consumption. Among these improvements, the addition of hydrogel to soil is widely used in the agriculture field with a view to improve agricultural soil properties. The presented study is conducted on sandy soil without cultivation to find out the best dose of hydrogel that can increase the efficiency of soil moisture retention in high percentage and for the longest duration through treating sandy soil with different doses of hydrogel by two different methods of treatment, which leads to reduce the consumption of irrigation water and preserving the quantity and quality of groundwater.

Hydrogels are cross-linked hydrophilic polymeric networks that can retain large quantities of water and aqueous solutions within their structure, without dissolving in it [10]. Hydrogels can be divided into two categories depending on their source natural or synthetic [11]. Natural hydrogels can be classified into 3 groups: protein-based materials, polysaccharide-based materials, and those derived from decellularized tissue [12]. Synthetic hydrogels preparation was firstly reported in the end of 60's by Wichterle O and LÍM D [13]. However, they were toxic, and had a short life of service. Many publications, articles, and reports have been done in the last decades on synthetic hydrogels focused on their preparation, characterization, and application [14] in order to make them more developed. Due to their wide use in various fields [15].

Copolymerization/cross-linking free-radical polymerizations are commonly used to produce hydrogels by reacting hydrophilic monomers with multifunctional cross-linkers [10]. They can absorb water a hundred times of their dry weight and desorb it under stress condition [16]. The hydrophilicity of the network is due to the presence of chemical residues such as hydroxylic (-OH), carboxylic (-COOH), amidic (-CONH-), primary amidic (-$CONH_2$), sulphonic (-SO_3H), and others that can be found within the polymer backbone or as lateral chains [17], this is what has gained hydrogels specific characteristics that made it possible to use them successfully in many different fields such as agriculture sector as soil conditioners [18], drug delivery [19], biomedical applications [20], tissue engineering [21], pharmaceuticals [22], wound dressing [23], diagnostics [24], separation devices [25], artificial snow [26], chemical valves [27] and food additives [28]...etc.

Table 1:Natural polymers and synthetic monomers used in hydrogel fabrication [29].

Natural polymer	Synthetic monomer
Chitosan	Hydroxyethylmethacrylate(HEMA)
Alginate	N-(2-hydroxypropyl)methacrylate(HPMA)
Fibrin	N-vinyl-2-pyrrolidone(NVP)
Collagen	N-isopropylacrylamide(NIPAAm)
Gelatin	Vinylacetate(VAc)
Hyaluronic	acidAcrylicacid(AA)
Dextran	Methacrylicacid(MAA)
Polyethyleneglycolacrylate/methacrylate(PEGA/PEGMA)	
Polyethyleneglycoldiacrylate/dimethacrylate(PEGDA/PEGDMA)	

2. Materials and Methods

2.1. Studied region

This study was carried out in the laboratory of Biodiversity and application of Biotechnology in the Agricultural Domain. The samples were taken from OuedSouf region (33° 21' 21.89" N, 6° 51' 47.48" E). This region is located at an altitude of 81m and it is characterized by sandy soil, cold winters, hot summers with average annual precipitation of 65 mm, and average temperature 21.6 ° C.

Table 2: Climate of the region.

Jan			Feb Oct	Mar Nov	Apr Dec	May	Jun	Jul	Aug	Sep		
Average temperature (° C)	9.9	11.8	16.4	21	25.7	30.2	33.3	32.7	28.6	23.1	15.5	10.8
Precipitation (mm)	13	4	8	8	3	1	0	1	6	5	8	8
Rainy days	2	1	1	1	1	0	0	0	1	1	1	1

2.2. Experimental design and soil sampling

AgroNanoGel Basichydrogel wasusedin thisexperimentwascarriedoutin Poland.Thechosen soil forthis study issandy soil.Thesamplesweredividedintothreegroups,wherethefirstgroupcontainssamplesthat weretaken from soil had neverbeen used forcultivation before(S1), and thesecond group, they weretaken from soil that had been used for cultivation for one year before the experiment (S2) and for the third group, they weretaken fromsoilthathadbeen usedforcultivation forthreeyearsbeforetheexperiment(S3).Then, all the samples were put in plastic pots that have holes in the bottom.

Table 3 :Main properties of AgroNanoGel Basic Hydrogel

Properties	AgroNanoGel Basic Hydrogel
Absorbency	(450-600ml/g)
pH	neutral
Biodegradability	10 years
Toxicity	Non-toxic
Influence on soil microorganisms	No negative impact on the soil microorganisms

In order to evaluate the impact of hydrogel on the soil moisture retaining capacity, its effect on soil moisture was studied through adding 20g of dry hydrogel to 1L of water to get the swelling form of hydrogel (gel form). Then, four doses of the gel (4%, 5%, 8%, 10%) were taken to treat the samples, and one sample was left without hydrogel (0% dose). The doses of hydrogel were added to samples in two different methods; the first one: hydrogel was placed in the middle of the samples and in the second method the addition of hydrogel was done as a homogeneous mixture (soil/hydrogel). All the samples were irrigated enough until saturated on the first day. After that, measurement of the moisture was started 48 hours after irrigation by using a moisture meter. The measurement operation was done at three levels: on the upper part of the samples at 3 cm of depth, on the middle of the samples at (9 to 10cm) of depth, and on the lower part at 15 cm of depth and it was done for 9 to 10 days. Finally, the experiment was performed with three replications.

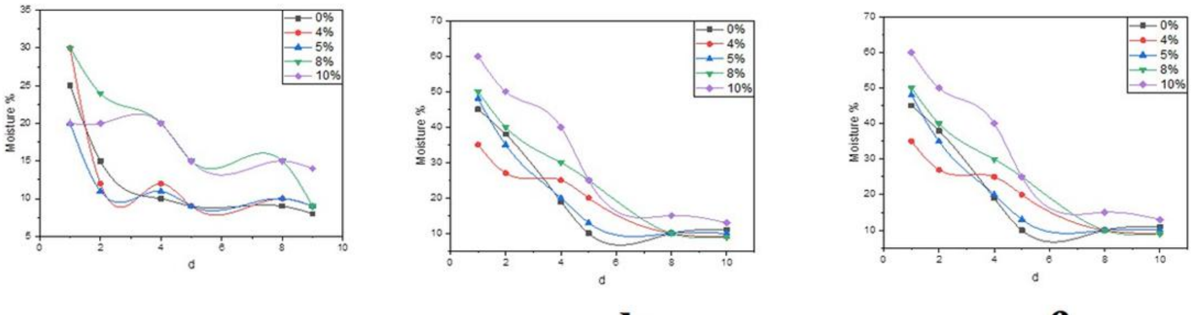
3.Results

3.1. Placed hydrogel in the middle

In this case, the doses of hydrogel were added to the samples in the middle of the plastic pots as a layer form. The obtained results are detailed as follows:

3.2.1. Measurement of moisture in the upper part

Poor values of moisture were taken in the upper part of the agricultural pots in all samples. Whereas the highest moisture on the last day of the experiment (13%) was marked in the (10%) sample for all groups (S1, S2 and S3) and this is because of the absence of hydrogel in this part, Fig. 1 represents the results.



a b c

Fig. 1 :Effect of hydrogel on moisture in the upper part in case of placed hydrogel, (a) first group (S1), (b) second group (S2), (c) third group (S3).

3.2.2. Measurement of moisture in the middle part

Good values of moisture were measured in all groups, where the highest treated sample (10%) was 22%, 40%, and 20% more moisture retaining than the untreated one (0%) in S1, S2, and S3 respectively. Figure 2 shows the results.

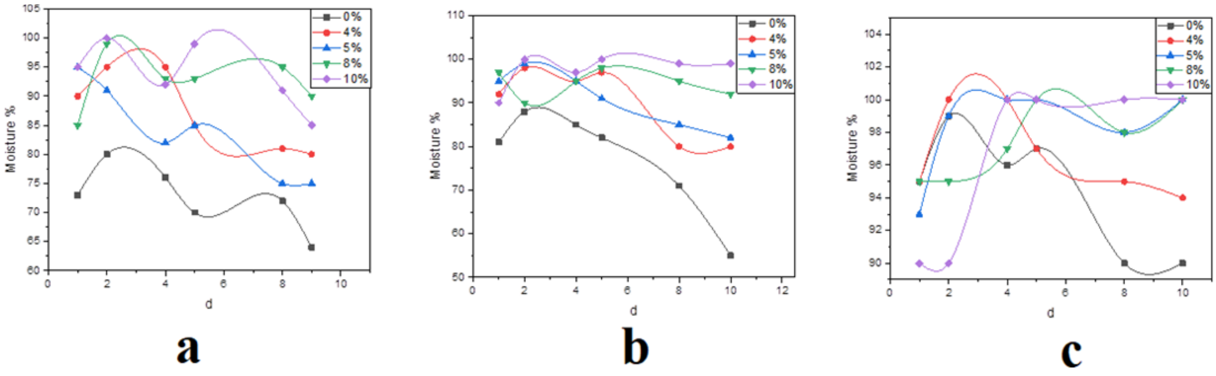


Fig. 2 : Effect of hydrogel on moisture in the middle part in case of placed hydrogel, (a) first group (S1), (b) second group (S2), (c) third group (S3).

3.2.3. Measurement of moisture in the lower part

High moisture values were recorded in S1 for (8% and 10%) samples with an average of 94% and 95% respectively, while (4% and 5%) samples showed a slight decrease. In the second group S2. The results showed a huge difference. The amended sample with the highest dose (10%) retained water exceeded 44% compared to the non-amended sample (0%). The moisture percentage in the amended samples by (8%, 5%, and 4% doses) was too close to the sample that was amended by (10%) during the first five days. Then, decreased gradually within the last five days which indicates that the swelling hydrogel began to lose some fractions of water. For the third group S3, all samples presented a high moisture percentage throughout all the days of the experiment. The results are described in Fig. 3.

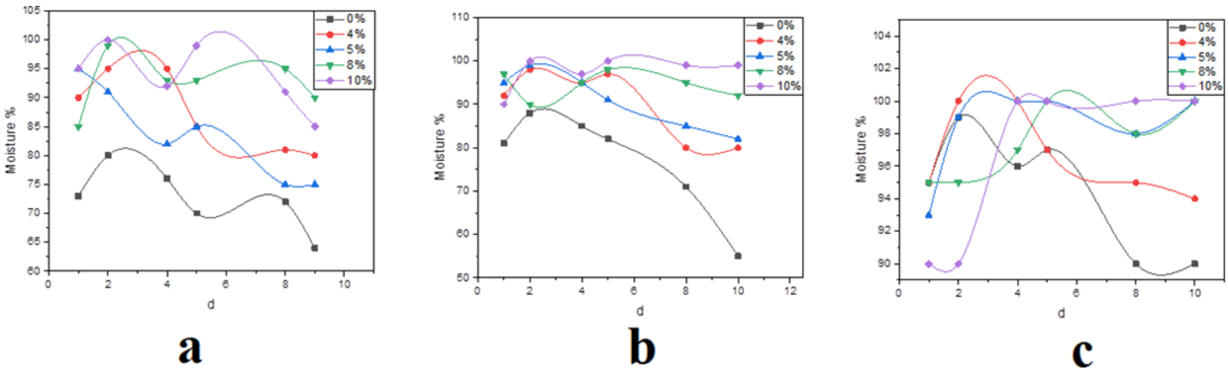


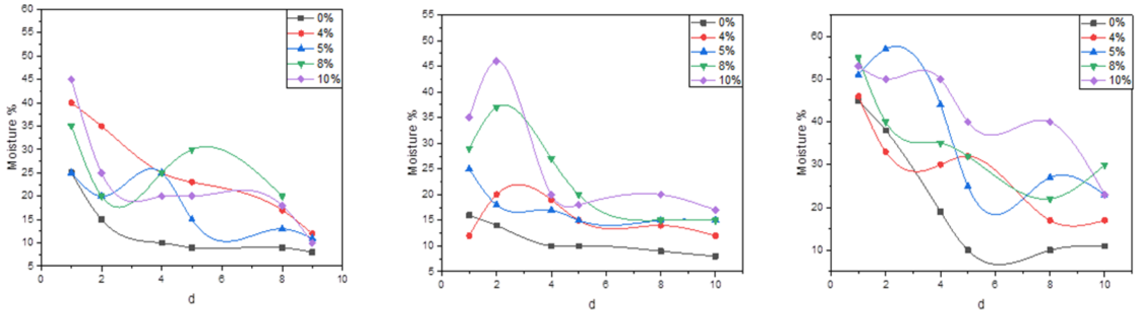
Fig. 3:Effect of hydrogel on moisture in the lower part in case of placed hydrogel, (a) first group (S1), (b) second group (S2), (c) third group (S3).

3.3. Homogeneous mixture (hydrogel/soil)

In this case, the doses of hydrogel were added to the samples as a homogeneous mixture (hydrogel/soil). The obtained results are described as follows:

3.3.1. Measurement of moisture in the upper part

The values of moisture were minor for the three groups in the upper part. However, it was observed that there is a slight difference between the treated samples and the untreated ones. see Fig. 4.

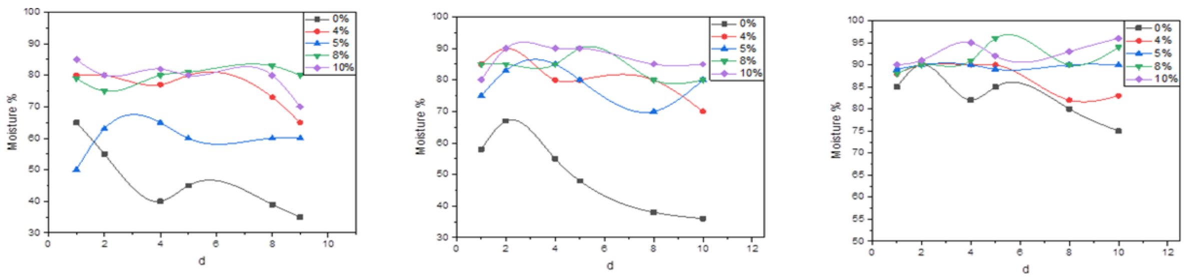


a **b** **c**

Fig. 4:Effect of hydrogel on moisture in the upper part in case of homogeneous mixture (hydrogel/soil), (a) first group (S1), (b) second group (S2), (c) third group (S3).

3.3.2. Measurement of moisture in the middle part

For S1, good values of moisture percentage were recorded for all samples, except the (5%) sample which was somewhat inferior compared to the others. In S2, the results showed a high moisture percentage for (8% and 10%) samples during all the days of the experiment. The sample (4%) showed a good moisture retaining capacity until the eighth day up to 80% moisture. Good results also were marked for the sample (5%) except on the eighth day where the moisture declined to 70%. However, a large difference was observed between all treated samples and untreated ones, where moisture in the (10%) sample was 49% higher than (0%) sample in the tenth day. By moving to S3, great results were obtained for all treated samples where the values of moisture in the last day of measurement were 80%, 89%, 93%, and 96% in (4%, 5%, 8%, and 10%) samples respectively. As a result of the effect of hydrogel, it was observed that all samples presented almost steady moisture for all groups during the study, the results are detailed in Fig. 5.



a **b** **c**

Fig.5:Effect of hydrogel on moisture in the middle part in case of homogeneous mixture (hydrogel/soil), (a) first group (S1), (b) second group (S2), (c) third group (S3).

3.3.3. Measurement of moisture in the lower part

High moisture was observed in the three groups S1, S2, and S3 except for (5%) sample in S1 and (4%) sample in S3 where were close to the untreated sample. All the treated samples in S2 presented maximum water holding capacity.

The highest moisture percentage was recorded in (10%) sample at average 99% which was followed by (8%) sample at average 96% then (4%) sample at average 95%, and the last one (5%) sample at average 91%, Fig.

6. The moisture values in S3 stayed steady at 100% for (8% and 10%) samples (see Fig. 6). The use of hydrogel granted 32%, 44% and 15% more moisture in S1, S2, and S3 respectively.

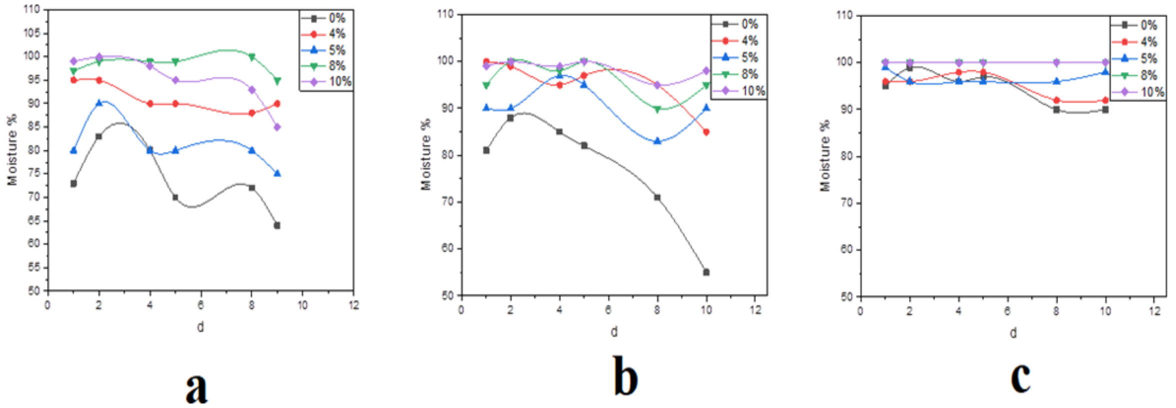


Fig.6:Effect of hydrogel on moisture in the lower part in case of homogeneous mixture (hydrogel/soil), (a) first group (S1), (b) second group (S2), (c) third group (S3).

4. Discussion

According to this study, it was observed that there is a direct relationship between doses of hydrogel and the retaining moisture in the soil, where the higher the dose, the higher percentage of soil moisture content, as a result of hydrogel structure which contains hydrophilic groups allowing hydrogel to absorb and retain significant quantities of water and the more the dose of hydrogel, the more the presence of the hydrophilic groups. Hence, this helps soil to be humid for a long time.

For the first case (hydrogel placed in the middle), the values of moisture in the upper part of all treated samples were equal to non-treated ones, because of the absence of hydrogel in this part. Conversely, high values of moisture were recorded in the middle part and the lower part in the treated samples due to the effect of hydrogel. The results also showed that the percentage of moisture in (8% and 10%) samples were very high in the early days of measurements then started decreasing slowly with time in the middle part. On the contrary, it was found that the percentage of moisture in (8% and 10%) samples were a little lower during the early days of measurements then, they started to increase gradually with time in the lower part, that describes work cycle of hydrogel (absorb, retain and release).As for the second case (homogeneous mixture (hydrogel/soil)), no significant difference was recorded between treated and untreated samples in the upper.

part due to the phenomenon of evaporation, which causes the evaporation of some water particles, which implies less soil moisture retention. By moving on the middle part and lower part, it was found that hydrogel has afforded the soil great and steady moisture percentages during the experiment due to valuable distribution of doses in the soil.
As a comprising between the three types of soil, it was noticed that the soil that was used for cultivation for three years (S3) is more moisture retention capacity than the soil that was used for cultivation for one year (S2), and as well as the soil never used for cultivation (S1), for the sake of the presence of some organic residues that contribute to reduce the permeability of the soil, which allows it to be able to retain more moisture.
The second method of hydrogel addition (homogeneous mixture hydrogel/soil) is better for cultivation than the first one (hydrogel placed in the middle) because the second method presented good moisture distribution within the soil. As for the first method, it presented poor moisture retention in the upper part and high moisture in the lower part, and excessive moisture or insufficient moisture is inappropriate for cultivation.

Conclusion

The application of hydrogel on sandy soil showed considerable improvements in moisture percentage which proved its efficiency in retaining a lot of quantity of water. The best results were recorded for (8% and 10%) doses in the three groups (S1, S2, and S3). However, a depressed moisture percentage was recorded in the untreated samples and this explains the weakness of sandy soil in retaining water for a long period of time.

Availability of data and material

The datasets collected and/or analyzed during the current study are available from the corresponding author on request. The corresponding author had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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