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DETERMINATION OF THE EFFECTS OF HYDROGEL ON IRRIGATION PROGRAM FOR MAIZE CULTIVATED IN THE FIELD CONDITIONS

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Abstract

The experiment was carried out at the research center of Canakkale Onsekiz Mart University in Turkey in summer of 2010 and 2011 to determine the effects of hydrogel (organic polymer) on the grain yield and plant development parameters. Maize DKC 5783, a commonly used variety by farmers in Turkey, was used as an indicator plant and the seeds were sowed to different lysimeters having a volume of 1 m^3.
The chemical properties of hydrogel and its water holding capacity were determined under laboratory conditions. According to the treatments, certain amounts of hydrogel were mixed to the first 20 cm of the soil from the surface level. Irrigation water was applied in a controlled manner by a scaled container to the root area of maize. Plant development parameters were observed in each development stage. As a result of this study, it was seen that the amount of hydrogel mixed to the soil in different amounts had a significant effect on the plant development parameters, grain yield and also irrigation water use efficiency.

***Key words**: hydrogel organic polymers, water use efficiency, maize, lysimeter.*

INTRODUCTION

In the world, one of the most important issues today is to meet the food demand of increasing population and this case put a heavy burden over the resources of water and agricultural areas. Therefore, researchers have recently been trying to get a higher yield per unit area by saying "per drop per crop". Irrigation sector has drawn much more attention to provide food supply for constantly increasing population and to achieve that there is only one way which is that the irrigation water use efficiency must be increased by applying a proper irrigation management. The management of irrigation systems, efficient use of water is now often a major goal, as well as production of the crop. Hence, it becomes necessary to quantify the performance of irrigation systems.
Nowadays, many research works have been trying to determine whether they can save water in agriculture or not by using hydrogel. Hydophilic gels called hydrogels are absorbing large quantities of water without dissolving, being characterized as a soft biocompatible material and also having three-dimensional structure consisted of hydrophilic network polymers.
Network of hydrogel is covalently crosslinked or physically involved, which can be produced either synthetically or naturally (Peppas, N.A. and Klier J., 1991). The network is formed by chemical or physical crosslinking. To do that, either chemical material are introduced to connect polymer chains or interactions between molecules are formed to provide links between chains, this feature makes that the hydrogel to absorb and maintain large quantities of water (Ratner and Hoffman, 1976; Peppas et al., 2000) and water holding capacity can also vary depending on the rate of crosslinking. A formation of hydrogel is given in Figure 1.

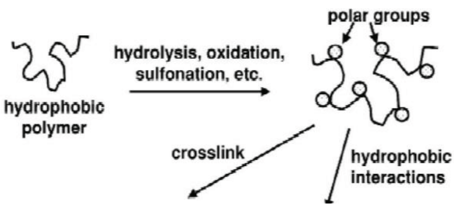

Figure 1. The chemical structure of the hydrogel

In irrigation, the general idea is to increase the soil moisture level up to field capacity (Kirda et al., 1999). Braunworth and Mack (1990) reported that the yield values of maize were very close together when the water level in the root depth never fell below 50% of available soil moisture and it was also reported in the same study that 15% of water restriction is be able to be applied since this application provided to get a higher yield of maize rather than decreasing yield (Yildirim and Kodal, 1996).

It is well known that irrigation is the most important parameter influencing crop yield. Deficit irrigation, especially applying in the vegetative growing period, is a great risk for the yield of maize (Moser et al., 2006). On the other hand, limited water use has also an important impact on the intake of fertilizer N, which is also, be affected in different varieties of maize (Kirda, 2007).

Kaman (2007) reported that to get an economical yield, at least 50% of water demand of maize must be applied to the root area of maize. Tayel and El-Hady (1981) treated soil with different rates of hydrogel in laboratory conditions to determine soil-water relations. Hydrogel was mixed with the rate of 0%, 0.05%, 0.10%, 0.15% and 0.20% to the soil and reported that hydrogel increases some physical properties of the soil such as total porosity, macro pores, water holding capacity and hydraulic resistance, while it decreases soil bulk density, hydraulic conductivity, leakage and evaporation. However, some researcher states that it shouldn't be used for plants with higher economical values since it has not been tested in all environmental conditions yet. El-Hady et al. (1981) mixed hydrogel to the sandy soil at the rates of 0 g, 0.05 g, 0.10g, 0.15g and 0.20g per 100g of soil and determined the increasing intake rates of urea, N, P, K, Mn and Zn and also water use efficiency, plant height, dry matter of plants with the increased amount of hydrogel. A research was carried out by Sayed et al. (1991) to determine the germination condition of the seeds of tomato, cabbage and cucumber under saline conditions. Seedlings were sown to the mixture of sand and hydrogel (25% sand + 75% hydrogel) and Hoagland as a nutrient solution was added to the mixture. After germination, the seedlings were transplanted to the mixtures as follows: 0:100, 25:75, 50:50, 75:25 and 100:0. Different solutions (NaCl, $CaCl_2$ and $MgCl_2$) in the rates of 0, 2000, 4000, 8000 and 32000 ppm were added to mediums every two weeks. All treatments, except for the solution of 3200 ppm, increased plant growth.

Naeem et al. (2004) tried to determine the effect of synthetic polymers (Kemisol and Kurasol) on water holding capacity and the yield of bitter gourd. The treatments were as follows; T1 was control treatment, T2 was including only 0.1% kemisol, T3:0.2% kemisol, T4:0.3% kemisol, T5: 0.1% kurasol, T6: 0.2% kurasol, T7: 0.3% kurasol, T8: 0.1% kemisol + 0.3% kurasol, T9: 0.2% kemisol + 0.2% kurasol, T10: 0.3% kemisol + 0.1% kurasol and added fertilizers of N, P, K at a rate of 100-80-40 kg ha^{-1}, and then reported that both of the two synthetic polymers increased water holding capacity, vegetative growth as compared with the control treatment.

Therefore, the main objective of this study was to determine the most optimal amount of hydrogel to be mixed into the soil without lowering the grain yield of maize, in open field and under controlled conditions in lysimeters.

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MATERIALS AND METHODS

Experimental Design and Irrigation: The field experiment was carried out at the Dardanos Agricultural Research Station of Canakkale Onsekiz Mart University in Canakkale (Dardanelles), Turkey, in the summer of 2010 and 2011. The location of the experimental area was 40.08°N, 28.20°E. The seeds of maize were sown to the lysimeters, located on the farm land and at an altitude of 3 meters above sea level. Lysimeters are made of 2 mm sheet plate, and surrounding soil did not cause any disturbance effect on the soil and plant enclosed by the lysimeter, which are also capable of reliable and accurate and long term measurements of water loss by evaporation and transpiration.

The dimension of each lysimeter has been consisted of 1 m in width, 1 m in length and 1 m in depth having an overall surface area of $1m^2$ and volume of 1 m^3. Each lysimeter has had one drainage hole controlled by a valve at the bottom edge with a diameter of 10 mm (in Figure 2).

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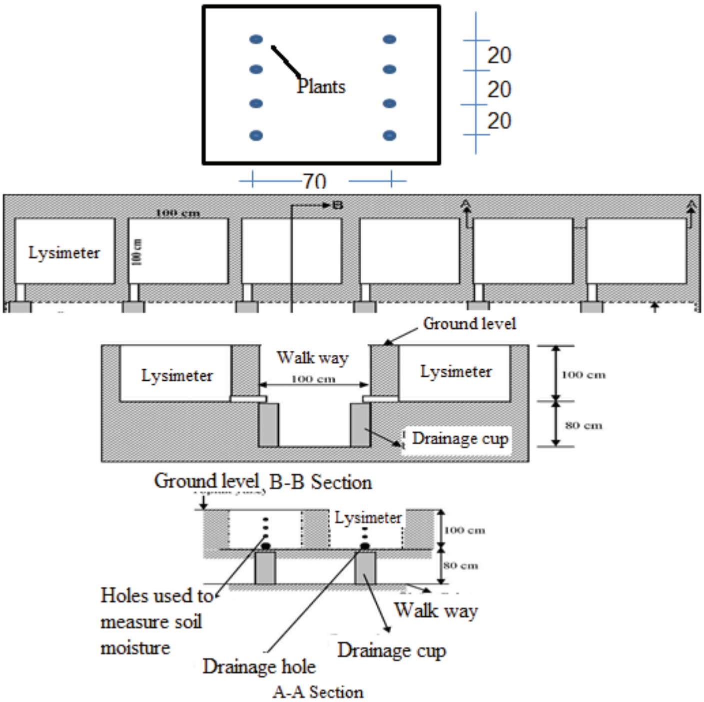

Figure 2. Top view of the experimental layout

At the site where the lysimeters were installed, soil was excavated. After that the top level of lysimeters was level with the soil surface and further soil was removed and a narrow trench was dug between two rows both to remove excess water from the lysimeters, if available and to measure the soil moisture level. Distance apart was 20 cm and placed some stones to prevent from excessive heating of side walls of the lysimeter. Distance between two rows was 70 cm to provide a comfortable walk between two lysimeters row (Figure. 2).

In the experiment, there were totally 12 lysimeters. Eight seeds of maize (DKC 5783) were sown in one lysimeter in the form of two rows. The seeds were spaced 0.7 m apart and spacing between plants in each row was 0.20 m, hence one plant had a surface area of 0.14 m^2 in the lysimeter.

Irrigation attempt was made before sowing to provide a suitable environment for seeds of maize and water was refilled up to field capacity. Irrigation was initiated on 4th July 2010 and 6th July 2011, and a similar irrigation volume was applied to all treatments in May to establish a good vegetative and root development.

After seedlings provided a good development, irrigation treatments commenced.

Each lysimeter in all treatments took the same recommended amount of fertilizer; triple super phosphate (20 kg da^{-1}), amonium nitrate (40 kg da^{-1}) and K_2SO_4 (5 kg da^{-1}) in both years (1 da =1000 m^2). The total amount of P and 40% of the N and K fertilizers were applied at planting thoroughly mixed with irrigation water. The remaining 60% of the N and K were added equally twice at 15 and 20 day intervals.

Water was conveyed from the well at the site, which was 5 m away from the lysimeters, by PVC pipes and soil moisture was determined gravimetrically with 7 day intervals. According to the soil moisture level in the medium, the amount of irrigation water to be applied was calculated and applied to the each lysimeter by using scaled container. The experimental treatments included four different applications as follows:

L0 = control treatment (not including hydrogel);

L1 = the amount of hydrogel mixed in the medium was to absorb water only 50% of the field capacity;
L2 = the amount of hydrogel mixed in the medium was to absorb water up to field capacity;
L3 = the amount of hydrogel mixed in the medium was to absorb water two times higher than field capacity.
Hydrogel in changing amounts according to the trials was mixed with the soil in the depth of 20 cm from the surface level.
The experiment was laid out using a randomized complete block design with 3 replications. Each replicate included 8 plants.
The irrigation water use efficiency (IWUE) (kg m^{-3}) was defined according to Howell et al. (1990):

$$IWUE = Y / I$$

where Y is yield (kg ha^{-1}), and I is applied water (mm).
Physical properties: some physical soil properties as field capacity, wilting point, water holding capacity, and infiltration rate and bulk density were determined in the irrigation laboratory of agricultural faculty of Canakkale Onsekiz Mart University.
Chemical properties: some chemical properties of hydrogel and also the capacity to absorb water were determined in the chemistry laboratory of Science Faculty of Canakkale Onsekiz Mart University. The following properties for the soil used to grow maize were determined: soil pH, electrical conductivity, and total available N, P and K.
Evapotranspiration (ET) was calculated with the water balance equation given below:

$$ET = I + P + C_r - D_p - R_f \pm \Delta SW$$

where ET is evapotranspiration (mm), P is rainfall (mm), and ΔSW is the change in soil water content (mm) determined gravimetrically. In the equation, Capillary rise (C_r), Deep percolation (D_p) and Runoff (R_f) were ignored since there was no drainage water in each treatment.

Plant and fruit development parameters were observed during the experiment and plant height, stem diameter, grain yield, the length and diameter of corncob were determined for each plant in the treatment. Data on plant development parameters and yield and quality parameters were analyzed using MINITAB software. Means were separated by Duncan's Multiple Range Test at the probability level of 1% and 5% ($p < 0.01$, $p < 0.05$).

RESULTS AND DISCUSSIONS

Some physical properties of maize obtained in the experiment are given in Table 1. The average grain yield values, as seen in Table 1, decreased in 2011 as compared to 2010. All yield and plant development parameters were higher in both years in the L3 treatment, in which the amount of hydrogel is to absorb water as much as twice of field capacity and on the other hand, the lowest of these parameters were obtained from the treatment not including hydrogel (L0). Information related with irrigation is given in table 2.
The average grain yield values, as seen in table 1, decreased in 2011 as compared to 2010. All yield and plant development parameters were higher in both years in the L3 treatment, in which the amount of hydrogel is to absorb water as much as twice of field capacity and on the other hand, the lowest of these parameters were obtained from the treatment not including hydrogel (L0). Information related with irrigation is given in table 2. In the similar manner with plant growth parameters, the amount of applied irrigation water was lower in 2011 as compared to 2010. While the highest amount of water was applied in the treatment of L3. the lowest was in the L2. in which the amount of hydrogel was to absorb water up to field capacity. Irrigation water use efficiency (IWUE) is given in table 3.
Even though the yield was higher and the highest amount of water was applied in the treatment of L3. IWUE was lower than the treatments of L1 and L2. Even in these treatments (L1 and L2). The amount of applied water and grain yield were lower than the L3 treatment.

Table 1. Yield and development parameters of maize in 2010 and 2011

2010											
	Plant height (cm)						Stem diameter (mm)				
	1. Tek.	2. Tek.	3. Tek.	Average			1. Tek.	2. Tek.	3. Tek.	Average	
L0	108	114	87	103.0	d	**L0**	11.2	10.2	9.9	10.4	d
L1	139	159	187	161.7	b	**L1**	12.7	16.6	17.5	15.6	b
L2	156	168	134	152.7	c	**L2**	14.8	13.5	14.3	14.2	c
L3	176	196	213	195.0	a	**L3**	16.3	20.8	22.1	19.7	a
	The length of corncob (cm)						The diameter of corncob (mm)				
	1. Tek.	2. Tek.	3. Tek.	Average			1. Tek.	2. Tek.	3. Tek.	Average	
L0	14.8	14.2	14.0	14.3	c	**L0**	29.8	27.8	27.9	28.5	c
L1	16.2	19.8	20.4	18.8	b	**L1**	33.4	38.6	38.6	36.9	b
L2	17.8	16.6	17.3	17.2	b	**L2**	35.6	33.5	34.6	34.6	b
L3	19.5	22.9	23.9	22.1	a	**L3**	38.7	44.7	45.9	43.1	a
	Thousand grain weight (gr)						Grain yield (kg/da)				
	1. Tek.	2. Tek.	3. Tek.	Average			1. Tek.	2. Tek.	3. Tek.	Average	
L0	252	249	312	271.0	b	**L0**	751	735	908	798.0	b
L1	289	261	334	294.7	b	**L1**	872	798	1012	894.0	b
L2	267	248	305	273.3	b	**L2**	805	749	920	824.7	b
L3	346	337	389	357.3	a	**L3**	1028	1007	1158	1064,3	a
2011											
	Plant height (cm)						Stem diameter (mm)				
	1. Tek.	2. Tek.	3. Tek.	Average			1. Tek.	2. Tek.	3. Tek.	Average	
L0	101	98	86	95.0	c	**L0**	12.3	9.9	10.2	10.8	c
L1	132	145	177	151.3	b	**L1**	11.8	15.6	16.9	14.8	b
L2	145	155	125	141.7	b	**L2**	13.3	12.8	13.5	13.2	b
L3	168	176	198	180.7	a	**L3**	17.5	19.8	21.6	19.6	a
	The length of corncob (cm)						The diameter of corncob (mm)				
	1. Tek.	2. Tek.	3. Tek.	Average			1. Tek.	2. Tek.	3. Tek.	Average	
L0	13.4	13.5	15.3	14.1	c	**L0**	28.7	26.7	26.7	27.4	c
L1	15.8	18.7	19.8	18.1	b	**L1**	32.6	37.6	37.8	36.0	b
L2	16.5	15.8	16.3	16.2	b	**L2**	32.4	31.4	33.5	32.4	b
L3	17.8	21.8	23.4	21.0	a	**L3**	36.9	43.2	44.5	41.5	a
	Thousand grain weight (gr)						Grain yield (kg/da)				
	1. Tek.	2. Tek.	3. Tek.	Average			1. Tek.	2. Tek.	3. Tek.	Average	
L0	235	239	228	234.0	b	**L0**	718	733	698	716.3	b
L1	265	255	287	269.0	b	**L1**	799	786	881	822.0	b
L2	260	255	276	263.7	b	**L2**	777	762	827	788.7	b
L3	355	324	365	348.0	a	**L3**	1032	935	1057	1008.0	a

Table 2. Irrigation performance during the experiment

Treatments	FC (%)	**2010** – Number of irrigation and amounts in each irrigation (mm)							Total
		1	2	3	4	5	6	7	
L0	27.40	21.8	13.4	33.2	52.2	48.2	43.7	45.0	257.4
L1	25.07	20.1	20.6	35.6	46.7	45.2	39.3	41.9	249.6
L2	23.59	19.6	16.4	30.5	39.6	40.4	38.8	39.6	225.0
L3	26.71	38.0	28.8	44.8	55.6	52.0	52.1	46.5	317.7
Treatments	FC (%)	**2011** – Number of irrigation and amounts in each irrigation (mm)							Total
		1	2	3	4	5	6	7	
L0	27.40	21.5	31.5	37.2	45.7	34.9	41.8	39.6	252.2
L1	25.07	20.9	23.5	30.6	34.7	33.3	48.0	47.1	238.1
L2	23.59	18.7	24.7	31.2	39.1	30.3	35.1	43.6	222.7
L3	26.71	23.7	38.0	49.2	53.0	41.5	48.3	56.5	310.2

Table 3.Plant development parameters and irrigation amounts

Treatments		Plant height (cm)	Stem diameter (mm)	The length of corncob (cm)	The diameter of corncob (mm)	Thousand grain weight (gr)	Grain yield (kg/da)	Irrigation amounts (mm)	IWUE (kg/da mm)
2010									
Control	L0	103.0	10.4	14.3	28.5	271	798	257	3.1
FC/2	L1	161.7	15.6	18.8	36.9	295	894	250	3.6
FC	L2	152.7	14.2	17.2	34.6	273	825	225	3.7
FCx2	L3	195.0	19.7	22.1	43.1	357	1064	318	3.4
2011									
Control	L0	95.0	10.8	14.1	27.4	234	716	252	2.8
FC/2	L1	151.3	14.8	18.1	36.0	269	822	238	3.5
FC	L2	141.7	13.2	16.2	32.4	264	789	223	3.5
FCx2	L3	180.7	19.6	21.0	41.5	348	1008	310	3.2

FC: Field Capacity

As a result, the highest water use efficiency was obtained in the L2 treatment in 2010 and it was obtained in the L1 and in the L2 treatments in 2011. In both years, the IWUE was the lowest in the L0 treatment not including hydrogel every two years.

CONCLUSIONS

In conclusion, while L2 treatment seems to be suitable in terms of irrigation water use efficiency. However, overall results indicate L1 treatment is more appropriate since the used amount of hydrogel is the half of L2 and quarter of L3 treatments. therefore it is important to use less amount of synthetic material (hydrogel) for the environment.

In the studies conducted out on hydrogel used in agriculture indicated that the use of hydrogel provides more advantageous in irrigation practices than those not including hydrogel. However, many of those research works had been conducted in the greenhouse conditions and they mixed the hydrogel inside the medium in pots uniformly but it is almost impossible to mix it into the depth of effective root area uniformly under open field conditions.

In the present study, we can suggest the most suitable application of hydrogel was achieved from the L1 treatment. However, we can recommend also the following things for further research works.

If we mixed the hydrogel in 30 cm depth from the surface level rather than 20 cm what would have happened the grain yield plant development parameter and irrigation water use efficiency.

If we used other water sensitive plants instead of maize what would have happened to those parameters.

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