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ASSESSMENT OF EFFECTS OF DIFFERENT IRRIGATION WATER REGIME ON WINTER WHEAT YIELD AND WATER USE EFFICIENCY

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Abstract

This study was carried on to determine the effect of different irrigation regime on winter wheat crop and water-use efficiency (WUE). For this purposes the experiment was conducted with 4 different irrigation treatment which was I_1*; Rainfed,* I_2*; Full irrigation (irrigate when calculated soil water depletion is 60 mm)* I_3*; Limited irrigation (2 irrigation maximum) one at tillering and another at grain filling,* I_4*; No irrigation after establishment until heading, after which irrigation when soil water depletion is 60 mm below field capacity at Saraykoy Research Station in Murted Basin. The experimental design was completely randomized block design with four replications. Soil moisture was measured with neutron probe. At the end of the research study conducted during the wheat growth period for the years 2009-2010 and 2010-2011, in average wheat yield was found to be 3.35 t* ha^{-1}*, 4.54 t* ha^{-1}*, 4.22 t* ha^{-1} *and 4.31 t* ha^{-1} *respectively according to the plots (*I_1*,* I_2*,* I_3*,* I_4*). The highest yield was obtained from the full-irrigation plot while the lowest yield was obtained from the no-irrigation plot. No statistically significant difference was found between the plots subjected to the irrigation treatments while a difference of* $P < 0.05$ *was obtained between the no-irrigation and full-irrigation plots. Average harvest index values were found to be respectively 29%, 31%, 32%, 31% and 32% again according to the plots. A significant negative correlation was found between grain yield, total harvested biomass and the WUE. The results presented in this work suggest that the amount of soil water content affects grain yield and water use efficiency. It might be recommended that irrigation concentrated in the after heading period increase WUE in Central Anatolia Region of Turkey. Crop water stress index is a useful tool for detecting crop water stress.*

Key words: *wheat, water use efficiency, irrigation.*

INTRODUCTION

One of the most important consequences of the climate change, perhaps the most important one, is its negative effects on water sources. In addition to the problem of drought that may occur in the future, factors such as rapid population growth, increasing demands for water sources, increasingly changing trend of sectors in using water and degradation in water quality increase the importance of the use of water sources (Barnett et al., 2005).

Turkey, particularly the Central Anatolia Region, has been in danger of a major drought due to the negative effects of the climatic factors and lack of rainfalls. Agricultural drought is based on the amount of water in the root zone of plants in the soil that can be used by plants. The periods when the soil does not have the sufficient amount of water to meet the water needs of plants are indicated as the agricultural drought. Water scarcity in arid and semi-arid regions and the fact that drought and salinity have become the most widespread environmental problem affecting the plant production lead to many successive problems in social and economic aspects.

The most important factor affecting the yield under arid and semi-arid conditions in the regions such as the Central Anatolia Region is to use the limited water supply in the most efficient fashion. The main objective under the conditions of limited water is to get the maximum benefit from the unit water. To achieve it: i) it is necessary to know about the water use effect of the plant and improve the plant water yield (to increase the marketable plant yield per unit water received by the plant); ii) to reduce the water running away from the root zone other than the water needed by the plant; iii) and to increase the soil water storage in the plant root zone by means of soil and water management treatments on the base of farm and basin (Clay et al., 2001).

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Water Use efficiency indicates the amount of dry matter produced per unit water used. WUE increases for the plant will naturally close its stomata (pores) so as to avoid evaporation under the conditions of stress. Therefore, the increase in water use efficiency normally leads to a decrease in the amount of total dry matter.
The aim of this study was to determine the effect of different irrigation regime on winter wheat crop and water-use efficiency.

MATERIALS AND METHODS

Experimental sites are located in Ankara Murted Basin (39° 57' N and 32° 53' E) of Central Anatolia region of Turkey. A field experiment was conducted to demonstrate the effect of water stress on yield and some agronomic characteristics of wheat under different irrigation treatments during the period of October 2009 to July 2011 in Research Farm Station of Soil, Fertilizer and Water Resources Central Research Institute in Ankara, Turkey.
The soil of the experiment areas is mostly ranging in texture from silty clay about 0.30 m thick lying on the surface with a layer of clay texture roughly in 1.5 m below the surface. Field capacity (FC) on the volume basis of the top and basement soil layer is described to be 33 and 37 %, and wilting point, 17 and 23 % respectively.
Wheat and barley are the most important crops in region, but the yields are irregular, and crops fail in years of drought. Most of the wheat is planted in the late fall, as soon as there is significant moisture for seeding. *Bayraktar* wheat variety was used as trail crop. Wheat seeds were obtained from National Seeds Research Institute.
The climate is characterized as semi-arid in this region. In Ankara-Murted Basin temperature differences between night and day and summer and winter are sharp, and rain is relatively infrequent. Winters are long and cold with heavy snowfall while summers are short but hot. The rainiest months are November and May. Almost no effective rain falls during the summer.
Annual rainfall is about 350 mm and evaporation is 1300 mm as an average for the past 30 years.
There was large difference between daily maximum and minimum temperature in the experimental period.
Irrigation water was used with surface irrigation method. Irrigation water quality is high saline (Electrical conductivity EC; 1.76 dS/m) and non-alkaline.

Crop Management and Experimental Design

The experiment consists of 4 irrigation regimes with 4 replications, giving a total of 16 plots (Figure 1). Treatments were;
I_1 = Rainfed (No additional irrigation)
I_2= Full irrigation (irrigate when calculated soil water depletion is 60 mm)
I_3 = Limited irrigation one at tillering and another at grain filling
I_4= No irrigation after establishment until heading, after which irrigation when soil water depletion is 60 mm below field capacity.

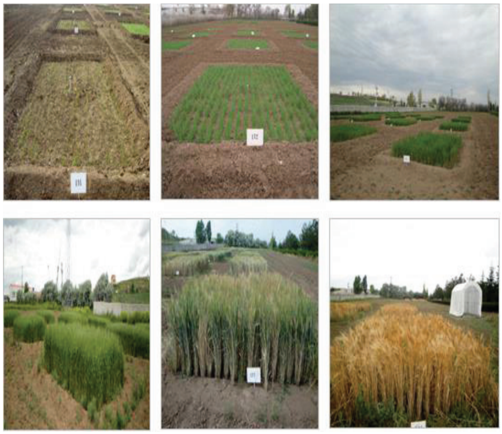

Figure 1. Field experiment design

Plot dimensions were taken 3.5 m x 5 m = 17.5 m^2 for seeding and it will be 1.2 m x 4 m = 4.8 m^2 for harvesting. Experimental field was cultivated and experimental plots were installed before sowing. According to soil fertility analysis results for average 2009-2011 growing season commercial N fertilizers were applied in a band about 10 cm to the side of the seed row (220 kg/ha Ammonium sulphate were applied before sowing and 350 kg/ha Ammonium sulphate were applied at 15 March). Sufficient phosphates were applied (175 kg/ha DAP) to ensure adequate P nutrition. Winter wheat was planted around 20 October for every year.
Precipitation, air temperature (maximum, minimum and average), class A pan evaporation, wind speed, relative humidity, global radiation and sunshine hours were obtained on hourly basis from meteorological station (50 m away from experimental site).
One Soil Moisture Neutron Probe aluminium access tube was inserted to 100 cm depth in each plot. During access tube installation care were exercised to minimize gap and soil disturbance. Soil samples were taken each plot to make chemical and physical soil analysis.

Soil moistures content in the plots was monitored using a neutron probe (CPN) with aluminium access tubes. The measurements were taken at 0-20, 20-40, 40-60 and 60-90cm soil depth. The neutron probe observation was made two times a week in all depths mentioned earlier. The neutron probe was calibrated at the beginning of the growing season at 2008 and calibration equation was $P_V = 18.195CR + 8.2138$, $R^2 = 0.963^{**}$ (P_V: volumetric soil water content, CR: count ratio). Calibrations were repeated every year before plot installation.

The amount of soil water in the 0-90 m depth was used to initiate irrigation. These data were also used to calculate crop evapotranspiration (ETc).

Figure 2. Irrigation application

ETc was calculated as the soil water balance residual for the time periods between two successive soil water content measurement dates. Prior to wheat planting, all trial plots were precision levelled to zero-grade and runoff were eliminated by earthen embankments around the wheat plots. Irrigation water was applied with basin method (Figure 2).

RESULTS AND DISCUSSION

Daily precipitation and ET_o graph for experimental period was given at Figure 2.

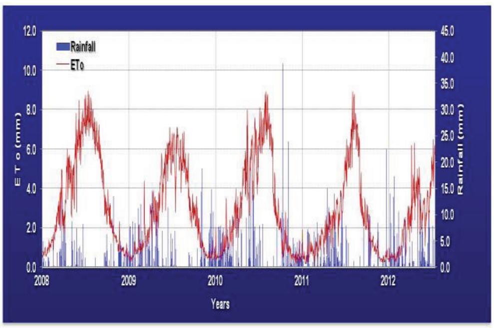

Figure 2. Daily rainfall and ETo distribution for growing seasons

As apparent from the graph, although the amount of rainfall during the winter months in 2010-2011 was not high, it reached high levels in autumn and spring season.

According to the plots, irrigation treatments were made taking account of the soil moisture measured. For the full-irrigation plot, the initial soil moisture content value was increased to the field capacity. In the subsequent irrigations, when the soil water content was 60 mm lower than the field capacity value, it was re-irrigated to the field capacity.

During the trail, the soil moisture content did not fall down to the level requiring irrigation until end of April for 2009-2010 and 2010-2011 growing season, due to the high level of the fall and winter precipitation throughout all years.

According to the trial plots; total irrigation water was applied at the I_2, I_3 and I_4 at 270.0, 171.0 and 162.0 mm, 205.0, 116.0 and 120.0 mm respectively during the growth period of 2009-2010 and 2010-2011.

Soil moisture measurements were made twice a week after the wheat sowing. The measurements were suspended until the beginning of April due to the winter conditions and the terrain covered with snow in January, February and March. In the beginning of April, the soil water content reached to the same level in almost all the plots after the snow cover melted away. The measured values of the soil moisture content, the amount of rainfall and irrigation water applied according to the plots are provided in the same graph. The growth graphs plotted separately for the periods 2009-2010 and 2010-2011, from April to the harvest, are given in the Figure 3.

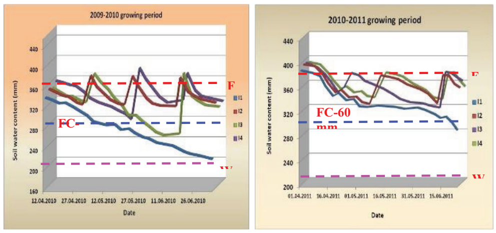

Figure 3. Soil water content data (for the growth period of 2009-2010 and 2010-2011)

The soil moisture content declined to the values of wilting point in the periods towards the harvest in the plot (I_1) to which no irrigation was applied during the growth period of 2009-2010. When the value of soil moisture felt 60 mm below the FC value in the plots of full irrigation (I_2) and irrigation after the period of heading (I_4), the deficit moisture was completed to the FC via irrigation. The moisture present in the soil was brought up to the FC value in the plot (I_3) to be irrigated for once at the tilling and grain filling for once. Changes in the soil moisture showed a compatible change depending on the rainfall and irrigation treatments.

As apparent from the Figure 3, the soil moisture content remained above the values of wilting point even in the plot (I_1) to which no irrigation was applied for the growth period of 2010-2011 due to the rainfalls. The soil moisture content was brought up to the field capacity in the full irrigation plot (I_2) after planting and the deficit moisture was completed to the FC when the soil moisture value felt 60 mm below the FC value in the subsequent irrigations.

After the period of heading, the first irrigation in the (I_4) plot was applied in May while the second irrigation in June. The moisture present in the soil was brought up to FC value in the plot (I_3) to be irrigated at tilling stage for once and at the grain filling for once for the purposes of the irrigation treatments although the moisture value present in the soil did not felt 60 mm below the FC in April.

Plant Water Consumption

ET value was calculated according to the "Soil Water Budget".

$$ET = I + P + \Delta S - R - D$$

were:

I = Irrigation water (mm),
P = Precipitation (mm),
ΔS = Change in soil water content (mm),
R = Surface flow (mm),
D = Percolation from the root zone to depth.

Monthly and seasonal plant water consumptions are given in the Table 1 in line with the applied irrigation water and rainfalls.

Soil water changes in the soil of 0-90 cm depth were used for the plant water consumption calculations. The highest water consumption was occurred at full irrigation treatments.

Table 1. Monthly and seasonal water consumption by plots

Years	Treatments	ET (mm)							
		Oct.*	Nov.	Decem.	Apr.	May	June	July**	Total
2009-2010	I_1	33.39	61.78	112.44	60.61	58.01	70.27	25.84	422.34
	I_2	49.47	77.96	112.43	125.67	120.14	95.29	27.89	608.85
	I_3	37.48	49.88	110.55	122.64	119.75	112.35	21.98	574.63
	I_4	33.31	57.82	106.37	68.60	92.25	107.23	20.71	486.29
2010-2011	I_1	17.53	58.33	59.31	72.50	68.16	76.92	56.23	408.98
	I_2	25.27	63.82	82.65	101.48	129.42	96.25	54.71	553.60
	I_3	14.42	50.40	57.39	105.21	99.39	105.27	57.48	489.56
	I_4	15.14	53.21	52.47	86.14	103.81	93.53	56.34	460.64

Crop yield

The highest yield was obtained from the full-irrigation (I_2). Yield values of rainfed (I_1) treatment was 23%, 15% and 19% less than irrigated (I_2, I_3, I_4) treatments respectively.

Harvest index values of the plots were calculated using the average yield and biomass values (HI = grain yield/Biomass yield) in respect with the treatments. The highest harvest index was found in the plot I_4, with the percent of 32.8 in the first year (Table 2).

Table 2. Average yield, biomass and harvest index values by plots

Years	Treatments	Grain yields (t/ha)	Biomass (t/ha)	HI
2009-2010	I_1	3.54	11.61	30.5
	I_2	4.58	14.90	30.7
	I_3	4.15	13.25	31.3
	I_4	4.36	13.28	32.8
2010-2011	I_1	3.16	11.54	27.4
	I_2	4.49	14.52	30.9
	I_3	4.28	13.68	31.3
	I_4	4.25	13.70	31.0

As a result of the variance analysis applied on the yield values which were obtained from the trial plots, no statistically significant difference at the level of 0.05 was found among the plots in both years (Yurtseven, 1984). Variance analysis is provided in the Table 3.

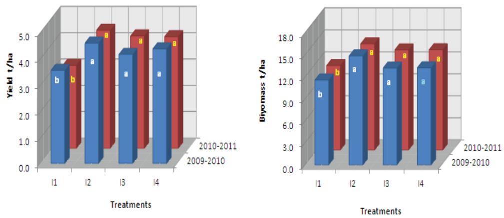

Figure 4. Duncan classes of average biomass & yields for the treatments

Table 3. Wheat yield variance analysis values

Years	Variation Source	D.F	S.S	M.S	F	Table F	
						0.05	0.01
2009-2010	Blocks	3	0.97	0.32	0.63	3.86	6.99
	Treatments	3	2.42	0.81	4.71*	3.86	6.99
	Error	9	4.62	0.51			
	General	15	8.01				
2010-2011	Blocks	3	0.96	0.32	1.49	3.86	6.99
	Treatments	3	4.34	1.45	20.15**	3.86	6.99
	Error	9	1.94	0.22			
	General	15	7.24				

*, **, Statistically significant at P<0.05, P<0.01 respectively

In the Duncan test, two different groups emerged for the years 2009-2010 and 2010-2011. No class difference was found between the plots I_2, I_3 and I_4 and all took part in the first group. The no-irrigation plot I_1 constituted the second group. The classification concerning the Duncan Test results were given on the Figure 4. The reason why there is no group difference between the irrigation plots is that spring and winter precipitation was high in both years.

Water Use Efficiency (WUE)

WUE values calculated according to the years when the trial was carried out are given in the Table 4. It was reported that in general, the wheat WUE ranges from 4.0 to 18.3 kg/ha/mm globally on a yield basis (Anderson, 1992; Oweis et al., 2000).

Table 4. WUE values by plots

Years	Treatments	ET (mm)	Yields (t/ha)	Irrigation (mm)	WUE (kg/m^3)
2009-2010	I_1	422	3.54	-	8.38 ^{b}
	I_2	609	4.58	290	7.52 ^{b}
	I_3	575	4.15	183	7.22 ^{b}
	I_4	486	4.36	162	8.97 ^{a}
2010-2011	I_1	409	3.16	-	7.72 ^{b}
	I_2	554	4.49	205	8.10 ^{b}
	I_3	490	4.28	120	8.73 ^{b}
	I_4	461	4.25	104	9.22 ^{a}

As for the WUE in 2009-2010, the best outcome was provided by the plot I_4 (irrigation when the soil water potential diminished 60 mm beginning from the period of heading stage). It was respectively followed by I_1 (no-irrigation) and I_2 (full irrigation). The water use had the lowest efficiency in the plot I_3 (irrigation in which the moisture present in the soil was brought up to the field capacity was applied for once at the tilling stage and at the grain filling stage for once). For the growth period of 2010-2011, WUE was in the plot I_4 with a value of 9.2 kg/m^3 and it was respectively followed by I_3, I_2 and I_1 with the values of 8.7, 8.1 and 7.7 kg/m^3. The more effective water-use in winter wheat crop was obtained with treatment I_4 (no irrigation until heading, after will irrigate calculated soil water depletion is 60 mm).

CONCLUSION

Efforts to get more crops per unit area are quite important and necessary for human nutrition in today's world having limited resources as well as a rapidly growing population.

At the end of the research study conducted during the wheat growth period for the years 2009-2010 and 2010-2011 in average wheat yield was found to be 3.35 t/ha, 4.54 t/ha, 4.22 t/ha and 4.31 t/ha respectively according to the plots (I_1, I_2, I_3, I_4). The highest yield was obtained from the full-irrigation plot while the lowest yield was obtained from the no-irrigation plot. No statistically significant difference was found between the plots subjected to the irrigation treatments while a difference of $P < 0.05$ was obtained between the no-irrigation and full-irrigation plots. Average harvest index values were found to be respectively 29%, 31%, 32% 31% and 32% again according to the plots.

The plot I_4 that was irrigated in the same way after the period of heading for both years appeared to have the highest value in the water use efficiency. It might be recommended that irrigation concentrated in the after heading period increase WUE in Central Anatolia Region of Turkey.

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