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Determination of Water Requirements and Response of Wheat to Irrigation at Different Soil Moisture Depletion Levels

NAEEM MAHMOOD[1] AND RAI NIAZ AHMAD
Water Management Research Centre, University of Agriculture, Faisalabad–38040, Pakistan
[1]Corresponding author's e-mail: nmood_pk@yahoo.com

ABSTRACT

An experiment was conducted to determine water requirement and response of some wheat cultivars to irrigation at different soil moisture depletion (SMD) levels. Four wheat genotypes viz., AS2002, SH2002, Inqlab 91 and Uqab 02 were subjected to irrigation at 50% and 70% SMD levels. Moisture contents for irrigation were recorded from a root zone of 90 cm (from four depths viz., 10 – 15, 15 – 30, 30 – 60 and 60 – 90 cm). Data on meteorological parameters like temperature, rainfall, relative humidity and pan evaporation were also recorded. Rate of soil moisture depletion and pan evaporation showed a positive relationship with the temperature during the whole growing season. The amount of water applied to wheat at 50% and 70% SMD was 214.80 mm and 251.42 mm, respectively. Results indicated that grain yield, harvest index and water use efficiency were greater when irrigation was applied at 50% SMD and was reduced at 70% SMD. SH2002 was the top yielder among the four cultivars tested at each level of irrigation.

Key Words: SMD; Water requirement; Soil moisture; Grain yield; WUE; Wheat

INTRODUCTION

Water shortage in the country demands to develop new technologies and methods of irrigation that can be help full to utilize this precious input in an effective way. In addition there is also a need to carry out practices of irrigation water management to achieve high water use efficiency. Wheat, being the major cereal crop of Pakistan, faces periods of water stress/drought due to shortage of water and seasonal canal closure during the months of December and January. In Punjab, wheat is normally irrigated 4 to 5 times. First irrigation is given at 15-20 days after sowing at crown root initiation (CRI) stage. The subsequent irrigations are provided with an interval of 30 – 35 days. This water shortage stresses re-scheduling of irrigation which should not affect grain yield significantly but can reduce the water applied to the crop. Water requirements of wheat vary from 180 to 420 mm (Balasubramaniyan & Palaniappan, 2001). Thus, there is sufficient room to carry out research to find out what minimum amount of water should be applied to have maximum yield per millimeter of water applied. Study of soil moisture contents and the patterns of moisture depletion as the crop grows could help to sort out a suitable irrigation schedule for this objective. A lot of scientific work in this respect has been documented. Mohamed (1994) reported that irrigation at 60% ASMD gave the highest grain yield and harvest index in wheat while WUE was the highest with 85% ASMD. Ahmad *et al.* (1996) observed that increasing SMD from 50% to 75% markedly reduced total yield. Karim *et al*. (1997) observed that irrigation at 35% available soil moisture depletion (ASMD) gave highest yield (4.71 t ha^{-1}) with the application of 120 kg N while irrigation at 65% ASMD produced satisfactory yield (4.13 t ha^{-1}) with highest WUE (196.5 kg $ha^{-1}cm^{-1}$) with application of 80 kg N. Similarly, Aydin *et al.* (2000) reported that irrigation at 66% ASMD was the most effective in terms of grain yield in wheat. Tahmasabi and Fardad (2000) applied irrigation at 10, 25, 50 and 75% soil moisture depletion and observed that grain yields were 3384, 3050, 3094 and 2273 kg ha^{-1}, while water use efficiency was 1.13, 1.05, 0.82 and 0.86 kg m^{-3}, respectively. Narang *et al*. (2000) found that yield of all wheat cultivars studied decreased with increasing levels of SMD. Water use efficiency was highest with 60% ASMD.

Climatic factors like temperature, relative humidity, wind speed, etc., affect the rate of consumptive use. Balasubramaniyan and Palaniappan (2001) stated that high temperature increases the rate of evapotranspiration while relative humidity (RH) has its effect on transpiration. Stomata of most species tend to close when RH is low and open when it is high. The rate of transpiration is relatively low and increases as the moisture in the air decreases. They further stated that movement of air removes accumulated water vapour near leaf surfaces and increase the transpiration. However, high wind velocities often induce stomata closure due to rapid water loss from the guard cells causing a decrease in transpiration.

Water is needed to carry out normal physiological activities of the plant. However, the actual water requirement is the quantity of water required to meet the demands of evapotranspiration and the metabolic activities of the plant i.e., consumptive use (CU). Since the water used in actual metabolic processes is insignificant (about 1%), water requirement is usually equal to evapotranspiration or consumptive use. Thus, keeping these facts in view, the studies were carried out to determine the water requirements of some wheat genotypes and to relate soil moisture content behaviour with the changing climatic parameters.

MATERIALS AND METHODS

The experiment was conducted during rabi 2003-4 at the research area of the Water Management Research Centre, PARS, University of Agriculture, Faisalabad. The experimental site was a loamy sand having field capacity of 13%, permanent wilting point at 4.0% and bulk density of 1.55 g cm^{-2}. The experiment was conducted using a 2 Factor Randomized Complete Block Design with three replications in split-plot arrangements. Four wheat genotypes (AS2002, SH2002, Inqlab 91 & Uqab 02) were sown in individual plots of size 4 × 12 m, in lines of 25 cm apart using a hand drill and were subjected to following irrigation treatments.

T_1 = Irrigation at 50% soil moisture depletion (SMD)

T_2 = Irrigation at 70% soil moisture depletion

SMD was determined by estimating soil moisture content. For this purpose soil samples were taken from the effective root-zone of the wheat plant which is 0 – 90 cm. The root-zone was divided into 4 sections viz., 0-15, 15-30, 30-60 and 60-90 cm. Soil samples were collected from these 4 sections with the help of a sampling tube. The fresh weight of the soil sampled was immediately recorded with the help of a portable weighing balance. After weighing, the samples were stored in tin pans which were then placed in an electric oven for 24h at 100°C. The dry weight of the samples was then recorded. Soil moisture contents were then calculated as under:

$$Soil\ moisture\, content(\%) = \frac{Dry\, weight of\ the\, sample}{Fresh\, weight of\ the\, sample} \times 100$$

A soaking dose of 76 cm as 'rauni' was applied to all plots for the seed bed preparation. The following irrigations were applied according to the specified treatments. The amount of water applied to each treatment was calculated on the basis of the soil moisture contents at the time of irrigation by using the following expression.

$$d = M.C \times B.D \times D$$

where,

d = depth of water to be applied

M.C = moisture content (%)

B.D. = bulk density of the soil

D = depth of root-zone to be irrigated

A measured amount of irrigation was, thus, applied to each plot with the help of a cut-throat flume (3' × 8" size).

All other agronomic practices were carried out uniformly. At maturity data were collected on grain yield, straw yield and harvest index. Water use efficiency was also calculated as the ratio of grain yield and water applied in terms of kg ha^{-1}mm^{-1}. In addition, meteorological data on parameters like temperature, relative humidity, rainfall, etc., and daily pan evaporation was also recoded.

Soil textural analysis. To determine the percentages of silt, clay and sand, individual soil samples were collected from 0-15, 15-30, 30-60 and 60-90 cm depth of soil from 3 randomly selected points from each replication. Each of the four samples collected from one point were bulked to form one sample for that point. In this way three soil samples were prepared for further textural analysis. Each of these three samples was analyzed separately. Textural analysis was carried out with the help of sieve set consisting 10 sieves of 2.8, 1.70, 1.0, 0.6, 0.355, 0.212, 0.075, 0.045, 0.038 and < 0.038 mm size, respectively. The soil sample was thoroughly mixed and ground and then passed through these sieves with the help of a mechanical sieving machine. The weight of whole soil sample and individual sieves before (empty) and after the sieving (with soil) was recorded. In this way an assortment of sand, clay and silt was obtained. Percentage of sand, clay and silt was then determined on the basis of total weight of the sample. Average percentage of sand, silt and clay was then calculated from the three samples analyzed separately (Table I).

The soil textural class was then determined with the help of a textural triangle (Brady & Weil, 1996) showing textural classes based on the percentages of sand, silt and clay. Thus, on the basis of above analysis the soil type of the experimental site was determined as loamy sand.

The data collected were subjected to analysis of variance according to Steel and Torrie (1984) to sort out significant differences among treatments. Least Significant Difference test was used to compare treatment means.

RESULTS AND DISCUSSION

Daily temperature, relative humidity and pan evaporation (E*pan*) recorded during the experimental period are presented in Fig. 1 and 2. Similarly, mean values of these parameters are presented in Table II. Temperature and humidity showed a direct influence on the rate of daily evaporation. Positive correlation coefficients between temperature and E*pan* (Table II) clearly indicated that as the temperature increased the rate of evaporation also increased, however, a negative correlation between relative humidity and rate of pan evaporation indicated an inverse relationship. Thus, rate of evaporation was low during the months of December and January when temperature was low and humidity was high. Excessive rain fall during the month of February (29.7 mm) further reduced the rate of evaporation. The rate of evaporation started to increase as the temperature started to rise and humidity started to decrease during the months of February through April. The variations in temperature can be related to patterns of soil moisture depletion (Figs. 3 & 4). Rate of moisture depletion was low during earlier growth period during the months of November, December and January when temperature was low. As the temperature rose up in the later part of the growth period, the rate of soil moisture depletion also

Table I. Percentages of sand, silt and clay in the experimental site

Ingredient	R1	R2	R3	Average
Sand	84.9	80.4	78.3	81.2
Clay	14.9	19.3	21.2	18.47
Silt	0.83	0.27	0.54	0.55

Table II. Simple correlation coefficients of maximum temperature (T) and relative humidity (R.H) with pan evaporation (E*pan*) during the growing season

Growing period	Mean max T (°C)	R.H. (%)	Epan/day (mm)	Correlation with Epan	
				T	R.H
December, 2003	21.3	86.8	1.7	0.505**	-0.323
January, 2004	17.5	88.4	0.3	0.411*	-0.504**
February, 2004	23.0	85.9	2.5	0.610**	-0.129
March, 2004	31.6	81.0	5.5	0.397*	-0.403*
April, 2004	38.0	69.8	8.4	0.272	-0.210

** $P \leq 0.01$, * $P \leq 0.05$

Table III. Total water applied (mm) to wheat, rain fall and ETc (calculated using pan evaporation) during the growing period

	50% SMD	70% SMD	ETc*
1st irrigation	56.98	83.48	63.80
2nd irrigation	80.43	85.39	57.73
3rd irrigation	77.39	82.55	68.39
Water applied	214.80	251.42	
Rainfall	37.60	37.60	
Total	252.40	289.02	199.92

* ETc = reference crop evapotranspiration

Fig. 1. Maximum, minimum temperature and relative humidity during the crop growth period (straight line indicates mean)

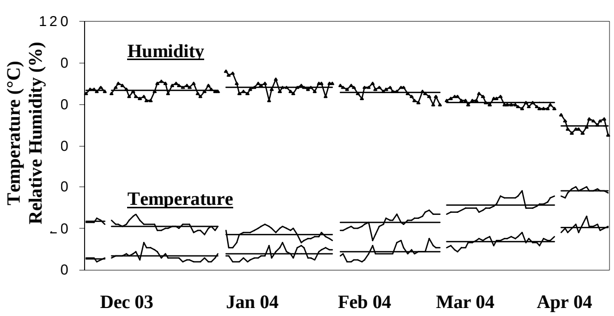


Fig. 2. Daily pan evaporation during the crop growth period (straight line indicates mean)

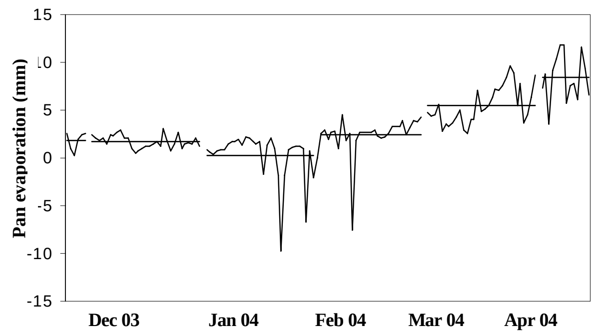


Fig. 3. Patterns of soil moisture depletion in 50% SMD treatment

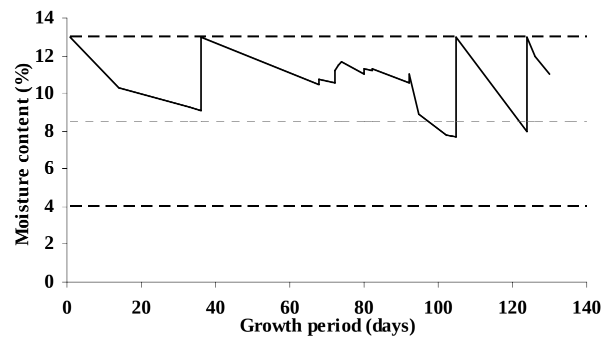
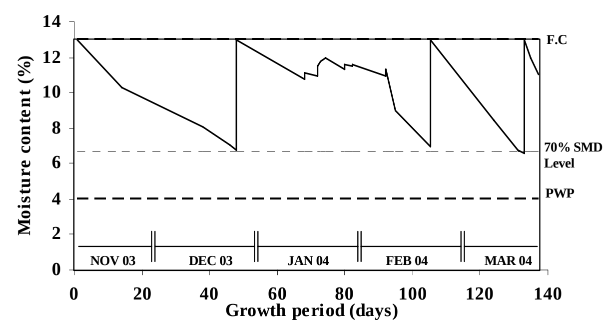


Fig. 4. Patterns of soil moisture depletion in 70% SMD treatment



increased. Due to seasonal canal closure, water shortage and excessive rains during the months of February and March, the irrigation application was altered and the wheat was irrigated three times.

Amount of total water applied to each of the irrigation treatment, rain water and the calculated reference evapotranspiration (ET*c*) are given in Table III. The amount of water applied to wheat at 50% and 70% SMD was 214.80 mm and 251.42 mm, respectively.

Data collected on grain yield, straw yield, harvest index, water applied and WUE was subjected to statistical analysis (Table IV). The results displayed a significant effect of irrigation treatments on grain yield, harvest index, amount of water applied and water use efficiency. Wheat varieties were also found significantly different in terms of grain yield, straw yield and WUE. The interactive effect of irrigation and varieties was found non-significant for all the parameters studied.

A comparison of treatment means (Table V) indicated that maximum (2966.5 kg ha^{-1}) grain yield of wheat was

Table IV. Analysis of variance for the traits studied

SOV	Df	Grain yield	Straw yield	Harvest Index	Water Applied	Water Use Efficiency
Replication	2	662021.0	8346937.2	4.156*	187.215	16.89
Treatments	1	2515265.6*	3342752.3	46.28**	8009.491*	125.25**
Error(a)	2	57359.2	728571.9	0.11	56.918	1.06
Varieties	3	565024.5*	24508070.1*	7.63	0.010	11.25*
T × V	3	229341.1	671925.0	6.69	0.009	4.78
Error(b)	12	135290.1	362779.2	7.12	0.009	2.59

** $P \leq 0.01$, * $P \leq 0.05$

Table V. Mean values of the traits studied showing statistical significance

Treatments	Grain yield (kg ha^{-1})	Straw Yield (kg ha^{-1})	Harvest Index (%)	Water Applied (mm)	Water Use Efficiency (kg ha^{-1}mm^{-1})
A. Irrigation					
I_1 (50% SMD)	2966.5 a	10085.2	22.67 a	214.8 b	13.82 a
I_2 (70% SMD)	2319.1 b	9338.8	19.90 b	251.4 a	9.25 b
LSD	420.7	-	0.59	13.25	1.80
B. Varieties					
V_1 (AS2002)	2324.3 b	8956.9 b	22.52	233.09	10.17 b
V_2 (SH2002)	3062.0 a	10276.1 a	22.72	233.09	13.43 a
V_3 (Inqalab91)	2581.2 b	9408.2 b	21.64	233.16	11.17 b
V_4 (Uqab 02)	2603.8 ab	10206.7 a	20.26	233.10	11.36 b
LSD	462.7	757.7	-	-	2.02
C. Interaction					
I_1V_1	2687.1	9512.4	22.17	214.8	12.51
I_1V_2	3589.7	10970.5	24.51	214.8	16.73
I_1V_3	2638.5	9750.7	21.79	215.0	12.29
I_1V_4	2950.9	10137.3	22.52	214.8	13.74
I_2V_1	1961.5	8401.4	18.88	251.4	7.83
I_2V_2	2534.3	9581.8	20.93	251.4	10.13
I_2V_3	2523.9	9095.8	21.78	251.4	10.05
I_2V_4	2256.6	10276.1	18.00	251.4	8.99
LSD	-	-	-	-	-

obtained when it was irrigated at 50% SMD. Grain yield obtained with irrigation at 70% SMD was 2319.1 kg ha^{-1}. A similar trend was observed in case of harvest index. These results are similar to those of Mohamed (1994), Ahmad *et al*. (1996), Kaim *et al*. (1997) and Narang *et al*. (2000) who also reported a loss of grain yield by increasing SMD level from low to high.

Delayed 3rd irrigation in case of 50% SMD treatment resulted in loss of 4th irrigation in this treatment which could have been given if 3rd irrigation could be applied in time. This reduced the total amount of irrigation water in 50% SMD treatment as compared to 70% SMD treatment (214.8 and 251.4 mm, respectively). Thus, water use efficiency was greater (13.82 kg ha^{-1}mm^{-1}) in 50% SMD treatment and was lesser (9.25 kg ha^{-1}mm^{-1}) in 70% SMD treatment. Tahmasabi and Fardad (2000) and Narang *et al*. (2000) also reported higher water use efficiency at lower SMD levels. On the contrary Mohamed (1994) and Karim *et al*. (1997) reported higher water use efficiency at higher SMD levels.

A comparison of varietal differences displayed that SH2002 produced the maximum (3062.0 kg ha^{-1}) grain yield followed by Uqab 2002 (2603.8 kg ha^{-1}). Lowest grain yield (2324.3 kg ha^{-1}) was produced by AS2002. A similar trend were observed for straw yield which was highest (10276.1 kg ha^{-1}) in SH2002 and was significantly reduced and minimum (8956.9 kg ha^{-1}) in SH2002. WUE was also greater (13.08 kg ha^{-1}mm^{-1}) in AS2002 and was the minimum (9.92 kg ha^{-1}mm^{-1}) in AS2002.

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