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Effects of Soil Moisture Depletion at Different Growth Stages on Yield and Water Use Efficiency of Bread Wheat Grown in Semi Arid Conditions in Ethiopia

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ABSTRACT

A field experiment was conducted at the Malkassa Agricultural Research Center (MARC) in Ethiopia, during the off season of 2009 from January to April. The purpose of the study was to evaluate the effect of soil moisture depletion at different growth stages on yield and water use efficiency of bread wheat (*Triticum aestivum* L.) variety Hawi*f* grown under semi arid conditions. Three soil moisture depletion (SMD) levels and 4 growth stages of SMD were used as the main- and sub-plots, respectively, and were arranged as split plots in a randomized complete block design with 4 replications. Irrigation was applied when the soil moisture was depleted by 50% (D1; control), 60% (D2) and 75% (D3) of available soil water (ASW) at 4 growth stages: 1) vegetative (V), 2) heading (H), 3) flowering (F) and 4) grain filling (G). All the plots were irrigated to field capacity after planting. Soil samples were taken before and after each irrigation event for the first 3 wk after planting. Thereafter, irrigation frequency was established according to treatments. All the treatments were irrigated when 50% of ASW was depleted for the whole growing season, except for the growth stages where SMD treatments were imposed. The SMD levels significantly affected dry matter, grain yield (GY), water use efficiency (WUE) and thousand seed weight (TSW) of the Hawi*f* bread wheat. The 50% SMD gave the highest GY, TSW, spike length, plant height and WUE at each growth stage. Increasing the SMD level significantly reduced the yield and yield components of the Hawi*f* bread wheat. Grain yield reduction was 26.6 and 30.8% for D2 and D3, respectively, compared with D1.

Keywords: bread wheat, soil moisture depletion, growth stages

INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important staple food crops in the world. Ethiopia is the major producer of wheat in Eastern Africa accounting for over 70% of the total wheat area in the region (Gebre-Mariam, 1991). The two major species of wheat grown in Ethiopia are tetraploid durum and hexaploid bread wheat (Tesemma and Jemal, 1982). Annual crops are

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moderately to highly sensitive to water stress and the inadequate supply of irrigation water influences the growth and yield (Mishra *et al.*, 1995; Alderfasi and Nielsen, 2001). Under semi arid conditions, water resources are usually scarce and hence a limiting factor for crop production. Soil moisture deficit (SMD) at a particular magnitude may occur either continuously over the total growing period of the crop or it may occur during any individual growth period. However, different crops have different requirements and respond differently to SMD under different climatic conditions. Therefore, information on optimal irrigation management and the adverse effects of soil moisture depletion levels at different growth stages of bread wheat and yield performance is essential for decision making in irrigation management. The crop developmental stages at which most crops are sensitive to water deficit or meteorological factors are the vegetative, flowering and fruiting stages (Doorenbos and Kassam, 1979; Karam *et al.*, 2009). Research results have confirmed that some deficit irrigation is successful in increasing the water use efficiency for various crops without causing severe yield reduction (Geerts and Dirk, 2009).

The objectives of the present study were: 1) to examine the effect of soil moisture depletion levels at different growth stages on the yield of bread wheat variety Hawi*f* under semi arid conditions in Ethiopia and 2) to evaluate crop water use efficiency.

MATERIALS AND METHODS

General description of study area

The field study was conducted on the experimental farm of the Malkassa Agricultural Research Center (MARC) at the Ethiopian Institute of Agricultural Research (EIAR) from January to April in 2009. The area is located about 15 km southeast of Nazareth town and 106 km from Addis Ababa at about latitude 8°24′ N and longitude 39°34′ E at an altitude of 1550 meters above sea level. The soil type on the experimental farm was classified as Haplic Andosol with a textural class of loam to silt clay (Table 1). The area is characterized as semi arid with low and erratic rainfall having a long term (in excess of 30 yr) mean annual rainfall of about 787 mm/yr with peaks in July and August. The long term (1977˘2008) average rainfall from January to April was 28 mm. The mean monthly maximum temperatures range from 24.7 °C in August to 33 °C in June, while the mean monthly minimum temperatures range from 4 °C in November to 17.5 °C in June. The mean temperature from 1977 to 2008 was about 21 °C.

Soil analysis

To identify some of the chemical and physical properties of the soil, representative composite soil samples were collected from the experimental site from depths of 0˘30 cm, 30˘60 cm and 60˘90 cm using an auger. The samples were sent to the National Soil Testing Center (NSTC) in Addis Ababa for analysis. Some of the

Table 1 Some physical properties of experimental field soil.

Depth (cm)	FC (%)	PWP (%)	BD (g/cm^3)	Sand (%)	Silt (%)	Clay (%)	Texture
0 ˘ 30	34.0	18.0	1.05	44	36	20	loam
30 ˘ 60	36.4	21.0	1.10	34	40	26	loam
60 ˘ 90	35.8	20.0	1.14	16	44	40	silty clay
Mean	35.4	19.7	1.1	31.3	40	28.7	

FC = field capacity; PWP = permanent wilting point; BD = bulk density.

physical properties of the soil are given in Table 1.

The soil in the experimental field was classified mainly as loam textured for the upper soil depth (0˘60 cm), whilst it was silt clay for the soil depth 60˘90 cm. The soil water holding ability at field capacity (FC) and the permanent wilting point (PWP) were on average 35.4 and 19.7%, respectively. The average soil bulk density (BD) was 1.10 g/cm^3; hence, the total available soil water was about 172.7 mm/m.

Experimental design and layout

The experimental field was ploughed, harrowed and leveled. The experimental area was then divided into 48 plots of size 5 × 3.6 m each with a furrow length of 5 m and 0.60 m spacing, maintaining a buffer zone of 2.4 m and 4.8 m between plots not adjacent to and adjacent to the irrigation canal, respectively. The treatments consisted of irrigation applied at three levels of soil moisture depletion (SMD): 50% (D1), 60% (D2) and 75% (D3) of available soil moisture that made up the main plots and the 4 stages of crop growth˘namely vegetative (V), heading (H), flowering (F) and grain filling (G) that made up the sub plots. The experiment was laid out in a split plot in a randomized complete block design with 4 replications. The control treatment involved irrigation supplied at 50% (D1) SMD throughout the growing period of the crop. An early maturing bread wheat (*Triticum aestivum* L., var. Hawi*f*) was planted on 6 January 2009 on both sides of the ridge with 25 cm between rows. Di-ammonium phosphate (DAP) fertilizer was side-dressed at the rate of 100 kg/ha at planting time and 150 kg/ha urea was applied in two equal amounts, half at planting and other half at tillering. All plots were irrigated to field capacity after planting. Soil samples before and after irrigation were collected 3 wk after planting for soil moisture determination and then irrigation intervals were established for each treatment. Thereafter, irrigation was applied as per treatment. The depth of irrigation was 0˘30 cm, for the vegetative stage, 0˘45 cm for the heading and flowering stages and 0˘60 cm for the grain filling stage. The regimes applied resulted in different irrigation intervals and amounts of irrigation water (data not shown) between the treatments and within the treatments at different growth stages. The irrigation interval was 5, 6, 7 d for D1, 6, 8 and 9 d for D2 and 7, 9 and 11 d for D3 at the vegetative, heading and flowering, and grain filling stages, respectively. The heading and flowering stages had the same irrigation interval schedule because the irrigation depth was the same for both stages. Treatments were imposed from tillering to the end of the booting (vegetative stage), heading, flowering and grain filling stages, and were irrigated when 50% of ASW was depleted, except during the imposed period. Each plot received a predetermined amount of irrigation water through field canals using a 7.5 cm Parshall flume device. All cultural practices, other than treatment variables, were carried out according to the standard practices recommended for the area.

Agronomic data collection

Plant height and dry matter were measured at harvest. The plant heights of 10 randomly selected plants per plot were measured from the soil surface to the top canopy of the plant. The same 10 random plant samples were oven dried for 72 h at 68 °C and the dry weight was recorded**.** The spike length excluding awns was also recorded. As the kernels matured, the crop in the harvest area of 6.3 m^2 per plot (excluding border rows) was harvested and collected in clean sacks to record the weight. The harvested crop was sun-dried for 3 d and threshed separately using wooden sticks and finally the seed was separated, cleaned and weighed to record the grain yield for each plot. The weight of one thousand seeds per plot was recorded to 3 decimal places using a sensitive weighing balance. The harvest index (HI) and water use efficiency (WUE) were also calculated.

Statistical analysis

Data were arranged and summarized for statistical analysis. Analysis of variance was performed using SPSS.v.16.0 and IRRISTAT.v.5.0. Fisher s least significant difference (LSD) was used for mean comparisons. The test for a significant statistical difference was set at $P < 0.05$.

RESULTS AND DISCUSSION

Crop physiological performance

Bread wheat (variety Hawi*f*) is an early maturing variety and the growth period was 94 d from germination until harvesting for the control treatment. At harvest, SMD had a significant effect on plant height but not on dry matter. The highest plant height and dry matter were observed under treatment D1. This result agreed with Hang and Miller (1983), Ghamarnia and Gowing (2005) and Ibrahim *et al.* (2010) who all observed that water stress reduced the dry matter of wheat. Dry matter varied in a narrow range of about 24.9˘27.0 kg/ha. The interaction effects between SMD and each growth stage (GS) were not significantly different for plant height and dry matter. D3F produced the lowest dry matter of 23.3 kg/ha which was not significantly different (Table 3). D3F also had the lowest plant height of 71.37 cm, while D1G had the highest plant height of 78.64 cm (Table 3).

Yield and some yield component

The effect of SMD levels, stages of growth and their interaction on GY, TSW and spike length and WUE and HI are shown in Tables 2 and 3. Statistical analysis revealed that the SMD levels had a significant ($P < 0.05$) effect on GY, TSW and WUE. The maximum values for grain yield, TSW, WUE and spike length were obtained from the D1 SMD treatment and these values were greater than those of either D2 or D3. Increasing soil moisture depletion levels decreased the grain yield by about 26.6% and 32.8% for D2 and D3, respectively, compared with D1. However, there were no significant grain yield differences between

Table 2 Effect of soil moisture depletion (SMD) and stage of growth on yield and yield components of bread wheat.

Soil moisture depletion	Plant height (cm)	Dry matter (kg/ha)	Grain yield (t/ha)	TSW (g)	Spike length (cm)	HI	WUE (kg/ha/mm)
D1	77.05	27.0[a]*	3.14[a]	35.97[a]	7.71	0.269	6.52[a]
D2	73.97	24.9[b]	2.37[b]	34.21[b]	7.25	0.260	5.09[b]
D3	74.64	24.9[b]	2.11[b]	32.72[c]	7.32	0.285	4.53[b]
LSD(0.05)	NS	1.768	0.3719	0.844	NS	NS	0.779
CV(SMD) %	4.6	7.94	16.14	2	7.93	18.53	16.74
Stage							
V	75.80	25.9	2.45	34.53[a]	7.24[b]	0.263	5.19
H	75.06	25.6	2.59	34.33[a]	7.59[a]	0.273	5.49
F	73.70	25.0	2.66	34.59[a]	7.59[a]	0.281	5.64
GF	76.29	25.9	2.45	33.81[b]	7.29[ab]	0.267	5.20
LSD (0.05)	NS	NS	NS	0.593	0.304	NS	NS
CV (Stage) %	6.32	11.67	11.89	1.91	5.52	10.64	10.8

* Means in the same column with the same lower case letters are not significant at $P < 0.05$.
NS = not significant; HI = harvest index; TSW= thousand seed weight; WUE= water use efficiency.
Stages of growth are represented by V = vegetative; H = heading; F = flowering; GF = grain filling.
D1, D2, D3 represent 50, 60 and 75% SMD levels, respectively.

D2 and D3. These results agreed with the results reported by Hochman (1982), Karam *et al.* (2009) and Johari-Pireivatlou (2010). Increasing soil moisture depletion decreased grain yield and vice versa. Similarly, many researchers reported that the yield of wheat decreased under water stress (Hochman, 1982; Singh and Malik, 1983; Abayomi and Wright, 1999; Qadir *et al.,* 1999; Benmoussa and Achouch, 2005; Moussavi-nik *et al.*, 2005; Mirbahar *et al.,* 2009). This result confirmed that water was a limiting factor for crop production. Grain yield increased when the frequency of irrigation increased and similar results were reported by Ibrahim *et al.* (2010). Simple linear regression and correlation between water use efficiency and grain yield was highly significant ($P < 0.01$). These two variables had a strong positive relationship with an R^2 value of 99.77%, indicating that increasing water use efficiency resulted in an increase in the grain yield (Equation 1 and Figure 1):

$$Y = 1.9777X + 0.35812 \quad (1)$$

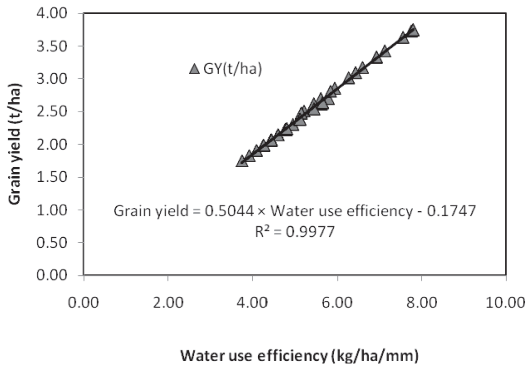

Figure 1 Relationship between water use efficiency and grain yield of Hawi*f* bread wheat, showing the good fit ($R^2 = 0.9977$) to the raw data (▲) for the plotted linear equation ( ) of: grain yield = 0.5044 × water use efficiency ˘ 0.1747.

Table 3 Effect of interaction between soil moisture depletion and growth stages on yield and some yield components of bread wheat (var. Hawi*f*).

Interaction (SMD*GS)	Plant height (cm)	Dry matter (kg/ha)	Grain yield (t/ha)	Thousand seed weight (g)	Spike Length (cm)	Harvest index	WUE (kg/ha/mm)
D1 * V	76.53	27.3	2.85	36.56	7.56	0.263	5.93
* H	76.11	26.8	3.32	36.05	7.85	0.268	6.89
* F	76.62	27.0	3.32	36.28	7.77	0.283	6.91
* GF	78.64	27.0	3.06	34.99	7.67	0.261	6.36
D2 * V	75.10	25.1	2.29	33.99	7.0	0.269	4.90
* H	74.53	25.5	2.38	34.02	7.76	0.264	5.11
* F	73.12	24.8	2.51	34.60	7.48	0.266	5.38
* GF	73.11	24.4	2.32	34.24	6.76	0.241	4.98
D3 * V	75.88	25.3	2.20	33.05	7.15	0.258	4.73
* H	74.24	24.6	2.08	32.93	7.16	0.288	4.48
* F	71.37	23.3	2.16	32.72	7.53	0.295	4.65
* GF	77.13	26.4	1.98	32.2	7.43	0.299	4.26
LSD (0.05)	NS	NS	NS	NS	NS	NS	NS
CV (SMD * Stage)%	7.82	21.87	20.04	3.42	9.66	14.75	19.94

NS = not significant at $P < 0.05$; GS = growth stage; HI = harvest index; TSW= thousand seed weight; WUE= water use efficiency.
Stages of growth are represented by V = vegetative; H = heading; F = flowering; GF = grain filling.
D1, D2, D3 represent 50, 60 and 75% SMD levels, respectively.

where: Y = grain yield (t/ha)

X = water use efficiency (kg/ha/mm)

The SMD levels had a significant effect on TSW. D1 was superior to D2 and D3, and D2 was superior to D3. The reduction in the thousand seed weight was 4.9 and 9.0% for D2 and D3, respectively, compared with D1, and 4.6% for D3 compared with D2. Therefore, increasing soil moisture depletion decreased the thousand seed weight of the bread wheat (variety Hawi*f*). This result agreed with the results of Sionit *et al.* (1980) Hochman (1982), Singh and Malik (1983), Qadir *et al*. (1999), Ahmadi and Baker (2001), Moussavinik *et al.* (2005), Mirbahar *et al.* (2009) and Johari-Pireivatlou (2010) who found that moisture stress decreased the TSW of wheat varieties. The SMD levels had no significant effect on spike length (SPL) and HI. However, the maximum spike length was recorded in D1 and tended to decrease with increasing SMD levels. D3 and D2 had the highest and lowest values for HI of 0.285 and 0.260, respectively, but neither was significantly different. The increase in the HI for D3 could have been due to the decrease in the above ground biomass that was affected by the high soil moisture depletion. This result disagreed with the result of Johari-Pireivatlou (2010) who reported that none of the levels of water stress had increased the HI of four wheat lines. The values of HI obtained in the present experiment was low (0.269˘0.285) and this result agreed with Satorre and Slafer (1999) who reported that HI was low (under 0.50) in most of the regions in the world.

The growth stage of the water stress had no significant effect on GY, WUE, and HI at the same SMD. However, applying the SMD at different growth stages significantly affected TWS and spike length. Mirbahar *et al*. (2009) reported that water stress decreased the spike length of 25 wheat varieties (*Triticum aestivum* L.). The G and V stages had the lowest TSW (33.81 g) and spike length (7.24 cm). The F stage had the highest TSW (34.59 g) that was significantly greater than in the G stage (33.81 g). The low GY in the vegetative stage could have been due to the soil moisture stress at tillering, stem elongation and booting, and this may have caused a reduction of the tillerings which in turn reduced the final grain yield of the Hawi*f* bread wheat.

Comparison of the means showed that the interaction effect of the SMD and growth stages of the Hawi*f* bread wheat had no significant effect on GY, WUE, TSW and spike length (Table 3). D1 produced a nonsignificantly superior yield to all other interactions. In addition, D3G produced the nonsignificantly lowest GY (1.98 t/ha), WUE (4.26 kg/ha/mm) and TSW (32.2 g). Although, the results of the experiment covered only one season, the low soil fertility and planting about 6 mth before the optimal date could have been the main reasons that the mean yield of Hawi*f* bread wheat was about 3.14 t/ha. Taking advantage of the optimal planting date increased the dry matter and grain yield compared with early and late sowing (Musick and Dusek, 1980) and increasing the amount of nitrogen increased the grain yield (Karam *et al*., 2009).

CONCLUSION

Soil moisture depletion at different growth stages significantly affected dry matter, grain yield and WUE and TSW of the bread wheat variety Hawi*f*. Increasing moisture depletion levels decreased the grain yield, thousand seed weight and water use efficiency of bread wheat variety Hawi*f* grown in a semi arid region of Ethiopia. The treatment D1 (50% of SMD) was superior to the two other irrigation levels and produced the greatest plant height, dry matter, yield and yield components at each growth stage. The greatest water use efficiency was observed when the soil moisture was prevented from falling below 50% of available soil water throughout the growing period. At each growth stage, the results of this experiment suggest that an irrigation schedule should be applied when 50% of the available soil water is depleted.

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