Agricultural Science, Engineering and Technology Research
Vol. 1, No. 3, September 2013, PP:
Available online at http://asetr.org/

Research article

Impact of Soil Moisture Depletion Levels at Different Growth Stages on Growth, Evapotranspiration and Biomass yield of Bread Wheat Grown under Semi Arid Condition

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ABSTRACT

Wheat is produced under low and irregular rainfall in most of semi-arid areas of Ethiopia. Growth and yield are therefore reduced due to the occurrence of water stress during the growing season in the country. A field experiment was conducted at the Malkassa Agricultural Research Center (MARC), from January to April of 2009. The aim of the study was to evaluate the effect of different soil moisture levels at different growth stages on growth, evapotranspiration and biomass yield of the "Hawi" bread wheat. Three soil moisture depletion (SMD) levels (50% (D1), 60% (D2) and 75% (D3)) and 4 growth stages of SMD (vegetative (V), heading (H), flowering (F) and grain filling (G)) were used as the main and subplots, respectively, and were arranged as split plots in a RCB design with 4 replications. Soil samples were taken before and after each irrigation event. The study showed that plant height, fresh weight and dry mater at vegetative were not significantly affected by soil moisture depletion. But dry matter at grain filling was significantly ($P<.05$) affected by soil moisture depletion. The soil moisture depletion imposed at vegetative stage was significantly affected plant height, fresh weight and dry matter at level of ($P<0.05$), ($P<0.01$) and ($P<0.05$), respectively. Dry matter at grain filling stage was significantly ($P<0.01$) affected by the interaction effect between soil moisture depletion and growth stages. The relationship between seasonal evapo-transpiration and biomass was positive and highly significant ($P<0.01$) whereas the soil moisture depletion levels had a significant ($P<0.01$) effected on straw yield and biomass yield. The effect of soil moisture depletion, growth stages and their interaction effect on evapotranspiration at vegetative stage were highly significant ($P < 0.01$). Simple linear regression and correlation between water use efficiency (WUE_b) and biomass was highly significant ($P < 0.01$). Biomass and WUE_b has strong positive linear regression and correlation, where $R^2 = 99.7$. Increasing moisture depletion levels decreased the dry matter, evapotranspiration, and biomass yield and water use efficiency for biomass of bread wheat. Irrigating wheat crop when 50% of available soil moisture is depleted produced highest plant height and dry matter, biomass and water use efficiency of the "Hawi" wheat in semi-arid condition of Ethiopia.

Key Words: Bread wheat, Soil moisture depletion, Growth stages

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the most important small cereal crops in Ethiopia; it ranks fifth both in terms of area and production after teff, maize, barley and sorghum (Kassahun, 1996). Ethiopia is one of the largest wheat producers among the countries in the Sub-Saharan Africa (Hailu, 1991). Wheat is an important cereal crop and adapted to a wide range of climate condition. In arid and semi regions the yield of wheat is limited by water deficit stress. The poverty in dry land areas is partly caused by inadequate availability of water for crop and livestock. The shortage of water is due to the low rainfall as normally perceived but rather by a lack of capacity for sustainable management and use of available water, which has further generated numerous economic, social and ecological issues. Research results confirmed that some deficit irrigation were successful in increasing water used efficiency for various crops without causing severe yield reduction (Geerts and Dirk, 2009). Water stress is also an important limitation to crop production due to its effect on reduction in photosynthetic activity and increase of leaf senescence. Therefore, the objective of this study was to evaluate the effect of soil moisture depletion levels at different growth stages on growth, biomass and evapotranspiration of bread wheat grown in semi-arid condition.

2. MATERIALS AND METHODS

General Description of Study Area

Field experiment was conducted at the experimental farm of Malkassa Agricultural Research Center (MARC) Ethiopian Institute of Agricultural Research (EIAR) during January-April in 2009. Malkassa is located 8^{o}24'N latitude and 39^o 34'E longitude with an altitude of 1550 meters above sea levels (masl). The soil texture in the experimental farm is loam to silt clay. The area is characterized as a semi arid with low and erratic rainfall of about 787 mm per annum. The mean temperature over 30 years (1977-2008) is about 21^{0}C.

Soil analysis

Representative composite soil samples were collected from the experimental site from the depth of 0-30 cm, 30-60 cm and 60-90 cm using an auger to identify some of the chemical and physical properties of the soil. The soil water holdings at field capacity (FC) and permanent wilting point (PWP) are on average 35.4 and 19.7%, respectively (Mahamed *et al*., 2011). The averaged soil bulk density (BD) is 1.10 g/cm^3 (data not shown). Hence the total available soil water is about 172.7 mm/m. Chemical properties of soil site is shown in Table 1.

Table 1: Some chemical properties of experimental field soil.

Depth (cm)	pH	ECe (dS/m)	TN (%)	Av.P. ppm	OC (%)	Na	K	Ca	Mg	CEC
						Cmol (+)/kg				
0 – 30	8.4	0.25	0.12	10.70	1.23	1.04	4.29	26.8	4.13	39.7
30 – 60	8.7	0.36	0.09	2.90	0.98	1.39	5.18	27.8	4.62	32.3
60 - 90	8.5	0.34	0.08	4.92	0.74	0.54	4.54	25.1	4.21	37.4

Note:- ECe = Electrical conductivity; TN = Total nitrogen; OC = Organic matter; Av.P. = Available phosphor; Na = Sodium; K = Potassium; Ca = Calcium; Mg = Magnesium; and CEC = Cation exchange capacity

Experimental design and layout

Experimental field was ploughed leveled and then divided into 48 plots of 5 x 3.6 m^2 plot size with furrow length and width of 5 m and 3.6m respectively, and 0.60 m spacing. The treatments consisted of an irrigation applied at three levels of soil moisture depletion (SMD), viz., 50% (D1). 60% (D2) and 75% (D3) of available soil moisture were main plots and four stages of crop growth, *viz*., vegetative (V), heading (H), flowering (F) and grain filling (G) were sub plots and were laid out in a split plot in randomized complete block design with four replications. The "Hawi" bread wheat (*Triticum aestivum* L.) was planted on 6^{th} January 2009 on both sides of ridges with 25 cm between rows. The 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 splits of equal rate, 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 three weeks after planting for soil moisture determination and then irrigation intervals were established for each treatment. Thereafter, the irrigation was applied as per treatment. The depth of irrigation was 0-30cm, for vegetative stage, 0-45cm for heading and flowering stages and 0-60cm grain filling stage. Based on this, the irrigation interval and amount of irrigation water (Table 2) was different between the treatment and within treatment at different growth stages. Treatments were imposed from vegetative stage, heading, flowering and grain filling stages, and were irrigated when 50% of Available soil water (ASW) was depleted, except the imposed period. Each plot received predetermined amount of irrigation water through field canals using a 7.62 cm (three inches) Parshall flume device. All cultural practices, other than treatment variables, were done according to the standard practices recommended for the area.

Table 2: The net and gross irrigation (in parenthesis) water applied (mm) at different soil depths

Soil moisture depletion (%)	Amount of irrigation water applied per irrigation (mm) at different depth		
	0-30cm	0-45cm	0-60cm
50 (D1)	26.4 (37.7)	38.9 (55.6)	50.8 (72.6)
60 (D2)	31.7 (45.3)	46.6 (66.6)	61 (87.1)
75 (D3)	39.6 (56.6)	58.3 (83.3)	76.2 (108.9)

Estimation of Crop evapotranspiration

Crop water requirement which is also expressed as crop evapotranspiration (ET_{crop}) in mm/day or mm/period was computed from the water balance method and was expressed as;

$$\Delta S = P_e + I + W - R - D - ET$$

Where P_e is precipitation (mm), I is irrigation (mm), W is contribution of ground water (mm), R is runoff (mm), D is drainage (mm), ET is actual crop evapotranspiration (mm) and $\Delta S = S_i - S_{ii}$ is water storage in soil layer, after irrigation (S_i) and before irrigation (S_{ii}). The groundwater level was assumed to be at depth more than 3 meters at the research site and as a result the upward flow (W) to the root zone was considered to be negligible. The amount of gross irrigation water was carefully applied such that no runoff and drainage occurred. Hence, runoff (R) and drainage (D) were also ignored in the water balance equation. During the growing period, small rainfall (P) has occurred in January which did not cause neither runoff nor deep percolation, therefore, the only input was the irrigation water applied. Therefore, the ET_{crop} of wheat was computed using the following expression.

$$ET_{crop} = P_e + I - \Delta S$$

Where I is irrigation in mm, ΔS is the change in soil water storage in mm, P_e is precipitation in mm and ET_{crop} is the crop water requirement in mm.

Agronomic data collection

Plant height, fresh weight and dry matter were measured at vegetative and grain filling stags. Plant height of 10 randomly selected plants per plot was measured from the soil surface to top canopy of the plant. The same 10 random plant samples were oven dried for 72 hours at 68^0C and dry matter was recorded. The crops in the harvest area of 6.3 m^2 per plot (excluding border rows) were harvested and collected in clean sacks to record their weights. The harvested crop was sun-dried for three days and finally the seed was separated. The straw yield was recorded for each plot.

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 comparison.

3. RESULTS AND DISCUSSIONS

Plant height, fresh weight and dry mater at vegetative and were not significantly affected by soil moisture depletion. But dry matter at grain filling was significantly ($P<.05$) affected by SMD. The soil moisture depletion imposed at vegetative stage was significantly affected plant height, fresh weight and dry matter at level of ($P<0.05$), ($P<0.01$) and ($P<0.05$), respectively. Dry matter at grain filling was significantly ($P<0.01$) affected by the interaction effect between SMD and GRS. The D3F gave the lowest dry matter of 22.5 kg/ha (Table 3). The D3V gave the lowest plant height of 75.99 cm, while D3G gave the highest plant height of 80.99 cm (Table 3). The shortest plant height of about 31.31cm was observed at vegetative stage and was significantly different among the growth stages. This result agreed with the result of Kimurto *et al*. (2003) and Choudhury and Kumar (1980) who reported that plant height of wheat was reduced by water stress. Soil moisture depletion levels of 60 and 75% has affected the fresh weight and dry matter at vegetative stage and gave lowest fresh weight and dry matter yield of about 26.04kg/ha and 8.64kg/ha, respectively. At the grain filling stage 50% of SMD level gave non-significant highest plant height and maximum fresh weight, while dry matter was significantly affected by SMD, GRSs (Table 2) and interaction effect between SMD levels and GRS (Table 3). The highest (29.5 kg/ha) and lowest dry mater (26 kg/ha) was obtained from 50% and 75% SMD levels, respectively (Table 2). The D3F gave the lowest dry matter of about 22.5 kg/ha, followed by D2F (23.2 kg/ha) and D2H (24.2 kg/ha). This result agreed with the result of Hang and Miller, 1983, Ghamarnia and Gowing (2005) and Ibrahim *et al.* (2010) who observed that the water stress reduced dry matter of wheat. Soil moisture depletion levels significantly ($P <0.01$) affected biomass yield as shown in the (Table 4). Treatment D1 was significantly different from D2 and D3 and gave the highest biomass yield of about 11.71 t/ha. The treatment D3 was also significantly different from D2 and gave lowest biomass yield of about 7.4 4t/ha (mean). This result agreed with those of Kang *et al*. (2002) and Inoue *et al*. (2008) who reported that the biomass was largest in high soil moisture treatment. The relationship between seasonal evapo-transpiration and biomass was positive and highly significant at $P<0.01$ (2-tailed) as shown in the figure 2. The soil moisture depletion levels had a significant at ($P <0.01$) effected on straw yield (Table 4). The 75 % SMD reduced straw yield up to 5.34 t/ha, whereas 50 % SMD produced the highest straw yield of 8.59 t/ha. These results indicated that increasing soil depletion decreased the biological yield of the "Hawi" bread wheat.

The water use efficiency for the biomass was affected by soil moisture depletion levels and was highly significant ($P < 0.01$). The D1 was significantly different from D2 and D3 which are also significantly different. The highest (24.33 kg/ha/mm) and the lowest (16 kg/ha/mm) WUE for biomass yield was observed at 50 and 75 % SMD levels, respectively. This indicated that 75 % soil moisture depletion reduced WUE for biomass. The results agreed with the result of Blum (2005) and Moussavi-nik *et al*., (2005). Simple linear regression and correlation between water use efficiency (WUE_b) and biomass was highly significant at $P < 0.01$(2-tailed). Biomass and WUE_b has strong positive linear regression and correlation, where $R^2 = 99.7$ (figure 1).

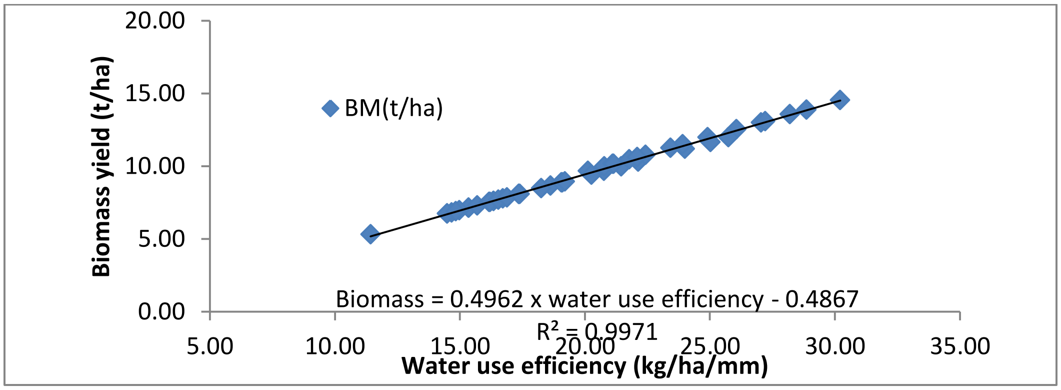

Figure1: Relationship between water use efficiency and biomass (BM) yield of "Hawi" bread wheat, showing the good fit (R^2 = 0.9972) to the raw data ( )for the ploted linear equation ( ) of : Biomass yield = 0.4962 x water use efficiency -0.4867.

Evapo-transpiration (ET)

The effect of soil moisture depletion, growth stages and their interaction effect on evapotranspiration at vegetative stage were highly significant (P < 0.01). At vegetative stage all treatments were irrigated when 50 % of available soil water was depleted except for treatments D2V and D3V. The highest and the lowest ET were achieved from D1 and D3.The interaction effect of soil moisture and growth stages significantly affected ET as shown in figure 3. The treatments D2V and D3V gave the lowest ET of about 5.30 and 5.47 mm/day, respectively, compared with D1V and were significantly different from all other stages (Table 5). The reason that D2 gave lower ET than D3 was animal incident grassed the leaves after germination. The SMD levels applied at different growth stages significantly affected ET at vegetative, flowering and grain filling stages (Table 4). This result agreed with the report of Padhi *et al*. (2010) who reported when soil moisture depletion increased, ET linearly decreased until the soil water reaches the permanent wilting point level in the soil. Also Sesen and Yasar (2006) reported that ET significantly decreased by water stress.

The interaction effect between soil moisture depletion and GRs was significant at grain filling stage only. The treatment 75 % SMD level (D3G) gave highest ET of about 6.93 mm/day because irrigation amount during grain filling stage was higher than 50 and 60% SMD levels. Also the treatment 60% SMD level (D2G) gave the lowest ET during grain filling stages (Figure 2). The interaction effect between SMD levels and biomass, straw yield and water use efficiency for biomass was not significant. But the treatment D1F gave the highest BM, SY and WUE_b for biomass, while the treatment D2G gave the lowest BM, SY nad WUEb for biomass (Table 5)

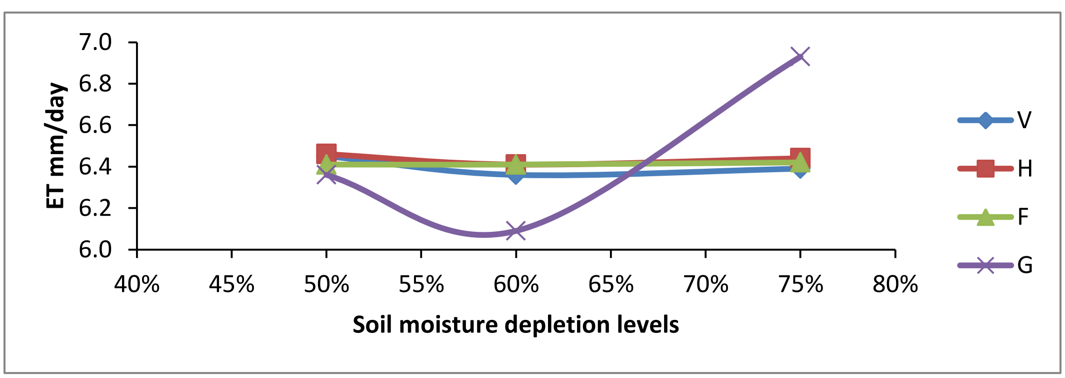

Figure 2: The interaction effect between soil moisture depletion levels and growth stages on evapotranspiration at grain filling stage.

Table 2: Effect of soil moisture depletion on growth of "Hawi" bread wheat

Soil moisture depletion level (SMD)	Vegetative stage			Grain filling stage		
	Plant height (cm)	Fresh weight (Kg/ha)	Dry matter (kg/ha)	Plant height (cm)	Fresh weight (Kg/ha)	Dry matter (kg/ha)
D1 (50%)	33.4	31.9	9.6	79.45	63.6	29.5a
D2 (60%)	33.2	30.2	9.1	78.45	58.9	25.8b
D3 (75%)	32.9	32.4	8.9	78.31	57.5	26.0b
LSD (0.5)	NS	NS	NS	NS	NS	2.946
CV (a) %	8.30	10.33	11.29	1.97	15.48	12.57
Stages						
V	31.31b	26.04c	8.64b	78.66	62.2	28.0a
H	33.66a	33.53a	8.93ab	79.81	60.6	28.0a
F	33.55a	30.89b	9.42ab	78.48	60.6	25.1b
GF	34.14a	35.59a	9.828a	78.00	56.5	27.3a
LSD (0.5)	2.016	3.743	0.947	NS	NS	1.989
CV (b) %	6.56	17.29	12.31	4.71	10.74	8.49

NOTE:- Means in the same column with the same letters are not significant at P < 0.05 or P < 0.01 by Fishers' LSD. NS = not significant; HI = harvest index, TSW= thousand seed weight, WUE= water use efficiency;V = vegetative, H = heading, F= flowering and G= grain filling stage, D1, D2, D3 represent 50, 60 and 75% SMD levels, respectively.

Table 3: The effect of interaction between soil moisture depletion and growth stages on yield and some yield components of bread wheat (var. Hawi) grown in semi-arid condition

Interaction (SMD*GS)	Vegetative stage			Grain filling stage		
	Plant height (cm)	Fresh weight (Kg/ha)	Dry matter (kg/ha)	Plant height (cm)	Fresh weight (Kg/ha)	Dry matter (kg/ha)
D1 * V	34.1	28.70	9.10	80.93	66.20	30.4ab
* H	32.21	30.60	9.30	80.90	63.80	31.7a
* F	34.26	31.80	10.20	79.14	64.30	29.5ab
* GF	33.18	36.70	9.70	76.84	60.10	26.4bcd
D2 * V	30.28	25.2	8.20	79.06	62.50	27.5bc
* H	4.67	35.00	9.80	79.58	58.80	24.2cde
* F	33.24	29.60	8.90	78.99	59.20	23.2de
* GF	34.46	31.00	9.50	76.16	55.10	28.1ba
D3 * V	29.59	24.2	8.60	75.99	58.00	26.1bcd
* H	34.10	35.00	7.7	78.95	59.20	28.0ba
* F	33.15	31.20	9.20	777.32	58.40	22.5e
* GF	34.76	39.10	10.20	80.99	58.40	27.5bc

LSD (0.05)	NS	NS	NS		NS	NS	3.446
CV (a*b)%	10.58	20.14	16.70		5.11	18.84	15.17

Note:- Means in the same column with the same letters are not significant at P< 0.05 or P< 0.01 by Fishers' LSD; All abbreviations are as mentioned in the table 2

Table 4: Effect of soil moisture depletion levels on biomass and evapotranspiration of "Hawi" bread wheat grown under semi-arid of Ethiopia

Soil moisture depletion (SMD)	Biomass yield (t/ha)	Straw yield (t/ha)	WUE_b (kg/ha/mm)	Evapotranspiration (mm/day)			
				Vegetative stage	Heading stage	Flowering stage	Grain filling
D1	11.71a	8.6a	24.33a	5.86a	6.37	6.20b	6.42b
D2	9.27b	6.9b	19.90b	5.68c	6.46	6.47a	6.32c
D3	7.44c	5.3c	16.00c	5.76b	6.29	6.30ab	6.55a
LSD (0.05)	1.69	1.255	3.317	0.070	NS	0.210	0.062
CV(a) %	19.1	20.9	19.11	1.41	2.99	3.84	2.87
V	9.29	6.9	19.7	5.54c	6.30b	6.34ab	6.40
H	9.58	7.0	20.29	5.87a	6.55a	6.22b	6.44
F	9.58	6.9	20.29	5.80b	6.34b	6.47a	6.41
G	9.45	7.0	20.02	5.86ab	6.30b	6.26b	6.46
LSD(0.05)	NS	NS	NS	0.069	0.114	0.170	NS
CV(b) %	12.08	14.8	12.1	1.64	1.41	3.36	1.35

Note: All abbreviations are as mentioned in the table 2

Table 5: Effect of interaction between soil moisture depletion and growth stages on biomass and water use efficiency for biomass and evapotranspiration of "Hawi" bread wheat

Interaction (SMD*GS)	Biomass yield (t/ha)	Straw yield (t/ha)	WUE_b (kg/ha/mm)	Evapotranspiration (mm/day)			
				vegetative	heading	flowering	Grain filling
D1*V	10.8	8.0	5.93	5.86a	6.33	6.24	6.45b
D1*H	12.5	9.2	6.9	5.88a	6.47	6.21	6.46b
D1*F	11.8	8.6	6.91	5.82ab	6.34	6.22	6.41b
D1*G	11.7	8.6	6.36	5.88a	6.35	6.15	6.36b
D2*V	8.5	6.3	4.9	5.30d	6.42	6.42	6.36b
D2*H	9.1	6.5	5.11	5.87a	6.79	6.39	6.41b
D2*F	9.5	7.0	5.38	5.72b	6.37	6.70	6.41b
D2*G	10.0	7.6	4.98	5.85a	6.29	6.37	6.09c
D3*V	8.5	6.3	4.73	5.47c	6.16	6.35	6.39b
D3*H	7.2	5.1	4.48	5.86a	6.40	6.07	6.44b
D3*F	7.3	5.2	4.65	5.86a	6.32	6.50	6.42b
D3*G	6.7	4.7	4.26	5.85a	6.26	6.27	6.93a
LSD(0.05)	NS	NS	NS	0.1209	NS	NS	0.115
CV(a*b) %	22.7	25.63	19.9	2.16	3.31	5.10	3.17

Note: All abbreviations are as mentioned in the table 2

4. CONCLUSION

In general, increasing SMD levels reduced evapotranspiration due to the less available water for wheat consumption. Increasing moisture depletion levels decreased the dry matter, biomass yield and water use efficiency for biomass of bread wheat (Hawi, *var*.). Irrigating wheat crop when 50% of available soil moisture is depleted produced highest plant height, dry matter, biomass and water use efficiency for biomass of the “Hawi” wheat grown under semi arid in Ethiopia. Finally, there is need for further research on the effect of soil moisture deficit on yield and yield components of the ‘Hawi’ Bread wheat grown in semi arid condition in Ethiopia.

5. ACKNOWLEDGEMENTS

The authors would like to the thank Rural Capacity Building Project coordinator at Ministry of Agriculture and Rural Development (MOARD) of Ethiopia and Somali Region Pastoral and Agro-pastoral Research Institute (Sorpari) who granted the scholarship to the first author. Grateful thanks are due to Associate Professor, Dr. Rungsarit Kaveeta, Department of Agronomy, Faculty of Agriculture, Kasetsart University who assisted in data analysis and interpretation.

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