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Wheat response to water stress condition at different growth stages in Amibara, Ethiopia

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To evaluate the effect of water stress at different crop growth stages on yield, yield components and water use efficiency, a field experiment was carried out in 2015/2016, 2016/2017 and 2017/2018 for bread wheat (Gambo variety) at Werer Agricultural Research Center. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications having 15 experimental treatments. Combination of water stress with crop growth stages was applied in the major investigation of the experiment. The highest grain yield was obtained from the control treatment irrigation at all stages (no stress). Stressing irrigation water at initial stages and maturity stages gave second highest yield (29.23 and 28.57 qt/ha) and lower water use efficiency (0.43 and 0.35 kg/m^3) respectively. While irrigating only at the initial stage gave highest water use efficiency (0.79 kg/m^3) and lowest grain yield. Application of irrigation water at all stages except initial and maturity gives optimum grain yield (26.73 qt/ha) and water use efficiency (0.62 kg/m^3) for the study area. Therefore, wheat should not be stressed at development and mid stage to obtain optimum water use efficiency (WUE) without a significant grain yield reduction.

Key words: Grain yield, growth stages, water use efficiency, irrigation.

INTRODUCTION

Agricultural sector plays a major role in poverty reduction for sub-Saharan African countries; almost half of its population currently remains under poverty line (World Bank, 2016). The agriculture sector is not only the determinant of economic growth but also an activity of essential importance in social development, being the largest sector that contributes to almost two third of employment and gross national income of these nation.

Among scarce natural resource water is mainly used by irrigated agriculture. Of the total water withdrawals 70% and more than 60 to 80% of total water consumptive use is utilized by irrigation (Huffaker and Hamilton, 2007). By 2025, the irrigated land should have to increase by more than 20% and the irrigated crop yield should be increased by 40% to secure food for about 8 billion people (Lascano and Sojka, 2007). Considering this fact, the productivity of agricultural water is highly demanding investigation to gain experience in improving performance, efficiency and profitability of utilized water for irrigation (Sleper et al., 2007).

The target crop wheat (*Triticum aestivum* L.) is one of the vital food crops in the world with an average yield of

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3.00 ton/ha (FAO, 2013). The production of wheat in Africa lays under 10-20% of its potential. Wheat is widely produced in Ethiopian highlands and mid-altitudes. Out of 18 major Agroecological zones in the country, it is grown in more than eight of the Ethiopian zones (ATA, 2014). The production trend of wheat in Ethiopia is increased by 45% from 2.92 million tons in 2012 to 4.23 million tons in 2016 and area of cultivation increased by 16% from 1.43 million ha in 2012 to 1.66 million ha in 2016, and the national average wheat productivity increased by 21% from 2.1 t/ha in 2012 to 2.54 t/ha in 2016. The country also has the potential of 300,000 ha of land for irrigated wheat production in the lowlands and 1.66 million hectares which are currently developed under rain fed. Recent research for development initiatives across Africa indicates that physically possible and economically profitable to grow more wheat and attain greater wheat self-sufficiency through effective application of proven, scalable and transformative wheat technologies (Wheat for Africa Updates, 2017).

Among the agricultural operations, irrigation is determinant of yield level; but it is a very decisive limiting factor whenever water is applied insufficiently. Under any case, application of irrigation water should be managed with intelligence to make the best use of it. Poor management of irrigation water has serious adverse effects, such as crop water stress due to waterlogging and hypoxia in root zone, nutrient loss with drainage water, pollution, water loss, soil salinity and increased susceptibility of crops to root diseases. Therefore, given the fact that proper utilization of irrigation water is a challenge, and of importance for irrigated wheat crop production to ensure food self-sufficiency for the country, it is paramount to generate technologies, knowledge and information suitable for sustainable use of soil and water resources. As a result, there is a promise of improving irrigated crop productivity under arid and semi-arid regions, thus further increasing the effectiveness and efficiency of the national endeavor. The objective of this experiment is to identify the stages of crop growth that are sensitive to water stress; to determine critical times for application of irrigation water in similar areas where there is limited water resources, and to determine the water productivity of wheat crop under stressed conditions.

MATERIALS AND METHODS

Description of study area

The study was conducted at Werer Agricultural Research Center Ethiopia, located at 9°16'N latitude and 40°9'E longitude, with a mean altitude of 750m m.a.s.l. The soil at the experimental site was Vertisol with bulk density of 1.17 g/cm^3. The field capacity and permanent wilting point on a mass basis were 46 and 30.4%, respectively. The climate of the area is characterized as semi-arid with bi-modal low and erratic rainfall pattern, with annual average of 590 mm. The mean temperature varies from 26.7 to 40.8°C. The total monthly rainfalls of the study area during the growing season are described in Table 1.

Experimental design

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications having 15 experimental treatments using bread wheat (Gambo variety). A Combination of water stress with the crop growth stages was applied in the major investigation of the experiment.

Soil-water measurement

Irrigation water was applied as per the treatment to refill the crop root zone depth close to field capacity. The amount of irrigation water applied at each irrigation was measured using Parshall flume. Soil moisture content before irrigation was monitored gravimetrically at different depths intervals up to maximum root depth to determine optimal irrigation scheduling. Each of the treatments received an irrigation depth of 54 mm for establishment. The appropriate growing stages date and establishment date were obtained from FAO 56. The treatment description, combinations, irrigation depth and number of irrigations for each treatment are described in Table 2.

Crops and management

The 'Gambo=Quaiu # 2' wheat variety, which is recommended for lowlands and irrigated farming system was used for the trial. Sowing generally starts at mid of October and harvesting in early January. The experimental plot size was 5x10m sown in eight ridges with two side plants. The samples were taken manually from the inside of six ridges from each experimental plot.

Assessment of water productivity

Water productivity has been estimated as a ratio of grain yield to the total crop evapotranspiration (ETc) through the growing season and it has been calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$CWP = (Y/ET)$$

Where, CWP is crop water productivity (kg/m³), Y is crop yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m³/ha).

Statistical analysis

Yield and yield components data, also water productivity data were analyzed using statistical analysis system (SAS package) version 9. The Generalized Linear Model (GLM) procedure was applied for the analysis of variance. Mean comparisons were carried out to estimate the differences between treatments. Least significance difference (LSD) at 5% probability level was used to compare treatments.

RESULTS AND DISCUSSION

Plant height

Water stress at different growth stages showed a very high significant difference on height of wheat ($p<0.000$, Table 3). The highest plant height (57.72 cm) was determined at a treatment of irrigating all stages except

Table 1. Total monthly rainfall of the study area during cropping season.

Month	Rainfall (mm) during cropping season		
	2015/2016	2016/2017	2017/2018
October	0	31.2	0
November	6.5	21.2	0
December	0	0	0
January	0.5	0	0
Total	7	52.4	0
Effective rainfall	0.3	26.3	0

Source: Werer Agricultural Research Center Agro-Meteorological Observatory Station.

Table 2. Treatments combinations, irrigation depth and number of irrigations.

Treatment	Growth stage				Irrigation depth (mm)	Number of irrigations	Total irrigation amount (mm)
	Initial	Development	Mid-season	Maturity			
Irrigated at all growth stages	1	1	1	1	54.76	15	821.4
Irrigated at all stages, except the initial stage	0	1	1	1	54.76	13	711.88
Irrigated at all stages, except the development stage	1	0	1	1	54.76	11	602.36
Irrigated at all stages, except the mid- stage	1	1	0	1	54.76	11	602.36
Irrigated at all stages, except the maturity stage	1	1	1	0	54.76	13	711.88
Irrigated at all stages, except initial and development	0	0	1	1	54.76	8	438.08
Irrigated at all stages, except initial and mid	0	1	0	1	54.76	8	438.08
Irrigated at all stages, except initial and maturity	0	1	1	0	54.76	8	438.08
Irrigated at all stages, except development and mid	1	0	0	1	54.76	6	328.56
Irrigated at all stages, except development and maturity	1	0	1	0	54.76	8	438.08
Irrigated at all stages, except mid and maturity	1	1	0	0	54.76	8	438.08
Irrigated only at maturity stage	0	0	0	1	54.76	3	164.28
Irrigated only at mid stage	0	0	1	0	54.76	5	273.8
Irrigated only at development stage	0	1	0	0	54.76	5	273.8
Irrigated only at initial stage	1	0	0	0	54.76	3	164.28

1 means irrigated and 0 means not irrigated during the crop growth stages.

maturity (stressing at maturity) and has no significant differences with a treatment of irrigating all growth stages (no stressing). The minimum plant height (31.42 cm) was determined at a treatment of irrigating only at maturity stage and this is significantly lower than all other treatments.

Effective tiller

Water stress at different growth stages of wheat has shown a significant difference in effective tiller. The highest effective tiller (8.25) was determined at a treatment of irrigating all stages except initial stage (stressing at initial stage) and the minimum (4.72) was determined at a treatment of irrigating only the maturity stage. Both have a significant difference with the other treatments.

Spike length

Spike length was highly affected by water stress at different growth stages of wheat ($p < .0001$; Table 3). The maximum spike length (8.90 cm) was determined when all stages were irrigated except the mid-season stage; and it is significantly different from all the other treatments. The minimum spike length (6.08 cm) was

Table 3. The 15 irrigation treatments on wheat yield and its components.

Treatment	PH (cm)	ET	SL (cm)	NS/S	NK/S	GY (qt/ha)	WUE (kg/m^3)
Irrigated at all growth stage	56.92^{a}	6.61^{abc}	8.75^{ab}	**14.64^{a}**	32.53^{ab}	**29.93^{a}**	0.36^{ef}
Irrigated at all stages, except the initial stage	56.69^{ab}	**8.25^{a}**	8.42^{ab}	13.44^{abc}	31.97^{abc}	29.23^{a}	0.43^{bcdef}
Irrigated at all stages, except the development stage	50.00^{abcde}	6.64^{abc}	8.71^{ab}	13.5^{abc}	28.68^{abcd}	25.46^{ab}	0.43^{bcdef}
Irrigated at all stages, except the mid- stage	52.50^{abcde}	7.56^{ab}	**8.90^{a}**	14.33^{ab}	31.37^{abc}	19.43^{bcd}	0.33^{f}
Irrigated at all stages, except the maturity stage	**57.72^{a}**	6.03^{bc}	8.69^{ab}	14.83^{a}	**35.23^{a}**	28.24^{a}	0.40^{def}
Irrigated at all stages, except initial and development	44.17^{de}	7.53^{ab}	7.64^{b}	12.19^{bc}	25.51^{cde}	15.07^{cde}	0.33^{f}
Irrigated at all stages, except initial and mid	49.61^{abcde}	6.08^{bc}	8.71^{ab}	12.94^{abc}	28.57^{abcd}	15.07^{cde}	0.35^{f}
Irrigated at all stages, except initial and maturity	53.81^{abcd}	7.11^{ab}	8.50^{ab}	13.17^{abc}	27.03^{bcde}	**26.73^{ab}**	**0.62^{ab}**
Irrigated at all stages, except development and mid	45.64^{cde}	6.42^{abc}	8.57^{ab}	13.83^{abc}	23.61^{de}	13.41^{de}	0.41^{cdef}
Irrigated at all stages, except development and maturity	50.61^{abcde}	6.56^{abc}	8.71^{ab}	14.28^{ab}	29.22^{abcd}	24.18^{ab}	0.56^{bcd}
Irrigated at all stages, except mid and maturity	54.83^{abc}	6.89^{ab}	8.44^{ab}	14.17^{abc}	27.98^{bcd}	22.66^{abc}	0.50^{bcdef}
Irrigated only at maturity stage	31.42^{f}	4.72^{c}	**6.08^{c}**	9.69^{d}	20.17^{e}	9.72^{e}	0.60^{abc}
Irrigated only at mid stage	43.39^{e}	6.69^{ab}	7.78^{ab}	12.53^{abc}	23.07^{de}	12.89^{de}	0.46^{bcdef}
Irrigated only at development stage	47.19^{bcde}	6.89^{ab}	7.93^{ab}	11.81^{cd}	23.91^{de}	15.54^{cde}	0.56^{bcde}
Irrigated only at initial stage	46.69^{cde}	6.69^{ab}	8.75^{ab}	13.94^{abc}	26.23^{bcde}	12.90^{de}	**0.79^{a}**
CV (%)	21.02	31.07	15.76	19.23	26.89	41.09	45.19
LSD (0.05)	9.698	1.947	1.222	2.386	6.948	7.685	0.201
p	<.0001	.0596	<.0001	.0003	<.0001	<.0001	<.0001

PH: Plant height, ET: Effective tiller, SL: Spike length, NS/S: Number of spikelets per spike, NK/S: Number of kernels per spike, GY: Grain yield, and WUE: Water use efficiency. Means followed by different letters in a column differ significantly and those followed by same letter are not significantly different at p<0.05 level of significance. Bold font entries highlight the most significant results of interest.

determined when the irrigation treatment was applied only at a maturity stage.

Number of spikelet per spike

The number of spikelets per spike of wheat was significantly influenced by water stress at different growth stages (Table 3). The highest number of spikelets per spike (14.83) was determined at irrigation of all stages except maturity, and this has no significant difference with treatment of irrigation at all stages. The minimum number of spikelets per spike (6.08) was determined when irrigation was applied only at the maturity stage.

Number of kernel per spike

The number of kernels per spike of wheat was highly significantly influenced when water stress was applied at different growth stages ($p < 0.0001$, Table 3). The maximum number of kernel per spike (29.22) was determined from treatment of irrigation of all stages except maturity (stressing at maturity) and has shown significance difference from the other fourteen treatments (Table 3). The minimum number of kernels per spike (20.17) was determined at irrigation only at the maturity stage (stressing all stages except maturity).

Grain yield

Water stress at different growth stages showed a very highly significant influence on grain yield of wheat ($p<0.0001$, Table 3). The highest grain yield (29.93 qt/ha) was obtained at a treatment of irrigation of all stages (no stress) and this has no significance differences with the treatment of irrigation of all stages except initial stage (stressing at initial stage) and irrigation of all stages except maturity (stressing at maturity) treatment (Table 3). The minimum grain yield (9.72 qt/ha) was obtained at a treatment of irrigation only at maturity stage. Three treatments, irrigation all stages except development, irrigation all stages except initial and maturity, and irrigation all stages except development and maturity showed statistically no significance difference on grain yield of wheat. The grain yield of wheat is reduced with increased stress, whereas the water use efficiency increased with stress level increased (Meskelu et al., 2017)***.*** The relationship between grain yield, water use efficiency and seasonal irrigation depth are illustrated in Figure 1.

Water use efficiency (WUE)

The water use efficiency of wheat was significantly influenced due to water stress at different growth stages

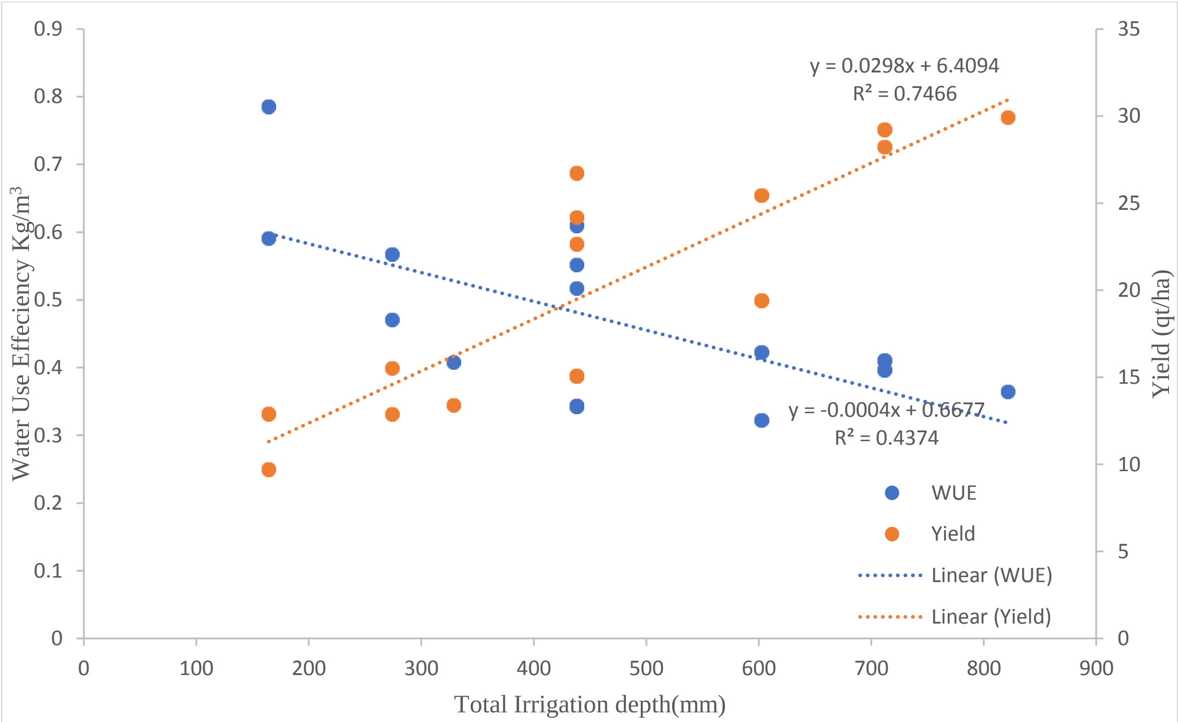

Figure 1. Relationship between grain yield, water use efficiency and seasonal irrigation depth. The r-square value for the regression estimate for yield (r^2 ~ 0.75) is substantially higher than that for the regression estimate of WUE (r^2 ~ 0.44) and reflects the greater scatter in the plotted points for WUE compared to yield.

(p<0.001). The WUE level depends on the controlled range of water stress applied at different crop growth stages. The results showed that the highest water use efficiency (0.79 kg/m^3) was obtained using a treatment of irrigation only at the initial stage. Treatments such as, stressing at mid, initial and development, initial and mid stages show statistically no significance differences and gave the lowest water use efficiencies (0.33 - 0.35 kg/m^3). Irrigation at all stages (no stress) treatments showed the second lowest water use efficiency (0.36 kg/m^3). This result also is consistence with previous experiments conducted at different countries on wheat crops (Galavi and Moghaddam, 2012; Pradhan et al., 2013).

Conclusion

Poor irrigation water management has adverse effects on water productivity, crop yield, yield components and environment. Irrigation water application at different crop growth stages determines the grain yield and water use efficiency. Irrigating wheat only at the initial stage gives a high-water use efficiency, but lower yield; and irrigation at all stages gave one of the lower water use efficiency values. In general, treatments applying irrigation at all stages, except initial and maturity, give optimal yield and better water use efficiency than the remainder of treatments in the experiment. So, stressing irrigation water at initial and maturity growth stages of wheat (Gambo variety) cultivated under irrigation shows better performance of the study area, in both yield and water use efficiency.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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