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To evaluate the effect of soil moisture stress at different crop growth stages on yield, yield components and water use efficiency, a field experiment was carried out in 2015/16, 2016/17 and 2017/18 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 were applied in the major investigation of the experiment. The highest grain yield was obtained from the control treatment irrigation all stages (no stress). Stressing irrigation water at initial stages and maturity stages gave second highest yield (29.23 qt/ha, 28.57 qt/ha) and lower water use efficiency (0.43kg/m^3, 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.

Keywords*:* Grain yield, Growth stages, Water use efficiency, Irrigation

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 60-80% 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).

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 (Kaur *et al*., 2020).

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 was to identify the stages of crop growth that are sensitive to Water stress; thereby to determine critical times for application of irrigation water in similar areas where there is a limited water resources, and to determine the water productivity of wheat crop under stressed conditions.

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The study was conducted at Werer Agricultural Research Center Ethiopia, located at 9º16'N latitude and 40º9'E longitude, with a mean altitude of 740 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 ^{0}C to 40.8 ^{0}C.

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.

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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 were applied in the major investigation of the experiment.

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 application 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 was obtained from FAO 56. The treatment description, combinations, irrigation depth and number of irrigations for each treatment are described in Table 2.

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

Treatments	Irrigation depth (mm)	Number of irrigations	Total irrigation amount (mm)
Irrigated at all growth stages	54.76	15	821.4
Irrigated at all stages, except the initial stage	54.76	13	711.88
Irrigated at all stages, except the development stage	54.76	11	602.36
Irrigated at all stages, except the mid- stage	54.76	11	602.36
Irrigated at all stages, except the maturity stage	54.76	13	711.88
Irrigated at all stages, except initial & development	54.76		

The wheat variety, which is recommended for lowlands and irrigated farming system was used for the trial (Esatu et al., 2020). Sowing is generally started at mid of October and harvesting in early January of the cropping season of the year from 2015-2018. 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.

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/m^3),

Y is crop yield (kg/ha) and

ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

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.

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Statistical analysis has shown a significant difference for plant height, effective tiller, spike length, number of spikelet per spike, number of kernel per spike, grain yield and crop water productivity under different irrigation treatments (Table 3).

Table 3: Presents the results of the 15 irrigation treatments on wheat yield and its components.

Treatment	PH (cm)	ET	SL (cm)	NS/S	NK/S	GY (kg/ha)	CWP (kg/m^3)
Irrigated at all growth stage	56.92^{a}	6.61^{abc}	8.75^{ab}	14.64^{a}	32.53^{ab}	2993^{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}	2923^{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}	2546^{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}	1943^{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}	2824^{a}	0.40^{def}
Irrigated at all stages, except initial & development	44.17^{de}	7.53^{ab}	7.64^{b}	12.19^{bc}	25.51^{cde}	1507^{cde}	0.33^{f}
Irrigated at all stages, except initial & mid	49.61^{abcde}	6.08^{bc}	8.71^{ab}	12.94^{abc}	28.57^{abcd}	1507^{cde}	0.35^{f}
Irrigated at all stages, except initial & maturity	53.81^{abcd}	7.11^{ab}	8.50^{ab}	13.17^{abc}	27.03^{bcde}	2673^{ab}	0.62^{ab}
Irrigated at all stages, except development & mid	45.64^{cde}	6.42^{abc}	8.57^{ab}	13.83^{abc}	23.61^{de}	1341de	0.41^{cdef}
Irrigated at all stages, except development & maturity	50.61^{abcde}	6.56^{abc}	8.71^{ab}	14.28^{ab}	29.22^{abcd}	2418^{ab}	0.56^{bcd}
Irrigated at all stages, except mid & maturity	54.83^{abc}	6.89^{ab}	8.44^{ab}	14.17^{abc}	27.98^{bcd}	2266^{abc}	0.50^{bcdef}
Irrigated only at maturity stage	31.42^{f}	4.72^{c}	6.08^{c}	9.69^{d}	20.17^{e}	972^{e}	0.60^{abc}
Irrigated only at mid stage	43.39^{e}	6.69^{ab}	7.78^{ab}	12.53^{abc}	23.07^{de}	1289de	0.46^{bcdef}
Irrigated only at development stage	47.19^{bcde}	6.89^{ab}	7.93^{ab}	11.81^{cd}	23.91^{de}	1554^{cde}	0.56^{bcde}
Irrigated only at initial stage	46.69^{cde}	6.69^{ab}	8.75^{ab}	13.94^{abc}	26.23^{bcde}	1290de	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

Code abbreviations. 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.

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

Water stress at different growth stages of wheat has shown a significant difference on 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 was highly affected by water stress at different growth stages of wheat (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 determined when the irrigation treatment was applied only at a maturity stage.

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.

The number of kernels per spike of wheat was highly significantly influenced when water stress was applied at different growth stages (Table 3). The maximum number of kernel per spike (29.22) was determined from treatment of irrigation all stages except maturity (stressing at maturity) and has showed 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).

Water stress at different growth stages showed a very highly significant influence on grain yield of wheat (Table 3). The highest grain yield (2993 kg/ha) was obtained at a treatment of irrigation 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 (972 kg/ha) was obtained at a treatment of irrigation only at maturity stage. Three treatments; i.e., irrigation all stages except development, irrigation all stages except initial & maturity, and irrigation all stages except development & maturity showed statistically no significance difference on grain yield of wheat. The grain yield of wheat is reduced with increased stress, whereas the crop water productivity increased with stress level increased (Meskelu *et al*., 2017).

The crop water productivity of wheat was significantly influenced due to water stress at different growth stages (Table 3). The WUE level depends on the controlled range of water stress applied at different crop growth stages. The results showed that the highest crop water productivity (0.79 kg/m^3) was obtained using a treatment of irrigation only at the initial stage. Treatments such as, stressing at mid, initial & development, initial & mid stages show statistically no significance differences and gave the lowest crop water productivity (0.33 0.35 kg/m^3, Table 3). Irrigation at all stages (no stress) treatments showed the second lowest crop water productivity (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).

Poor irrigation water management has adverse effects on water productivity, crop yield, 12(re)7(duc)4(e)4(d)-3TmMon4(m[s)]TJETBT1 0 0 16.73424 269.21 Tm[ )]TJETBT1

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