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Effect of Moisture Stress at Different Growth Stage on Wheat (*Triticum Aestevum L.*) Yield and Water Productivity at Kulumsa, Ethiopia

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Abstract

Water scarcity is among the major limiting factor that affects crop production in which efficient utilization of limited irrigation water is vital. A field experiment was conducted for two consecutive years at Kulumsa Agricultural Research Centre during the dry season based on the objective to determine the effect of moisture stress at different growth stages on yield and water productivity of wheat. Fifteen treatments combined and imposed at four growth stages were used in A Randomized Complete Block Design (RCBD) with three replications. The two years combined result indicated that moisture stress at different growth stages highly significant ($P < 0.05$) influenced plant height and grain yield of wheat. On the other hand, there was no significant ($p > 0.05$) variation among treatments on hectolitre weight, total kernel weight, and above-ground biomass. A maximum plant height of 70.5 cm was obtained when wheat is irrigated at the initial and development stages only. The highest grain yield (4.71 ton/ha) was obtained at control treatments where all the growth stage is irrigated which were followed by a treatment in which moisture stress happens only during the late season. On the other hand, the lowest grain yield (2.23 ton/ha) was obtained when wheat irrigated only during the late season, stressing the rest growth stages which leads to a reduction of 52.7% from the control treatment. Generally, the study showed that the grain yield of wheat was highly affected when moisture stress is imposed during the initial and development stages. In addition to this, the highest (4.71 ton/ha) and lowest (2.23 qt/ha) aboveground biomass were obtained at the control and when irrigation was applied only during the late season, respectively. The highest water productivity of 4.56 kg/m3 was obtained when only the initial stage is irrigated. Treatments that received lower irrigation water showed better water productivity especially when moisture stress was not imposed during the initial and development stages. Therefore, in areas where irrigation water is not limited, wheat should be irrigated during all growth stages and if there is limited water resource for irrigation water it could be irrigated only during the initial stages or initial and development stages to maximize water productivity.

Keywords: Growth Stages • Moisture stress • Wheat • Water Use Efficiency

Introduction

A growing worldwide population strongly increases the demands for clean water for different sectoral water uses (e.g. irrigation, domestic, energy, manufacturing uses) Climate change induced increases in the frequency and intensity of hydro-climatic extremes (e.g. droughts, floods), combined with increasing intensification of agriculture, industrialization, urbanization, and water extractions and uses, aggravate water quality deterioration, particularly in developing countries.

Irrigated agriculture is undoubtedly the largest consumer of freshwater, accounting for approximately more than two-thirds of the total freshwater use. It has been estimated that nearly 40% of the global food supply is produced by irrigation agriculture, which makes irrigation water becoming the largest single consumer of water on the earth. The shortage of irrigation water due to the competition of the industry and urban consumption threatens food security worldwide. It is crucially important to effciently manage irrigation and water consumption while maintaining or preferably yield through the development of technologies.

In the context of improving water productivity, there is a growing interest in water-saving practices like deficit irrigation, an irrigation practice whereby water supply is reduced below maximum level and mild stress in all or part of the growth stage of crops is allowed with minimal effects on yield.

Drought negatively affects crop growth and yield. Irrigation scheduling is an effective water management for overcoming soil water deficiency and improving yield [1]. Water stress prevents growth by diminishing the water turgor of the plant cells, which adversely affects biochemical and physiological processes in plants One of the primary physiological consequences of water deficit is the prohibition of photosynthesis, because of deficit in Ci (intercellular CO_2 concentrations) as a result of chlorophyll destruction, stomatal closure, and disorder of photochemical system .The production of Reactive Oxygen Species (ROS) is a physiological response of plants to drought stress. Increasing ROS can damage cell membranes by enhancing lipid peroxidation [2]. Plants have an extended defensive mechanism for mitigating the harmful effects of ROS via the activation of enzymatic and non-enzymatic antioxidants.Under conditions of scarce water supply and drought, these practiced in irrigated agriculture could lead to greater economic gains by maximizing yield per unit of water. Therefore, in areas with water shortages, it is important to see in which particular conditions to apply stress in crops. For example, this could be applied through selecting the tolerant growth stage of a particular crop which leads to higher water productivity. This enables irrigators to understand specific crop growth stages and the level of stress to be imposed to enhance water productivity as the yield response can vary depending on crop sensitivity at that growth stage [3,4].

The crop water need is related to moisture-sensitive periods [5]. Defined such periods as “certain development phases in which the plant is, or appeared by its observed response, to be more sensitive to moisture conditions than at other stages of development”. If moisture-sensitive periods could be identified for wheat crops under field conditions, it would have an important implication for irrigation practices.

Wheat is one of the vital food crops in the world in general and in Ethiopia in particular with an average yield of 3.00 and 2.11 t/ha, respectively (FAO, 2013; CSA, 2013). Different research reports worldwide revealed that wheat could be grown in different water-saving practices where there is a water scarcity for irrigation despite moisture stress that could affect its yield [2].

All stages of crop growth are not uniformly susceptible to water scarcity. On the other hand, some stages can cope-up with water shortage very well, while others are more susceptible and water shortages at such stages may result

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in distinct yield losses. Moisture stress is known to reduce biomass, tillering ability, grains per spike, and grain size at any stage when it occurs. So, the overall effect of moisture stress depends on the intensity and length of stress [6]. Water stress imposed during later stages might additionally cause a reduction in the number of kernels/ear and kernel weight [7]. Efficient and purposeful utilization of water is, therefore, important underwater shortage conditions. Because of the above consideration, the present study was conducted to determine the optimum water requirement for the wheat crop, identification of sensitive growth stages in wheat to water deficit conditions, and estimate the effect of drought on water relation and yield of wheat crop under climatic conditions of Kulumsa and similar agro-ecology of Ethiopia.

Materials and methods

Description of the study site

The experiment was conducted at Kulumsa Agricultural Research Center, Tiyo District, Arsi Zone of Oromia Region State, Ethiopia. The study area is situated at a latitude of 8.02°N and a longitude 39.15°E with an altitude of 2200 m above sea level. The climate condition of the study area is characterized by a sub-humid dry zone with a mean annual rainfall of 820 mm, among which most of the rain occurring in the main cropping season of spring and summer months. The mean minimum and maximum temperature is 7.71°C in December and 25.07°C in March, respectively. The most dominant soil texture of the study area is clay loam, with a bulk density of 1.25 g/cm^3. The mean moisture content at field capacity and the permanent wilting point is 33.6% and 21.8%, respectively; with total available water of 118 mm per meter depth of the soil.

Crop management and experimental design

The experiment was laid out in randomized complete block design with three replications. For this study, fifteen moisture stresses were imposed at different growth stages of wheat as treatment (Table 1). The land preparation and pre-irrigation were performed before sawing. Kingbird bread wheat Variety was sown by hand drilling in a row, with a seeding rate of 125 kg/ha. Plot size of 4.0 m x 5.0 m, was used and a seed was sown in a double row left and right of the ridge with a spacing of 20 cm. The recommended rate of N and P (73-30 kg N-P ha-1) were applied from di-ammonium phosphate and urea, respectively. Half dose of N and a full dose of P were applied during sowing as a basal application while the remaining half dose of N was applied at the tillering stage. All cultural practices were done to all treatments in accordance with the recommendation made for the area. Irrigation water was applied as per the treatment to refill the crop root zone depth at field capacity. A two-inch Parshall flume was used to measure irrigation water input for each treatment and irrigation was applied using the furrow irrigation method.

Table 1: Treatments combination.

Treatments	Description
1	Irrigate all growth stages (Check)
2	Irrigate all stages except initial stage
3	Irrigate all stages except development stage
4	Irrigate all stages except mid-season stage
5	Irrigate all stages except maturity stage
6	Irrigate all stages except initial and development stages
7	Irrigate all stages except initial and mid-season stage
8	Irrigate all stages except initial and maturity stages
9	Irrigate all stages except development and mid-season stages
10	Irrigate all stages except development and maturity stages
11	Irrigate all stages except mid-season and maturity stages
12	Irrigate only at maturity stage
13	Irrigate only mid-season stage
14	Irrigate only development stage
15	Irrigate only initial stage

Data collection and analysis

The grain data was collected from 3 m* 3 m net plot by excluding the border. Harvesting was performed when physiologically mature and the straw color turns to yellow. Above-ground biomass was determined by harvesting central rows from the net plot area at physiological maturity and weighed after sun drying to a constant weight and converted to a hectare basis. Grain yield was further adjusted to 12.5% moisture content. Yield, yield component, and growth parameters were recorded and the harvesting index was calculated using the following formulas.

$$Harvesting\ Index(\%) = \frac{Grain\ Yield\left(\frac{kg}{ha}\right)}{Biomass\left(\frac{kg}{ha}\right)} * 100$$

Water Productivity was calculated using the following formulas (Faramarzi et al., 2010):

$$Water\ Productivity\left(\frac{kg}{m^3}\right) = \frac{Grain\ Yield\left(\frac{kg}{ha}\right)}{Irrigation\ Amount\left(\frac{m^3}{ha}\right)}.$$

The collected data were subjected to analysis of variance using the Statistical Analysis System (SAS) software version 9.0 with the General Linear Model (GLM) procedure (SAS Institute Inc., 2002). Mean separation was employed using the Least Significant Difference (LSD) at 5% probability level to compare the differences among the treatments means.

Result and discussion

Plant height

The analysis of variance revealed that moisture stress at different growth stages of wheat had a highly significant ($P < 0.01$) effect on plant height (Table 2). A maximum plant height of 71.90 cm was obtained due to T-1 (Irrigate All Stages). However, the maximum plant height obtained at T-1 was statistically similar to plant height observed at treatment T-2, T-4, T-5, T-7, T-8, T-11, and T-14. On the other hand, the minimum plant height of 52.70 cm was observed at treatment T-13. However, the minimum plant height observed was statistically similar with treatment T-6, T-9, and T-12 (Table 2). The data showed that application wheat moisture stress during

Table 2: Effect of moisture stress at different growth stage on yield and yield component of wheat at Kulumsa during 2015/16 and 2016/17.

Treatments	PH (cm)**	HLW	TKW	HI	AGY**	ABY
1	71.9^{a}	225	29.6	44.9	47.1^{a}	85.7
2	67.8^{abc}	214	28.7	44.8	31.1^{cde}	59.9
3	60.2^{de}	210	24.8	43.3	29.8^{cde}	55.9
4	67.3^{abc}	209	26.5	44.4	35.8^{bc}	75.4
5	68.8^{ab}	211	28.4	45.5	42.9^{ab}	76.2
6	59.1^{ef}	191	26.6	45.2	24.1^{de}	49.8
7	65.8^{abcd}	210	28.3	43.1	28.1^{cde}	60.5
8	68.7^{abc}	210	28.6	45.3	35.3^{bc}	81.1
9	58.3^{ef}	205	24.6	40	27.7^{cde}	65.7
10	62.2^{cde}	199	29.3	46.6	28.9^{cde}	58.2
11	66.4^{abcd}	208	27.8	46	33.6^{bcd}	79.8
12	58.5^{ef}	212	24.3	44.7	22.3^{e}	45.7
13	52.7^{f}	218	25.8	44.5	22.9^{e}	60.1
14	64.1^{bcde}	207	27.5	45.6	31.2^{cde}	77.2
15	59.9^{de}	205	25.5	43.1	23.8^{de}	63.7
$LSD_{0.05}$	6.58	Ns	Ns	ns	9.93	ns
CV (%)	9	11.1	14.9	12.9	27.8	34.9

the initial and development stage (T-6) and, initial, development and mid growth stages (T-12) leads to a reduction of 17.80% and 17.39% from the control, respectively. This finding is in line with former reports of [8] who reported moisture stress at the initial stage has a lower effect during the early vegetation phase of the crop and thereafter it increased sharply.

Therefore, moisture stress at the development stage leads to a reduction of plant height highly. Different research findings also revealed that moisture stress affects plant height in wheat [9,10]. On the other hand, Akram (2011) reported that moisture stress only at anthesis stage (mid-season stage) have shown similar result with no stress treatment. This might be the total plant height growth accomplish during the development crop stage.

Hectoliter weight, thousand kernel weight, and harvesting index

The analysis of variance revealed that moisture stress at different growth stages of wheat had no significant ($p > 0.05$) influence on hector liter weight, thousand kernel weight, and harvesting index of wheat crop (Table 2). The recorded value of hectoliter weight ranges from 191 kg/hl to 225 kg/hl. The value of a thousand kernel weight ranges from 24.3 g to 29.6 g. The harvesting index ranges from 40.0% to 46.6%. This is in line with the former report of Elias *et al*. (2017) who reported different levels of moisture stress had no influence on the harvesting index [11]. also reported a similar finding due to moisture stress, despite different wheat varieties showed different harvesting indexes.

Grain and above ground total biological yields

The analysis of variance revealed that moisture stress at different growth stages of wheat had a highly significant ($P < 0.01$) effect on the grain yield of wheat (Table 2). A maximum grain yield of 47.1 qt/ha was obtained due to control (irrigation all stage) treatment. However, the highest grain yield obtained at the control treatment was statistically similar to the grain yield obtained when moisture stress was imposed only during maturity (late season). On the other hand, a minimum grain yield of 22.3 qt/ha was obtained when wheat irrigated only during the late season, stressing the rest growth stages. However, the minimum grain yield obtained when irrigation was applied only during the late season was statistically similar with all treatments except treatments 1, 5, 4, 8, and 11. The application of irrigation water only during the late season leads to a reduction of 52.7% than the control treatment. On the other hand, the comparable yield of wheat was obtained when moisture stress was applied during only the late season.

Generally, the study showed that moisture stress during initial and development stages affected grain yield highly especially when combined with other stages. This is in line with the former findings of Ashinie and Kindie (2011) who reported that grain yield per plant in wheat was affected by a maximum of 72% when moisture stress happens at tillering, as it happens from initial to development stages. The results are inconsistent with the former findings of Akram (2011) who reported a higher grain yield of wheat obtained at full irrigation. The finding is also in line with Elias *et al*. (2017) who reported moisture stress at all stages due to the reduction of irrigation depth significantly affected grain yield of wheat.

The analysis of variance revealed that moisture stress at different growth stages had a highly significant ($p < 0.01$) influence on aboveground biomass production of wheat (Table 2). The highest aboveground biomass of 47.1 qt/ha was obtained when irrigation water was applied in all stages (control treatment). However, the maximum aboveground biomass obtained at control treatment was statistically similar to the biomass obtained when irrigating all stages except at maturity. On the other hand, the minimum aboveground biomass of 22.3 qt/ha was obtained when irrigation water is applied only during maturity (T-12). However, the minimum aboveground biomass obtained at T-12 was statistically similar with all the treatments except 1, 4, 5, 8, and 11 (Table 2). The reduction of irrigation water from irrigation of all stages to irrigating only during the late-season (maturity stage), aboveground biomass was reduced by 52.7%. Generally, treatments that received lower irrigation water showed lower aboveground biomass production especially when the development stage is stressed.

Different researchers reported that moisture stress affects biomass production of crops in general and wheat in particular [9] Moisture stress in crop reduces chlorophyll content and damage the reaction center. The decreased aboveground biomass might be due to a reduction of the photosynthesis process as water is the major component and more than 90% of biomass production is from the photosynthesis process.

Similar finding was also reported on maize that, a trend of biomass production shows decreasing with increasing moisture stress indicating well-irrigated maize yields higher biomass production [12] .This might be due to increasing moisture stress, the dry matter production of crops decreases directly by decreasing cell division and enlargement as moisture stress affect photosynthesis.

Note: Means followed by the same letters in a column are not significantly different from each other at a 5% probability level.

Water use Efficiency (WUE)

Soil moisture stress at different growth stages of wheat has shown a highly significant ($p < 0.01$) influence on WUE (Table 3). The highest water productivity of 4.56 kg/m^3 was observed at T-15 treatment (irrigate only initial stage) which was followed by T-14. The maximum WUE observed at T-15 was statistically superior to all other treatments. On the other hand, the minimum water productive of 0.71 kg/m^3 was observed at T-2 treatment. However, this was not statistically different from WUE obtained at treatments of 1, 3, 4, 5, 6, 8, 10, and 13 (Table 3). Irrigating only the initial stage (T-15) and limiting other stages saved 83.64% of irrigation water. However, this

Table 3: Effect of moisture stress at different growth stage on water productivity, water-saving, yield reduction, and crop response factor at Kulumsa during 2015/16 and 2016/17.

TRT	Water Applied (mm)	Grain Yield (kg/ha)	Water Use Efficiency (kg/m^3)	Water Saved (%)	Yield Reduction (%)	Crop Response Factor(K_y)
T1	486.5	4705.2	0.94f	-	-	-
T2	406.9	3131.4	0.71f	16.36	33.45	2.04
T3	342.6	2975.8	0.79f	29.58	36.76	1.24
T4	324.5	3575.5	1.16ef	33.3	24.01	0.72
T5	385.5	4288	1.16ef	20.76	8.87	0.43
T6	263	2412.8	0.75f	45.94	48.72	1.06
T7	143.9	2807.7	2.45b	70.42	40.33	0.57
T8	305.9	3527	1.13ef	37.12	25.04	0.67
T9	180.6	2771.4	1.45de	62.88	41.1	0.65
T10	241.6	2892.4	1.16ef	50.34	38.53	0.77
T11	223.5	3363.3	1.95c	54.06	28.52	0.53
T12	101	2234.2	1.68cd	79.24	52.52	0.66
T13	162	2290.4	1.15ef	66.7	51.32	0.77
T14	143.9	3115.6	2.75b	70.42	33.78	0.48
T15	79.6	2384.3	4.56a	83.64	49.33	0.59

improvement in water productivity leads reduction of grain yield by 49.5% as compared to control treatment. Generally, treatments that received lower irrigation water showed better water productivity as compared to treatments that received higher irrigation water. When moisture stress is applied both at the initial and development stage water productivity highly is affected.

Different studies conducted on wheat reveal moisture stress affects the water use efficiency of irrigated wheat [13]. reviewed different research and concluded for field crops, a well-designed reducing irrigation water supply can optimize water productivity over an area when full irrigation is not possible. [14] reported that grain yield per plant in wheat was affected by a maximum of 72% when moisture stress happens at tillering which is the initial stage. Moreover, [15] reported that the greatest yield loss is associated when moisture stress that happen during the planting to the jointing stage. That why most of the treatments with irrigation at the initial stage scored higher water use efficiency than the other especially with treatments that received higher irrigation water [16-20].

Conclusion and Recommendation

The experiment was conducted at Kulumsa Agricultural Research Center; the maximum grain yield was obtained from full irrigation followed by irrigating all stages except the late-season. The result of the experiment showed that the maximum Water Use Efficiency (WUE) was obtained from irrigating only during the initial stage. The study revealed that stressing wheat crops at the initial and development stages highly reduces the grain yield and water use efficiency. The highest grain yield (47.1 qt/ha) was obtained at control treatments where all the growth stage is irrigated followed by a treatment in which moisture stress happens only during the late season. On the other hand, the lowest grain yield (22.3 qt/ha) was obtained when wheat irrigated only during the late season, stressing the rest growth stages which leads to a reduction of 52.7% from the control treatment.

Generally, the study showed that the grain yield of wheat was highly affected when moisture stress is imposed during the initial and development stages. In addition to this, the highest (47.1 qt/ha) and lowest (22.3 qt/ha) aboveground biomass obtained at the control and when irrigation applied only during the late season, respectively.

In conclusion, in areas where irrigation water resource is not scarce, application of full crop water requirement or holding irrigation water only during maturity stage is recommended. In areas where irrigation water is scarce holding irrigation water at all stages except initial and development stages to save a considerable amount of water for the production of wheat crop in the study area or similar agroecology and soil type.

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