academicresearchJournals

Vol. 5(2), pp. 90-97, March 2017
DOI: 10.14662/ARJASR2016.055

ISSN: 2360-7874
http://www.academicresearchjournals.org/ARJASR/Index.htm

Academic Research Journal of Agricultural Science and Research

Full Length Research

Effect of Moisture Stress on Yield and Water Use Efficiency of Irrigated Wheat (*Triticum aestivum* L.) at Melkassa, Ethiopia

Elias Meskelu[1]*, Abraham Woldemichael[2] and Tilahun Hordofa[3]

[1]Wondo Genet Agricultural Research Center, P.O.Box 198, Shashemene, Ethiopia; [2]Hawassa University, P.O.Box 05, Hawassa, Ethiopia; [3]Melkassa Agricultural Research Center
*Corresponding author's email: emeskelu@yahoo.com

Accepted 13 February 2017

Field experiment was carried out at Melkassa Agricultural Research Center, Ethiopia located 8°24'36'' to 8°26'24'' N and 39°19'12'' to 39°19'48'' E with altitude of 1550 m.a.s.l. The objective was to establish optimum moisture stress threshold level for improving water productivity of irrigated wheat under limited water resource scenario. Seven moisture levels (100% ET_C, 85% ET_C, 70% ET_C, 60% ET_C, 50% ET_C, 40% ET_C, and 30% ET_C) were imposed on wheat (*Triticum aestivum* L.) variety kekeba as a treatment and laid out in randomized complete block design with three replications. It was found out that different levels of moisture stress had a very highly significant (p<0.001) effect on plant height, spike length, number of grains per spike, aboveground biomass, grain yield, straw yield and water use efficiency. It also affected thousand seed weight highly significantly (p<0.01) and had no significant (p≥0.05) effect on number of tillers per square meter and harvesting index. Grain yield reduced with increased stress, whereas WUE was increased with stress level increased. The highest grain yield of 4559.0 kg/ha and WUE of 1.86 kg/m^3 were obtained at 100% ET_C and 30% ET_C, respectively. Moreover, 85% ET_C and 70% ET_C treatments showed no significant variation with 100% ET_C in grain yield. However, WUE observed at 70% ET_C treatment was significantly higher than 100% ET_C treatment. Grain yield obtained at 40% ET_C was significantly higher than that obtained at 30% ET_C though WUE of both treatments were statistically similar. Therefore, wheat could be irrigated at 70% ET_C to increase WUE without a significant grain yield reduction. Moreover, it could also be irrigated at 40% ET_C in areas where WUE is top priority with a compromise in grain yield reduction.

Keywords: Irrigation, moisture stress, water productivity, wheat

Cite this article as: Meskelu E, Woldemichael A, Hordofa T (2017). Effect of Moisture Stress on Yield and Water Use Efficiency of Irrigated Wheat (*Triticum aestivum* L.) at Melkassa, Ethiopia. Acad. Res. J. Agri. Sci. Res. 5(2): 90-97

INTRODUCTION

Water is a finite resource used in various sectors including agriculture, domestic and industrial (Pereira *et al*., 2009). The competition for both quality and quantity of water is alarmingly increasing from time to time due to human activities like population growth, urbanization, increased living standards, growing competition for water, and pollution. These are aggravated by climate change and variations in natural conditions (Pereira *et al*., 2009). However, the environmental resources like land and water are limited and even decreasing due to overexploitation, pollution and climate change (FAO, 2011).

Irrigated agriculture produces nearly 40% of food and agricultural commodities in the world with only 16% of cultivated land (Bos *et al*., 2008). However, it is the main water-consuming sector worldwide, which accounts 70 percent of the entire water withdrawn from aquifers, streams and lakes (FAO, 2011). Water is vital for crop production, which its shortage has an influence on crop yields. It is among the main limiting factors for productivity of agriculture worldwide, which is majorly due to the temporal and spatial variation of rainfall distribution and low amount of water available especially in arid and semi-arid areas (FAO, 2003).

The target crop wheat (*Triticum aestivum* L.) is one of the vital food crop in the world with an average yield of 3.00 t/ha (FAO, 2013). In Ethiopia, it is the fourth most important cereal crop in terms of both production volume and cultivated area, which grows mostly in highland areas. The average yield in the country is 2.11 t/ha (CSA, 2013). However, these areas are cultivated to their maximum potential continuously for a long time and the moisture stress in arid and semi-arid areas is the major limitation for cultivation of wheat though adequate arable land is available. On the other hand, wheat is successfully grown with reduced irrigation in different part of the world where scarcity of water resource for irrigation is common (Shao *et al*., 2011). Different research (Baozhen *et al*., 2014; Hamid *et al*., 2012) revealed that moisture stress affects wheat yield and improve water use efficiency. Moreover, when properly practiced, it enhances the quality of crop products like protein content of maize and wheat, quality of fiber in cotton, sucrose concentration of sugar beet and wine color density (FAO, 2002).

In Ethiopia, most of the highlands receive higher rainfall than the lowland arid and semi arid areas where rainfall in most cases is erratic and unreliable. In recent years, there is a significant decline in the main rainy season from June to September in different part of the country (Cheung *et al*., 2008). Therefore, determination of the effect of different levels moisture stress on water productivity is important to utilize the limited water resource without significantly affecting irrigated crop yield. The purpose of this study is to explore the level of minimum irrigation water application needed to improve the water productivity through establishing water stress threshold level for irrigated wheat (*kekeba* variety) under limited water supply condition.

MATERIALS AND METHODS

Description of experimental site

The study was conducted at Melkassa Agricultural Research Center Ethiopia, 8^{O}24'36" to 8^{O}26'24"N latitude and 39^{O}19'12" to 39^{O}19'48" E longitude at a mean altitude of 1550 m.a.s.l during 2015/2016 dry season. The soil at the experimental site was clay loam in textures with bulk density of 1.1 g/cm^3. The field capacity and permanent wilting point on mass base were 32% and 17%, respectively. The climate of the area is characterized as semi-arid with uni-modal low and erratic rainfall pattern with annual average of 822.3 mm. About 67% of the total rainfall of the area falls from mid-June to mid-September. The mean maximum temperature varies from 26.2^{O}C to 30.9 ^{O}C while mean minimum temperature varies from 10.7^{O}C to 16.3^{O}C (Table 1).

Experimental design and procedure

The experiment was laid out in randomized complete block design with three replications. The treatments consist of seven irrigation levels (100%ET_C (control), 85% ET_C, 70% ET_C, 60% ET_C, 50% ET_C, 40% ET_C and 30% ET_C). Wheat seed of variety *kekeba* (Picaflor#1) was sown by drilling manually in a row, after the land is prepared well and pre irrigated, with seeding rate of 125 kg/ha on 27th October, 2015. Plot size of 5 m x 3.6 m, which consists of 5 ridges spaced at 60 cm. Seed was sown in a double row in the ridge with spacing of 20 cm. Each plots were fertilized with 64 kg/ha N and 20 kg/ha P. Half dose of N and full dose of P were applied during sowing of wheat whereas the rest half dose of N was applied 35 days after planting.

The irrigation scheduling was done based on the optimum irrigation treatment (100% ET_C) and stressed treatments received lower amount based on their levels on the same irrigation date. Daily ETo was computed using CropWat model version 8.0 based on the daily climatic data collected from a weather station at the Center. Crop coefficient, optimum depletion level and root depth were adopted from FAO Irrigation and Drainage Paper 56 (FAO, 1998). Effective rainfall during the growing period was determined using the CropWat model on a daily basis based on the dependable rainfall. 3-inch Parshall flume was used to measure irrigation water input for each treatment and irrigation was applied using furrow irrigation method.

Crop sampling, harvesting and data collection

The crop was harvested on March 8, 2016 using a sickle at ground level just above the soil when the spikes were completely ripened and all the straw color turns to yellow. For grain yield and aboveground biomass yield, all the wheat discarding the outside rows and the end 50 cm of the plot both side (4 m x 1.8 m) area was harvested. Randomly five plants were collected for growth and yield

Table 1. Long-term monthly climatic data of the study area

Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Relative humidity (%)	Wind speed (m/s)	Sunshine hour (hr)	Rainfall (mm)
January	27.7	11.7	49.7	3.1	8.9	17.0
February	28.9	13.4	42.9	3.2	9.0	24.5
March	30.3	15.1	34.8	3.0	8.4	51.9
April	30.2	15.4	47.0	2.7	8.3	55.4
May	30.9	15.5	46.8	2.7	8.9	54.6
June	29.9	16.3	51.5	3.2	8.5	76.9
July	26.8	15.7	62.0	3.2	7.0	189.4
August	26.2	15.3	68.7	2.5	7.1	196.0
September	27.6	14.4	62.4	1.7	7.5	90.4
October	28.7	11.8	46.7	2.3	8.5	43.7
November	28.3	10.7	44.7	2.9	9.7	11.0
December	27.5	10.8	46.2	3.1	9.5	11.5

Source: Melkassa Agro-Meteorological Observatory Station

component data like plant height, spike length and number of grains per spike. Harvested samples were dried in sun for a week before data collected for aboveground biomass and for threshing. Data on grain yield was collected after threshing and cleaning manually and it was adjusted on 13.5% standard moisture content for wheat. Straw yield was calculated by subtracting grain yield from aboveground biomass, both in sun-dried condition. Thousand seed was counted using seed counter and weight was adjusted to the standard. Water use efficiency, harvesting index and yield response factor were calculated based on the following formulas (Chandrasekaran *et al*., 2010; FAO 2002).

$$WUE = \frac{GY}{I_n + RF_e} \qquad HI = \frac{GY}{AgBM} * 100\% \qquad K_y = \frac{1-(\frac{Y_a}{Y_m})}{1-\left(\frac{ET_a}{ET_m}\right)}$$

Where: - WUE: water use efficiency (kg/m^3); HI: harvesting index (%); GY: grain yield (kg/ha); AgBM: aboveground biomass (kg/ha); I_n: seasonal net irrigation depth (m^3/ha); RF_e: effective rainfall (m^3/ha); Y_a: actual yield of each treatment (kg/ha); Y_m: maximum yield from full irrigation treatment (kg/ha); ET_a: actual evapotranspiration of each treatment (mm); ET_m: maximum evapotranspiration by full irrigation treatment (mm) and K_y: yield response factor

Data were analyzed using statistical analysis system (SAS) version 9.0 procedure of general linear model for the variance analysis. Mean comparisons were carried out to estimate the differences between treatments using Fisher's least significant difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Different levels of moisture stress had significant effect on all recorded parameters except harvesting index. Yield and yield components were reduced with increased moisture stress due to decrease in irrigation amount, while water use efficiency improved. Based on this study, 70 and 40% ET_C are the maximum threshold levels in grain yield and WUE, respectively.

Crop water requirement: Seasonal crop water requirement varies based on the treatment level. The highest and minimum seasonal crop water requirement obtained was 423.2 mm and 146.0 mm at 100% ET_C and 30% ET_C, respectively (Table 2). The study reveals, high stress level leads to early maturity and optimum irrigation treatment matured a week after 30% ET_C treatment. The result is in line with Li *et al.* (2011).

Plant height: Plant height was very highly significantly affected ($p<0.001$) due to different levels of moisture stress (Table 3). Maximum plant height of 87.5 cm was obtained due to irrigation water application with optimum irrigation treatment, which was statistically similar with that of 85% ET_C and 70% ET_C. Minimum plant height of 62.3 cm was observed due to irrigation water application of 30% ET_C (Table 4). The decrease in irrigation level from 100% ET_C to 30% ET_C leads to a decrease of 28.8%. Plant height and other growth parameter are affected when there is moisture stress because of reduction in photosynthesis and reduce total biomass production of the plant. This finding is in line with different former findings on wheat (Maqbool *et al*., 2015; Guo *et*

Table 2. Seasonal net irrigation water depth applied for each treatment

Dates	Irrigation amount of treatments (mm)						
	100% ET_C	85% ET_C	70% ET_C	60% ET_C	50% ET_C	40% ET_C	30% ET_C
02.11.2015	27.2	27.2	27.2	27.2	27.2	27.2	27.2
19.11.2015	37.6	32.0	26.3	22.6	18.8	15.0	11.3
04.12.2015	72.0	61.2	50.4	43.2	36.0	28.8	21.6
16.12.2015	90.8	77.2	63.6	54.5	45.4	36.3	27.2
30.12.2015	90.8	77.2	63.6	54.5	45.4	36.3	27.2
14.01.2016	90.8	77.2	63.6	54.5	45.4	36.3	27.2
Effective R.F	14.2	14.2	14.2	14.2	14.2	14.2	14.2
Total	423.2	363.8	304.4	264.8	225.2	185.6	146

Table 3: Analysis of variance of yield and yield component

Source of variation	Degree of freedom	MS								
		PH	SL	NGPS	AgBM	GY	STY	TSW	WUE	HI
Replication	2	17.81^{ns}	0.113^{ns}	19.64*	122434^{ns}	921182^{ns}	629183^{ns}	1.50^{ns}	0.039^{ns}	5.64^{ns}
Treatment	6	141.62***	0.885***	59.12***	1350421***	11071797***	4121545***	6.38**	0.231***	4.29^{ns}
Error	12	7.17	0.075	3.75	48449	285788	167583	1.06	0.015	3.78
R^2		0.91	0.86	0.90	0.95	0.93	0.93	0.76	0.89	0.45

MS: mean squares, PH: plant height, SL: spike length, NGPS: number of grains per spike, AgBM: aboveground biomass, GY: grain yield, STW: straw yield, TSW: thousand seed weight, WUE: water use efficiency, HI: harvesting index. ***=very highly significant at $p<0.001$ level of probability, **=highly significant at $p<0.01$ level of probability, and *=significant at $p<0.05$ level of probability and ns= non-significant at $p<0.05$ level of probability.

Table 4. Yield components and yield of wheat as influenced by different moisture stress levels

Treatments	PH (cm)	SL (cm)	NGPS	AgBM (kg/ha)	GY (kg/ha)	STY (kg/ha)	TSW (g)	WUE (kg/m^3)	HI (%)
100% ET_C	87.5^a	8.3^a	44.1^a	12473.4^a	4559.0^a	7491.6^a	34.0^a	1.08^f	40.0
85% ET_C	84.5^{ab}	8.3^a	42.4^{ab}	11373.5^b	4399.9^a	6759.2^b	34.0^a	1.21^{ef}	40.7
70% ET_C	82.8^{ab}	8.3^a	40.3^{bc}	10725.5^b	4212.1^{ab}	6415.0^b	32.8^{ab}	1.38^{de}	40.2
60% ET_C	81.0^b	8.0^{ab}	37.9^{cd}	9699.1^c	3821.0^{bc}	5676.7^c	32.4^{abc}	1.44^{cd}	41.5
50% ET_C	76.2^c	7.6^b	37.1^{cd}	9250.0^c	3660.3^c	5318.7^c	31.6^{bcd}	1.63^{bc}	42.5
40% ET_C	74.9^c	7.5^b	36.6^d	7685.2^d	3161.4^d	4455.7^d	30.6^{cd}	1.70^{ab}	42.0
30% ET_C	62.3^d	6.9^c	30.6^e	7175.9^d	2719.2^e	4374.9^d	30.5^d	1.86^a	39.1
CV (%)	3.38	3.49	5.04	5.47	5.81	7.08	3.2	8.43	4.76
$LSD_{0.05}$	4.76	0.49	3.44	951.03	391.58	728.27	1.84	0.221	ns

PH: plant height, SL: spike length, NGPS: number of grains per spike, AgBM: aboveground biomass, GY: grain yield, STY: straw yield, TSW: 1000-seed weight, WUE: water use efficiency and HI: harvesting index. 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. ns: non-significant at $p<0.05$.

al., 2013; El Hwary and Yagoub, 2011).

Spike length: Different soil moisture levels on wheat showed a very highly significant ($p<0.001$) influence on spike length (Table 3). The highest spike length was observed at a control treatment (100% ET_C) and has no significant differences with irrigation applications of 85, 70 and 60% ET_C (Table 4). The minimum spike length was observed at 30% ET_C application and this is significantly lower than all other treatments. Spike length was reduced by 16.9% as the amount of irrigation water application reduced from 100% ET_C to 30% ET_C. Maqbool *et al.* (2015) and, El Hwary and Yagoub (2011) have reported similar findings.

Number of grains per spike: Grain per spike was very highly significantly ($p<0.001$) influenced due to the effect of different moisture stress levels (Table 3). Maximum number of grains per spike of 44.1 was obtained at 100% ET_C. On the other hand, the minimum number of grains per spike of 30.6 was obtained due to irrigation water application of 30% ET_C. The reduction of irrigation water amount from 100% ET_C to 30% ET_C reduced the number of grains per spike by 30.6%. This might be due to reduction in nutrient uptake, photosynthesis and translocation of food within the plant as moisture available in the soil reduced and plants stressed. Maqbool *et al*. (2015) and, El Hwary and Yagoub (2011) have reported similar findings on wheat. Tolessa *et al*. (2015) and Assefa *et al.* (2014) have reported a number of grains per spike for *kekeba* variety as 41.4 and 43.0, respectively.

Aboveground total biomass: The different soil moisture levels on wheat showed also a very highly significant ($p<0.001$) influence on aboveground total biomass (Table 3). The maximum and minimum above ground total biomass of 12473.4 kg/ha and 7175.9 kg/ha was scored at 100% ET_C and 30% ET_C, respectively (Table 4). Reduction of irrigation water amount from 100% ET_C by 15, 30, 40, 50, 60 and 70% reduced the biomass production by 8.8%, 14.0%, 22.2%, 23.4%, 38.4% and 42.5%, respectively. Different researchers reported similar result on wheat (Maqbool *et al*., 2015; Guo *et al*., 2013; Tavakoli and Moghadam, 2012). The decreased aboveground biomass in moisture stressed treatments might be due to reduction in photosynthesis in which amount of water and chlorophyll is important. According to Shamsi (2010), relative water content, proline, soluble carbohydrates and chlorophyll, chlorophyll content decreased with increased stress level. Moisture stress affects photosynthesis capacity through reduction of chlorophyll content and damage of the reaction center of photosystem (Guo *et al*., 2013). As the level of moisture stress increase, the amount of water applied is not sufficient for the production of higher biomass.

Grain yield: Different moisture stress levels on wheat has shown a very highly significant ($p<0.001$) influence on grain yield per hectare production (Table 3). The highest grain yield (4559.0 kg/ha) was obtained at a control treatment (100% ET_C) and has no significant differences with irrigation applications of 85% ET_C and 70% ET_C treatments. On the other hand, the minimum grain yield (2719.2 kg/ha) was observed at 30% ET_C application and this was statistically inferior to all other treatments (Table 4). Different studies conducted on wheat reveal moisture stress affects grain yield production of irrigated wheat (Maqbool *et al*., 2015; Guo *et al*., 2013; Tavakoli and Moghadam, 2012). The reduction of irrigation water from the 100% ET_C to 30% ET_C leads to reduction of grain yield by 40.4%. The data reveal that, reduction of irrigation water by 40, 50 and 60% from the optimum irrigation treatment reduced grain yield production per hectare by 16.2%, 19.7% and 30.7%, respectively. Moreover, grain yield obtained at different stress level had non-linear relation with seasonal irrigation depth (Figure 1). Different research showed that, wheat could tolerate moisture stress to some level either in its full growth season or in some particular growth stages. Tavakoli and Moghadam (2012) concluded wheat output could be substantially and consistently increased in semi-arid climate zone when 66% of full irrigation with appropriate management practiced.

As the stress level increase, soil get dries rapidly, the rate of absorption of water by roots falls short of transpiration. Thus internal water deficit in crop created. This affects photosynthesis and results in reduction of leaf area, cell size and assimilation of CO_2 to produce food. Thus, better water and nutrient availability contribute for better plant growth and yield of higher-level irrigation water treatments. Tavakoli and Moghadam (2012) report similar result in wheat.

Straw yield*:* Straw yield of wheat was very highly significantly ($p<0.001$) influenced due to different levels of moisture stress (Table 3). The highest straw yield (7491.6 kg/ha) was observed at a control treatment (100% ET_C) and it was superior to all irrigation application level treatments. The minimum straw yield (4374.9 kg/ha) was observed at 30% ET_C application and this has no significant difference with irrigation application of 40% ET_C treatment. Reduction of irrigation water amount from 100% ET_C to 30% ET_C reduced the straw yield production by 41.6%. Tavakoli and Moghadam (2012) reported similar results in wheat. According to Shamsi (2010), the effect of moisture stress reduces chlorophyll content, which leads to minimize biomass production.

1000-seed weight: The different soil moisture levels on

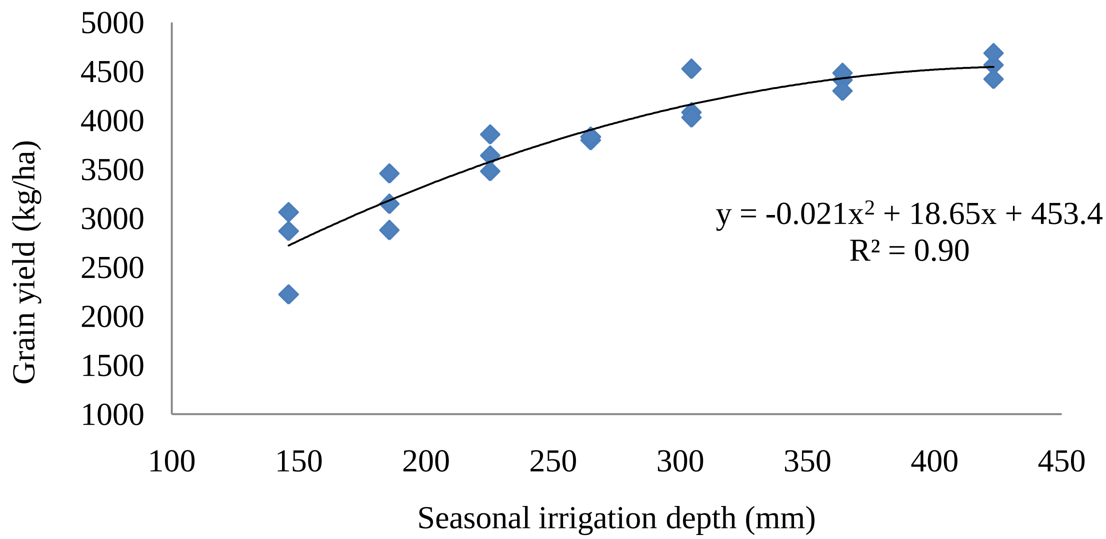

Figure 1. Relationship between grain yield of each plots and seasonal irrigation depth

wheat has shown a highly significant ($p<0.01$) influence on thousand seed weight (Table 3). The highest thousand seed weight (34.0 g) was observed at 100% ET_C and 85% ET_C and has no significant differences with irrigation applications of 70% ET_C and 60% ET_C. The minimum thousand seed weight (30.5 g) was observed at 30% ET_C(Table 4).Heavier seed weight observed at 100% ET_C and 85% ET_C might be due to more translocation of food processed in photosynthesis due to sufficient amount of water in root zone relative to other treatments. Different workers reported similar findings (Maqbool *et al*., 2015; El Hwary and Yagoub, 2011).

Water use efficiency (WUE): The different soil moisture stress levels on wheat has shown a very highly significant ($p<0.001$) influence on WUE (Table 3). The highest water use efficiency (1.86 kg/m^3) was observed at 30% ET_C treatment and has no significant difference with irrigation application of 40% ET_C. On the other hand, the minimum water use efficiency (1.08 kg/m^3) was observed at 100% ET_C application and this was not significantly different with 85% ET_C treatment. However, 70% ET_C treatment was significantly higher than 100% ET_C treatment, improving WUE by 27.8%, though statistical similarity was observed in grain yield (Table 4). The reduction of irrigation water from the 100% ET_C to 30% ET_C leads to improve water use efficiency of wheat by 72.2%. The data reveal that irrigation of wheat to 60% ET_C, 50% ET_C and 40% ET_C enhance water use efficiency by 33.3%, 50.9%, and 57.4%, respectively than the 100% ET_C treatment. The low water use efficiency for 100% ET_C may be attributed to higher irrigation water use, much of which was lost through soil evaporation and deep percolation. However, in stressed treatments, irrigation water might be used for productive purpose in the crop effectively. There was a non-linear relation between WUE and grain yield due to different moisture stress levels (Figure 2).

Different studies conducted on wheat reveal moisture stress affects water use efficiency of irrigated wheat (Pradhan *et al*., 2013). Shamsi *et al.* (2010) for instance reported that water use efficiency of wheat varied from 0.66 to 1.34 kg/m^3 between different irrigation regimes. Hamid *et al.* (2012) on the other hand found that irrigation of wheat below optimum level to some extent save about 22% of irrigation water with no significant loss in yield. Moreover, Tavakoli and Moghadam (2012) reported wheat could be irrigated to 66% of full irrigation with appropriate management to improve water use efficiency. Fereres and Soriano (2007) 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. Moreover, they concluded that relatively higher level of irrigation water supply, in most cases 60% of full requirement, should be applied for practicing deficit irrigation.

Harvesting index*:* The different soil moisture stress levels on wheat has shown no significant ($p>0.05$) influence on harvesting index (Table 3). However, average harvesting index varies from 39.1 to 42.5% (Table 4). This might be as the amount of irrigation amount reduced, both grain yield and aboveground biomass production reduced similarly. Khakwani *et al.* (2011) reported a similar finding on the study of different varieties at different stress levels, although different varieties show significant variation.

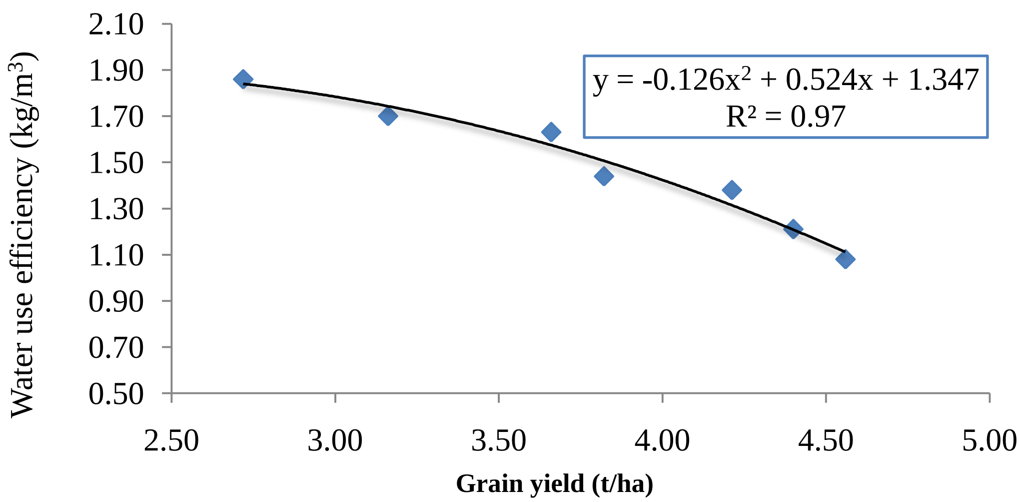

Figure 2. Relationship between grain yield and WUE due to different moisture stress levels

Yield response factor: The result reveals that lower yield response factor was associated with lower stressed treatments in which values of 85% ET_C, 70% ET_C, 60% ET_C, 50% ET_C, 40% ET_C and 30% ET_C were 0.23, 0.25, 0.41, 0.39, 0.51 and 0.58, respectively. The result reveals the sensitivity of yield increased as moisture stress increased. According to FAO (2002), yield response factor of different crops and different stress condition varies from 0.20 for tolerant crops to 1.15 for sensitive crops. Reducing irrigation water during practicing deficit irrigation in wheat at flowering and grain filling resulted a yield response factor of 0.39. Reduction of irrigation water amount during the entire growing season leads to yield response factor of 0.76 in wheat (FAO, 2002).

CONCLUSION

Moisture stress affects the phenology, which leads to earlier maturity. Shorter plant height and spike length was also resulted due to reduced irrigation depth. The number of grains per spike was reduced and lighter grain weight was observed as the irrigation water went down from 100% ET_C to 30% ET_C. Moisture stress at any level decreased aboveground biomass and straw yields. However, grain yield was not significantly affected until irrigation water reduced to 70% ET_C.

WUE enhanced by 72.2%, from 1.08 kg/m^3 to 1.86 kg/m^3 as irrigation water reduced from control to only 30% ET_C. Reducing irrigation water leads to improving WUE without grain yield reduction at 70% ET_C that leads to save 30% of irrigation water volume used in optimum irrigation, and with a yield reduction for more moisture stressed scenarios. Yield response factor was gradually increased, as the moisture stress level increased, from 0.23 to 0.58. The rate of grain yield reduction is amplified as the moisture stress level increased. Therefore, though water use efficiency is increased as the amount of irrigation water reduced, the grain yield penalty for the same amount of irrigation water saved was escalate as the moisture stress increased.

Therefore, the wheat variety *kekeba* should be irrigated up to 70% of the full irrigation amount based on irrigation water requirement as per the CropWat model in furrow irrigation and increasing WUE by 27.8% with seasonal net irrigation depth of 304.4 mm in the study area. However, for high water stressed area to enhance the water productivity, it could be irrigated to only 40% of the full irrigation amount. This could improve the water use efficiency to 1.70 kg/m^3 with a compromise of yield reduction by 30.7% with seasonal net irrigation depth of 185.6 mm, as grain yield is higher at 40% ET_C than 30% ET_C with statistically similar WUE.

ACKNOWLEDGEMENT

The authors are grateful to Land and Water Research Directorate, Ethiopian Institute of Agricultural Research, for providing funds for the experiment. They are also thankful to Melkassa Agricultural Research Center and staff members of Agricultural Water Management Research Department for their support and technical assistance in the field experimentation.

REFERENCES

Assefa Workineh, Berhanu Abate and Demelash Kefalle. 2014. Participatory evaluation and selection of bread wheat (*Triticum aestivum* L.) varieties: Implication for sustainable community based seed production and farmer level varietal portfolio managements at Southern Ethiopia. World Journal of Agricultural Research. 2 (6): 315-320.

Baozhen, H., Qingwu, X., Yinghua, Z., Stewart, B. and Zhimin, W. 2014. Deficit irrigation in winter wheat: The U.S. Southern High Plains and North China Plain. Journal of Arid Land Studies. 24 (1): 129-132.

Bos, M. G., Kselik, R. A. L., Allen, R. G. and Molden, D. J. 2008. Water requirements for irrigation and the environment. Springer, Dordrecht, Netherlands.

Chandrasekaran, B., Annadurai, K. and Somasundaram, E. 2010. A textbook of agronomy. New Age International. New Delhi, India.

Cheung, W.H., Senay, G. B. and Singha, A. 2008. Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. Int. J. Climatol. 28: 1723 – 1734.

CSA (Central Statistical Agency). 2013. Agricultural sample survey 2012/2013 (2005 E.C.) Report on area and production of major crops. Volume I.

El Hwary, T. B. and Yagoub, S. O. 2011. Effect of skipping irrigation on growth, yield, yield components and water use efficiency of wheat (*Triticum aestivum* L.) in semi arid region of Sudan. Agric. Biol. J. N. Am. 2(6): 1003-1009.

FAO (Food and Agricultural Organization). 2013. World food and agriculture statistical yearbook. FAO, Rome, Italy.

FAO (Food and Agriculture Organization). 2011. The State of the world's land and water resources for food and agriculture. Managing systems at risk. FAO, Rome, Italy.

FAO (Food and Agricultural Organization). 2003. World agriculture: Towards 2015/2030. An FAO perspective. Bruinsma, J (ed). Earthscan Publications, London.

FAO (Food and Agriculture Organization). 2002. Deficit irrigation practice. Water Reports Paper No.22. FAO, Rome, Italy.

FAO (Food and Agriculture Organization of the United Nations). 1998. Crop evapotranspiration guidelines for computing crop water requirements. Irrigation and Drainage Paper 56. FAO, Rome.

Fereres, E. and Soriano, M. A. 2007. Deficit irrigation for reducing agricultural water use. Journal of Experimental Botany.58 (2): 147–159.

Guo, R., Hao, W. P., Gong, D. Z., Zhong, X. L. and Gu, F. X. 2013. Effects of water stress on germination and growth of wheat, photosynthetic efficiency and accumulation of metabolites. In: Soriano, M. H. (ed). Soil processes and current trends in quality assessment. Chapter 13. InTech. Rijeka, Croatia.

Hamid, D. J., Karim, N. N. and Mohsen, A. 2012. Effect of deficit irrigation regimes on yield, yield components and some quality traits of three bread wheat cultivars (*Triticum aestivum* L.). Intl J Agri Crop Sci. 4 (5): 234-237.

Khakwani, A. A., Dennett, M. D. and Munir, M. 2011. Drought tolerance screening of wheat varieties by inducing water stress conditions. Songklanakarin J. Sci. Technol. 33 (2): 135- 142.

Li, P., Chen, J. and Wu, P. 2011. Agronomic characteristics and grain yield of 30 spring wheat genotypes under drought stress and non-stress conditions. Agronomy journal. Agron. J.103:1619–1628.

Maqbool, M. M., Ali, A., Haq, T., Majeed, M. N. and Lee, D. J. 2015. Response of spring wheat (*Triticum aestivum* L.) to induced water stress at critical growth stages. Sarhad Journal of Agriculture. 31(1): 53-58.

Pereira, L.S., Cordery, I. and Iacovides, I. 2009. Coping with water scarcity: Addressing the challenges. Springer Science+Business Media B.V. Paris, France.

Pradhan, S., Chopra, U. K., Bandyopadhyay, K. K., Singh, R., Jain, A. K. and Chand, I. 2013. Effect of water and nitrogen management on water productivity and nitrogen use efficiency of wheat in a semi-arid environment. International Journal of Agriculture and Food Science Technology. 4 (7): 727-732.

Shamsi, K. 2010. The effects of drought stress on yield, relative water content, proline, soluble carbohydrates and chlorophyll of bread wheat cultivars. Journal of Animal & Plant Sciences. 8(3): 1051- 1060.

Shamsi, K., Petrosyan, M., Noor-Mohammadi, G. and Haghparast, R. 2010. The role of water deficit stress and water use efficiency on bread wheat cultivars. Journal of Applied Biosciences.35: 2325- 2331.

Shao, L.W., Zhang, X.Y., Sun, H. Y., Chen, S. Y. and Wang, Y. M. 2011. Yield and water use response of winter wheat irrigation in the North China Plain. Journal of Soil and Water Conservation. 66(2): 104-113.

Tavakoli, A. R. and Moghadam, M. M. 2012. Optimization of deficit irrigation and nitrogen rates on bread irrigated wheat at northwest of Iran. Intl J. Agri. Crop Sci. 4.

Tolessa Taye, Chemada Fininsa and Getaneah Woldeab. 2015. Yield variability of bread wheat under wheat stem rust pressure at Bore field condition of Southern Oromia. J. Agric. Sci. Food Technol. 1 (2): 11-15.