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Crop Water Productivity of Irrigated Teff in a Water Stressed Region

Yenesew Mengiste Yihun · Abraham Mehari Haile · Bart Schultz · Teklu Erkossa

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Abstract In water stressed regions such as the Central Rift Valley of Ethiopia, increasing Crop Water Productivity (CWP) is imperative for sustainable food and water security. This paper presents CWP of Teff (*Eragrostic Tef*), a staple food in Ethiopia and an important export crop. Field experiments were conducted under irrigated agriculture during the dry seasons in the periods: 1) November 2010 to March 2011; and 2) December 2011 to April, 2012 at Melkassa Agricultural Research Centre in Ethiopia. Teff crop was irrigated at sixteen different water application depths ranging from 100 to 25 % of the optimum Crop Water Evapotranspiration (ETc.) during the four growing stages, the initial, development, mid season and late season. The effect of seeding rates of 25 kg/ha and 10 kg/ha on lodging and yield of the crop was also determined. The main results were: 1) At 25 % deficit irrigation applied for the whole growth period, Teff CWP was the highest at 1.16 and 1.08 kg/m^3 respectively for the seeding rates of 25 kg/ha and 10 kg/ha; 2) the CWP slightly decreased to 1.12 and 1.07 kg/m^3 when the 25 % deficit was applied during the late season stage; 3) the crop yield response factor (K_y) of 1.09 and 1.19 was obtained for seeding rates of 25 kg/ha and 10 kg/ha respectively; the equivalent biomass response factor (K_y) was less at 0.88 and 0.96 respectively.

Keywords Teff · Deficit irrigation · Crop water productivity · Water stressed region · Ethiopia

Y. M. Yihun · A. M. Haile · B. Schultz
UNESCO-IHE, Delft, the Netherlands

T. Erkossa
International Water Management Institute (IWMI), Addis Ababa, Ethiopia

Y. M. Yihun (✉)
Core Land and Water Development, UNESCO-IHE, P.O. Box 3015, 2601 DA, Delft, the Netherlands
e-mail: y.yihun@unesco-ihe.org
URL: www.unesco-ihe.org

1 Introduction

The dryland areas of Ethiopia account for more than 70 % of the total land mass and 40 % of the arable land. However, these areas contribute less than 30 % of the country's total agricultural production. The country receives rainfall, but seasonal and concentrated in 3 months of the year from June to August. The traditional rainfed agriculture concentrated in the highlands appears to shoulder the responsibility of feeding the human population exceeding 77.2 million (Central Statistcal Agency (CSA) (2007)). Thus food insecurity has remained to be the major problem that is a great concern to the country. Therefore it is imperative to bring large areas of the arid, semi-arid and sub-humid regions with uneven rainfall distribution to irrigation.

Irrigation has a multi-faceted role in contributing towards food security, self-sufficiency, food production and exports (Hussain and Hanjra 2004). Scarce water resources and growing competition for water will reduce its availability for irrigation. At the same time, the need to meet the growing demand for food will require increased crop production from less water (Ali and Talukder 2008). Achieving greater efficiency of water use will be a primary challenge in the near future and will include the employment of techniques and practices that deliver a more accurate supply of water to crops.

Increasing Crop Water Productivity (CWP) as argued by FAO (2010) and (Geerts and Raes 2009) can be an important pathway for poverty reduction. This would enable growing more food and hence feeding the ever increasing population of Ethiopia or gaining more benefits with less water thus enhancing the household income. CWP can be improved by proper irrigation scheduling, which is essentially governed by crop evapotranspiration (ETc.). Therefore it is profoundly important to determine and know the crop water requirement, the crop coefficient and the yield response factor of Teff crop.

Teff is the major indigenous cereal crop of Ethiopia. Teff flour is primarily used to make a fermented, sour dough type, flat bread called Injera. Teff is also eaten as porridge or used as an ingredient of home-brewed alcoholic drinks. It also has a high iron content and high potential as an export crop to USA and European countries as it contains no gluten and is considered a healthy food grain (Roseberg et al. 2006). Approximately 1 million Americans suffer from celiac disease (gluten sensitivity) and Teff may provide a niche for meeting the dietary requirement (Spaenij-Dekking et al. 2005). Serious attempts are underway to expand its cultivation in Europe, notably in the Netherlands and the United States of America (Evert et al. 2009).

Teff is a highly demanded cereal and has higher market prices than the other cereals for both its grain and straw in Ethiopia. Farmers earn more for growing Teff than growing other cereals. More than half of the area under cereals in Ethiopia is for Teff production. Teff grain is not attacked by weevils, which means that it has a reduced postharvest loss in storage and requires no pest-controlling storage chemicals. (Habtegebrial and Singh, 2006) investigated the impact of tillage and Nitrogen fertilizer on yield of Teff. Many investigations have been carried out and indicate that Teff is adapted to environments ranging from drought-stressed to waterlogged soil conditions (Roseberg et al. 2006). Despite of this fact, with respect to Teff as a food crop in Ethiopia, where it originated and was diversified (Assefa et al. 2003), there has been only limited research on its agronomic and physiological responses to water and other physical stress. Although (Mengistu 2009) studied the physiological responses of Teff to water stress in green house conditions its degree of tolerance for specific levels of water application at field scale has not yet been investigated. Hence, it is important to examine the response of Teff' to full and limited irrigation conditions at field scale.

2 Materials and Methods

2.1 Experimental Site

The field experiment was conducted at Melkassa Agricultural Research Centre (MARC), Ethiopia (Fig. 1). The research centre is located in the Great Central Rift Valley at 8°24′N latitude, 39°21′E longitude, and altitude of (1,300 – 1,800 m+MSL [mean sea level]). The area is among the semi arid regions and characterized by erratic rainfall, frequent drought and a harsh cropping environment. The mean minimum and maximum monthly temperatures of the area are 22 °C and 34 °C respectively. Teff is one of the common crops grown in the area that is considered as a reliable and low-risk crop. It is grown during the summer rainy season from June to August. The texture of the soil is Clay Loam.

2.2 Climatic Data Collection and Analysis

Climate data including daily rainfall, maximum and minimum temperature, relative humidity, sunshine hours and wind speed were obtained from the meteorological station near the experimental field. The ETo calculator was used to determine the daily reference evapotranspiration (ETo) for the growing season of 2010/2011 and 2011/2012. ETo calculator is software developed by the Land and Water Division of FAO. Its main function is to calculate Reference evapotranspiration (ETo) based on computation guidelines detailed in (Raes 2009).

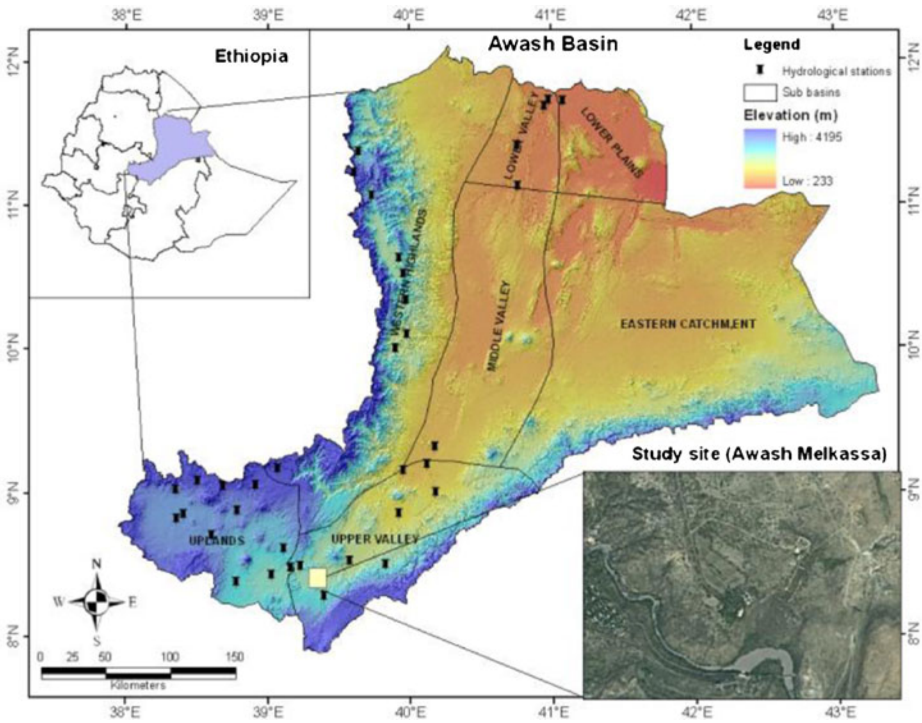

Fig. 1 The study area – Awash Melkassa

2.3 Field Experiments

The field experiments were carried out in the dry season of 2010/2011 and 2011/2012. A selected combination of depth of irrigation water application (amount) and growth stage (Time) of Teff (Eragrostis Tef) was used in order to determine the optimum water application depth at specific growth stage that results in optimum crop water productivity (CWP). This research investigated the sensitivity of each growing stage to drought stress in detail. Four different levels of irrigation water supply were scheduled, full crop water requirement 0 % deficit (ETc.), 25 % deficit (applying 75 % of crop water requirement), 50 % deficit (applying 50 % of crop water requirement) and 75 % deficit (applying 25 % crop water requirement) (Fig. 2).

In Fig. 2, T_1 to T_{16} refer to different treatments (crop stands) under various combination of four growth stages (I to IV) and irrigation applications starting from no deficit (0%D) to the maximum of 75 % deficit (75 % D).

The phenological cycle was divided into four phases which are considered to be most relevant from the view point of their response to irrigation, i.e. initial stage (P1), development stage (P2), mid season stage (P3) and late season stage (P4). A four by four factorial combination of sixteen treatments with three replications was set in the experimental field to make a total of forty-eight trials (Fig. 2). Each set of these 48 trials was tested at seeding rates of 10 and 25 kg/ha. Thus the total field experimental plots established in MARC were 96.

2.4 Soil and Cultivar

Soil samples were collected depending on the root depth of the experimental crop Teff at the time of sowing. The physical soil characteristics are given in the Table 1.

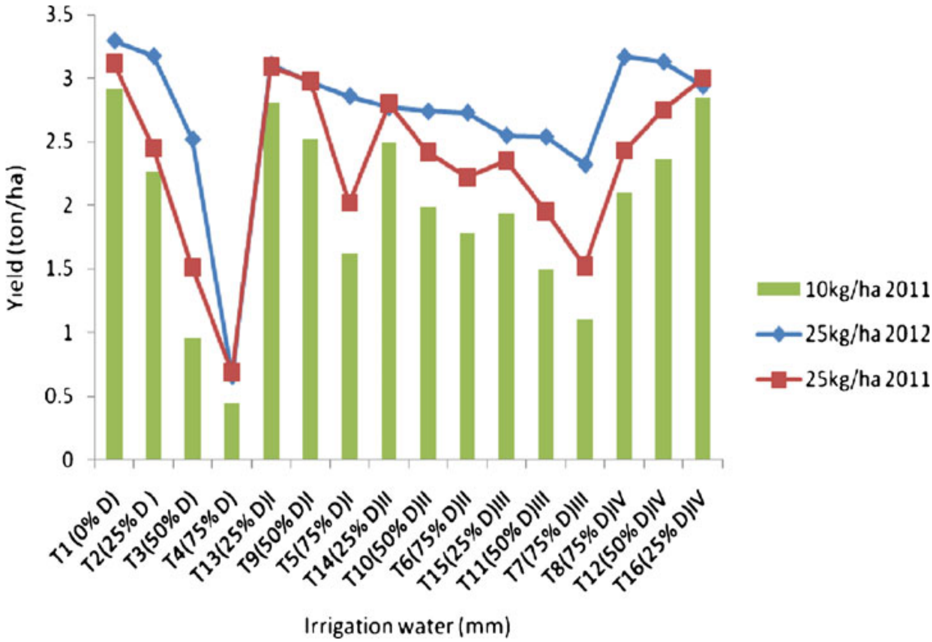

Fig. 2 Yield of Teff under different irrigation treatments for the experimental season of 2010–2011 and 2011–2012

Teff (EragrosticTef) cultivar, locally called “kuncho” was selected and its CWP was assessed under the 16 different treatments as outlined in Fig. 2. The assessments were done based on actual grain and biomass yields obtained during two irrigation seasons: 1) November 2010 to March 2011; and 2) December 2011 to April, 2012. “kuncho” was selected because as compared to the other local varieties released by Melkassa Agricultural Research Centre (MARC), it is the most favourite among the locals, has high market value within the country and the region.

Each treatment had three replicates thus a total of 48 experimental fields were analysed. Each experimental field has an area of 8 m^2 (2.0 m×4.0 m). The individual fields were separated from each other by means of soil bunds.

Irrigation was applied manually using a watering can with a known capacity. In line with the rate of applications of fertilizers in the research area, 130 kg/ha of diamonium nitrogen phosphate (DAP) was spread in each field just before planting. Likewise 35 kg/ha of urea was applied at tillering stage.

The dates of the main phenological stages, like sowing date, date of 90 % emergence, 50 % flowering, duration of flowering, senescence and maturity were recorded. Plant height was measured in every ten days interval from the fixed sample of each experimental plot. Above ground biomass observations were made in every 10 days from undisturbed sample area of 1 m^2. The above ground biomass was dried with an oven drier for 48 h at 60 °C and then weighted. Grain yields were measured after maturity from pooled samples of an area of 2.0×3.0 m^2 in each plot. The crop was harvested manually. The grain and total biomass fresh weight were weighted at maturity and then were dried and weighted on a sensitive balance.

2.5 Soil Moisture Monitoring

Soil moisture was regularly monitored using Neutron Probe. Irrigation was applied in accordance with the different water deficit conditions. In the case of a full irrigation application (no deficit), the soil moisture was constantly kept at field capacity. The Neutron Probe was calibrated using Gravimetric Method whereby soil samples were collected from soil depths of 15, 30 and 45 cm before sowing and in every 5–7 days interval up to maturity. The measured soil moisture in weight basis was multiplied by bulk density to convert to volume basis.

Table 1 Soil physical characteristics of the experimental field

Soil property	Soil depth (cm)		
	0–30	30–60	60–90
Particle size distribution (%)			
Sand (> 50 μm)	37.8	38.3	36.8
Silt (2–50 μm)	35.0	36.6	39.7
Clay (<2 μm)	27.3	25.1	23.6
Textural class	Clay Loam	Loam	Loam
Bulk density, g/cm^3	1.4	1.5	1.8
Field Capacity (FC), Vol%	29.3	31.6	34.4
Permanent Wilting Point (PWP),Vol%	16.7	18.4	21.3
Total Available Water (TAW), mm/m	125.6	132.2	141.5

2.6 Seasonal Evapotranspiration Calculation Using Soil-Water Balance Approach

Evapotranspiration (ET) was calculated on the basis of the general water balance equation:

$$P + I + U = D + R \pm \Delta W + ETa \tag{1}$$

Where P is the effective rainfall (mm), I is irrigation water applied (mm), U is the upward flux (mm), D is deep percolation (mm) below the crop root zone, W is change in soil moisture storage in the soil profile (mm) and ETa is the crop evapotranspiration (mm).

In this experiment, as the field is sufficiently levelled, water is applied only to refill to field capacity and the water table is far below the root zone, D and U can be neglected. Surface runoff was assumed to be zero as the irrigation water is protected by constructed soil bunds around each plot. The reduced soil water balance equation becomes:

$$ET = I + P \pm \Delta W \tag{2}$$

2.7 Crop Water Productivity (CWP)

Crop Water Productivity (CWP) is defined on different definitions by different researchers (Bessembinder et al. 2005). In this paper, CWP is defined as the amount or the value of product over volume or value of water depleted or diverted.

CWP is computed as the ratio of grain yield to actual crop water use:

$$CWP = Y/ETa \tag{3}$$

Where, CWP is expressed in kg/m^3 on a unit water volume basis, Y is grain yield (Kg/ha) and ETa (m^3/ha) is actual crop evapotranspiration.

2.8 Statistical Analysis

The statistical difference in Teff yield and biomass for different treatments were analysed using MSTAT-C statistical package for Analysis of Variance (ANOVA). MSTAT-C is a computer based statistical software package developed by the crop and soil science department. The Least Significant Difference (LSD) test was performed at Alpha level of 1 % (highly significant) and 5 % (Significance) Level.

3 Result and Discussion

3.1 Effect of Moisture Level on Grain Yield and Above Ground Biomass Yield of Teff

The seasonal total rainfall from June to August in 2010 and 2011 is 555 mm and 437.2 mm respectively. The long term average growing season of rainfall was 768 mm. But for the dry season irrigation experiment no effective rainfall was recorded. The irrigation amounts for different treatments are given in Table 2.

The effect of moisture level on grain yield for different seeding rates is shown in Fig. 3. Using Least Significant Difference (LSD) test, first confirming that the F-test was significant at 5 % and 1 % significance level, it was found that the effect of different level of moisture on Teff grain yield shows a highly significant ($p<0.01$) and significant ($p<0.05$) difference. Moreover the above ground biomass yield has resulted in highly significant difference with

Table 2 Irrigation application under different treatments (water deficit conditions) for both experimental seasons

Treatments	2010–2011		2011–2012	
	No of Irrigation (nos)	Irrigation amount (mm)	No of Irrigation (nos)	Irrigation amount (mm)
T1 (0%D)	15	281	10	380
T2 (25%D)	15	211	10	294
T3 (50%D)	15	141	10	225
T4 (75%D)	15	70	10	156
T5 (75%D)I	15	271	10	325
T6(75%D)II	15	238	10	354
T7(75%D)III	15	163	10	350
T8(75%D)IV	15	241	10	367
T9(50%D)I	15	274	10	307
T10(50%D)II	15	252	10	332
T11(50%D)III	15	202	10	359
T12(50%D)IV	15	254	10	352
T13(25%D)I	15	278	10	294
T14(25%D)II	15	267	10	315
T15(25%D)III	15	242	10	318
T16(25%D)IV	15	267	10	349

In Table 2, T_1 to T_{16} refer to different treatments (crop stands) under various combinations of four growth stages (I to IV) and irrigation applications starting from no deficit (0%D) to the maximum of 75 % deficit (75 % D)

the different level of moisture. The water deficit at the initial stage and late season stage for both 75 % deficit and 50 % deficit, gave non-significantly ($p>0.05$) different yields from the optimum application of treatment ET1 (100 %). However, for all levels of water deficit at the mid season stage and 50 % and 75 % deficits throughout the growth stages the yields were significantly different ($p<0.01$) as compared to 0 % deficit.

In the experimental season of 2010–2011, irrigation was applied every 3 days interval, more frequent but less water. But in the experimental season of 2011–2012, a comparatively more amount of irrigation water was applied in 6 days interval.

3.2 Grain Yield, Crop Water Productivity (CWP) and Relative Yield Decrease of Teff

The main grain yield, crop water productivity and relative yield reduction for the different treatments for the 2010–2011 experimental years are presented in Table 3. The response of Teff to various levels of irrigation water is different. During 2010–2011, when 100 % of ETc. is applied (0 % deficit- treatment T1 in Table 3), grain yield of Teff for the seeding rate of 25 kg/ha and 10 kg/ha was found to be 3,120 and 2,910 kg/ha respectively. In case of treatment T2 (75 % of ETc. irrigation application i.e. 25 % deficit) the yields values were reduced to 2,450 and 2,270 kg/ha respectively. A much more significantly lower yields of 690 kg/ha and 450 kg/ha were obtained for treatments with 75 % irrigation deficit (T4) throughout the whole growth stage for both 25 kg/ha and 10 kg/ha seeding rates respectively.

It can be inferred from Table 3 that 75 %, 50 % and 25 % irrigation water reduction throughout the whole growth stage decreased the Teff yield by 77.9 %, 51.6 % and 21.5 %

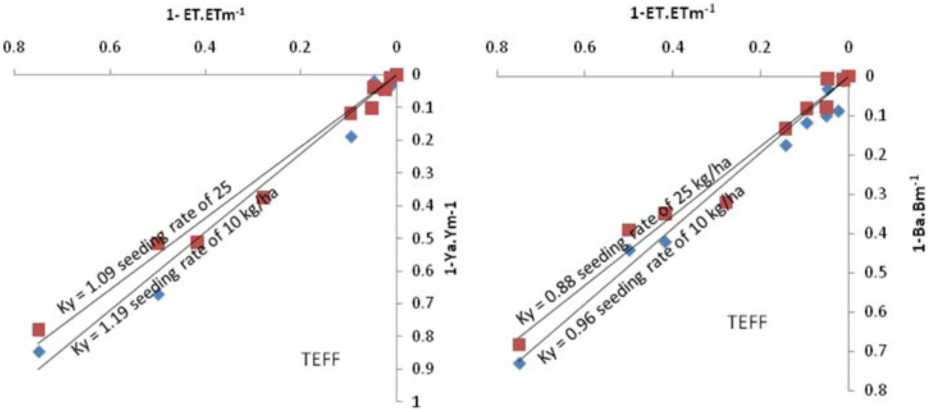

Fig. 3 Water production functions of Teff yield and biomass

respectively. These results are in agreement with Kloss et al. (2012) who showed that dealing with improvement of WP is closely related to the irrigation practice of regulated deficit irrigation and has a direct effect on yield as the amount of water applied decrease intentionally the crop yield drops.

Decreasing the recommended seeding rate of 25 kg/ha to 10 kg/ha increases the capacity of the Teff stalk to increase its strength and is able to have a greater resistance of the stem against lodging because of heavy panicle at maturity. In addition smaller seeding rate increases the tillering potential. For seeding rate of 10 kg/ha, a maximum yield of 2.91 and 3.05 t/ha respectively was obtained from the treatment which received the optimum crop water requirement (T1) during the 2010/2011 and 2011/2012 experimental season. Generally regardless of the seasons, the patterns of response to irrigation treatment were similar and showed significant and positive response. As the current price of Teff seed increases 10 fold, decreasing the seeding rate can save seed to cultivate additional ha of land.

Higher crop water productivity values of 1.16 and 1.08 kg/m^3 was obtained for seeding rate of 25 kg/ha and 10 kg/ha, respectively from treatment which received 75 % ETc. throughout the growth stage in the experimental season of 2010–2011. Whereas for the experimental season of 2011–2012 higher crop water productivity value of 1.12 and 1.31 kg/m^3 were obtained with seeding rate of 25 kg/ha and 10 kg/ha respectively (Table 4). Katerji et al. (2010)) observed that CWP varied with years and locations and ranged from 1.34 to 1.81 kg/m^3, which were similar to the results reported by Zhang and Yang (2004) with CWP ranging between 1.01 and 1.72 kg/m^3.

During 2011/2012, grain yields and biomass followed a similar trend to those of 2010/2011. Treatments T7 (75%D) III, T11 (50%D) III and T15 (25%D) III which were conducted under adequate watering conditions throughout the first two periods of the growing season, and followed by a period of stress at the mid season stage with 75%D, 50%D and 25%D resulted in the second, the third, and the fourth lowest yield respectively by 30 %, 23 % and 23 % for the seeding rate of 25 kg/ha. This yield reduction is significant compared with stressing the crop during late season stage having a reduction of 11 %. This tendency might be attributed to the fact that adequate watering conditions early in the season led to the development of an abundant leaf cover and a shallow root depth. When a severe stress follows, the crop rapidly depletes the soil water stored in the root zone and wilts before the completion of additional root development at greater soil depths. This result is in agreement with the irrigation experiment of grain sorghum and maize, showed that the extent of yield reduction following evapotranspiration deficit depends on

Table 3 Effect of moisture levels and seeding rate on grain yield and crop water productivity of Teff at growing season 2010–2011

*Treatment name	Irrigation (mm)	Grain yield (kg/ha) at SDR of		Crop Water Productivity (CWP) at SDR of		Relative grain yield reduction at SDR of		Relative evapotranspiration deficit at SDR of	
		25 kg/ha	10 kg/ha	25 kg/ha	10 kg/ha	25 kg/ha	10 kg/ha	25 kg/ha	10 kg/ha
T1 (0%D)	281	3,120	2,910	1.11	1.04	0	0	0	0
T2 (25%D)	211	2,450*	2270	1.16	1.08	0.21	0.22	0.25	0.25
T3 (50%D)	140	1,510**	960	1.08	0.68	0.52	0.67	0.50	0.50
T4 (75%D)	70	690**	450	0.98	0.64	0.78	0.85	0.75	0.75
T5 (75%D)I	271	2,020*	1,620	0.75	0.60	0.35	0.44	0.04	0.04
T6 (75%D)II	238	2,200*	1,780	0.92	0.75	0.29	0.39	0.15	0.15
T7 (75%D)III	163	1,520**	1,100	0.93	0.67	0.51	0.62	0.42	0.42
T8 (75%D)IV	241	2,430*	2,100	1.01	0.87	0.22	0.28	0.14	0.14
T9 (50%D)I	274	2,980NS	2,520	1.09	0.92	0.04	0.13	0.02	0.02
T10 (50%D)II	252	2,420*	1,990	0.96	0.79	0.22	0.32	0.10	0.10
T11(50%D)III	203	1,950**	1,490	0.96	0.74	0.38	0.49	0.28	0.28
T12 (50%D)IV	254	2,750NS	2,360	1.08	0.93	0.12	0.19	0.10	0.10
T13 (25%D)I	278	3,090NS	2,810	1.11	1.01	0.01	0.03	0.01	0.01
T14 (25%D)II	267	2,800NS	2,490	1.05	0.93	0.10	0.14	0.05	0.05
T15 (25%D)III	242	2,350*	1,930	0.97	0.80	0.25	0.34	0.14	0.14
T16 (25%D)IV	267	3000NS	2,850	1.12	1.07	0.04	0.02	0.05	0.05

In Table 3, T_1 to T_{16} refers to different treatments under various combination of four growth stages (I to IV), irrigation applications starting from no deficit (0%D) to the maximum of 75 % deficit (75 % D) and SDR refers to seeding rate. Treatement means with **,* and NS refers to highly siginificant ($P<0.01$), siginificant ($P<0.05$) and NS non significant varation

the growth period (Stewart et al. 1975). From deficit irrigation experiments on vegetables and cereals, it was found that lowest yield is obtained during the full stress (75 % deficit) throughout the growing season. However, stressing the crops during initial and late season stage of the growing season does not affect the crop yield significantly.

Figure 3 shows the graphical relationship between the relative yield and biomass reduction with moisture stress for the experimental season of 2010–2011. The crop response factor (K_y) the slope of total grain yield and above ground biomass reduction versus moisture stress graph was found to be 1.09 and 1.19 respectively for 25 kg/ha and 10 kg/ha seeding rate and 0.88 and 0.96 respectively for 25 kg/ha and 10 kg/ha seeding rate. The relative biomass reduction increases as the evapotranspiration deficit increases. Here K_y for biomass yield is found to be 0. 88 which is less than unity in contrast with the yield response factor of grain yield.

$K_y<1$ indicates that biomass production is less sensitive to water stress. According to Kirda (2002), only those crops and growth stages with a lower yield response factor ($K_y<1$) can generate significant savings in irrigation water through deficit irrigation. A response factor greater than unity indicates that the expected relative yield decrease for a given evapotranspiration deficit is proportionately greater than the relative decrease in evapotranspiration. This means that the advantages coming from the deficit irrigations are unlikely (Kirda 2002). This implies that Teff is sensitive to water stress conditions. As shown in Tables 3 and 4, the yield has decreased from 3.12 to 0.69 t/ha and 3.30 to 0.66 t/ha respectively in the experimental years of 2010–2011 and

Table 4 Grain yield, biomass yield, crop water productivity (CWP) and relative yield decrease (RYD) by treatment for 25 kg/ha for the experimental season of 2011–2012

Treatments	Yield (t/ha)	Biomass (t/ha)	Irrigation applied (mm)	CWP (Kg/m^3)	RYD relative yield reduction	Relative ET deficit
T1 (0%D)	3.30	14.0	380	0.87	0.00	0.0
T2 (25%D)	3.18 ns	11.2*	294	1.08	0.04	0.2
T3 (50%D)	2.52*	6.7**	225	1.12	0.24	0.4
T4 (75%D)	0.66**	4.5**	156	0.42	0.80	0.6
T5 (75%D)I	2.86 ns	6.2**	294	0.98	0.13	0.2
T6 (75%D)II	2.73 ns	8.2 ns	315	0.87	0.17	0.2
T7 (75%D)III	2.32*	8.0*	318	0.73	0.30	0.2
T8 (75%D)IV	3.17 ns	11.0 ns	349	0.91	0.04	0.1
T9 (50%D)I	2.97 ns	6.7**	307	0.97	0.10	0.2
T10 (50%D)II	2.74*	9.0**	332	0.82	0.17	0.1
T11 (50%D)III	2.54*	12.0 ns	359	0.71	0.23	0.1
T12 (50%D)IV	3.13 ns	11.3 ns	351	0.89	0.05	0.1
T13 (25%D)I	3.11 ns	8.8**	325	0.96	0.06	0.1
T14 (25%D)II	2.77*	10.0 ns	354	0.78	0.16	0.1
T15 (25%D)III	2.55*	11.5 ns	350	0.73	0.23	0.1
T16 (25%D)IV	2.94 ns	11.7 ns	367	0.80	0.11	0.0

In Table 4, T_1 to T_{16} refers to different treatments under various combination of four growth stages (I to IV) and irrigation applications starting from no deficit (0%D) to the maximum of 75 % deficit (75 % D). Treatement means with **,* and NS refers to highly siginificant ($P<0.01$), siginificant ($P<0.05$) and NS non significant varation

2011–2012. On the other hand, as presented in Table 3, for the higher seeding rate of 25 kg/ha, respective of higher water productivity of 1.16 and 1.08 kg/m^3 was obtained from treatments which received 25 % and 50 % deficit irrigation throughout the whole growth season. Whereas for lower seeding rate of 10 kg/ha, higher water productivity of 1.08 and 1.07 kg/ha was obtained from treatment which received 25 % deficit irrigation throughout the growth stage and 25 % deficit during the late season stage respectively. By growing more yields with less water, more water will be available to irrigate arable land in a water scarce semi-arid region of Ethiopia.

4 Conclusions

The following major conclusions could be drawn from the study:

- A maximum grain yield of 3.3 t/ha was obtained under irrigation when Teff was not subject to any water stress. This is three fold the yield farmers currently harvest from rainfed agriculture.
- The crop was very sensitive to water stress during the mid season stage. Even when it is only subject to 25 % deficit, its yield decreased by about 1 t/ha. Stressing the crop either by one-half or three-quarters at the mid season stage, results in lower yields next to stressing the crop throughout the growth season.
- The yield and water productivity differences are insignificant between a full irrigation and a 25 % deficit irrigation distributed throughout the growth period at seeding rates of 25 kg/ha and 10 kg/ha. Thus, when water is scarce and irrigable land is relatively abundant as is the

case in Ethiopia, adopting the 25 % water deficit irrigation with 10 kg/ha seeding rate is recommended.

- A maximum water deficit of 50 % during the late season stage has an insignificant impact on Teff yield and water productivity.

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