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Water Productivity of Teff under Semi-Arid Climates

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Abstract
In the arid and semi-arid regions where the availability of irrigation water is a limiting factor for crop production, the knowledge of the water productivity of crops is imperative. Teff is a crop specific to Ethiopia where much of its properties are not duly studied. The purpose of this study was to systematically investigate teff's response to moisture stress and to estimate its water productivity. This field experiment was conducted to investigate the effects of irrigation level on the performance and water productivity of teff. The experiment was laid out in randomized complete block design with three replications. The treatments considered were seven levels of water application (0.5 ETc, 0.6 ETc, 0.7 ETc, 0.8 ETc, 0.9 ETc, ETc and 1.25 ETc). Effects of irrigation levels on teff grain yield was highly significant ($p < 0.01$) whereas significant ($p < 0.05$) on biomass. The maximum teff grain yield (1053 kg/ha) and biomass (4267 kg/ha) were recorded from the 1.25 ETc experimental plots. But, a minimum yield (329 kg/ha) and biomass (2747 kg/ha) were recorded from the 0.5 Etc experimental plots. It was also observed that 50% reduction in the amount of irrigation water decreased the teff production in terms of grain yield and biomass by 69% and 36% respectively, while a 100% ETc water application decreased total teff grain and biomass by only 18% and 14%, respectively. A yield response factor (Ky) of 1.07 was determined. The water productivity for teff biomass ranged from 1.2 kg/m^3 (for the 1.25 ETc) to 2.0 kg/m^3 (for the 0.5 ETc).The water productivity for teff yield was the highest (0.34 kg/m^3) at 0.7 Etc irrigation water application. The average height of the crop for the maximum (1.25 ETc) and minimum (0.5 ETc) irrigation water application were 54.6 and 85.9 cm, respectively. The harvest indices of teff for 1.25ETc and 0.5 ETc were found to be 12% and 25%, respectively. It is, therefore, concluded that the advantage of deficit irrigation is unlikely in teff grain yield production but advantageous in teff biomass.
Keywords: water productivity, teff, semiarid, deficit irrigation

INTRODUCTION

In the arid and semi arid regions, the limited availability of water is in most cases the major constraints to rain-fed agriculture. In the arid regions, the amount of rainfall is usually not sufficient to sustain the crop production. Whereas, in the semi-arid regions it is not so much the quantity, but the uneven distribution of rainfall in time and space that makes rainfed agriculture a risky enterprise. Ethiopia is a country where this problem needs no reminder. This unpredictability, coupled with the lack of local capacity to deal with the situation, creates a persistent threat to household food insecurity in many parts of the country. Surprisingly, arid and semi-arid areas are home to one sixth of the world's population (Hatibu, 2004). The dry land areas of Ethiopia account for more than 66% of the total land mass. However it contributes only less than 30% to the country's total agricultural production (Reddy and Kidane, 1994). The traditional rainfed agriculture concentrated in the high lands appears to shoulder the responsibility of feeding the human population exceeding 73.9 (FDRE-PCC, 2007). Thus food insecurity has remained to be the major problem that is a great concern to the country. In order to mitigate the food insecurity problem with its roots in the high population growth rate and low food production level mainly attributed to insufficient soil moisture, it is imperative to bring large areas of the arid, semi-arid and sub-humid regions with uneven rainfall distribution under irrigation and other appropriate technology interventions (Zenebe, 2000). Irrigation has a multi-faceted role in contributing towards food security, self-sufficiency, food production and exports. It encompasses a wide range of interventions that enhance productivity and result into profitability for the rural farming population and the nation as a whole. For the substantial areas managed by smallholder farmers through traditional irrigation systems or water harvesting, it assists with both food and cash crops production enabling farmers and surrounding communities to benefit both directly and indirectly from the crops produced. In large-scale commercial farms, it enables crop production for local and export markets with large-scale commercial farms, it enables crop production for local and export markets with significant impacts on the country's economy (Chiza, 2005). Yield and quality of crops suffer due to insufficient water supply and improper scheduling of irrigation. Available irrigation water has to be utilized in a manner that matches the water need of the crop. The knowledge of crop water requirement is an important practical consideration to improve water use efficiency in irrigated agriculture. Water use efficiency can be improved by proper irrigation scheduling, which is essentially governed by crop evapotranspiration (ETc). From an economics viewpoint, when water is not a limiting factor maximum profit for farmers may be obtained with the fulfillment of the entire crop water requirements. For many crops, high yield as well as high water use efficiency values could be obtained provided the right choice of the period of water application is made. 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 (Davison et al., 2004). It is high in iron content and contains very little gluten (Roseberg et al., 2006). For Ethiopian farmers, teff straw is no lesser important than the grain since it is the most preferred animal feed source, particularly during the long, dry seasons of the year when other livestock feed sources are scanty. Cattle prefer to feed on teff straw rather than on any other cereal straw. Teff straw is also the preferred binding material for walls, bricks and household containers made of clay in Ethiopia (NRC, 1996). Teff is also gaining popularity as healthy food (Spaenij-Dekking et al., 2005) in the western world menus and serious attempts are underway to expand its cultivation in Europe, notably the Netherlands, and the United States of America (Evert et al., 2009). In low moisture stress area, where more than one sowing is commonly practiced in years of total rain failure, farmers have to store seeds of various crops for a long period. In such situations teff seed, which has no storage pests, is the ideal crop (Seyfu, 1993). Moreover, the area used for teff production is increasing from time to time (Hailu and Seyfu, 2000). For example, it covered 1,818, 375 (in 2001/02) and 1,989,068 (2003/04) hectares of land which is 28.5 and 28.4 percent of the area covered respectively by the whole cereals in each production year (CSA, 2006). Generally, teff is a reliable cereal under unreliable climate. That is why, in many areas where recurrent moisture stress occurs, teff production replaces the production of maize and sorghum (Seyfu, 1993). In addition, it is useful as rescue or catch crop in moisture-stress areas. For example, around Kobo or Zeway, farmers first plant maize around April. If the crop fails due to moisture stress, they plow it under and plant sorghum. If this one also fails, it is again plowed under and as last resort farmers sow teff. In some areas teff is sown because farmers cannot grow wheat, maize, or sorghum due to moisture stress. However, this practice is not widespread, and farmers should be encouraged to reserve teff for use if crops of other cereals fail, especially in drought-prone areas. Although literatures indicated that teff is adapted to environments ranging from drought stressed to waterlogged soil conditions (Roseberg et al., 2006), its degree of tolerance for specific level of water application is not yet investigated. Hence, it is important that teff's response to moisture stress be undertaken. In view of that, therefore, this research was proposed and done to estimate the water productivity of teff.

MATERIALS AND METHODS

Experimental Site Description

The experiment was conducted at Dire Dawa, geographically positioned between $9^0$27' N and $9^0$49'N latitude and $41^0$38'E and $41^0$38'E longitude and at an altitude of 1160 m a.s.l in Haramaya University Research Farm commonly known as "Tony Farm". Dire Dawa is found at 515 km east of Addis Ababa. It is situated in the semi-arid tropical belts of eastern Ethiopia at the middle of the eastern Hararghe mountain chain. The area experiences a bimodal type of rainfall and the mean annual precipitation is 556.5 mm. The mean annual maximum and minimum temperature varies between 28.30C to 34.90C and 15.10C to 22.70C, respectively. The area is classified under semi-arid climate. The texture of the soil is alluvial. The site was selected for two reasons: (1) the climate is dry and water stress to plants could be applied, and (2) land and irrigation facilities are readily available.

Experimental Treatments and Design

The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. There were a total of seven treatments based on different levels of irrigation water throughout the growing season. The seven irrigation levels used were: 0.5 ETc, 0.6 ETc, 0.7 ETc, 0.8 ETc, 0.9 ETc, ETc (full irrigation) and 1.25 ETc. Full irrigation implies the amount of irrigation water applied in accordance with the computed crop water requirement with the aid of CROPWAT program. The 0.5 ETc, 0.6 ETc, 0.7 ETc, 0.8 ETc, 0.9 ETc and 1.25 ETc treatments were then determined based on the computed crop water requirement. The reason using 1.25ETc beyond ETc is that to see a clear difference in teff yield and biomass production under this treatment from the ETc treatment.

Experimental procedure and management practice

The field was ploughed and well pulverized to break clods. 3 m long by 3 m wide plots were prepared. The soil was compacted to facilitate germination (Melese, 2007). Teff crop was planted on each plot at a rate of 20 kg/ha (Seyfu, 1993). The variety of teff seed used was DZ-Cr-387 (Kuncho), an early maturing variety obtained from Debreziet Agricultural Research Center. Fertilizer was applied immediately before sowing using the rate recommended by Mulat et al. (1997): 100 kg/ha diammonium phosphate (90 g per experimental unit) and 50 kg/ha urea (45 g per experimental unit). Weeding was carried out on a weekly basis. Application of irrigation water was made using watering bucket (manually) and graduated cylinders. Irrigation scheduling was done based on soil water depletion replenishments using the CROPWAT program and adopting 4 day irrigation interval. Crop water requirement was calculated using CROPWAT program based on the FAO Penman-Monteith method. Soil water level was monitored by usingprofile probe after calibrated using the gravimetric soil moisture content determination method. Soil sample was taken from well irrigated plots just before irrigation to check the moisture content at management allowable depilation level and two day after irrigation to check the moisture content to field capacity level. The regular tillage and agricultural operations of growing teff were followed. All other agronomic practices were kept normal and uniform for all the treatments including pre-irrigation and one irrigation after germination.

Data collection

Plant height was measured at tinning, heading and physiological maturity and harvest of the crop from the ground level to the tip of the panicle using five randomly selected plants. Total above ground biomass was collected at crop maturity in order to estimate grain yield and above ground biomass of teff under the different treatment combinations. The fresh weight was measured using spring balance on the field. Fresh field and representative fresh biomass sample were taken and dried in oven at 70^0C for 24 hours (Sahlemedihin and Taye, 2000) to obtain moisture correction factor and calculate dry biomass. The grain yield was measured, after threshing to separate the seed from the straw and cleaning the chaff, using sensitive laboratory balance. Both the dry biomass and grain yield obtained from experimental plot ($9m^2$) were converted to hectare bases. Root development is monitored by using root auger specially made for root sampling and were scanned with root scanner with the help of Win-RHIZO® software to estimate total length (cm), total surface area (cm^2), total root volume (cm^3), and average diameter

Calculation of Water Productivity (WP) and Harvest Index

Water productivity was estimated as a ratio of aboveground dry matter at maturity or grain yield to the total Etc through the growing season and it was calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$CWP = (Y/ET)$$

Where, CWP is crop water productivity (kg/m^3), Y crop yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Harvesting index (HI) is the amount of teff grain yield production per biomass production

$$HI = Y/BM$$

Where:HI – Harvesting index (decimal)
Y – Yield of teff (kg/ha)
BM – above ground biomass of maize (kg/ha

Data Analysis

Data were subjected to analysis of variance (ANOVA) using GenStat computer program. The Least Significant Difference (LSD) test was applied at 5 % level of significance to compare means among the treatments.

RESULTS AND DISSCUSSION

Effect of Water Levels on Plant Height

In order to evaluate the effect of irrigation levels on plant height, the plant height from ground level to apex stem were measured and the results are presented in Table 1 and Appendix Table 16 and the analysis of variances are presented in Appendix Tables 17, 18, 19, and 20. The analysis of variance showed that the effect of irrigation level on plant height was highly significant ($p < 0.01$), (Appendix Tables 16, 17, 18 and 19).Results also revealed that that 0.5 ETc level of water application resulted in shortest plant height (54.6 cm) and the longest plant height was obtained (85.9 cm) under 1.25 ETc level of water application. From Appendix Table 14, it can be seen that, plant height increased consistently (from 0.5 ETc treatment) to 85.9 cm (from1.25 ETc treatment). From these findings it can be concluded that as the irrigation level increases the plant height also increases. A similar finding has been reported by Aklilu (2009) who concluded that a 50% Etc resulted in 43.5 cm height of pepper whereas, a 75 and 100% ETc resulted in 56.8 and 60.7cm height, respectively.

Table 1. Effect of water level on teff height

Treatments	Height (cm)
0.5 ETc	54.6^{a}
0.6 ETc	58.2^{a}
0.7 ETc	62.1^{ba}
0.8 ETc	69.4^{cd}
0.9 ETc	72.2^{d}
ETc	81.7^{e}
1.25 ETc	85.9^{f}
CV (%)	3.2
LSD (0.05)	3.92

*Means followed by different superscripts are statistically different

4.4. Effect of Moisture Levels on Biomass

Data on the above ground biomass are presented in Table 2. The variability among the biomass data were statistically significant ($p < 0.05$). The highest biomass obtained (4267 kg/ha) corresponds to the plot with the highest amount of water application (345 mm) whereas the lowest amount of biomass obtained (2747 kg/ha) corresponds to the plot with the lowest amount of water application (138 mm). The biomass obtained consistetnly decreased with the decrease in the amount of water applied. This is to be expected since the water stress affected the biomass production. The justification for this could be an increase in water stress resulted in stomata closure, leading to reduced transpiration and photosynthesis rates and biomass accumulation (Bouman and Toung, 2001). Similar results for the same crop have been reported in previous works (Tigist, 2008). Reducing the water application from 1.25 ETc to 0.5 ETc resulted in 35.61% relative biomass reduction. On the other hand, an increase in soil moisture availability favors photosynthesis rate and accordingly results in higher dry matter production per plant. Similarly, Marouelli *et al.* (1991) and Kinde (1997) reported that soil water stress during vegetative and reproductive stages resulted in the reduction of above ground dry biomass. Moreover, the increase in the dry biomass with increasing soil water application level could also be attributed to the increase in vegetative growth as plant height, leaf area, and lateral shoot number. Figure 1 shows the graphical relationship between average biomass reduction and moisture stress. The yield reduction factor (K_y) – the slope of total biomass reduction versus moisture stress graph was found to be 0.59. The relative biomass reduction increases as the evapotranspiration deficit increases. Here K_y for biomass is found to be 0.59 which is less than unity in contrast with K_y of grain yield. $K_y < 1$ indicates that biomass production is less sensitive to water stress.

Table 2. Effect of moisture levels on biomass and yield

Treatment	Biomass (kg/ha)	Yield (kg/ha)	Relative biomass reduction (%)	Relative yield reduction (%)
0.5 ETc	2747.2[a]	329.34[a]	35.61	68.73
0.6 ETc	3091.7[ab]	448.45[a]	27.54	57.42
0.7 ETc	3313.0[abc]	653.06[b]	22.35	37.99
0.8 ETc	3432.3[bc]	623.36[b]	19.56	40.81
0.9 ETc	3435.8[bc]	721.96[bc]	19.47	31.44
ETc	3682.0[cd]	858.92[c]	13.70	18.44
1.25 ETc	4266.7[d]	1053.11[d]	0	0
CV (%)	9.6	11.5		
LSD (0.05)	585.5	137.4		

*Means followed by different superscripts are statistically different

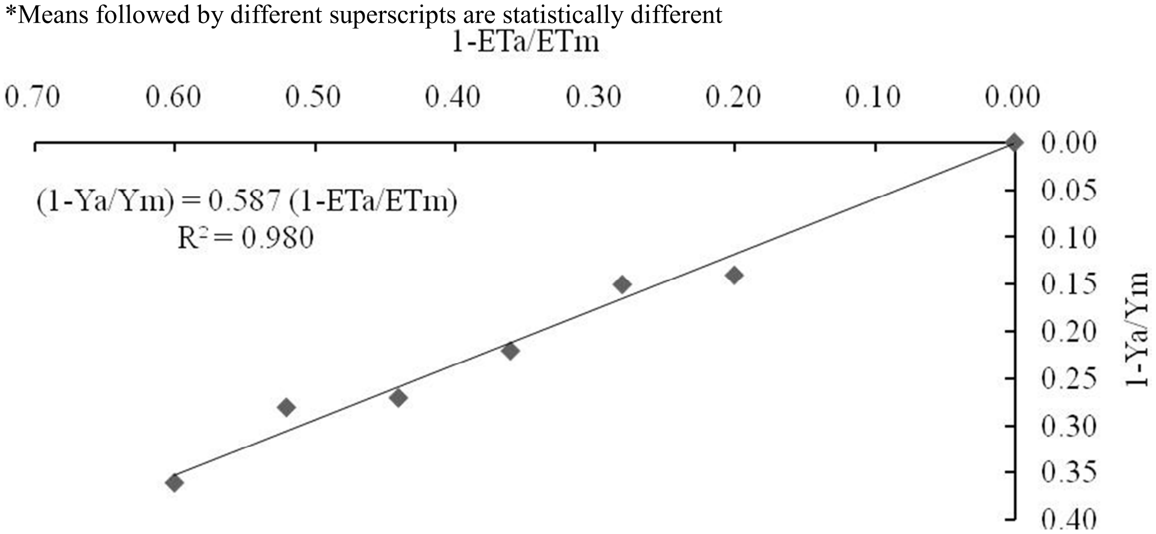

Figure 1. Water production function of teff biomass

Effect of Moisture Levels on Yield

The relative yield reductions with respect to the relative ET reduction are presented in Table 2. The effect of irrigation levels on teff yield was highly significant ($p < 0.01$) . The highest yield obtained (1053 kg/ha) corresponds to the treatment with the highest amount of water (345 mm) whereas, the lowest water applied (138 mm) resulted in 329 kg/ha of yield. The highest yield obtained (1053 kg/ha) corresponds to the treatment with the highest amount of water (345 mm) whereas, the lowest water applied (138 mm) resulted in 329 kg/ha of yield. It was observed that 50% reduction in the amount of irrigation water decreased the teff yield by about 69%

where as a 10 % reduction in the applied water decreased total teff yield by 31%. As irrigation levels increased from 0.5 ETc to 0.8 ETc and from 0.8 ETc to 1.25 ETc the yield increased by 43% and 59%, respectively. Similar tendencies for different crops have been reported in earlier works (Mugabe and Nvakatawa, 2000; Zhang and Yang, 2004; Brisson and Casals, 2005). In an irrigation experiment with chilli peppers in New Mexico, the application of 20% less water than the full supply reduced the total dry matter and fruit yields by about 10% (Wien, 1997). Tewodros (2009) also found that a 25% and 50% reduction in the amount of water applied decreased tomato yield by about 19.77 and 30.08%, respectively. This is also in agreement with the report of Tiwan *et al.* (2003) who observed that 100% irrigation supply had higher cabbage yield than 60% and 80% irrigation water supply through drip irrigation system. Antony and Singandhupe (2004) also concluded that the total yield of capsicum was lower at lower levels of irrigation. Figure 2 shows the relative yield reduction with respect to the relative reduction in the amount of water applied. The slope of the curve, the yield response factor, was found to be 1.07. According to FAO (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 value of K_y greater than 1 shows a yield decrease proportionality more than the evapotranspiration decrease. In other words, this means that the advantages coming from the deficit irrigations are unlikely (Kirda, 2002). Similarly, Doorenbos and Kassam (1979) also reported that when K_y is greater than 1, yield loss is more important than evapotranspiration deficit.

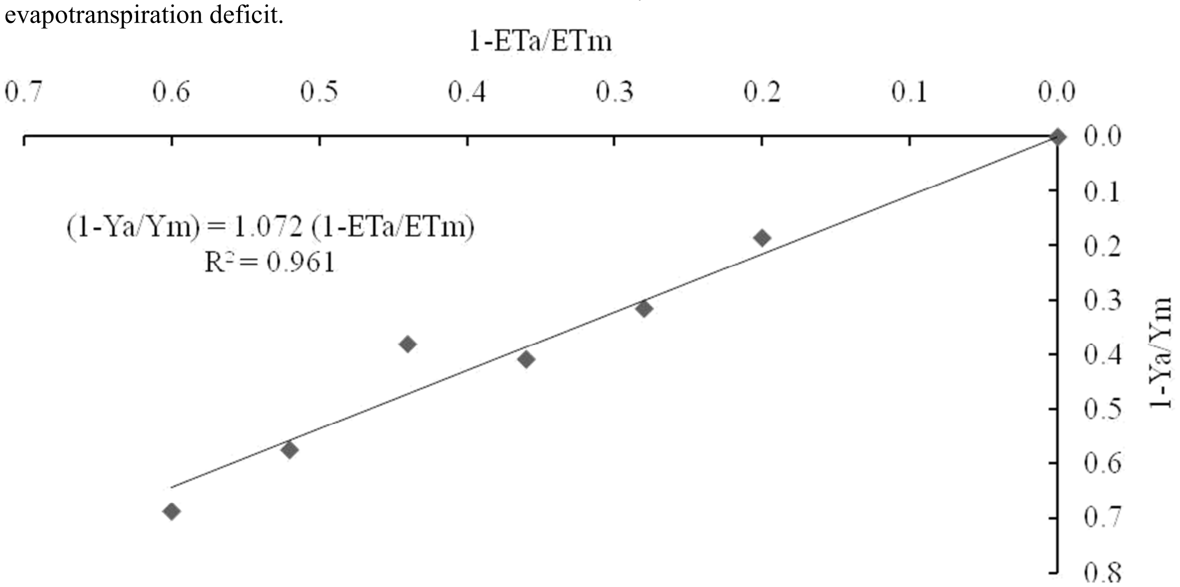

Figure 2. Water production function of teff yield

Evaluation of Root Development

Table 3 presents the root analysis output from plots where the seven water level treatments were applied. Results revealed that, withholding water by 50% of the crop evapotranspiration decreased the root length by 74%. Malik et al. (1979) and Taylor (1983) indicated that drought reduced the growth, development,and distribution of cotton roots. Root growth of 55 days old cotton was reduced after 6 days of withholding water (Ball et al., 1994). The number of roots elongating decreased by 35% during the drought.

Table 3. Root growth parameters after harvest

T Treatments	Length (cm)	Surface area (cm^2)	Area (cm^2)	Volume (cm^3)	Mean Diameter (mm)
0.5 ETc	845.94	63.98	20.37	0.39	0.241
0.6 ETc	1634.29	122.25	38.91	0.73	0.238
0.7 ETc	2092.69	141.77	45.13	0.76	0.216
0.8 ETc	2141.64	140.74	44.8	0.74	0.209
0.9 ETc	2808.44	204.49	65.09	1.18	0.232
ETc	3015.49	199.54	63.51	1.05	0.211
1.25 ETc	3278.04	228.47	67.3	1.74	0.201

Water Productivity of Teff Yield and Biomass

Water productivity of teff yield and biomass as a function of the amount of applied water is presented in Table 4. The highest water productivity (0.34 $kg/m^{3)}$ of yield was obtained under 0.7 ETc irrigation water application whereas the lowest water productivity (0.24 kg/m^3) of teff yield was obtained under 0.5 ETc irrigation water application. On the other hand, the water productivity of biomass ranges from 1.2 kg/m^3 (from 1.25 ETc treatment) to 2.0 kg/m^3 (from 0.5 ETc treatment). According to Zwart and Bastiaanssen (2004), globally measured average WP values per unit water depletion are 1.09, 1.09, 0.65 and 1.80 kg/m^3 for wheat, rice, cotton, and maize respectively.

Table 4. Water productivity of yield and biomass of teff

Treatment	Applied water (m^3)	WP of Yield (kg/m^3)	WP of Biomass (kg/m^3)
0.5 ETc	1382	0.24^a	2.0^a
0.6 ETc	1658	0.27^a	1.9^a
0.7 ETc	1935	0.34^b	1.7^a
0.8 ETc	2211	0.28^a	1.6^{ba}
0.9 ETc	2488	0.29^a	1.4^{ba}
ETc	2763	0.31^{ba}	1.3^b
1.25 ETc	3454	0.3^a	1.2^{cb}
CV (%)		12.1	11.6
LSD (0.05)		0.062	0.336

*Means followed by different superscripts are statistically different

The trend of WP in this experiment is in agreement with the findings of Yuan *et al.* (2004) who reported that the trends for both the WP for plant biomass and WP for the production of total fresh berry yields. The authors concluded that the lower the amount of irrigation water received, the higher the water productivity obtained for the drier plant biomass and berry yields. Mao *et al*. (2003) reported that highest WP of cucumber yield was obtained in treatment groups with minimal irrigation levels. Similarly, Sezen *et al*. (2005) reported that higher WP was obtained with lowest irrigation level in field grown beans. However, lower irrigation level resulted in lower total yield. Irrigation level differences significantly influenced biomass water productivity as indicated in Table 4. The amount of water applied had an inverse relationship with the biomass water productivity. Water productivity probably will become more important as access to water become more limited (Shdeed, 2001). Highest water productivity of biomass (2.0 kg/ m^3) was obtained in 0.5 ETc irrigation water application while the lowest (1.2 kg/m^3) was found at 1.25 ETc water application.

Harvest Index

Table 5 presents effect of moisture levels on Harvest Index. The effect of water levels on harvest index has similar trends with grain yield and biomass. There were significant differences among harvest indices at different irrigation levels. The highest harvest index (25%) was found under 1.25 ETc irrigation water application whereas, the 0.5 ETc irrigation water application resulted in lowest (12%) harvest index. Similar works have been reported by Chang et al., (1972) and Beser (1997). They have reported that the continuous flood irrigation had the highest harvest index, whereas, those treatments with moisture stress showed lowest value. Seifu (1993) reported that the HI of teff varies between 7 and 38 %.

Table 5. Effect of moisture levels on harvest index

Water Levels	Harvest Index
0.5 ET_c	0.12^a
0.6 ET_c	0.14^b
0.7 ET_c	0.18^c
0.8 ET_c	0.2^d
0.9 ET_c	0.22^{ef}
ET_c	0.23^f
1.25 ET_c	0.25^g
CV (%)	5.6
LSD (0.05)	0.019

*Means followed by different superscripts are statistically different

Conclusions

The yield response factor (ky) of teff grain is 1.07. From this it can be concluded that the advantages coming from the deficit irrigation are unlikely for teff grain yield.The yield response factor (ky) of teff biomass yield is 0.59. This shows that biomass yield loss is less important than ET deficiency. When water is not a limiting factor applying 345 mm amount of water enables to give the maximum grain and biomass yield per unit water applied. When water is a limiting factor applying minimum (138 mm) amount of water is able to yield grain and biomass though small.

Recommendation

As the WP for teff yield is greater (2.1 kg/m^3) in 0.7 ETc irrigation water application, it is recommended to apply irrigation at a 0.7 ETc irrigation water application. When moisture is a limiting factor, 0.5 ETc irrigation water application is recommended for biomass production since it has found the highest water productivity of biomass under this water level. In this research, teff is harvested within shorter period (in two monthes and 15 days) than the expected time limit and also the biomass water productivity is higher in 0.5 ETc irrigation water applications. So it is recommended to irrigate teff at a 0.5 ETc for forage purpose as teff's straw is prefered for its feed value. As one of the predicament of graduate research, the experiment is a one season one site experiment. Hence further investigation is recommended using different varieties of teff and different climatic conditions.

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