OPTIMIZING TEFF PRODUCTIVITY IN WATER STRESSED REGION OF ETHIOPIA

OPTIMISER LA PRODUCTIVITE DE TEFF DANS LA REGION DE STRESS HYDRIQUE DE L'ETHIOPIE

YENESEW MENGISTE YIHUN[1], BART SCHULTZ[2], ABRAHAM MEHARI HAILE[3], TEKLU ERKOSSA[4]

ABSTRACT

Smallholder rainfed agriculture, characterized by a low-input and low-output system, has been the main stay of the Economy of Ethiopia. In the past two decades, growing population pressure in the highland areas of rainfed agriculture on a rapidly dwindling water resources and declining natural resource base has put irrigated agriculture to a prominent position on the country's development agenda. Deficit irrigation is viewed as one of the best alternative methods of irrigation to optimize crop and water productivity of the 10 million ha arable land of Ethiopia.

Teff is a rainfed crop and is the major staple food crop in Ethiopia. It has no gluten and is considered a healthy food grain. This paper reports on the field experimental findings on Teff productivity under deficit irrigation in Melkassa, one of the water stressed regions in Ethiopia. The experiment was done with a factorial combination of various levels of irrigation application (100, 75, 50, 25 and 0% of the optimum irrigation requirement) and different dates of irrigation during the four growth stages of Teff. The seeding rates were 15 and 25 kg/ha.

Irrigating Teff at 75% of its optimum irrigation requirement with a seed rate of 15kg/ha has resulted in a yield of 5 ton/ha. At 50% irrigation application and 25 kg/ha seed rate, the productivity was 3 ton/ha. Both are significantly higher than the average yield of 1 ton/ha for rainfed Teff. Proper land preparation contributed to the increase in yield as it minimized water and nutrient loss from the irrigated field. Also, the lower seeding rate significantly reduced lodging problems and boosted the productivity.

1 PhD student at UNESCO-IHE Institute of Water Education, E-mail: y.yihun@unesco-ihe.org
2 Professor of Land and Water development, UNESCO-IHE, Delft, the Netherlands
3 Senior Lecturer, UNESCO-IHE, Delft, the Netherlands
4 Irrigation Engineer, IWMI, Addis Ababa, Ethiopia

These results indicate that with the available limited water resources, large arable land in the water stressed regions of Ethiopia could be brought under Teff cultivation thus significantly increasing the total production. This would reduce the Teff price that has increased five-fold in the past 5 years from 2,000 Birr (about US$ 130) per ton to 10,000 birr (US$ 650) per ton.

Key words: *Deficit irrigation, Ethiopia, Teff, Productivity, Water stressed regions.*

RESUME ET CONCLUSIONS

Les ressources en eau limitées et la concurrence croissante pour l'eau permettra de réduire sa disponibilité en irrigation. A même temps, pour satisfaire la demande croissante de nourriture, il faudra accroître la production agricole avec moins d'eau. Réaliser une meilleure efficacité de l'utilisation de l'eau sera un défi majeur dans le proche avenir. Il nécessite l'utilisation des techniques et des pratiques pour fournir aux cultures un débit plus précise de l'eau, atténuer la pénurie d'eau dans différentes régions du monde en augmentant la productivité des ressources en eau existantes et produire plus de nourriture avec moins d'eau. L'augmentation de la productivité de l'eau réduit la pénurie d'eau et laisse plus d'eau à d'autres fins, comme les utilisations humaines et les écosystèmes.

Ce document rend compte des résultats des expérimentations menées sur le terrain en matière de la productivité de Teff par l'irrigation déficitaire. Ces conclusions sont fondées sur les recherches en cours à Melkassa, l'une des régions en Ethiopie affrontées par le stress hydrique. L'expérimentation sur le terrain comprend une combinaison factorielle de différents niveaux de la demande d'irrigation (100, 75, 50, 25 et 0% des besoins en irrigation optimale) et des différentes dates d'application d'irrigation au cours de quatre stades de croissance de teff. Le teff est la principale culture vivrière en Ethiopie. Il a un fort potentiel d'être la culture d'exportation aux États-Unis et aux pays européens car il ne contient pas de gluten et est donc considéré comme un grain de la nourriture saine. Ces combinaisons factorielles ont été testées pour les taux de semis de 15 à 25 kg / ha.

L'irrigation de Teff à 75% de ses besoins en irrigation optimale tout au long de la saison de croissance avec un taux de semis de 15kg/ha a donné lieu à un rendement de 5 tonnes/ha. L'application de 50% d'irrigation et de 25 kg/ha de semis a donné lieu à une productivité inférieure de 3 tonnes/ha. Ces rendements sont nettement plus élevés que la productivité moyenne de 1 tonne / ha en agriculture pluviale. La préparation adéquate des terres contribue à l'augmentation du rendement car il réduit la perte d'eau et des éléments nutritifs du champ irrigué. De même, la baisse du taux de semis réduit considérablement les problèmes de la productivité.

Ces résultats indiquent qu'avec les ressources disponibles en eau limitées, il est possible de mettre en culture de Teff les grandes terres arables des régions à stress hydrique de l'Ethiopie, ce qui pourra accroître la production totale. Cela pourra réduire le prix du teff qui a multiplié cinq fois au cours de 5 dernières années de 2.000 birr (environ 130 $ EU) par tonne à 10.000 birr (650 $ EU) par tonne.

Mots clés : *Irrigation déficitaire, Ethiopie, Teff, productivité, régions à stress hydrique.*

1. INTRODUCTION

In the arid and semi arid regions, the limited availability of water is in most cases the major constraint in agriculture. Rainfall in such regions is erratic in space, time and quantity of its occurrence, rendering rainfed agriculture a risky enterprise; and Ethiopia is no exception to this. Amazingly, arid and semi-arid areas are the 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 and contribute less than 30% to the country's total agricultural production. The traditional rainfed agriculture in the high lands appears to shoulder the responsibility of feeding the population exceeding 73.9 million (FDRE-PCC, 2007). Thus food insecurity has remained a great concern to the country. Therefore it is imperative to bring large areas of the arid, semi-arid and sub-humid regions 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 (Chiza, 2005 and Hussain and Hanjra, 2004).

Ethiopia has an estimated irrigation potential of 3.5 million hectares (Awulachew et al., 2007b). During 2005/2006 the estimated area under irrigated agriculture was 625,819 ha, which, in total, constitutes about 18% of the potential (MoWR, 2006). It is planned to expand irrigation development by an additional 528,686 ha by the year 2010 (Atnafu, 2007; MoWR, 2006), which will constitute about 33% of the potential.

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. Achieving greater efficiency of water use will be the main task in the near future and will include the employment of techniques and practices that deliver a more accurate supply of water to crops.

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 no gluten (Roseberg et al., 2006).

Teff has higher market prices than the other cereals, for both its grain and straw. *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. *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 USA (Evert et al., 2009).

The knowledge of crop water requirement is an important practical consideration to improve water use efficiency in irrigated agriculture. Therefore it is important to determine and know the crop water requirement, the crop coefficient and the yield response factor of teff crop.

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 studies on *teff's* response to moisture stress be undertaken. Accordingly, the study reported in this paper has the following specific objectives: To estimate the crop water requirement, crop water productivity of teff and to identify crop growth stages during which the crop (teff) can withstand water stress with minimal effect on yield.

2. MATERIALS AND METHODS

2.1 Study site

The field experiment is conducted at one of the experimental sites of Melkassa Agricultural Research Centre (MARC). The research centre is located in the hot Great East African Rift Valley at 8°24′N latitude, 39°21′E longitude, and altitude of (1300-1800 m +MSL); the area is among the semi arid regions characterized by erratic rainfall (768mm mean annual rainfall), frequent drought and has a harsh cropping environment. The mean minimum and maximum monthly temperatures of the area are 22 °C to 34 °C respectively. The texture of the soil is Clay Loam. This area is a typically Teff-growing area as it is a reliable and low-risk crop.

2.2 Climatic data collection and analysis

Climate data were obtained from Melkassa meteorological station. Daily weather data of rainfall, max and min temperature, relative humidity, sunshine hours and wind speed were obtained from the meteorological station near the experimental field. The daily reference evapotranspiration (ETo) of Melkassa for the growing season of 2010 and 2011 were computed. Eto calculator (FAO, 2009) was used to compute the ETo using the above key input meteorological variable.

2.3 Field Experiment

The field experiments were carried out in Melkassa Research Centre of Ethiopia in both rainy and dry season of the year 2010/11 and 2011/12. A factorial combination of depth of irrigation water application and growth stage of Teff were used as experimental design in order to determine the optimum water application depth at specific growth stage under a water scarcity condition. Four different level of irrigation water namely, full crop water requirement (ETc), 25% deficit 50% deficit and 75% deficit were adopted. The crop growing season of Teff was divided into four major growth periods: initial stage (P1), development stage (P2), mid season stage (P3) and late season stage (P4). A 4 x 4 factorial combination of sixteen treatments with three replications were set in the experimental field. These factorial combination were tested at seed rates of 10 and 25 kg/ha.

2.4 Soil water data collection and analysis

The water source of the area is Awash River from where the farmers divert water to irrigate their fields. The quality of the irrigation water were evaluated in the laboratory for main soluble ions like calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}) and Potassium (K^{+}) as cations and carbonate and bicarbonate as anions. Flame absorption and flame photometry techniques (Kruis, 2002) were used in the case of calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na) cations. Calorimetric, turbidimetric and titration methods were employed for the chloride (Cl), sulphate (SO_4) and bicarbonate (HCO_3) anions. In addition salinity hazard and pH were also quantified.

2.5 Soil and crop data collection and analysis

Soil samples were collected depending on the root depth of the experimental crop Teff at the time of sowing. A 1.0 m x 1.0 m pit was dug. Undisturbed soil sample were taken at 0- 30 cm, 30 - 60 cm and 60-90 cm by using core sampler with 3 replications. The initial soil moisture and the physical soil characteristics used as input data for the Aquacrop model were determined.

Two varieties of Teff, Gemechis and Kuncho was selected and used for the Experiment. The sowing date for rainfed and irrigated field was July 20, 2010 and January 1, 2011. Each plot was 2.0 m x 4.0 m, spaced 1.5 m apart. The individual plots were isolated by means soil bunds. Irrigation was applied from watering can, simulating sprinkler irrigation. Recommended fertilizer amounts were added.

The dates of the main phenological stages were recorded. Plant height was measured at ten days interval from the fixed sample of each experimental plot. Above ground biomass observation were made in every 10 days from a disturbed sample area of 1 m^2. The above ground biomass were dried with an oven for 48 h at 60 ^{0}C and then weighted. Canopy cover was measured by using LAI-2200 plant canopy analyzer for each treatment at ten days interval. Grain yield were measured after maturity from pooled sample of an area1.5 m x 3.0 m in each plot. The grain and total biomass fresh weight were weighted at maturity and then were dried and then weighted on sensitive balance.

2.6 Water Productivity (WP)

WP refers to the amount or the value of product over volume or value of water depleted or diverted (Bessembider et al., 2005). It can be expressed in general physical and economic terms. Oweis and Hachum (2006) defines Physical productivity as the quantity of the product divided by the amount of water depleted or diverted (kg.m^{-3}). Economic water productivity is defined as value per unit of water or the Net Present Value (NPV) of the amount of the product divided by the NPV of the amount of water diverted or depleted (Seckler et al., 2003; Perry,2007). We adopted WP as the productivity of both Grain and Biomass of Teff per unit amount of water applied in rainfed, and various irrigation scenarios. Molden and Rijsberman (2001) and Rijsberman (2001) give a simple argument to the above statement: by growing more yields with less water, more water will be available to irrigate arable land in water scarce semiarid region/area.

i) Grain Water Productivity (Grain WP) was calculated using Eq. 1:

$$Grain\,WP = \frac{GY}{\sum Tr} \qquad \text{(Eq. 1)}$$

Where GY is the grain yield measured in the field (kg.ha^{-1}) and Tr is the transpiration in m^3ha^{-1}.

ii) Biomass Water Productivity (Biomass WP) was computed using equation (Eq. 2)

$$Biomass = \frac{BY}{\sum Tr} \qquad \text{(Eq.2)}$$

Where BY above ground biomass measured in kg.ha^{-1}

2.7 Calibration and validation of AquaCrop for Teff

The collected information on weather, soil characteristics, sowing date and sowing density and irrigation applications constituted the input data needed to run for each simulation.

Model efficiency (ME) developed by Nash and Sutcliffe (1970) was used to evaluate performance of models and to compare the simulated yield the field experimentally observed yield of Teff. ME is a measure of the robustness of the model:

$$ME = \frac{\sum_{i=1}^{n}(O_i - MO)^2 - \sum_{i=1}^{n}(S_i - O_i)^2}{\sum_{i=1}^{n}(O_i - MO)^2} \qquad \text{(Eq.3)}$$

Where ME is model efficiency, O is measured value, S is simulated value, MO is the mean observed value for n = 20 number of treatments.

Goodness of fit between the simulated and the observed data were assessed on the basis of the R^2 and root mean square error (RMSE).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - S_i)^2} \qquad \text{(Eq.4)}$$

The model efficiency is similar to the coefficient of determination (R^2). The model efficiency compares predicted values to the 1:1 line rather than the best regression line through the points.

3. RESULTS

Teff yields from each treatment are shown in Fig. 1. The average yield was 2.55 t/ha. Using LSD test, first confirming that the F-test was significant at 5% and 1% significance level, it was found that 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 T1. However, for water deficit at the development stage, mid season stage, or during all stages for 75% deficit throughout the growing season, the yields were significantly different ($p<0.01$) from treatment 1 (ET100). Treatments T7,T11 and T15 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, resulted in the 2nd, the 5th and the 6th lowest yields, respectively. 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. Maximum yield of *teff* was obtained under optimum irrigation (T1). T2 which was subjected to the highest water stress (75% deficit) throughout the growth period resulted in the minimum yield.

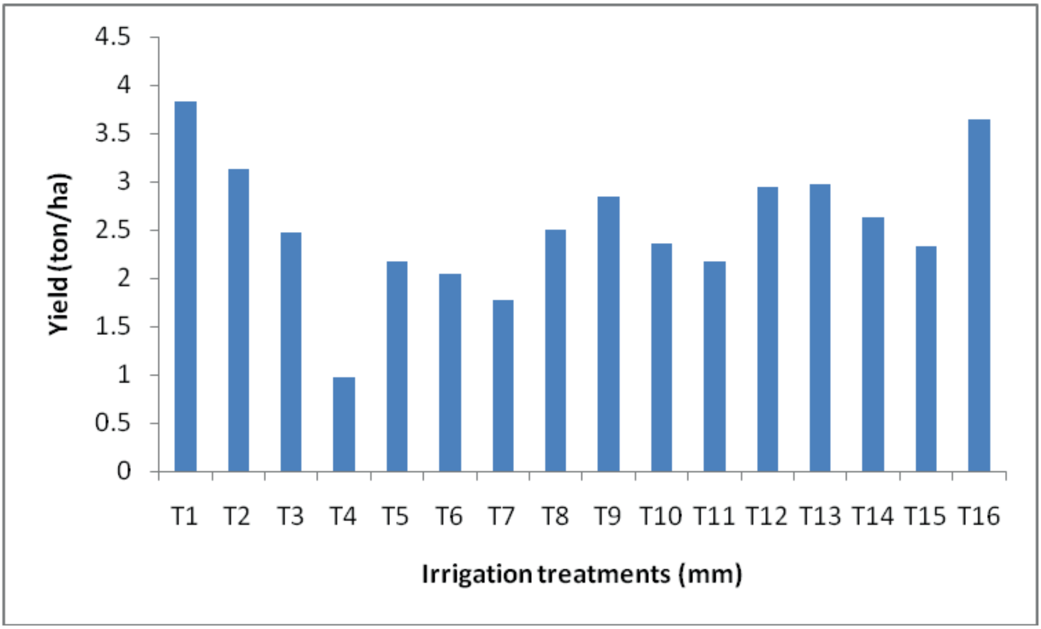

Fig. 1: Yield of Teff under different irrigation treatments

In treatments T8, T12 and T16 (75%, 50% and 25% deficit, respectively at the late season stage), the yield reductions were smaller. This yield reduction would have been much higher had the crop been subjected to water stress during any of the previous stages, especially in the mid season stage. The yield from T4 was much lower than those obtained from treatments with stress at individual growing stage of initial, development, mid season and late season stages. This shows it is better to stress the crop at a specified growing stage of the crop rather than totally stressing throughout the season.

Analysis of variance on dry matter production revealed that variation in level of irrigation water application significantly ($p<0.01$) influenced the dry mater production. An increase in level of irrigation water enhanced the dry matter production. Significantly higher dry matter production was obtained from the optimum irrigation and 75% and 50% deficit at the initial and the late season stages, respectively.

Decreasing the recommended seeding rate of 25 kg/ha to 10 kg/ha increases the capacity of teff stalk to increase its strength and withstand lodging because of heavy panicle at maturity. In addition, smaller seeding rate increases the tillering potential.

4. DISCUSSION

Stressing the crop during mid season stage reduced the yield significantly as compared to stressing the crop during the initial and late season stages (Doorenbos and Kassam, 1979). The most sensitive periods are those which correspond to flowering stage (Kirda and Kanber,1999). 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 (Kirda and Kanber,1999) . 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 (Bazza and Tayaa,1999).

T6, T10 and T14 received adequate irrigation during the initial, mid season stage and late season stage. The crop partially recovered from the stress during the development stage. The ability of crops to partially recover the effect of early water stress has also been observed in other studies (Kirda and Kanber, 1999). These studies revealed that under limited water condition, it is better to start subjecting the crops to stress early in the season. By doing so, the crop adapts to limited watering conditions with the stress not being severely concentrated in any one time period.

Analysis of variance revealed that total biomass production was significantly ($p<0.01$) influenced by variation in water application. The biomass production was proportional to the availability of water. As the stress intensity increased, biomass production decreased. These findings were in agreement with the experimental results reported in other studies which attributed lower leaf production and dry matter to water stress Bouman and Toung, 2001). A maximum biomass yield was obtained from treatment 1(getting optimum amount of water i.e. 100 % of ETC), whereas the minimum biomass yield was obtained from T4 (75% deficit throughout the growth season).

Since dry matter accumulation is the balance between photosynthesis and respiration, any activity that promotes photosynthesis and decreases respiration will usually increase dry matter production. Hence, as an increase in amount of water application favours photosynthesis rate and decreases respiration rate, it results in high dry matter production. Soil moisture stress during vegetative and reproductive stages results in the reduction of above ground dry weight (Soltani *et al*., 2000).

In this study the term Water Productivity (WP) was used instead of the traditional water use efficiency (WUE). This was thought to be better because (1) not all irrigation water is used in the evapotranspiration processes (2) a fraction of the ETc comes from sources other than irrigation. Treatments which received lower amount of water resulted in higher Water Productivity (WP). Higher Water Productivity is obtained from stressing the crop by 75% deficit at individual stage than stressing by 50% deficit.

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.

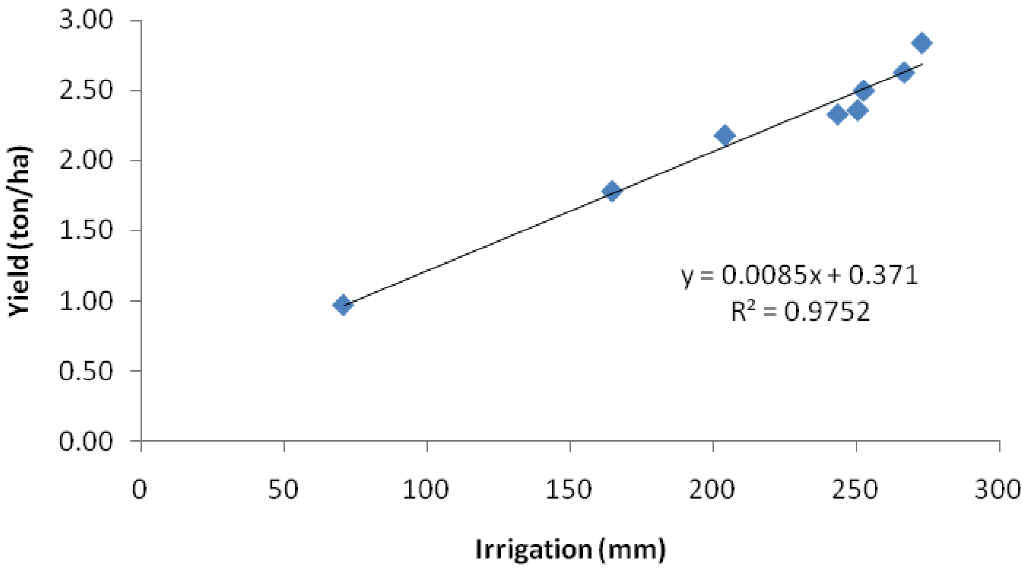

Fig. 2: Yield-irrigation relationship

Linear relationship was found between yield and seasonal irrigation (Fig. 2). Some studies have found similarly good linear relationships between yield and irrigation water applied in teff subject to deficit irrigation treatments (Payero etal., 2006; Farre and Faci, 2006). However, other studies found non-linear relationship between yield and seasonal irrigation (Tolk and Howell, 2003). The relationship between yield and irrigation is affected by factors such as climate, soil properties and irrigation practices (Farre and Faci, 2009). These factors should be taken into account when proposing deficit irrigation strategies.

5. CONCLUSIONS

Maximum above ground biomass yield and grain yield are obtained by applying optimum amount of water throughout the growing season. Fifty percent irrigation at the initial and late season stages resulted in statistically similar average grain yield and biomass as that of applying full irrigation requirement throughout the whole season. Meeting full water requirement during the first two growth stages of teff is not advisable if water shortage cannot be avoided during the remainder of the season, especially during the mid season stage. However, stressing teff either by one-half or three-quarters at the mid season stage, results in lower yields next to stressing the crop throughout the growing season. This indicates that the most critical period for irrigation is the mid season stage. However, if water stress is unavoidable at the mid stage, it is better to stress the crop one-half deficit than by three-quarters. When water stress is imposed early in the growing season, high yield of teff could easily be sustained provided adequate watering conditions take place during the rest of the growing season.

Teff water use efficiency is lowest when optimum or maximum irrigation water is applied throughout the growth season and highest when water is stressed by three-quarter throughout the growing season. Higher water use efficiency can be obtained by stressing teff crop by three-quarter deficit at individual growth stages than stressing by one-half deficit.

Overall, a strategy of stressing teff by one-half at the beginning and end of season, and using the water to irrigate a greater area, results in higher aggregate production than providing optimum irrigation throughout the season for a smaller area.

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