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Crop coefficient, yield response to water stress and water productivity of teff (*Eragrostis tef* (Zucc.)

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ABSTRACT

In the semi-arid region of Tigray, Northen Ethiopia a two season experiment was conducted to measure evapotranspiration, estimate yield response to water stress and derive the crop coefficient of teff using the single crop coefficient approach with simple, locally made lysimeters and field plots. During the experiment we also estimated the water productivity of teff taking into account long-term rainfall probability scenarios and different levels of farmers' skills. During the experimental seasons (2008 and 2009), the average potential evapotranspiration of teff ranged from 260 to 317 mm. The total seasonal water requirement of teff was found to lower in contrast to the assumptions of regional agronomists that teff water requirement is comparable to that of wheat and barley (375 mm). The average single crop coefficient values (k_c) for the initial, mid and late season stages of teff were 0.8–1, 0.95–1.1 and 0.4–0.5, respectively. The seasonal yield response to water stress was 1.04, which indicates that teff exhibits a moderately sensitive and linear response to water stress. The results suggest that teff is likely to give significantly higher grain yield when a nearly optimal water supply is provided. The study showed that, in locations where standard equipment is not affordably available, indicative (rough) crop evapotranspiration values can be obtained by using field plots and employing locally made lysimeters. The difference in economic water productivity (EWP) and the crop water productivity (CWP) for teff were assessed under very wet, wet, normal, dry and very dry scenarios. In addition two groups of farmers were evaluated, a moderately (I) and a highly skilled (II) group. The results showed that higher EWP and CWP were obtained under very wet scenario than very dry scenario. There was also a 22% increase in EWP and CWP under group II compared to group I farmers. The increase was due to a 22% reduction in unwanted water losses achieved through use of improved technology and better irrigation skills. Both EWP and CWP can be used to evaluate the pond irrigation water productivity (IWP) for a given climate, crop and soil type, and skill and technology level of the farmer. For special crops like teff extra criteria may be needed in order to properly evaluate the pond irrigation water productivity. During the experimental seasons, a high IWP for teff was attained when about 90% of the optimal water need of the crop was met. IWP can be used as an indicator as how much supplementary irrigation has to be applied in relation to the rainfall and other sources of water supply in order to assure greatest yield from a total area. However, the supplemental irrigation requirement of the crops may vary with season due to seasonal rainfall variability.

1. Introduction

The main cause of instability in food security in Ethiopia is the dependency on erratic rainfall (Helmut, 1990), as witnessed by the drought-induced food crises experienced in the last two decades. Teff is the staple food crop and principal source of carbohydrates for the majority of the Ethiopian population. Its production is critical for national food security. It is a gluten-free food crop grown predominantly by smallholders, which has attracted much interest in the international market (Spaenij-Dekking et al., 2005). It has high demand and market value, which makes farmers get more revenue than other crops. Teff straw is valuable as fodder since it is protein-rich, and it is preferred by cattle, making its market price relatively high (Ketema, 1997).

Teff is adapted to dryland farming in Ethiopia and is considered a drought-resistant crop. Despite its adaptation to dryland conditions, one of the major yield-limiting factors in teff production is water shortage. Increasing the on-farm efficiency of rain water

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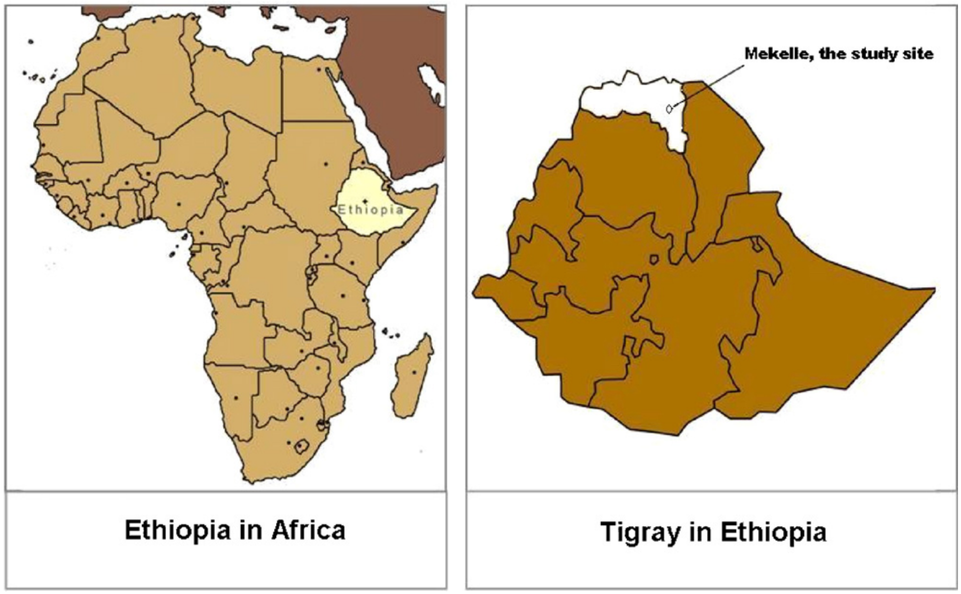

Fig. 1. Map of the study site (Mekelle area) in reference to Tigray region of Ethiopia.

usage would benefit not only the smallholders who grow it but would also improve food security in the whole country and bring in revenue from international sales.

Teff is normally not sown until the peak of the rainy period, which in Tigray is from the third week of July to the first week of August (Araya et al., 2010b). Wet sowing is preferred to avoid false start, to improve seedling establishment (Araya et al., 2010b) as well as to reduce shoot fly infestation. Often, the rainy period ends 40–50 days after the normal planting time of teff, but the duration of teff's growing period ranges from 80 to 85 days. Considering a normal season, the occurrences of late-season dry spells are more pronounced than intra-seasonal (within the rainy season) dry spells. The occurrence of late-season dry spells coincides with the critical crop growth stage, in particular, flowering and yield formation stages. Given that rain ceases in the middle of the growing stage, supplemental irrigation may be necessary for optimum growth (Araya et al., 2010b).

Rainwater harvesting (RWH) and management, especially on-farm storage ponds for supplemental irrigation offer an opportunity to mitigate the recurrent dry spells (Fox and Rockstrom, 2003; Ngigi et al., 2005). In the last 10 years, the government of Tigray promoted the construction of household ponds and more than 20,000 were constructed so far. There are possibilities to improve crop production by using on-farm storage ponds however water management has been one of the major problems. Teff's water requirement has not been studied in detail and is commonly assumed by local agronomist to be similar to that of wheat and barley (personal communication).

To estimate evapotranspiration accurately lysimeters should be used (Liu et al., 2002; Kang et al., 2003). However, they are very expensive and rarely available in Ethiopia. To address this problem, in our study we used a combination of field plots and locally made lysimeters. The single crop coefficient approach can be used to estimate the crop coefficient (Allen et al., 1998; Kang et al., 2003). The single crop coefficient is simple and applicable for the planning and designing of irrigation projects as well as for less frequent water application (Kang et al., 2003; Garcia et al., 2003). Hence, this method was the most suitable for our teff investigation, given the local constraints in the experimental conditions.

In order to increase the irrigation area coverage, there is need to increase the source of irrigation water supply and/or to improve the productivity of the irrigation scheme. The latter is sounder under the present condition because water management has become a problem as the farmers do not know enough about teff's water productivity. As water scarcity demands the maximum use of every drop of water, there is a need to calculate the water productivity of crops (Pereira et al., 2002; Bessembider et al., 2005; Fereres and Soriano, 2006).

Enhancing water use efficiency in irrigated agriculture includes increasing output per unit of water, reducing water loses and prioritizing water allocation (Howel, 2001). The sustainable use of water has to consider maximizing yield per unit of water rather than maximum yield per unit of area (Fereres and Soriano, 2006). Evaluations of irrigation schemes based on economic water productivity (EWP) and crop water productivity (CWP) are the essential indicators of efficiency of water use. However, many farmers, especially in northern Ethiopia, failed to take into account such important elements. In this study we have introduced these two elements (EWP and CWP) to study teff water productivity under the present pond water use. The crop productivity per unit water aspect should be analyzed in addition to the economic aspect because increasing crop production per unit of water does not necessarily increase the farmer's income due to the non-linearity of crop yield with the price of products

The objectives of this paper are to measure evapotranspiration and derive the crop coefficient of teff using a single crop coefficient approach from a simple, locally affordable field and locally made lysimeter; to determine the yield response to water stress and to estimate and evaluate teff water productivity under the present pond water use taking into account the long-term rainfall probability scenarios and skill and technology of the farmers.

2. Materials and methods

2.1. Experimental site

The experiment was conducted in 2008 and 2009 (August to October) in northern Ethiopia at Mekelle (latitude 13°29′N long 39°35′E, 2130 m.a.s.l) (Fig. 1). The soil at the experimental site is a Cambisol with total nitrogen of 1.22 g kg^{-1} and available phosphorus, 5.84 mg kg^{-1} (Habtegebrial et al., 2007). The texture of the surface soil (0–0.3 m) is silty clay. The water content at field capac-