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Evaluating the Consumptive Water Use of Teff in Consideration of Soil Water Movement in Central Ethiopia

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Abstract: Crop production in Central Ethiopia mostly depends on rainfall. Although the mean annual rainfall is adequate to grow crops, the crop production often suffers from severe drought stress resulting in unstable food security. Recently, several trials of irrigation techniques have been practiced in Ethiopia to improve the crop production systems and to save water, such as spate irrigation and consecutive irrigation reservoir system with water harvesting, etc. On the other hand, basic irrigation designing data were still limited (such as water consumption amount and crop coefficient, etc.). Especially, water consumption of teff (*Eragrostis tef*), which is a staple food in Ethiopia, is not clear. Incidentally, it has been reported that it is prone to overestimate consumptive water use by Soil Moisture Depletion Method a conventional one, because it has not been able to distinguish with upward and downward water movement. For this reason, we measured soil water content and matric potential in a teff cultivation field in order to identify upward and downward of soil water movement and to determine an effective soil layer from water flow direction by using Zero Flux Method (ZFM). In this article, we proposed a method to evaluate the consumptive water use of teff in consideration of soil water movement in order to make an effective irrigation plan for water conservation. The results of this study indicated that the ZFM caused reduce 30% of the amount of irrigation water in comparison with the conventional one.

Key Words: Ethiopia, Irrigation, Soil water movement, Teff

1. Introduction

Crop production systems in Central Ethiopia mostly depend on rainfall. Although the mean annual rainfall is adequate to grow crops, the crop production systems often suffer from severe drought stress resulting in unstable food security. Recently, several trials of irrigation techniques have been practiced in Ethiopia to improve the crop production systems, such as spate irrigation and consecutive irrigation reservoir system with water harvesting, etc. On the other hand, basic irrigation designing data were still limited (such as water consumption amount and crop coefficient, etc.). Especially, water consumption of teff (*Eragrostis tef*), which is a staple food in Ethiopia, is not clear. Incidentally, it has been reported that it is prone to overestimate consumptive water use by Soil Moisture Depletion Method a conventional one, because it has not been able to consider gravitational drainage. For this reason, we measured soil water content and matric potential in a teff cultivation field in order to identify upward and downward of soil water movement and to determine an effective soil layer from water flow direction by using Zero Flux Method (ZFM). In this article, we proposed a method to evaluate the consumptive water use of teff in consideration of soil water movement in order to make an effective irrigation plan for water conservation.

2. Materials and Methods

2.1. Cultivation Experiment

The experimental site is located in Adami Tule Agricultural Research Center (hereinafter referred to as “ATARC”), Oromia state of Central Ethiopia (7˚51’ N, 38˚42’E, 1,650 m a.s.l.) (**Fig. 1**). In this region, the period during June throughout September is usually classified as rainy season, and the other as dry season. The soil texture in experimental site is classified to be Sandy Loam according to the classification of the International Society of Soil Science.

In an upland cropping field, 1 m × 1 m cultivating plot was prepared. In this plot, changes in soil water content were recorded at a depth of 5, 15, 25 and 35 cm with soil moisture sensors (EC-5, Decagon Devices, Inc., Pullman, WA, USA) and data logger (Em50, Decagon Devices, Inc., Pullman, WA, USA). A broadcast sowing of teff seed was conducted on 4 Sep 2009 with no fertilizer application, and the harvesting of teff on 22 Dec 2009. The amount of irrigation was 8 mm per day except rainy days. In order to estimate potential evapotranspiration by Penman method (Allen *et al*., 1998), temperature, relative humidity, wind speed, solar radiation, and rainfall were recorded by HOBO Weather Station (Onset

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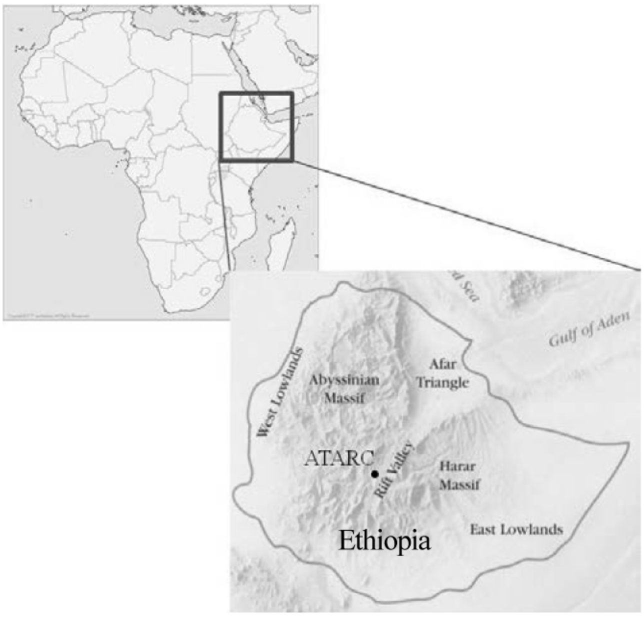

Fig. 1. Object site of investigation.

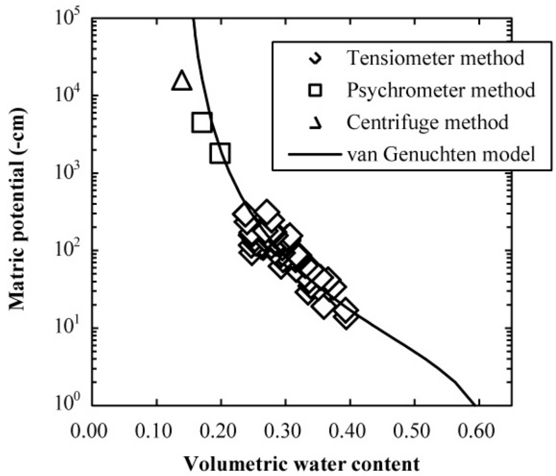

Fig. 2. Water retention of the soil in ATARC.

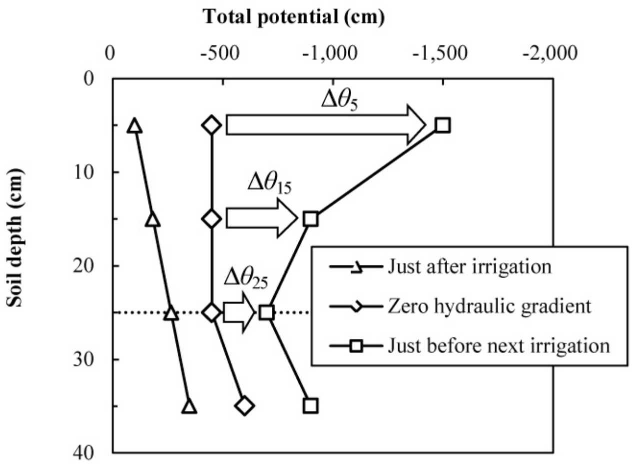

Fig. 3. Example of how to determine effective soil layer.

Computer Co., Bourne, MA, USA).

In this article, we estimated the consumptive water use of teff by Soil Moisture Depletion Method and Zero Flux Method in order to compare these methods.

In SMDM, a bottom of effective soil layer was defined as soil depth where soil water content remained at about the same level. The difference between consumptive water use by SMDM and evapotranspiration is reported to be less than 10% (Tanner, 1967). In terms of that, an observation point was defined as the bottom of effective soil layer on condition that the decrement of soil water content was less than 10% of the cumulative consumptive water use in effective soil layer. The equation is shown in (1)

$$\frac{\Delta\theta_N}{\sum\Delta\theta_N} < 0.10 \qquad (1)$$

Where $\Delta\theta$ is decrement of soil water content (m^3/m^3), N indicates soil depth (5, 15, 25 and 35 in the unit of cm). To take a hypothetical example, when the ratio of sum total of decrement of soil water content at a depth 25 cm to at a depth of 5, 15 and 25 cm was less than 10%, the effective soil layer was defined as from surface to 25 cm deep. The equations are shown in (2), (3).

$$\frac{\Delta\theta_{25}}{\Delta\theta_5 + \Delta\theta_{15} + \Delta\theta_{25}} < 0.10 \qquad (2)$$

$$ET = \Delta\theta_5 + \Delta\theta_{15} + \Delta\theta_{25} \qquad (3)$$

Where ET is evapotranspiration (mm).

On the other hand, in ZFM, soil water content was converted into matric potential in each depth, and then the soil depth where the sign of total potential reversed was defined as the bottom of effective soil layer (**Fig. 2**). Just after irrigation, the negative hydraulic gradient in all layers resulted in downward water movement. Thereafter the drier the soil layer from surface, the smaller the total potential, and then soil layer of zero hydraulic gradient appeared. This point was defined as the bottom of the effective soil layer. In this study, the consumptive water use was defined as the sum total of decrement of soil water content from the time that the hydraulic gradient became zero until the next irrigation. For instance, **Figure 3** showed that the soil depth of 25 cm was zero flux plane, namely, the bottom of the effective soil layer. Therefore the consumptive water use was also shown in the equation (3).

2.2. Irrigation plan

In order to clarify how the difference of the estimated crop coefficient by two methods has an influence on water conservation, we made the irrigation plan of teff in dry season (from October to January) of Central Ethiopia using the crop coefficients with Crop Wat 8.0 software developed by the Land

Table 1. Meteorological data and estimated potential evapotranspiration in ATARC.

Month	Min Temp ℃	Max Temp ℃	Humidity %	Wind km/day	Sun hours	ETo mm/day
Jan	11.0	28.0	53	190	9.1	4.8
Feb	12.5	29.1	50	164	8.7	5.0
Mar	13.3	30.0	51	156	8.1	5.1
Apr	14.2	29.4	58	156	7.8	4.9
May	14.7	29.1	61	173	8.5	5.0
Jun	14.7	27.5	63	225	7.6	4.8
Jul	15.1	25.1	68	207	5.6	4.0
Aug	14.2	25.6	70	164	6.3	4.0
Sep	13.2	26.8	68	121	7.0	4.1
Oct	11.3	28.2	55	164	8.7	4.9
Nov	10.3	27.5	52	173	9.4	4.8
Dec	10.2	26.9	53	181	9.6	4.6
Ave	12.9	27.8	59	173	8.0	4.7

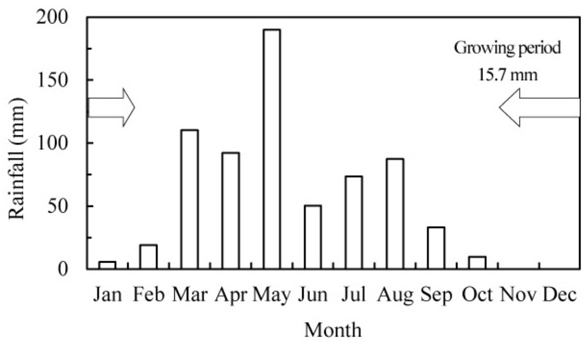

Fig. 4. Monthly rainfall corresponding to 10-year probable rainfall amount in ATARC (Feb 1987-Jan 1988).

Table 2. Soil property in ATARC.

Parameter	ATARC
Total available soil moisture (Field capacity-Wilting point) (mm/m)	170.0
Maximum rain infiltration rate (mm/day)	78.0
Maximum rooting depth (cm)	80
Initial soil moisture depletion (%)	0.0
Initial available soil moisture (mm/m)	170.0

and Water Development Division, FAO. The necessary data for running the software were about climate for estimation of potential evapotranspiration, monthly rainfall, and crop and soil property (**Tables 1 and 2**, **Fig. 4**). The irrigation timing was set when soil moisture content reached wilting point. The amount of each irrigation corresponded to refilling soil moisture content 100% field capacity. On the supposition of surface irrigation, the efficiency was set to be 60%.

3. Results and Discussion.

3.1. Cultivation experiment.

The results of the temporal change of the consumptive water use of teff by SMDM and ZFM showed that the maximum of value was 4 to 6 mm per day, and then the ears of teff was appeared at approximately the same time (40th day after sowing) (**Fig. 5**). Compared with the estimated values between two methods, the value estimated by SMDM was larger than by ZFM by 1 to 2 mm throughout the entire growing period (**Fig. 6**). The root system was distributed in soil layer from surface to 5 cm below. These results were due to the slightly larger amount of irrigation (8 mm/day) promoted the downward of soil water movement after irrigation. The growing period was classified into four periods with the day when the ears of rice appeared and the growth situation (**Table 3**).

Consequently, there was also the same trend in respect of crop coefficient. However, compared with crop coefficient of other miscellaneous crops, there was so validity in the estimated crop coefficient of teff (**Table 4**).

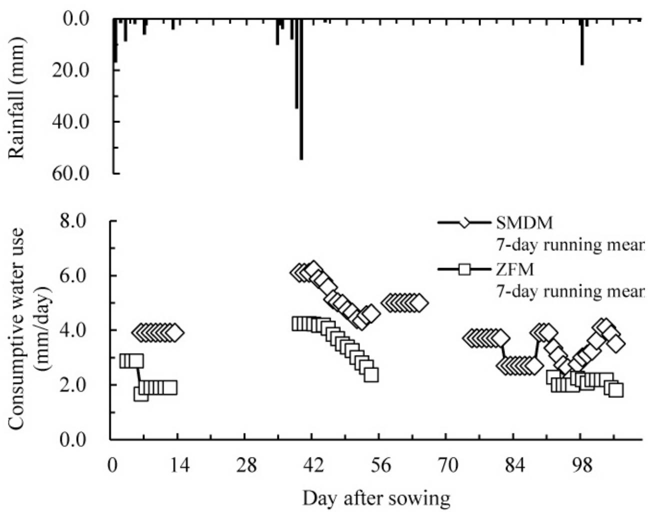

Fig. 5. Consumptive water use and daily rainfall.

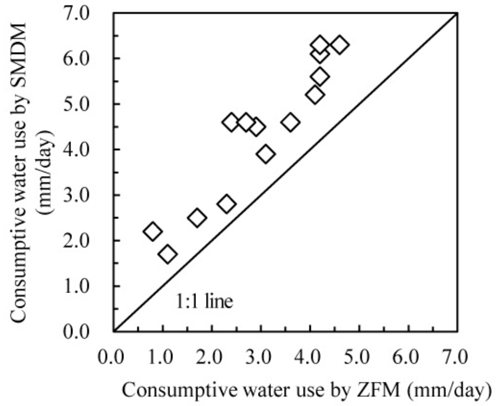

Fig. 6. Comparison of consumptive water use between SMDM and ZFM

Table 3. Potential evaporation, consumptive water use and crop coefficient per growing period.

Growing stage Growing period (day)		Ⅰ 0-22	Ⅱ 23-47	Ⅲ 48-73	Ⅳ 74-109
Potential evapotranspiration (mm/day)		3.0	3.7	3.4	3.2
Consumptive water use (mm/day)	ZFM	2.5	4.2	3.0	2.1
	SMDM	3.9	5.8	4.5	3.2
Crop coefficient	ZFM	0.85	1.13	0.89	0.66
	SMDM	1.29	1.57	1.33	1.00

Table 4. Crop coefficient of principal miscellaneous crop in middle stage (Doorenbos *et al.*, 1977).

	Crop coefficient (middle stage)
Maize	1.20
Millet	1.00
Sorghum	1.00
Barley	1.15

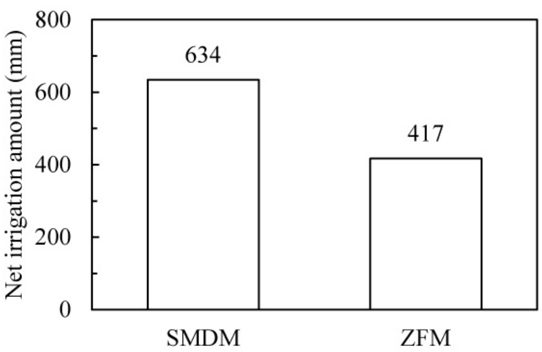

Fig. 7. Comparison of net irrigation amount with SMDM and ZFM.

Fig. 8. Water reservoir for irrigation in ATARC (150 m^3).

3.2. Irrigation plan

Compared with the cumulative net irrigation amount by SMDM and ZFM, it was revealed that using of ZFM could save water more than SMDM by 30% (**Fig. 7**). Consequently, there was an increase in yield of 20 kg from a test calculation with the scale of a reservoir installed in ATARC (150 m^3) (**Fig. 8**) and the general yield per hectare of teff in Ethiopia (0.9 t/ha).

4. Conclusion

It was revealed that crop coefficient of teff was no different from that of principal miscellaneous crops and using of ZFM could save water owing to the discrimination of upward and downward of soil water movement and to the exclusion of gravitational drainage. A further direction of this study will be to practice cultivation test of teff with the results in this study and to verify irrigation plan from the view point of growth and yield. Finally it will be possible to expand cultivation area and make effective use of irrigation water by improvement in water-harvesting technique and consecutive irrigation reservoir system.

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