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Effect of Drip and Surface Irrigation Methods on Yield and Water Use Efficiency of Onion (*Allium Cepa L.*) under Semi-Arid Condition of Northern Ethiopia

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Abstract
Water has been identified as one of the scarce inputs, which can severely restrict agricultural production and productivity unless it is carefully conserved and managed. It is a wide-ranging practice using every drop of water for crop production through suitable irrigation practices. Hence, a field experiment was conducted at Axum area (Northern Ethiopia) during the dry season of 2013 to 2014 using drip and furrow methods of irrigation to evaluate the effect of irrigation methods in combination with and without deficit irrigation practices on yield and water use efficiency (WUE) of onion under drip and surface method of irrigation. Four irrigation treatments viz., drip irrigation at 100, 80 and 60% crop evapotranspiration (ETc) and full furrow irrigation. Drip irrigation at 100% ETc gave significantly higher onion yield (28.0 t ha^{-1}), as compared to 80 and 60% ETc and furrow irrigation treatments. The onion irrigated at 100% ETc with drip method also registered 32.8% of increase in yield over furrow method of irrigation. However, irrigation water use efficiency was found highest (7.60 kg m^{-3}) with drip irrigation at 60% ETc and lowest (4.75 kg m^{-3}) with furrow irrigation. The amount of water saved at 100, 80 and 60% ETc under drip method was 29.4, 43.5 and 57.6 % respectively over furrow method and this would be sufficient to irrigate 0.42 to 1.36 a hectare of additional area of onion crop in which this earns better economic returns as compared to that of furrow irrigation method. Therefore, the study suggests farmers in the semi-arid conditions, having limited amount of water for irrigation, should adopt drip irrigation method instead of surface irrigation methods.
Keywords: Deficit irrigation, increase in yield, water saved, water use efficiency

1. Introduction

Increasing agricultural productivity in Ethiopia is a means both to improve the livelihoods of rural people and the sustainability of the economy as agriculture is the main stay of 80% of the Ethiopian population and accounts for 40% of the Gross domestic product (GDP) of the country (IWMI, 2010). Although Ethiopia has potentially abundant irrigable land and water resources, its agricultural system does not yet fully benefit from irrigated agriculture and the technologies of water management. As a result, agricultural productivity in Ethiopia is very low. The main factor behind this is low uptake of inputs like fertilizer by farmers due to the unreliable moisture availability in consequence of low and variable rain fall patterns. Hence, it is believed that, this production constraint should be reduced using secured access to irrigation. Accordingly, expansion of irrigated agriculture is the main focus of the food security strategy in the growth and transformation plan of the country (GTP, 2010).

Even though the Regional Government of Tigray has planned to promote irrigation development in the region, the practice of irrigated agriculture is to maximize crop yield per unit land by applying full crop irrigation requirements and often over-irrigating using traditional surface irrigation system. Unfortunately, surface irrigation system is typically less efficient in applying water in the region. According to Behailu *et al*., (2004), there is unproductive utilization the available water resource in the study area (my-nigus irrigation scheme) where the overall irrigation efficiency of the scheme is between 15 to 30 %. Despite of this fact, inadequate attention has been given on the utilization and management of the existing available water in which the total irrigated area and production level is still low. Water stored in the ponds, check dams and wells is of limited volume and in actual practice, most farmers have a large potentially irrigable land. Therefore it is urgent need to adopt efficient irrigation methods like drip irrigation which may increase the rational use of the scarce water in the region in general and the study area in particular.

Drip irrigation is introduced primarily to save water and increase the water use efficiency in agriculture. Studies carried out across different countries including Ethiopia have confirmed that drip irrigation plays a paramount role in increasing yield and water use efficiency of crops. it has the potential to use scarce water resources more efficiently to produce crops as water can be delivered precisely to the root zones rather than irrigating the entire field surface as with other methods (Tagar *et al*., 2012). The on-farm irrigation efficiency of properly designed and managed drip irrigation system is estimated to be about 90 %, while the same is only about 35 to 40 percent for surface method of irrigation (INCID, 1994). Reduction in water consumption due to drip method of irrigation over the surface method of irrigation varies from 30 to 70 percent for different crops (INCID, 1994, Postal, 2001). Sammis, (1980) conducted a study to compare the crop response under drip and furrow irrigation methods and he reported that the yield under drip irrigation was more than twice in comparison to the yield by furrow methods. Similarly, Tagar *et al.,* (2012) reported that drip irrigation method saved 56.4% water and gave 22% more yield as compared to that of furrow irrigation method. Halvorson et al. (2008) obtained higher fresh onion yields, irrigation water use efficiency, and economic returns with sub surface drip irrigation system compared to furrow irrigation systems.

Considering the importance of drip irrigation method in the sustainable use of irrigation water, efforts are being made to introduce family drip irrigation from 2005 onwards in Tigray region (Gebrekiros, *et al*., 2009). However, the adoption of the technology by small holder farmers is very low. Many farmers feel that the water drops are insufficient to satisfy crop needs as compared to the one traditionally used furrow irrigation. According to Gebrekiros, *et al*., (2009), the lower expansion of drip system utilization in the region, is mainly due to the lack of awareness including training and demonstration of the technology at field level under farmers' operating condition as farmers were not convinced with the significance of water drops to satisfy crop needs as furrow irrigation. In view of the limited water resource in the study areas, the long-term sustainability of drip irrigation system appears to depend on how much productivity improved after shifting from surface irrigation to drip irrigation. Hence, it is important to conduct a research and demonstrate both irrigation methods at farmers' field where farmers can easily convinced with the amount of water saved and yield increased.

Another way to address the issue of water shortage is through development of new irrigation scheduling techniques such as deficit irrigation, which is one way of maximizing water productivity for achieving higher yields per unit of irrigation water used in agriculture (Nagaz. *et al.,* 2012, Geerts and Raes, 2009, English and Raja, 1996; Kirda et al., 1999). In deficit irrigation application, the crop is exposed to a certain level of water stress either during a particular growth period or throughout the whole growing season, without significant reductions in yields. The expectation is that the yield reduction by inducing controlled water stress will be insignificant compared with the benefits gained through diverting the saved water to irrigate additional cropped area (Kirda et al., 1999; Gijón et al., 2007). In Ethiopia conditions, results on deficit irrigation have also been reported for potato in north-west by Demelash (2013); for tomato in the central Rift valley by Birhanu and Tilahun (2010) and onion in South-northern Ethiopia by Bekele and Ketema (2007) and Mulu and Alamirew (2012). However, previous findings showed that the amount of water applied and method of application varied across the reports by crop and study site. For example, the method used by Mulu and Alamirew (2012) has applied three levels (full, three-quarter and half) of the ETc of onion using sprinkler irrigation.

Onion is one of the most popular and the most cultivated vegetables in Ethiopia in general and in Tigray region in particular as it is considerably important in the daily Ethiopian diet. Farmers in the study area produce onion as a cash crop and it is the first in area coverage, but the yield is 10.7 t ha^{-1}, which is very less, compared to the national average (18.7 t ha^{-1}) (as cited by Kahsay *et al.,* (2013). Considering the above facts, the main objective of this study were to compare water saving, increase in yield of onion and water use efficiency of drip and furrow irrigation methods under deficit irrigation and to suggest measures helpful in promoting its adoption in the region.

2. Materials and methods

2.1. Description of the study area

This study was conducted during the dry season from October 2013 to March 2014 at Axum area, Central Zone of Tigray (northern Ethiopia). The experimental site is located between latitude of 14° 08' N, and longitude of 38° 45' E, and altitude of 2080 m a. s. l. The average annual rainfall of the area was 650 mm. Seasonal rainfall patterns at the experimental area shows uni-modal distribution, which extends from July to early September almost for about 60 days. The mean annual temperature was 15°C. The soil property of the experimental area is determined in mekele soil laboratory (Table 1). The source of water for this experiment was harvested from seepage of Mai-Negus micro-dam collected in "Dora" meaning night storage. The irrigation water quality based on salinity (electrical conductivity) (ECw) was found to be 320 micromhos cm^{-1} which is in the range between 250 and 750 micro mhos cm^{-1}. Thus, the use of such water for irrigation at optimum conditions is recommended (Gebrekidan, 2004).

2.2 Experimental Procedure

The experiment was laid out in randomized block design having four treatments replicated three times at a plot size of 1.5 m x 5 m with treatment settings in Table 2. Cultural management practices other than application of irrigation water were done according to the national recommendations. Onion seeds were sown for nursery rising and transplanted after 45 days on November 18, 2013. The distance between plots, rows and plants was 1m, 0.30 m and 0.10 m respectively. The drip system had 5 rows in each plot and 50 plants in each row, while in furrow irrigation system, the plot had designed with four furrows and three ridges as commonly practiced by farmers in the study area. For drip method, water was applied at three levels of irrigation 100%, 80%, and 60% of ETc. but only full irrigation (100% ETc) was used for the furrow method. Data was subjected to statistical analysis using SAS 9.1 software. Descriptive statistics (e.g., percentage) was used. In addition, analysis of variance (ANOVA) was performed to evaluate the statistical effect of the different irrigation treatments on onion yields and WUE.

2.3 Crop Water Requirements

The reference evapotranspiration (ETo) was estimated using the FAO Penman-Monteith equation using daily meteorological data observed from a nearby weather station (Axum Air-port meteorological station). The crop water requirements (ETc) over the growing season were determined by multiplying the ETo values with the onion crop coefficients (Kc) given by Allen et al. (1998) as 0.7 for the 1st, 0.90 for the 2nd, 1.05 for the 3rd and 0.75 for the 4th growth stages.

$$ETc = Kc * ETo \quad (1)$$

Irrigations were scheduled to avoid or minimize runoff and deep percolation. All treatments were irrigated at 5 days irrigation intervals for drip irrigation systems and once every 10 days, as the usual trend of farmers in the area, for furrow irrigation system where the amount irrigation water was applied using partial flume. Optimal or ''0% water deficit'' irrigation was calculated as the net amount of irrigation required to recharge the soil moisture deficit. However, the depth for other treatments was taken based on the percentage of optimal irrigation. Since there was no rain fall during the growth period, effective rain fall was nil. Hence, ETc was taken to be equal to net irrigation requirement (NIR). The amounts of irrigation water applied under the different irrigation treatments are shown in Table 3.

2.4 Onion yield and yield increase data collection procedures

The onion bulb yield was collected and weighed from the central rows of each plot; this is to avoid boarder effects. The harvested yield was graded into marketable and non-marketable categories of onion bulb according to the size. Onion bulbs with less than 2cm diameter were categorized under non-marketable (Lemma and Shimels, 2003). The yield was then measured in kg ha^{-1} for each drip and furrow irrigated plot. The increase in yield was computed as under:

$$\text{Increase in yield (\%)} = \frac{(Y1-Y2)}{Y1} \times 100 \quad (2)$$

Where, Y1 = Yield obtained in drip irrigation system (kg ha^{-1}) and Y2 = Yield obtained under furrow irrigation system (kg ha^{-1})

2.5 Water saving and water use efficiency of onion

The water use efficiency was calculated by dividing harvested yield in kg by unit volume of water (kg m^{-3}). Two kinds of water use efficiencies, namely, crop water use efficiency (CWUE) and irrigation water use efficiency (IWUE) are determined as:

$$CWUE = Ya/ETc \quad (3)$$

$$IWUE = Ya/IW \quad (4)$$

Where, Ya is yield (kg ha^{-1}), ETc is crop water requirement (m^3 ha^{-1}), and IW is irrigation water applied (m^3 ha^{-1}).

3. Results and discussion

3.2 Yield of onion

There were significant ($p < 0.05$) differences among irrigation methods and levels of irrigation water applications on onion bulb yield (Fig. 1, a and b). The result indicated that furrow method of irrigation under full irrigation resulted in low yield of (18.8 t ha^{-1}) as compared to that obtained under drip irrigation (28.0 t h^{-1}) and it was significantly different ($LSD_{0.05}$=1.52). Based on the results, drip irrigation treatments (T1 and T2) registered 32.8 % and 16.2% increased in yield respectively as compared to surface irrigation (T4). Therefore, the study indicated that, even if 20 % less quantity of water was supplied through drip irrigation (T2), 16.2 % higher yield of onion was obtained as compared to surface irrigation. However, decreasing the applied water by 20% and 40% of ETc led to higher yield reduction of onion 16.6% and 35.4% respectively as compared to full irrigation under drip method which is close to the yield reduction by furrow system under full irrigation application (32.7%) whereas 80 and 60% ETc water application saved 43.5 and 57.6% water respectively as compared to furrow method (Table 4). The low yield by furrow irrigation might be due to less availability of nutrients for crop growth due to leaching by runoff and deep percolation and with high weed infestation between the crops.

These findings are in agreement with those found by Halvorson et al. (2008) obtained about 15%

higher fresh onion yields under drip irrigation and used at least 57% less water than the furrow system. Similarly, Paul *et al.,* (2013) who concluded that drip irrigation system could increase the capsicum yield up to an extent of 57 % over surface irrigation method with the same quantity of water. Many other studies on the performance of drip irrigation method on different crop types reported that drip irrigation method gave more yield as compared to that of furrow irrigation method the same amount of water used (Enciso *et al.,* 2015, Tagar *et al.,* 2012, Sammis, 1980).

3.2 Irrigation water saved and Irrigation water use efficiency

Water use efficiency was significantly influenced by irrigation method and irrigation levels (Fig. 2, a & b). Considering full irrigation application, higher mean value of irrigation water use efficiency was observed under drip method with mean value of 7.1 kg m^{-3} which is 33.8% higher than that is obtained in furrow method (4.7 kg m^{-3}) and it was significantly different ($LSD_{0.05}$=1.31). This may be due to the uniform distribution of moisture in the effective root zone of onion crop in the soil profile under drip irrigation method and consequently minimal runoff, evaporation and percolation losses. Moreover, applying 0.6ETc under drip irrigation method improved IWUE by 38.2%, with water saving of 324.1 mm which is sufficient to irrigate 1.36 a hectare of additional area of onion crop in which this earns better economic returns as compared to that of furrow irrigation method. Similarly, drip irrigation saved 29.4%, 43.5% and 57.6% water, under 1.0ETc, 0.8ETc and 0.6ETc water application respectively, as compared to furrow irrigation as presented in Table 4.

These results are in agreement with that of (Enciso *et al.,* 2015) reported the irrigation use efficiency of onion obtained under drip irrigation system ranged from 17.5 to 25.2 kg m^{-3} while using at least 44% less water as compared to that of furrow system ranged from 4.2 to 6.2 kg m^{-3}. Similarly, Nagaz *et al.,* (2008) found that the irrigation efficiency under drip irrigation increased by 29% and saved 20.8% amount of irrigation water in comparison with furrow irrigated potato. Similar trend has been reported in WUE of various crops in comparison of drip and furrow irrigation methods: For capsicum by Paul *et al,* (2013), for pepper crop by Nagaz *et al.* (2012), for tomato crop by Tagar *et al,* (2012), for maize by Ayana (2011).

4. Conclusion

This study demonstrated that drip irrigation method under deficit irrigation practices is one of the irrigation management strategies which could contribute for water saving, increase yield and WUE in the semi-arid conditions like northern Ethiopia. Drip irrigation method saved 29.4 % and 43.5% water, and gives 32.8 % and 19.4 % more yields under 1.0ETc and 0.8ETc water application respectively, as compared to that of furrow irrigation method. In addition, higher irrigation water use efficiency of 7.1 kg m^{-3} was obtained at 1.0ETc in drip irrigation method which is 33.8% higher than the low irrigation water use efficiency of 4.7 kg m^{-3} obtained under furrow method.

In the present study drip irrigation method either alone or in combination with deficit irrigation, could increase the onion yield over surface irrigation method with the same quantity of water. It was also observed that, the amount of saved water would be sufficient to irrigate 0.42 to 1.36 ha of onion crop with the drip irrigation method. Therefore the present study suggests farmers in the study area who have limited amount of water in their ponds, check dams and hand dug wells ought to adopt drip irrigation method instead of traditional surface irrigation methods.

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Table 1: Some physical and chemical properties of soil layers determined from the study area.

Sampling depth (cm)	Particle size distribution (%)			Textural class	BD	OM	pH	EC	FC v/v	PWP v/v	TAW
	Sand	Silt	Clay	USDA	(g cm^{-3})	(%)	-	(ds m^{-1})	(%)	(%)	Mm m^{-1}
0-30	11	35	54	Clay	1.32	2.93	7.07	0.55	38.2	18.6	196
30-60	15	27	58	Clay	1.36	2.81	7.40	0.21	36.4	18.2	182
Average	13	31	56	Clay	1.34	2.87	7.24	0.38	37.3	18.4	189

BD, Soil bulk density; OM, Soil organic matter; EC, electrical conductivity; FC, field capacity; PWP, permanent wilting point, TAW, total available water

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Table 2: Treatments setting for the experiment

Treatments	Explanation
T_1	100% irrigation water requirement through drip irrigation method (1.0ETc)D
T_2	80% irrigation water requirement through drip irrigation method(0.8ETc)D
T_3	60% irrigation water requirement through drip irrigation method(0.6ETc)D
T_4	100% irrigation water requirement through furrow irrigation method(1.0ETc)F

Table 3: Crop water Requirement and Irrigation water applied (mm).

Irrigation method	Treatments	CWR	Effective rainfall	NIR	GIR
Drip irrigation	1.0ETc	337.4	0.0	337.4	396.9
	0.8ETc	269.9	0.0	269.9	317.6
	0.6ETc	202.4	0.0	202.4	238.2
Furrow irrigation	1.0ETc	337.4	0.0	337.4	562.3

CWR=Crop water requirement, NIR= Net irrigation water requirement, GIR= Gross irrigation water requirement

Table 4: Effect of irrigation method and amount on increase in yield, yield reduction and water saved

	Increase in yield		Yield reduction		Amount of water saved	
Treatment	(t ha^{-1})	%	(t ha^{-1})	%	(mm)	(%)
T1(1.0ETc)D	9.2	32.8	0.0	0.0	165.4	29.4
T2(0.8ETc)D	4.5	16.2	4.7	16.7	244.7	43.5
T3(0.6ETc)D	-0.7	-2.5	9.9	35.4	324.1	57.6
T4(1.0ETc)F	0.0	0.0	9.2	32.7	0.0	0.0

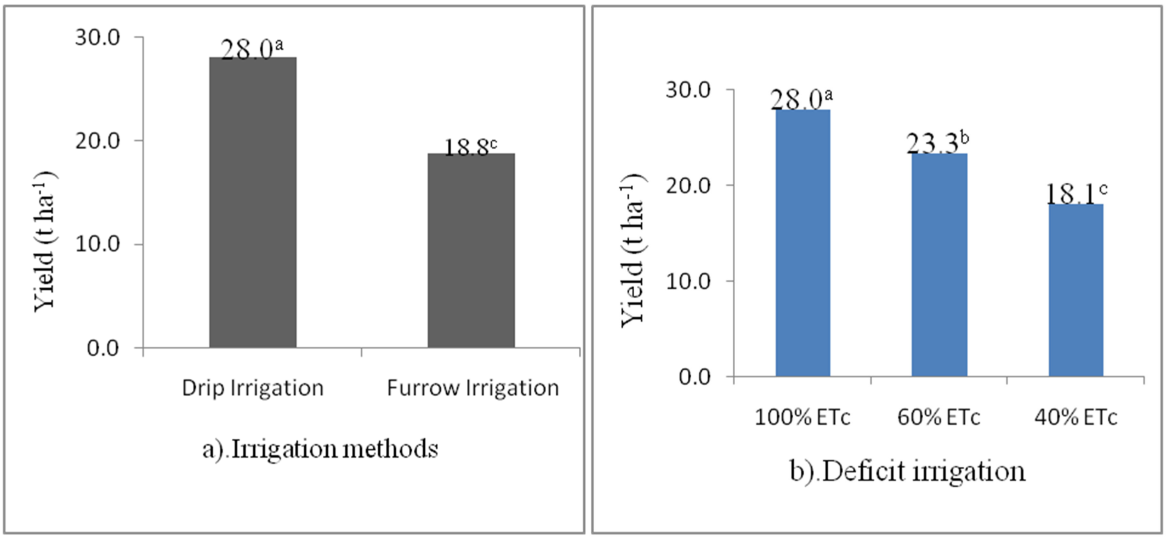

Fig. 1. Effect of irrigation methods (a) and deficit irrigation (b) on onion yield

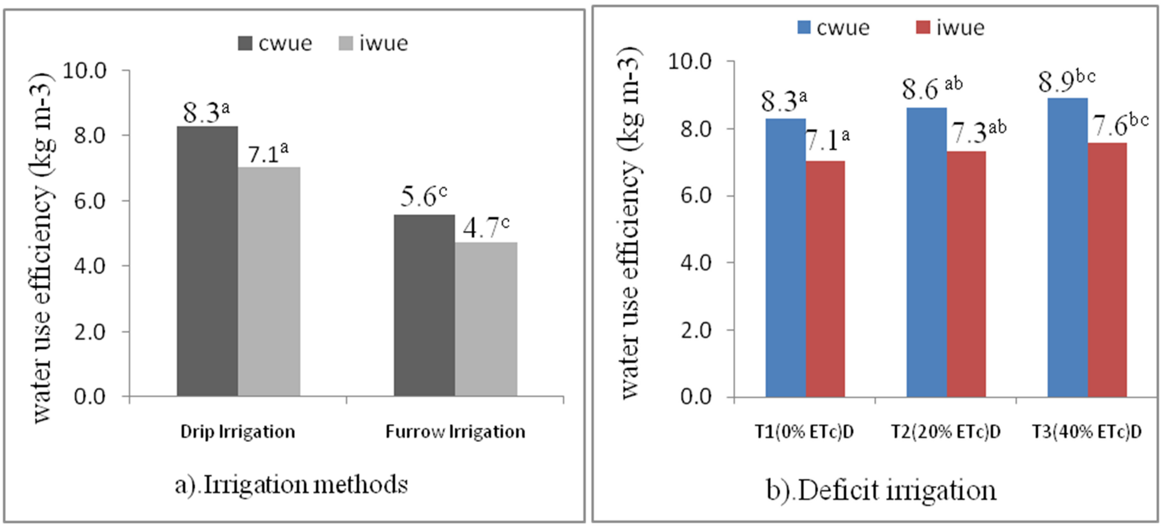

Fig. 2. Effect of irrigation methods (a) and deficit irrigation (b) on water use efficiency