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Yield and water use efficiency of furrow irrigated potato under regulated deficit irrigation, Atsibi-Wemberta, North Ethiopia

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ABSTRACT

The pressure on availability of water in Tigray regional state is likely to increase as the requirement for food production in couple with rapidly growing of the population is at increasing rate. Hence, improving water productivity using regulated deficit irrigation is important to reduce the water consumption while minimizing adverse effects on the crop yield. This study was conducted in the eastern zone of Tigray regional state, Atsibi Womberta district. The aim of this study was to determine the yield and water use efficiency of potato under deficit irrigation practice in the 2012 growing period. The effect of water deficit or water stress on crop yield and water use efficiencies were evaluated. Guasa variety potato was grown under eight (T_1–T_8) irrigation treatments. The treatments were replicated three times under completely randomized blocks experimental design. Water was applied to every furrow using watering can with fixed interval and variable depth irrigation scheduling technique was selected. Yield of potato was significantly ($p<0.05$) affected by water stress (deficit irrigation). The highest yield was found in T1 (18770 kg/ha) which was not subjected to water stress (full water requirement) whereas minimum yield of potato was obtained under the fully stressed treatment T8 (7037 kg/ha). There was no significant different between the yield of T1 (18770 kg/ha) and T6 (14440 kg/ha) which was 25% deficit throughout the growing season. According to the result obtained, stressed at the middle stage was affected more the yield of potato as compared to other treatments. This showed that stressing the crop at flowering/middle stage is sensitive to deficit irrigation. Giving 65% of crop water requirement throughout the growing season is better than stressing the crop only at the middle stage. The second sensitive period for water stress is the late crop stage. Crop water use efficiency was not statistically significant. Though it was not significantly different, T6 (2.86 kg/m^3) and T4 (1.60 kg/m^3) had the highest and the lowest water use efficiency respectively. This elaborated that applying 75% of crop water requirement has better water use efficiency than optimal or "no stress" irrigation. It can be conclude that using deficit irrigation is a good water management technique to save irrigation water without reducing the yield of potato. For dry land areas like The Tigray regional state of Ethiopia and other similar agro-ecology elsewhere in the world with scarce water and agricultural water management is very poor. The authors of this study would like to recommend farmers, water managers, water use associations and decision makers to use water efficiently using deficit irrigation and increase their agricultural production by expanding irrigable land with the same amount of water in a given irrigation scheme

1. Introduction

The history of agriculture in Tigray, North Ethiopia is the history of subsistence. Agriculture in this region is dependent on unreliable rainfall. The pattern of rainfall had been low, torrential and erratic in distribution. Availability of water resources for economic development in the semi-arid areas of Ethiopia is also strongly influenced by various anthropogenic and natural factors (Ayenew, 2007; Conway, 2005; Hurni et al., 2005; Nyssen et al., 2004). Consequently, repeated crop failure has been common experience in the region. In fact, farmers are not passive victims of drought. The farmers use a wide range of indigenous irrigation practices to overcome the problem of drought and to supplement their rain-fed agriculture. Moreover, the Government of Ethiopia is currently focused on

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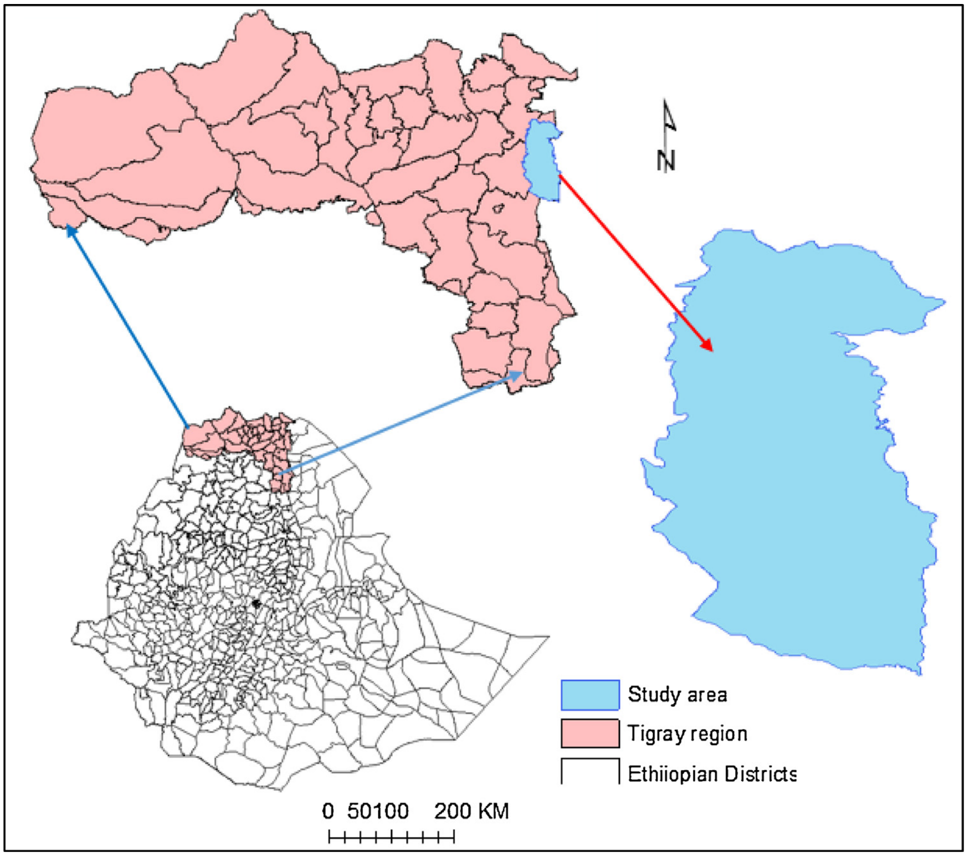

Fig. 1. Location map of the study area.

water resources development with special attention to water harvesting and small scale irrigation schemes in the semi-arid areas (Awlachew et al., 2006, 2011). Woldeab (2006) reported that surface irrigation from river diversions, spring development and pond systems is a common practice that has been used to irrigate small plots in the region. Currently, 125,000 ha of land is under irrigation using traditional methods (BoARD, 2011). The growth and transformation plan of the region indicated that irrigable land will be increased from 125,000 ha in 2011 to more than 350000 ha at the end of 2015 (GTP, 2011). The ultimate goal is to irrigate 50% of the total 1.5 million hectares of cultivated land in the coming years (Gebreslassie, 2014; Hagos et al., 2002). However, the attention given to agricultural water management by the irrigators as well as the government is very low. The pressure on the availability of water is likely to increase significantly as the requirement for food production and industrial use in couple with rapidly growing of the population is at increasing rate. Subsequently, improper on-farm irrigation management practices in the region may lead to erosion, poor water distribution, non-uniform crop growth, water logging, salinity, all of which decrease the yield per unit of land area and per unit of water applied (Eyasu, 2005). The conventional furrow irrigation practiced by farmers in the region is known to be less efficient particularly where there is shortage of irrigation water (Mulubrehan et al., 2014). Field application efficiency in most traditional irrigation schemes is still very low, typically less than 50% and often as low as 30% (FAO, 1995, 1997). Similarly water use efficiency of the traditional irrigation system is smaller compared to the well managed alternative methods of applications (Mintesinot, 2002; Horst et al., 2007; Mulubrehan et al., 2014).

In the context of improving water use efficiency, there is a growing interest in regulated deficit irrigation, an irrigation practice whereby water supply is reduced below maximum levels and yield stress is allowed with minimal effects on yield (Payero et al., 2006; Zhang et al., 2000, 2004; Aujla et al., 2005). Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains by maximizing yield per unit of water as well as by increasing of cultivable frequency or irrigable area (Abdullah et al., 2005; Bekele and Tilahun, 2007). For a given crop, farmers are inclined to use water efficiently, and water efficient crop selection also helps in getting optimum returns. This method is applicable by exposing the crops to a certain level of water stress during particular or the whole growing stages. Several literatures (e.g, Geerts and Raes, 2009; Ali et al., 2007; Du et al., 2010; Webber et al., 2006) shows that regulated deficit irrigation provides a means of reducing water consumption while minimizing adverse effects on the yield. Despite of its importance for semi-arid areas with limited water resources, such types of studies have not been practised in the region. As water resources is very much scares in the Tigray region, practicing deficit irrigation could help to increase agricultural production by expanding irrigable land with the given limited amount of water.

Therefore, this study aims at (i) determining the yield and water use efficiency of potato under deficit irrigation practices (ii) identify crop growth stages during which the crop can withstand water stress with limited effect on yield (iii) determining optimum irrigation schedule and crop requirement of potato for Atsibi Wemberta district and similar agro-climatology of Tigray region.

2. Materials and methods

2.1. Study area descriptions

The experimental site is located in the Northern Ethiopia, eastern zone of Tigray regional state and Atsibi Wemberta district

Table 1
Treatment setting for field experiment.

Treatment	Crop growth stage				Description
	Initial	Dev.	Middle	Late	
T1	1	1	1	1	All normal watering
T2	0	1	1	1	Stress during initial stage (P1)
T3	1	0	1	1	Stress during development stage (P2)
T4	1	1	0	1	Stress during middle stage (P3)
T5	1	1	1	0	Stress during late stage (P4)
T6	25%	25%	25%	25%	25% deficit throughout the growing season
T7	35%	35%	35%	35%	35% deficit throughout the growing season
T8	50%	50%	50%	50%	50% deficit throughout the growing season

Where: 1 indicates normal watering—watering 100% of ETc (net irrigation); 0 indicates stressed watering—watering 25% of ETc (net irrigation); 25% deficit was watering 75% of ETc (net irrigation); 50% deficit was watering 50% of ETc (net irrigation); 75% deficit was watering 25% of ETc (net irrigation).

(Fig. 1). It is located 65 km northeast of the capital of Tigray Regional State, Mekelle. The experimental site soil type is sandy loam. Agro-ecologically, the district is classified as "*Dega*" (high land with cold weather but dry land). Elevation of the study area ranges from 918 m to 3,069 m.a.s.l. 75% of the district is in the upper high-lands (2600 m.a.s.l or above) and only 25% is found in the midlands (between 1500 to 2600 and below 1500 m.a.s.l), (IPMS, 2005). The study area has different irrigation sources such as river diversion, ground water, underground tankers, ponds and springs. For this experimentation, sources of water from river diversion were used. In general, the study area is characterized by a semi-arid climate in which the majority of the rainfall occurs from June to September after a long dry season. Rainfall over the district is highly variable in temporal and spatial scales. More than 70% of the total annual rainfall is falling only in July and August with high storm intense (Abraha, 2014). The dry period over the basin is extended up to ten months and the maximum effective rainy season is from 50 to 60 days. The variations of rainfall over the area are mainly associated with the seasonal migration of inter-tropical convergence zone (ITCZ) and its complex topography (Nyssen et al., 2005). The mean annual precipitation in the area is below 620 mm per year and the mean annual air temperature is 20.7 °C.

2.2. Experimental design and crop varieties

The experimental design consists of completely randomized blocks with three replications. Within each block, eight irrigation regimes (Table 1) were randomly distributed. Furrow irrigation was practiced using can method for applying water. Each treatment has 3 m × 3 m plot size and the layout of the experiment is represented in Fig. 2. Adjacent treatment units were planted 1 m apart from each other to make sure border effect is negligible. The required crop water was calculated using CROPWAT computer programme considering the soil and climatic properties of the study area (Allen et al., 1998). The Guasa variety potato was selected for the experiment and it was planted with 30 cm between plant and 75 cm row spacing. This crop variety was selected for its good adaptability and most usable in the study area. The growing season of the crop was mainly divided into four major growth periods (Brouwn et al., 1989): initial, development, middle and late stages. Initial stage—runs from planting date to approximately 10% ground cover; development stage—runs from 10% ground cover to effective full cover; middle stage—runs from effective full cover to the start of maturity and Late stage—runs from start of maturity to harvest, or full senescence. Percent of ground cover and phenology of the crop was considered to decide the date of growth stages. Since potato is drought sensitive crop, the maximum water stress considered for the crop was 50% throughout the growth stage. However, in order to see the sensitivity of the crop on crop growth stage, 25% of crop water requirement was also tested.

2.3. Data collection and analysis

Soil samples were collected from 45 cm depth to characterize the soil in terms of physical characteristics such as soil, initial soil moisture content, the average bulk density and chemical characteristics including, EC, pH and organic matter The soil parameters were analysed in the soil laboratory of Mekelle agricultural research centre. Accordingly, the experimental site has field capacity (FC) of 35.8% and permanent welting point (PWP) of 18.2% with average total available water (TAW) 17.6% in volume percentage (Table 2).

Meteorological data's such as minimum and maximum temperature, relative humidity, wind speed and daily sunshine hours were collected from nearby weather station to determine reference crop evapotranspiration (Table 3). The evapotranspiration was calculated using Modified FAO Penman–Monteith method (Allen et al., 1998). The rainfall received during the growing season was almost 0 mm. The mean monthly rainfall, monthly rainfall and potential evapotranspiration distribution for the study year is explained in Fig. 3. Comparison of those graphs explicitly shows that there was no any source of moisture other than irrigation for the study period.

2.4. Determination of crop water and irrigation requirement

Crop water requirement of potato over the growing season was determined from the reference evapotranspiration and crop coefficient using Eq. (1). As there is no site specific estimated crop coefficient in the region, if not in the country, the respective crop coefficient for initial, middle and late growth stages were taken from (Allen et al., 1998). To minimize over and under estimation irrigation problems, the authors used farmers' experience on the numbers of days of each growing stages so as to estimate reliable Kc for the respective growing stages. Ninety percent of application efficiency was considered as can method of water application was used. Irrigation scheduling of the crop was computed using FAO CROPWAT program (Allen et al., 1998) by considering soil type with fixed interval and variable depth (refill to field capacity). Farmers in the study area commonly uses fixed irrigation scheduling because of the scarcity of water and for this experimentation, fixed interval and refill to field capacity irrigation scheduling criteria was adopted considering the local experiences. Moreover, this irrigation scheduling criteria will be easy for demonstration of the technology in the region.

$$ETc = Kc \times ETo \tag{1}$$

where ETc = crop evapotranspiration (mm/day), Kc = crop coefficient (dimensionless), and ETo = reference crop evapotranspiration (mm/day).

As indicated in Section 2.3, the amount of rainfall received during the experiment was zero and hence net irrigation requirement

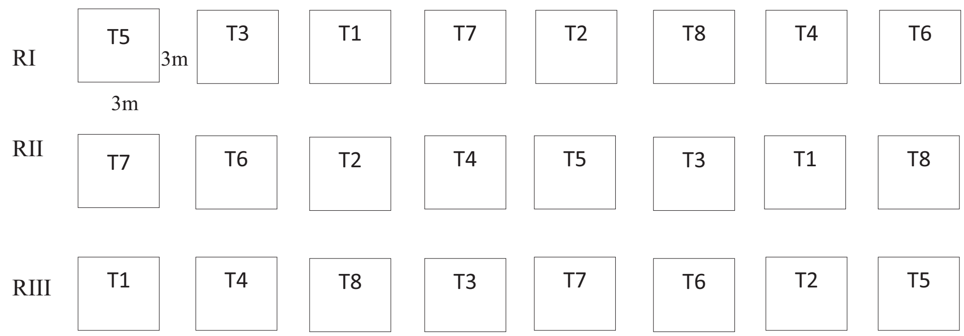

Fig. 2. Layout of the experimental plots.

Table 2
Soil physical and chemical properties for the experimental site.

Soil depth (cm)		Type of analysis									
	Bulk density	EC (ds/m)	pH	% Sand	% Silt	% Clay	Texture	Organic matter	FC vol.%	PWP vol.%	TAW vol.%
0–15	1.15	0.85	7.1	31	39	30	Clay loam	0.64	37.2	19.4	17.8
15–30	1.21	0.81	7.4	27	39	34	Clay loam	0.66	36.7	18.8	17.9
30–45	1.24	0.77	7.55	45	35	20	Loam	0.47	33.5	16.4	17.1
Average	1.20	0.81	7.35	34	38	28	Loam	0.6	35.8	18.2	17.6

Table 3
Mean monthly meteorological data of the study area.

Months	Tmax (°C)	Tmin (°C)	Humidity (hpa)	Wind speed (Km/h)	Sunshine hours (%)
January	26.38	8.07	10.97	4.5	83.3
February	27.17	8.99	11.05	4.9	81
March	28.53	11.28	11.81	5.26	79.8
April	29.15	12.63	12.95	5.44	78.2
May	29.19	12.64	12.19	5.69	79.3
June	29	12.63	12.11	5.26	71.9
July	24.69	12.21	16.38	5.08	51.5
August	24.11	12.41	17.05	5	46.1
September	26.07	11.16	13.92	5	69.1
October	26.74	9.69	13.31	6.01	83.6
November	26.05	8.5	13.09	4.14	84.3
December	25.43	7.52	11.54	3.89	84.1

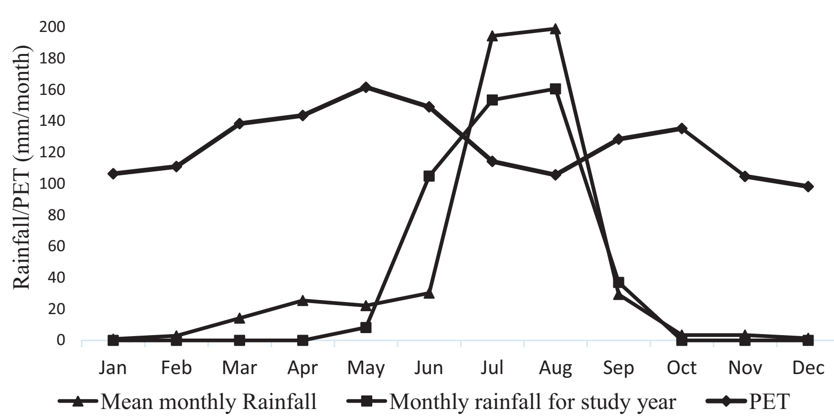

Fig. 3. Comparison of mean monthly, monthly rainfall for the study area and potential evapotranspiration in the study area.

was taken to be equal to ETc. Crop water use efficiency was calculated (Oweis and Zhang, 1998; Zhang et al., 1998)

$$\mathrm{WUE} = \frac{Y}{\mathrm{ETa}} \tag{2}$$

where WUE is water use efficiency, Y is the crop yield (kg/ha) and ETa, is the actual evapotranspiration (mm).

Crop evapotranspiration was predicted using the FAO Penman–Monteith equation and weather data, collected from the experimental site and crop coefficients for standard and stress conditions from FAO (Allen et al., 1998). ETa for the respective treatments were calculated using ETo and crop coefficient and these values were multiplied by percent of water applied at each stage and throughout the growth stage. The same amount of water was applied as pre-irrigation to every furrow of each plot before four days of planting the seeds. The purpose of this pre-irrigation was to bring the soil in root zone to field capacity and to create a good seed bed and favourable condition to the crop.

Table 4
Irrigation water requirement of potato in 10 days interval (mm).

	Amount of irrigation water per treatments							
Date	T1	T2	T3	T4	T5	T6	T7	T8
4-January	25.6	6.4	25.6	25.6	25.6	19.2	16.6	12.8
14-January	26.7	6.7	26.7	26.7	26.7	20.0	17.4	13.4
24-January	29.5	7.4	29.5	29.5	29.5	22.2	19.2	14.8
3-February	41.6	41.6	10.4	41.6	41.6	31.2	27.0	20.8
13-February	55.1	55.1	13.8	55.1	55.1	41.3	35.8	27.5
23-February	66.7	66.7	16.7	66.7	66.7	50.0	43.3	33.3
5-March	68.3	68.3	17.1	68.3	68.3	51.3	44.4	34.2
15-March	68.2	68.2	68.2	17.1	68.2	51.2	44.3	34.1
25-March	67.7	67.7	67.7	16.9	67.7	50.7	44.0	33.8
4-April	66.7	66.7	66.7	16.7	66.7	50.0	43.3	33.3
14-April	61.2	61.2	61.2	61.2	15.3	45.9	39.8	30.6
24-April	52.3	52.3	52.3	52.3	13.1	39.3	34.0	26.2
4-May	43.7	43.7	43.7	43.7	10.9	32.8	28.4	21.8
Total	673.3	611.9	499.6	521.4	555.4	505.0	437.6	336.7

Table 5
Yield and water use efficiency of potato and rank.

Treatment	Yield (kg/ha)	WUE (kg/m3)	Rank on Yield	Rank on WUE
T1	18770[a]	2.79	1	2
T2	11110[bc]	1.81	4	7
T3	13520[abc]	2.71	3	3
T4	8333[bc]	1.6	7	8
T5	10430[bc]	1.88	5	6
T6	14440[ab]	2.86	2	1
T7	10060[bc]	2.3	6	4
T8	7037[c]	2.09	8	5
LSD (0.05)	5250	ns	–	–
CV (%)	17.7%	19.2%	–	–

Means the parameter with the same letter are not significantly different at $P = 0.05$ according to LSD.

2.5. Crop agronomy and management

Vigorous potato seeds were carefully planted to the experimental plots based on the recommended spacing of 30 and 75 cm between plants and rows, respectively. Based on fertilizer recommendations to the study area, 195 kg/ha of DAP and 160 kg/ha Urea was applied for each treatment. DAP was applied at the time of planting and urea fertilizer was given twice and applied at the time of planting as well as a month after sowing. The crop was cultivated and weeded three times during the growing season. The treatments were planted in four furrows and yield data for further analyses were collected from the central two furrows of each treatment (1.5 × 1.8 m plot size).

2.6. Statistical analysis

Analysis was performed on yield and water use efficiency of potato using Gestate (Alvey et al., 1982) statistical software. The data of the experiment was analyzed in randomized complete block design (RCBD), and the mean difference was estimated using the least significant difference (LSD) comparison.

3. Result and discussion

3.1. Crop water requirements and irrigation scheduling of potato

Crop water requirements of each treatment were calculated by multiplying the reference evapotranspiration values with the potato crop coefficients 0.5, 1.05 and 0.75 for initial, middle and late stages, respectively (Allen et al., 1998). The Amount of irrigation water required at 10 days interval and number of irrigation events are summarized in Table 4. Fixed interval (every ten days) and variable depth (refill to field capacity) irrigation scheduling technique was selected. Optimal or "no stress" irrigation was calculated using the FAO CROPWAT program as the net amount of irrigation required to refill the soil moisture deficit (SMD) with weekly application of irrigation water. The depth applied to other treatments was taken simply as percentage of the optimal irrigation at specific growth stage or throughout the growing season.

3.2. Yield and water use efficiency of potato

The result displayed in Table 5 indicated that yield of potato was significantly ($p < 0.05$) affected by water stress (deficit irrigation). The highest yield was found in T1 (18770 kg/ha) which was not subjected to water stress (full water requirement) whereas minimum yield of potato was obtained under the fully stressed treatment T8 (7037 kg/ha). There was no significant different between the yield of T1 (18770 kg/ha) and T6 (14440 kg/ha) despite of the fact that it was stressed by 25% throughout the growing season. This finding is also supported by Tsegay et al. (2015); Bekele and Tilahun (2007); Yihun et al. (2013). Those studies have also reported that applying deficit irrigation with 75% of the crop water requirement were not affected the yield. According to these results, stressed at the middle stage was affected more the yield of potato as compared to other treatments. This clearly shows that stressing the crop at flowering/middle stage is sensitive to deficit irrigation. Giving 65% of crop water requirement throughout the growing season is better than stressing the crop only at the middle stage. The second sensitive period for water stress is the late crop stage. Similar result were reported by Payero et al. (2006); Zhang et al. (2004) and Aujla et al. (2005) which all conclusions have explained that the middle stage of the crops are sensitive for yield reduction.

Similarly, the crop water use efficiency was not significant. Even though there was no statistically significant difference, T6 (2.86 kg/m^3) and T4 (1.60 kg/m^3) had the highest and the lowest

Table 6
The amount of water saved, yield reduction, rank and relative water use efficiency.

Treatments	Irrigation (m3/ha)	Yield (kg/ha)	WUE (kg/m3)	Water saved (%)	Yield Reduction (%)	Relative WUE
T1	673.3	18770	2.79	0	0	1.00
T2	611.9	11110	1.81	9	41	0.65
T3	499.6	13520	2.71	26	28	0.97
T4	521.4	8333	1.6	23	56	0.57
T5	555.4	10430	1.88	18	44	0.67
T6	505	14440	2.86	25	23	1.03
T7	437.6	10060	2.3	35	46	0.82
T8	336.7	7037	2.09	50	63	0.75

Table 7
Tuber number, plant height, tuber weight and number of stem.

Treatment	Average tuber number	Height at maturity (cm)	Average tuber weight (gm)	Number of stem
T1	8.67^{a}	66.33^{a}	63.33^{a}	4.33^{a}
T2	4.33^{d}	53^{d}	49.67^{c}	3^{b}
T3	7.33^{b}	62^{abc}	57.67^{b}	4^{a}
T4	6^{c}	47.67^{e}	44^{d}	3.33^{b}
T5	6.33^{c}	57^{cd}	54^{bc}	4^{a}
T6	8.67^{a}	64.33^{ab}	63^{a}	4^{a}
T7	6.33^{c}	59b^{c}	53.67^{bc}	4^{a}
T8	4.33^{d}	46.33^{e}	43^{d}	3^{b}
LSD (5%)	0.935	5.169	4.753	0.4997
CV	8.3	5.2	5.1	7.8

Means the parameter with the same letter are not significantly different at $P = 0.05$ according to LSD.

water use efficiency, respectively. This result elaborated that applying 75% of crop water requirement throughout the growing season has better water use efficiency than applying optimal irrigation with (100%) crop water requirement.

As clearly shown in Table 6, T1 and T8 has the highest and the lowest yield, respectively. By taking T1 as a control (crop water requirement base, from all treatments, the highest and lowest amount of water saved was in T8 (50%) and T2 (9%), respectively. The amount of water saved in T6 was 25% which is higher than the other five treatments (T1, T2, T4 and T5). When the treatments are compared in terms of yield reduction with the control Treatments (T1), T6 (23%) and T3 (28%) have the least reduction while T8 (63%) have the highest yield reduction. Results of relative WUE is also presented in Table 5 which indicates that the highest and lowest values were obtained in T6 (1.03) and T2 (0.65), respectively. Similar studies were also reported by Bekele and Tilahun (2007) that the highest relative water use efficiency is achieved during irrigating of 75% of the crop water requirement and minimum yield reduction was also observed with the same treatment.

The rank of all treatments with regard to highest yield and WUE is presented in Table 5. T1 obtained the highest (18770 kg/ha) ranked as first and T8 obtained the lowest (7037 kg/ha) yield ranked as the least. The highest and the least water use efficiency was observed in T6 and T4, respectively. T3, with third rank in terms of water use efficiency and yield has no statistically significant difference with T6, however there is more than 900 kg/ha of yield difference with T6 that may have problems to be accepted by the farmers as such agricultural water management options are new to the local community in the region.

3.3. *Yield component of potato*

As presented in Table 7, tuber number has significant difference among the treatments. T1 (8.67) and T6 (8.67) had the highest value and T8 (4.33) and T2 (4.33) with the lowest value. However, T6 and T1 had not significantly different. Height at maturity also has significantly different with the highest value was observed from T1 (66.33) and T6 (64.33) and least values from T8 (46.33) and T4 (47.67). Deficit irrigation has effect on average tuber weight. The highest value was recorded from T1 (63.33) and T6 (63) and the least from T8 (43) and T4 (44). Similar result was observed for number of stems that have the highest value for T1 (4.33) and T6 (4) and the least for T8 (3) and T2 (3).

4. Conclusion

An experiment was carried out to understand the regulated deficit irrigation, an irrigation practice whereby water supply is reduced below maximum levels and yield stress is allowed with minimal effects on yield. The experimental design of this study was completely randomized blocks with three replications. Within each block eight irrigation regimes were randomly distributed. The result shows stressed at the middle stage can affect the yield more as compared to other treatments. This showed that stressing the crop at flowering/middle stage is sensitive to deficit irrigation. Giving 65% of crop water requirement throughout the growing season is better than stressing the crop only at the middle stage. This study clearly shows that applying 75% of crop water requirement has better water use efficiency than optimal or "no stress" irrigation. It can be conclude that using deficit irrigation is a good water management technique to save irrigation water without reducing the yield of crops. This water application technique is much important for dry land areas like the Tigray regional state of Ethiopia and other similar agro-ecology elsewhere in the world with scarce water and agricultural water management is very poor. The authors of this study would like to recommend farmers, water managers, water use associations and decision makers to use water efficiently using deficit irrigation and increase their agricultural production by expanding irrigable land with the same amount of water in a given irrigation scheme.

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