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Effects of Deficit Irrigation on Yield and Water Use Efficiency of Drip Irrigated Onion (*Allium cepa L.*) under Semi-Arid Condition of Northern Ethiopia

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

Despite the fact that water is the most limiting factor for irrigated crop production in the semi-arid areas of northern Ethiopia, limited scientific information has been reported on a more productive and responsible use of the limited irrigation water in agricultural systems. Hence, a field experiment was conducted at Axum area to investigate the influence of deficit irrigation on onion yield and its water use efficiency (WUE) under drip irrigation system. Eleven different water applications at different growth stages were evaluated using randomized complete block design replicated 3 times. The results revealed that the yield and yield components of onion increased significantly with increasing the amount of water application; whereas WUE significantly decreased with increasing water application. The maximum bulb yield (28.0 t ha-1) was obtained in the full-irrigation application. Onion crop subjected to 40% deficit of crop water requirement (ETc) decreased its yield by about 3 -10 t ha-1. However, the maximum WUE (7.60 kg m-3) was obtained in the 40% deficit throughout the growing season, with water saving of 15.88 cm which is sufficient to irrigate 0.67

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hectare of additional area of onion in which this earns better economic returns as compared to that of full irrigation application. The result also showed that onion is very sensitive to water stress during the development (2nd) and mid (3rd) stage of the crop. However, water stress on the 1st and 4th stage did not reduce the onion yield significantly. Hence, deficit irrigation should be applied during the less sensitive crop growing stages so as to improve water use efficiency with little or no impact on yield of onion in the semi-arid conditions like Tigray region.

Keywords: Deficit irrigation; crop water requirement; growth stage; onion yield; water stress.

1. INTRODUCTION

“Ethiopia is the second most populous country in sub-Saharan Africa and third on the continent with a population of 90 million. Agriculture is the main stay of 85% of the Ethiopian population. It also accounts for 43% of the Gross Domestic Product (GDP) of the country” [1,2]. “Even though rainfall is very erratic, and drought occurs very frequently, most Ethiopian farmers depend on rain-fed small holder agriculture. In Ethiopia, irrigation has contributed for about 5.7% and 2.5% to agricultural and overall GDP during the 2005/06 cropping season” [3]. “However, nowadays irrigated agriculture is the main focus of the food security strategy by the Ethiopian Government, as irrigation is becoming increasingly crucial in areas where seasonal rainfall is inadequate for crop production and frequent drought incidence has recorded” [4].

“Expansion of small-scale irrigation and the less dependency on rain-fed agriculture is taken as a means to increase food production and self-sufficiency of the rapidly increasing population of Ethiopia” [5,6]. “As a result, the Government of Ethiopia has been planning to expand irrigated agriculture using an additional irrigation land that could be accounted for about 33% of the irrigation potential of the country” [6]. “In line with the development strategy of the country, the Regional Government of Tigray (Northern Ethiopia) is also promoting irrigation development so as to increase and stabilize food production. As a result, a huge activity of small-scale irrigation development is going on in the region and many households are benefiting from those irrigation schemes as explained by the Tigray bureau of water resource” [7]. “However, little attention has been given to improve the utilization and management of the existing available water even though the total irrigated area and production level is still low. In areas where the available water supply limits agricultural production, deficit using drip irrigation is suggested as a means to increase the efficiency and productivity of limited land and water resources” [8]. “In arid and semi-arid areas such as in the northern Ethiopia, efficient and sustainable utilization of the limited available water resource is very crucial for increasing crop production” [9,10,11,6].

“Lack of appropriate and affordable water management practices such as drip irrigation that is geared towards poor farmers small plot conditions is a major constraint to spread deficit irrigation in Ethiopia. Drip-irrigation in this study context generally refers to the slow application of water through a set of emitters (holes) placed along water delivery lines precisely at the root zone of the plants” [11,12,13,14]. “Another water management practice is application of deficit irrigation using different irrigation techniques. Deficit irrigation is a water management practice for proper irrigation scheduling in which it is not necessarily based on full crop water requirement. But it is based on one’s plan to ensure the efficient use of available water. Hence, deficit irrigation is one way of maximizing water use efficiency (WUE) for achieving higher yields per unit of irrigation water applied” [15,16,17, 18,19,20,21]. “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 main objective of deficit irrigation is to increase the WUE of a crop by eliminating irrigations that have little impact on yield. The resulting yield reduction may be small compared to the benefits gained through diverting the saved water to irrigate other crops for which water would normally be insufficient under traditional irrigation practices” [17,22,23].

“Many investigations have been carried out worldwide regarding the effects of deficit irrigation on yield of horticultural crops” [24,25,26,27,28]. In Ethiopia conditions, results on deficit irrigation has also been reported for teff in the Rift valley by [6]; coffee in Southern Ethiopia by [4]; maize by [16] and [29]; potato by [30]; and onion in South-northern Ethiopia by

[18]; and [31]. However, previous findings showed that the amount of water applied, stress period and method of application varied across the reports by crop and study site. For example, the report by [31] has applied three levels (full, three-quarter and half) of the crop water requirement (ETc) of onion using centre pivot sprinkler irrigation. This indicated that evaluation of deficit irrigation applied at different growth stages and using drip irrigation on onion as a test crop is necessary in the northern Ethiopia conditions. In addition, less attention has been given to show the water use efficiency of a crop such as onion due to deficit irrigation applied using drip irrigation on clay textured soils. Consequently, farmers are still irrigating their crops using the traditional knowledge without any determined amount and frequency of irrigation in many semi-arid areas of Ethiopia. Thus, to efficiently utilize the scarce water resource for irrigation crop production such as onion it is essential to identify crop growth stages that are highly sensitive to water stress and also identify growth stages at which deficit irrigation could be imposed without significantly affecting crop yield.

So far, however, despite the significance of the problem of water shortage and inefficient use of the available water resources in the northern Ethiopia, research that aimed at improving irrigation water productivity of onion crop on heavy clay textured soil is inadequately documented. Hence, the objective of this research was to examine the effects of deficit irrigation applied at different growth periods of onion on yield and water use efficiency; and determine the most critical growth stage(s) of onion at which the plant is less sensitive to water stress under semi-arid conditions of northern Ethiopia.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experiment was conducted in Dura irrigation scheme, Tigray region, northern Ethiopia (Fig. 1). 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 soil type of the experimental site is clay and the field capacity (FC) and permanent wilting point (PWP) of the soil is 37.3% and 18.4% respectively, as indicated in Table 1. The study area is characterized by semi-arid climate where more than 80% of the rainfall occurs during the rainy season from June to September. The average annual rainfall of the area is 650 mm.

2.2 Experimental Design and Treatment

The field experiment was laid-out in randomized complete block design (RCBD) with 11 treatments replicated three times. For one period stress treatments, the crop was irrigated with 60% and 80% of the irrigation for onion crop water requirement (ETc). These two treatments created water stress of 40% and 20%, respectively, at the different onion crop growth stages, (Table 2). In case of partial stress treatments, 20% and 40% water stress was created throughout the growing season by applying the irrigation water at 80% and 60% of ETc, respectively. Application of water at 100% of ETc at all crop growth stages was considered as control treatment. There were 33 plots and each plot had a size of 1.5 m * 5 m, with spacing between plots and rows were 1 m and 0.30 m, respectively.

2.3 Experimental Management

Cultural management practices other than application of irrigation water were done according to the national recommendations. Seeds were sown for nursery rising and transplanted after 45 days from sowing time. The experimental site was plowed 3 times using the oxen driven traditional tool. Di-ammonium phosphate (DAP) (100 kg ha^{-1}) fertilizer was applied during the last land preparation (just at planting time) and nitrogen as 100 kg ha^{-1} of urea was applied during planting and 6 weeks after transplanting (WAP) (end of 2^{nd} stage). Weeds were controlled manually by hand weeding. The first weeding time was at 5 WAP and second was at 8 WAP. Onion thrips was observed in plots treated by treatments T1, T6, T7 and T10 at 2^{nd} growth stage. Such plots were treated with phenotrotine chemical immediately to control onion thrips. During maturity (15 WAP) when two-third of the leaves become yellow in color, bulb was harvested. This was adopted from the recommendation reported by [32].

2.4 Drip System Installation

"Surface drip irrigation system was used for water applying. Each irrigation treatment consisted of 5 drip lines of length 5 m and each line served for 50 onion plants. A total of 250 plants were planted in each plot. A total of 3 barrels were put at an elevation of 1.5 m to deliver water to the drippers. The amount of water needed to reach the plants was controlled by throttle valves on the sub-main lines. The tests for uniformity of water application in the system were checked by recording the time needed for the discharge to fill a vessel of known volume. The average discharge rate of emitters was found to be 0.4 l h^{-1}. The average uniformity coefficient for the whole system was about 90.5%, in which drip system performance was thus considered acceptable" [33].

2.5 Determination of Crop Water and Irrigation Requirement

The reference evapotranspiration (ETo) was estimated using the FAO Penman-Monteith equation [34] using daily meteorological data observed from a nearby weather station (Axum Air-port meteorological station). The crop water requirements (ETc) over the growing season stages were determined by multiplying the ETo values with the onion crop coefficients (Kc) given by [34] as 0.7 for the 1st, 0.90 for the 2nd, 1.05 for the 3rd and 0.75 for the 4th growth stages according to the following equation.

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

Optimal or ''0% water deficit (equal to ETc)'' irrigation was calculated as the net amount of irrigation required to recharge the soil moisture deficit and this was considered as control. However, the depth for the other treatments was taken based on the percentage of optimal irrigation at a specific growth stage or throughout the growing season. Since there was no rainfall during the growth period, effective rainfall was taken as a nil. Hence, ETc was taken to be equal to net irrigation requirement. The average periodic net irrigation in different days of the crop growth stages during this experiment is shown in Table 3. In addition, the irrigation water use efficiency (IWUE) was calculated by dividing harvested yield, Y (kg ha^{-1}) by total irrigation water applied, IW (m^3 ha^{-1}) as below:

$$IWUE = Y/IW \quad (2)$$

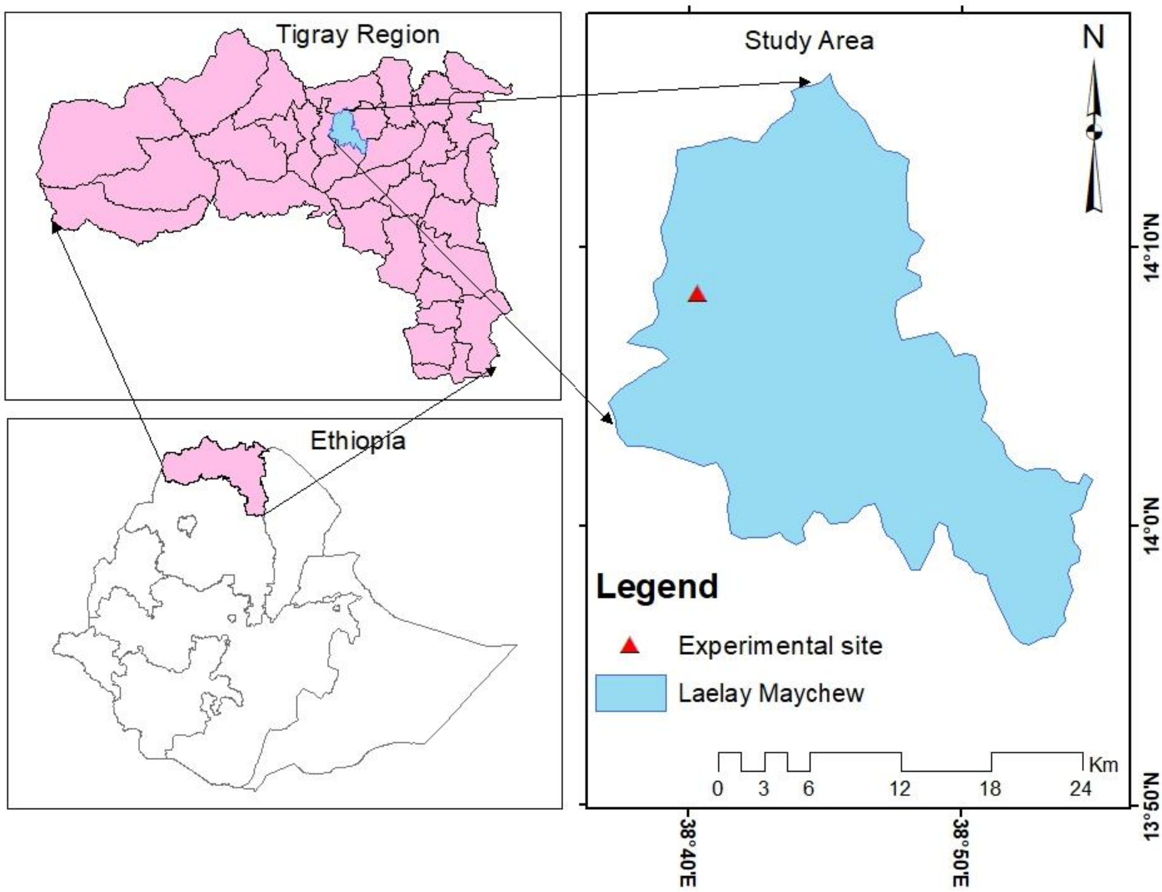

Fig. 1. Location map of the study area

Table 1. Some physical and chemical properties of soils determined from the experimental field

Sampling depth	Particle size distribution (%)			Textural class	BD	OM	pH	EC	FC v/v	PWP v/v	TAW
(cm)	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

Table 2. Description of different water deficit treatments applied in this study

Treatments	Irrigation water applied in different growth stages [a]				Description
	I	II	III	IV	
T_1	100%	100%	100%	100%	0% water deficit in all stages
T_2	80%	80%	80%	80%	20% water deficit in all stages
T_3	60%	60%	60%	60%	40% water deficit in all stages
T_4	80%	100%	100%	100%	20% water deficit in I stage
T_5	100%	80%	100%	100%	20% water deficit in II stage
T_6	100%	100%	80%	100%	20% water deficit in III stage
T_7	100%	100%	100%	80%	20% water deficit in IV stage
T_8	60%	100%	100%	100%	40% water deficit in I stage
T_9	100%	60%	100%	100%	40% water deficit in II stage
T_{10}	100%	100%	60%	100%	40% water deficit in III stage
T_{11}	100%	100%	100%	60%	40% water deficit in IV stage

[a]I stage: Initial stage of crop, II stage: Crop development stage, III stage: Bulb formation stage and IV stage: Bulb maturity stage

Table 3. Crop water requirement of onion at each growth stages during the experiment

Growth period	Treatments										
	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
	Crop water requirements (mm)										
1st stage	53.9	43.1	32.3	43.1	53.9	53.9	53.9	32.3	53.9	53.9	53.9
2nd stage	97.8	78.2	58.7	97.8	78.2	97.8	97.8	97.8	58.7	97.8	97.8
3rd stage	122.8	98.3	73.7	122.8	122.8	98.3	122.8	122.8	122.8	73.7	122.8
4th stage	63.0	50.3	37.8	63.0	63.0	63.0	50.3	63.0	63.0	63.0	37.8
Total	337.5	269.9	202.5	326.7	317.9	313.0	324.8	315.9	298.4	288.4	312.3

1st stage: 20 days after transplanting, 2nd stage: 50 days after transplanting, 3rd stage: 80 days after transplanting and 4th stage: 95 days after transplanting.

2.6 Onion Growth Components and Yield Data Collection Procedures

Agronomic data recorded during the course of the experiment included: plant growth components (plant height, number of leaves per plant) and onion yield under the different irrigation treatments. Plant height and number of leaves per plant were taken from the central rows of each plot at the end of each growth stages. Five random plants per row per plot, excluding the border rows, were taken as a sample to record plant height. This was done by measuring the main stem height from the ground level up to the tip of the leaf with the help of a ruler expressed in centimeter. For number of leaves, all completely developed leaflets was counted and recorded per plant. The bulbs produced were collected and weighed from the three central rows of each plot; this is to avoid border effects. “The harvested yield was graded into marketable and non-marketable categories of onion bulb according to the size and degree of damage. Onion bulbs with less than 2cm diameter were categorized under non-marketable” [35]. The degree of damage was determined subjectively by observing the level of visible mould growth, decay and shriveling of bulbs.

2.7 Statistical Analysis

Data were 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 growth, yields and WUE. Least Significant Difference (LSD) test at probability level (P) ≤ 0.05 was used to test any significant difference between treatment means.

3. RESULTS AND DISCUSSION

3.1 Yield Components of Onion

The average plant height measured at the end of each growth stages did not significantly ($p > 0.05$) vary among the treatments (T4 to T11) except between T1 (full irrigation) and T3 (60% water application throughout the growing season) in all growth stages. For example, at the end of the mid growth stage, the maximum and minimum plant height was observed to be 52.9 cm and 46.2 cm due to treatments T1 (full irrigation) and T3 (60% of full irrigation), respectively (Fig. 2). Moreover, the increments in plant height due to the difference in the level of water application between 40% water deficit (T3) and full irrigation (T1) across all growth stages (1st, 2nd, 3rd and 4th) were 5.9, 6.2, 14.5, and 9.6%, respectively. Such results indicate that the trend of growth of onion plants within each treatment was in an increasing pattern even though the highest increment was observed during the third growth stage (bulb formation stage).

The effect of water stress on number of leaves per plant was also shown in Fig. 3. During the 3rd growth stage, the maximum and minimum number of leaves per plant was observed to be 8 and 7 in treatments T1 and T3, respectively. However, there was no significant difference between treatments (T4 to T11). The sampling growth stage (time) x irrigation treatments interaction and the two-way interaction on onion plant height and number of leaves did not show significant differences at the 3rd and 4th growth stages (Figs 2 and 3). Generally, this study showed that plant growth components (plant height and number of leaves per plant) increase when the amount of irrigation water increases which is also in agreement with some previous studies [36,37,38].

3.2 Bulb Yield of Onion and Sensitive Growth Stages

There were significant ($p < 0.05$) differences in onion bulb yield among the different levels of irrigation water applications (treatments) (Table 4). Deficit irrigation (20 and 40% of ETc) application significantly decreased the onion bulb yield as compared to the full irrigation application. The highest yield was found to be 28.0 t ha^{-1} when full irrigation was applied. The yield was reduced to 23.4 t ha^{-1} due to T2 (80% of ETc was applied throughout the whole growth stage). More significantly lower yield of 18.1 t ha^{-1} was obtained due to treatment T3 (60% of ETc irrigation application). It can be seen from Table 4 that 20%, and 40% irrigation water reduction throughout the entire growth stage decreased the onion bulb yield by 16.6%, and 35.4%, respectively. The average bulb yield of onion due to all the treatments was 24 t ha^{-1}, with coefficient of variation (CV) of 3.6% among the treatments. This study showed that water deficit at 20% and 40% of ETc during the whole growth stages significantly reduced onion bulb yield, implying that as the amount of water deficit increases the yield decreases.

This study result on onion bulb yield is consistent with [23] who reported that increasing the amount of irrigation water significantly improved onion bulb yield. Similarly, [39] who concluded that water stress has to be avoided during the development (2nd) and bulbification (3rd) stages and only small deficits are acceptable if applied throughout the crop season. Similar results to this study has also reported by [40] who showed that improvement of water productivity is closely related to the irrigation practice of regulated deficit irrigation and has a direct effect on yield i.e., if the amount of water applied decreases intentionally the crop yield will drop. However, the findings by [41] indicated that onion plants are very sensitive to lack of soil water during the total growing season and the yield formation period (3rd), but rather insensitive in the vegetative (2nd) and ripening periods (4th). This is partly inconsistent to the present finding in which the vegetative (2nd) stage is sensitive. This might be due to the difference in crop management and other environmental factors which needs further study considering these differences.

Table 4. Yield and yield reduction of onion for the different irrigation treatments applied during this study

Treatment [a]	Yield per block, B (t ha^{-1})			Average yield (t ha^{-1})	Yield Reduction (Y_r) in %	Rank on Y_r
	B_1	B_2	B_3			
T1(0% D)	29.0	28.0	27.0	28.0^a	0.0	11
T2(20% D)	23.8	22.5	23.7	23.3^{cd}	16.6	5
T3(40% D)	17.8	18.7	17.8	18.1^f	35.4	1
T4(20% D)I	26.5	27.9	26.9	27.1^a	3.2	10
T5(20% D)II	23.7	24.9	24.0	24.2^{bc}	13.6	6
T6(20%D)III	21.4	24.1	22.9	22.8^{cde}	18.6	4
T7(20%D)IV	27.0	26.6	26.8	26.8^a	4.3	9
T8(40% D)I	24.8	23.6	24.4	24.3^{bc}	13.2	7
T9(40% D)II	22.3	22.9	21.5	22.2^{de}	20.7	3
T10(40%D)III	20.3	21.7	23.5	21.8^e	22.1	2
T11(40%D)IV	24.6	25.0	25.3	25.0^b	10.7	8

Treatment means with different letters in a column are significantly different.
T1 (0%D), % water deficit in all stages; T2 (20%D), 20% water deficit in all stages; T3 (40%D), 40% water deficit in all stages; T4 (20%D), 20% water deficit in 1st stage; T5 (20%D), 20% water deficit in 2nd stage; T6 (20%D), 20% water deficit in 3rd stage; T7 (20%D), 20% water deficit in 4th stage; T8 (40%D), 40% water deficit in 1st stage; T9 (40%D), 40% water deficit in 2nd stage; T10 (40%D), 40% water deficit in 3rd stage; T11 (40%D), 40% water deficit in 4th stage.

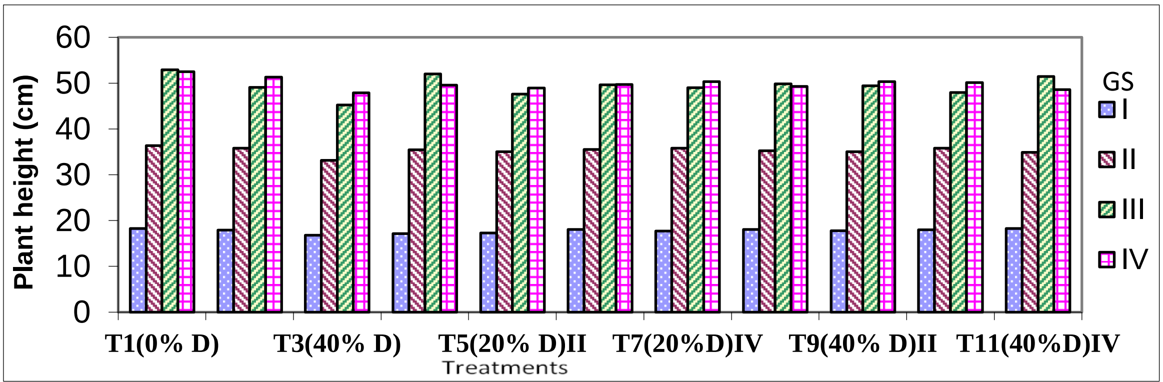

Fig. 2. Effect of water level treatments on plant height at different growth stages
Note: T1 , 0% water deficit in all stages; T2, 20% water deficit in all stages; T3, 40% water deficit in all stages; T4, 20% water deficit in 1st stage; T5, 20% water deficit in 2nd stage; T6, 20% water deficit in 3rd stage; T7, 20% water deficit in 4th stage; T8, 40% water deficit in 1st stage; T9, 40% water deficit in 2nd stage; T10, 40% water deficit in 3rd stage; T11, 40% water deficit in 4th stage and GS= Growth stage

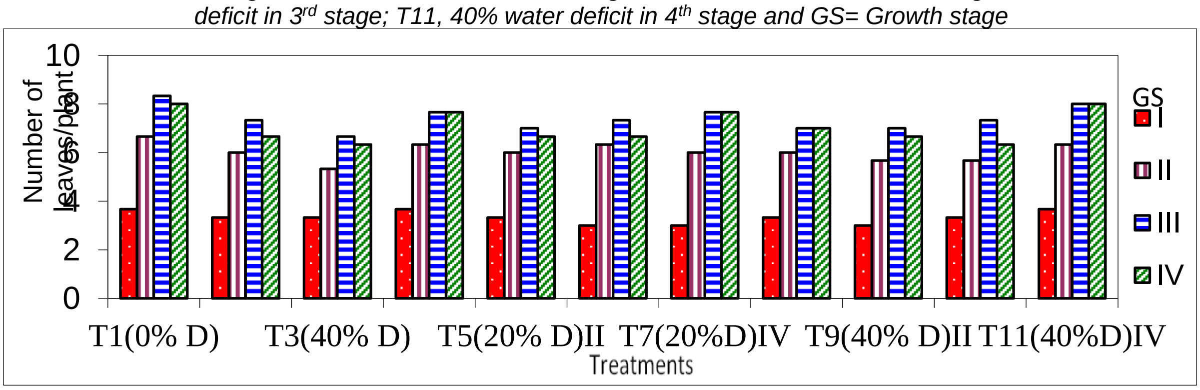

Fig. 3. Effect of water level treatments on number of leaves per plant at different growth stages
Note: T1 (0%D), 0% water deficit in all stages; T2 (20%D), 20% water deficit in all stages; T3 (40%D), 40% water deficit in all stages; T4 (20%D), 20% water deficit in 1st stage; T5 (20%D), 20% water deficit in 2nd stage; T6 (20%D), 20% water deficit in 3rd stage; T7 (20%D), 20% water deficit in 4th stage; T8 (40%D), 40% water deficit in 1st stage; T9 (40%D), 40% water deficit in 2nd stage; T10 (40%D), 40% water deficit in 3rd stage; T11 (40%D), 40% water deficit in 4th stage and GS=Growth stages

A deficit irrigation strategy of supplying water at 80% and 60% of ETc during the 1st and 4th stage did not reduce the onion yield significantly. This experiment revealed that water stress imposed at the 2nd and 3rd stages reduced the yield significantly. For example, the yield reduction at the 1st and 4th stages for the case of 20% water deficit was 3.2 and 4.3 t ha^{-1}, respectively. This is very low as compared to the yield reductions at the 2nd and 3rd stages which were about 13.6 and 18.6 t ha^{-1}, respectively. Based on this research results it can be advised that the most critical period of irrigation for onion is the 3rd growth stage followed by the 2nd growth stage. Hence, supplying full water requirement at the 1st and 4th crop growth stage is not advisable whenever there is shortage of irrigation water in the study area conditions. This result is supported by [22] who described that applying deficit irrigation at the 1st and 4th growth stages had insignificantly affected onion yield as compared to the optimum irrigation application. However, if the water deficit is in the 2nd and 3rd growth stages or during all stages as that of 25% ETc, 50% ETc, and 75% ETc, the yield was significantly different from optimal irrigation applied. Similarly, [23] showed that 20% and 40% water deficit throughout the growing season in loam soil experimental condition and subsurface drip irrigation system resulted in 20% and 32% onion yield reduction respectively. In line with the present finding, [18] also reported that a minimum yield was gained during the full stress, but stressing the crops during initial and final stages of the growing season did not affect the crop yield significantly. However, stressing the crop during the 3rd growth stage reduced the yield more significantly than stressing the crop during the 1st and 4th growing stages.

3.3 Yield - Water Relationship

A linear regression (relationship) was observed between the seasonal water applied (cm) and the total bulb yield (t ha^{-1}) for any of the treatments (Fig. 4). As the depth of irrigation application increases, the yield also increased for the application ranges considered in this study (20-34 cm depth of water). The variability of bulb yield is explained by the depth of irrigation water applied for 77% and the remaining could be described by other factors such as soil nutrient, climate that influence the crop. Many studies have been reported on yield-water relationship with a higher variability than this study. For example, studies on onion by [31] and [22] concluded that more than 90% of the yield variation was coming from the variability in depth of irrigation application regardless of the time of application. It is generally stated that yield is a function of seasonal water use, but the different variability among the growing season especially associated with the amount and distribution of the total seasonal water, rate of evaporation at different stages and other prevailing climate factors make it difficult to trace the relationship between these variables [42].

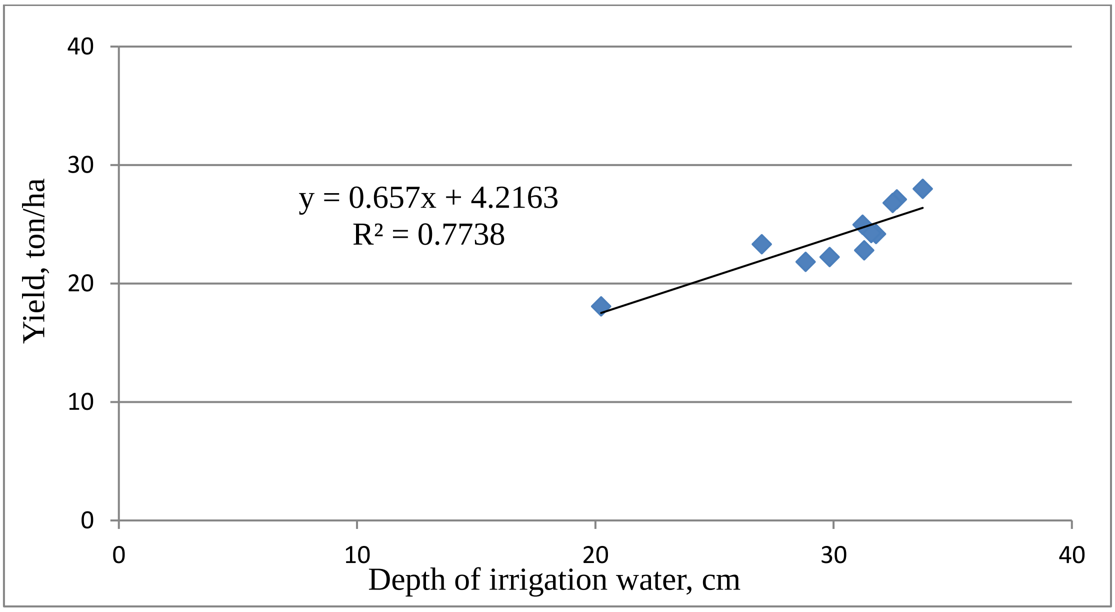

Fig. 4. Regression trend between onion yield and depth of irrigation water

Table 5. The correlation matrix of onion yield and some yield components of onion

	PH1	PH2	PH3	PH4	NL1	NL2	NL3	NL4	Yld
PH1	1.000	0.69*	0.60ns	0.56ns	0.08ns	0.57*	0.53ns	0.35ns	0.41ns
PH2		1.000	0.64*	0.82**	0.08ns	0.69*	0.63*	0.41ns	0.72*
PH3			1.000	0.53ns	0.56ns	0.89**	0.83**	0.82**	0.83**
PH4				1.000	0.07ns	0.52ns	0.54ns	0.30ns	0.52ns
NL1					1.000	0.50ns	0.59ns	0.58ns	0.43ns
NL2						1.000	0.83**	0.78**	0.85**
NL3							1.000	0.88**	0.81**
NL4								1.000	0.86**
Yld									1.000

**= significant at P< 0.05, ** = highly significant at P≤ 0.01, and ns = non-significant at P>0.05*

PH1= Plant height at the 1st stage, PH 2= Plant height at the 2nd stage, PH3= Plant height at the 3rd stage, PH4= Plant height at the 4th stage, NL1= number of Leaves per plant at the 1st stage, NL2= number of Leaves per plant at the 2nd stage, NL3= number of Leaves per plant at the 3rd stage, NL4 = number of Leaves per plant at the 4th stage, Yld = onion yield

Table 6. Irrigation water use efficiency (IWUE) and amount of water saved (%) in this study

Tret.	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11
IWUE (kg m^{-3})	7.05^{bc}	7.35^{ab}	7.60^{a}	7.05^{bc}	6.47^{de}	6.20^{e}	7.01^{bc}	6.53^{de}	6.34^{e}	6.44^{de}	6.80^{dc}
Water saved (%)	0	7.9	15.9	1.3	2.3	2.9	1.5	2.5	4.6	5.8	3.0
Rank on IWUE	3	2	1	4	8	11	5	7	10	9	6

$LSD_{(0.05)}$ = 0.4232

Tret. = Treatments, T1 , 0% water deficit in all stages; T2, 20% water deficit in all stages; T3, 40% water deficit in all stages; T4, 20% water deficit in 1st stage; T5, 20% water deficit in 2nd stage; T6, 20% water deficit in 3rd stage; T7, 20% water deficit in 4th stage; T8, 40% water deficit in 1st stage; T9, 40% water deficit in 2nd stage; T10, 40% water deficit in 3rd stage; T11, 40% water deficit in 4th stage

3.4 Correlation of Onion Yield and Growth Components

The positive and significant correlation among the yield and growth components (Table 5) indicates that the yield is directly dependent on the value of these growth components such as plant height and number of leaves per plant. This is especially manifested at the 2nd ($r = 0.72$, $P < 0.05$) and 3rd growth stages ($r = 0.83$, $P < 0.01$) that showed for the correlation between onion yield and plant height. The highest correlation between yield and number of leaves was observed at the 2nd ($r = 0.85$, $P < 0.01$) and 4th ($r = 0.86$, $P < 0.01$) growth stages. Plant height and number of leaves increases above ground biomass indicating that as the above ground biomass of onion increases the yield is expected to increase and vice-versa. This strong correlation might be due to the evaporative capacity of the crop at these stages which improves biomass. Thus, any management practices that provide favorable influences on these variables are likely to enhance bulb yield.

3.5 Water Use Efficiency of Onion

The analysis of variance indicated that deficit irrigation significantly ($p < 0.05$) affected the irrigation water use efficiency (IWUE) of onion crop (Table 6). The highest and the lowest mean value of IWUE for 20% deficit was observed to be 7.35 kg m^{-3} and 6.20 kg m^{-3} due to the treatments T2 and T6, respectively. Similarly, the 40% deficit irrigation was also significantly influenced by the IWUE. The highest mean value of IWUE was observed for T3 with mean value of 7.60 kg m^{-3} whereas the lowest value was found for T9 with average value of 6.34 kg m^{-3}. Overall, the highest value of IWUE was obtained for T3 (7.60 kg m^{-3}) and the lowest value was obtained from the 20% deficit treatment of T6 (6.20 kg m^{-3}). These values indicated an 18% increase in IWUE for 40% deficit over that of the 20% deficit. Moreover, applying 60% ETc (T3) throughout the growing season improved IWUE by 7.8%, with water saving of 15.88 cm which is sufficient to irrigate 0.67 hectare of additional area of onion crop in which this earns better economic returns as compared to that of full irrigation application. It can be observed that deficit irrigation applications increased the IWUE from 4% (T2) to 8% (T3) compared to the optimum application (T1). When 40% of ETc (T3) was applied for the whole growth period, onion IWUE was the highest (7.60 kg m^{-3}) and this slightly decreased to 7.35 kg m^{-3} when the 20 % deficit irrigation was applied throughout the growing season (Table 6).

Previous results consistent with the present findings of WUE were reported for onion crop by [31,22,42], who stated that deficit irrigation application for onion increased water use efficiency. Similarly, [23] reported that stressing the crop with 40% deficit irrigation at the second growth stage and throughout the growing season resulted in a minimum irrigation water use efficiency of 6.16 kg m^{-3} and a maximum of 8.57kg m^{-3}. In their drip irrigation experiment [25] reported that the lower volume of water received, the higher the efficiency obtained.

4. CONCLUSION

This research demonstrated that deficit irrigation is one of the irrigation management strategies which could contribute for water saving in the semi-arid areas. Based on this study, any deficit irrigation application is likely to induce a decrease in onion yield to some extent. However, the impact of deficit irrigation on crop yield can be insignificant as the water stress is applied to the crop during specific growth stages that are less sensitive to moisture deficiency. In this research, a deficit irrigation strategy applied at 80% and 60% of ETc during the 1st and 4th stages did not reduce the onion yield significantly. However, the crop was very sensitive to water stress during the 2nd and 3rd growth stage. On the basis of this, it can be concluded that applying full water requirement at the 1st and 4th crop growth stage is not advisable in water scarce areas like in the case study scheme of semi-arid northern Ethiopia conditions.

Application of deficit irrigation throughout the growing season increased the IWUE from a minimum of 4.2% (T2) to a maximum of 7.7% (T3) compared to the optimum application (T1). However, in the case of partial stress the IWUE value was low, which showed that the amount of water saved did not compensate the amount of the yield loss. Although the highest value of WUE was observed on the most severe stress treatments i.e., 40% water deficit throughout the growing season (T3), the yield reduction observed under this treatment did not allow for such reduction. The relatively high yield and water use efficiency values noted under 20% water deficit at the 1st stage (T4) and stage 4th (T7) treatments indicate that the high potential of the onion crop to resist irrigation waters of limited amount under one period stress. Based on these results, it can be concluded that the 20% water deficit at the 1st and 4th growth stage strategies offer significant advantage for both onion yield and IWUE. As a result of this, in situations where irrigation water is limited, a 20 % water deficit at the early (1st) and late (4th) growth stage is recommended for irrigation of onion crop under the semi-arid conditions of northern Ethiopia.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author (s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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