# Irrigation & Drainage Systems Engineering

**Research Article**

# Effect of Deficit Irrigation on Water Productivity of Onion (*Allium cepa*l.) under Drip Irrigation

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## Abstract

Deficit irrigation (DI) improves water productivity and irrigation management practices resulting in water saving by maintaining soil moisture content below optimum level throughout growth season. Field study was carried out on clay loam soil at Melkassa Agricultural Research Center, Ethiopia with the objectives to estimate water productivity of onion and evaluate the effect of water deficit on onion yield and quality using drip irrigation. The experiment contained five DI treatments of 90%, 80%, 70%, 60%, and 50% Crop water use (ETc) and the control (100% ETc) laid out in RCBD design with three replications. Irrigation water was applied at allowable soil moisture depletion (p=0.25) of the total available soil moisture throughout the crops growth stage. Statistical analysis revealed that plant height was not affected by the level of DI while, leaf number, bulb diameter, marketable bulb yield and total bulb yield had shown a highly significant (P<0.01) differences among DI treatments. The highest bulb diameter was observed from a control treatment that was significantly different to all other treatments. The highest total bulb yield of 15,690 kg/ha was observed from a control treatment which was not significantly different with treatment receiving 90% ETc. Highest water productivity of onion bulb yield was observed from treatment receiving 70% ETc and better onion bulb diameter was observed from treatment receiving 100% ETc to 70% ETc. The yield response factor ranged between 0.8 and 1.7. Thus, DI practices should be avoided for Ky values that are less than unity. Considering yield response factors (Ky) is limiting factor, 80% ETc application was a marginal and beyond that yield losses are intolerable. Thus, the practice of DI application up to 20% saved 45 to 108 mm depth of water from the gross onion irrigation water requirement.

**Keywords:** Deficit irrigation; Drip irrigation; Melkassa; Onion; Water productivity

## Introduction

Onion (Allium cepaL.) is the most important, widely grown vegetable crop throughout the world [1]. It is widely cultivated as a source of income by many farmers in many parts of the country. It is also one of the most important vegetable crops in Ethiopia. The crop is widely cultivated as cash crop by small-scale and private large-scale farmers. The country has a great potential to produce onion throughout the year both for local consumption and export. It can be produced throughout the year provided dependable rain and/or irrigation water is available. The majority of onion production is found in the Central Rift Valley (CRV) of Ethiopia; however, rainfall is unreliable and insufficient to support onion production that makes irrigation an indispensable practice.

The crop is shallow rooted and sensitive to water stress. As result the crop is commonly given light and frequent irrigation to avoid water stress [2]. Maximum yield could be obtained with the achievement of the entire crop water requirements. The rift valley area is a semi-arid with limited water resources and increasing demand for water combined with high evapo-transpiration rates limits the production and productivity of the crop. Hence, alternatives need to be explored for effective and efficient use of the existing water resources.

Under conditions of scarce water supply, application of deficit irrigation (DI) could provide greater economic returns than maximizing yields per unit of water. The DI has been considered worldwide as a way of maximizing water use efficiency (WUE) by eliminating irrigation that has little impact on yield [3-5]. With DI, the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season [6].

A variety of crops have been found to benefit from DI strategy and many researchers pointed out that yield loss that may result from DI is offset by the benefits of reduced water use [7-10]. The response of

Onion to water deficit has been reported by [11] and [12] that showed DI to increase the water use efficiency of onion.

Drip irrigation is one of the most efficient forms of irrigation technology that will allow to apply light and frequent irrigation. The experience from many countries showed that farmers who switch from surface irrigation to drip systems can cut their water use by 30% to 60% and crop yields often increase at the same time [12]. Therefore, the objectives of this study were to determine water productivity of onion and investigate the effect of DI levels on yield and quality onion bulb under drip irrigation.

## Description of the study area

A field experiment was conducted at Melkassa Agricultural Research Center (MARC) of the Ethiopian Institute of Agricultural Research (EIAR) in CRV Ethiopia (8°24' N lat. 39°21' E long. 1550 m.a.s.l.). Central Rift Valley of Ethiopia is a semi-arid environment with mean monthly maximum and minimum temperature of 33°C and 10.8°C, respectively. It is characterized by uni modal low and erratic rainfall pattern with average annual rainfall of 767 mm [13]. The soil is a clay loam type with 35% sand, 28.5 and silt and 36.5% clay. The top 30 cm of the soil at the experimental site has a field capacity of 30.7%, wilting point of 15.8% and bulk density of 1.1 g/cm^{3} while the total available water was about 49.4.

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## Materials and Methods

### Experimental layout and design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replicates. The treatments consisted of five soil moisture deficit levels, *viz.*, 90% ETc (10% deficit); 80% ETc (20% deficit); 70% ETc (30% deficit); 60% ETc (40% deficit) and 50% ETc (50% deficit) and a control treatment of 100% ETc (no deficit) (Table 1). Drip irrigation system was used for applying the required quantity of irrigation water. Each irrigation treatment consisted of three lateral lines of 5 m length. Each lateral line contained emitters spaced at 30 cm interval.

Onion variety Bombay red was raised on nursery bed and transplanted to field plots of 5 m × 2.7 m. Furrows spaced at 60 cm were used and transplanted on both side of a ridge at row and plant spacing of 20 and 10 cm, respectively. To ensure the plant establishment common irrigations was provided to all plots at two days interval before commencement of the differential irrigation. Irrigation water was applied at allowable soil moisture depletion (p=0.25) of the total available soil moisture throughout crops growth stage.

### Data collection and analysis

Data collection comprised plant height, leaf number, bulb yield and yield components that include bulb diameter, marketable and unmarketable bulb yield. Water productivity and effect of water stress on crop performance were quantified from WUE and yield response factors (Ky), respectively. Estimation of WUE was carried out as a ratio of total bulb yield to the total water applied [14].

$$\text{WUE}\left(\text{kg mm}^{-1}\right) = \frac{\text{Total bulb yield}\left(\text{kg}\right)}{\text{Crop Water Use}\left(\text{mm}\right)}$$

Crop water use (ETc) was determined for each treatment for the growing period using the soil-water balance equation [15].

$$ET_c = I + R_e + \Delta S - D + G_e$$

Where: I is irrigation water (mm); Re is effective rainfall (mm) and ΔS is the change in soil water storage for the period (mm). D is drainage below the root zone (mm) and Ge is the groundwater contribution (mm). The contribution of D and Ge were assumed to be negligible. The ΔS were assumed the same at the beginning and at harvest and have no contribution to plant ET.

The yield response factor (Ky) was estimated from the relationship [16].

$$\left(1 - \left(\frac{Y_a}{Y_m}\right)\right) = K_y\left(1 - \left(\frac{ET_a}{ET_m}\right)\right)$$

Where,

Ya is actual harvested yield

Ym is maximum harvested yield

Ky is yield response factor

ETa is actual evapo-transpiration

ETm is maximum evapo-transpiration

The data collected during the experimental period were subjected to statistical analysis using SAS computer program. Whenever treatment effects were significant, Least Significance Differences (LSD) test was used to assess the mean difference among treatments.

## Results and Discussion

Statistical analysis has shown a highly significant (P<0.01) difference for leaf number, bulb diameter, total and marketable bulb yield under the different DI treatments. However, no significant difference was observed for plant height and unmarketable bulb yield. The data on Tables 2 and 3 provide plant height, leaf number, bulb diameter, total bulb yield, marketable and unmarketable bulb yield.

### Plant height

The DI did not affect much onion plant height. The plant height ranged from 38 and 46 cm. The highest and lowest plant height was observed from treatment receiving 90% and 50% ETc, respectively. However, the control treatment and treatment receiving 80% ETc gave below the average plant height.

The increasing of plant height with adequate soil moisture application is related to water in maintaining the turgid pressure of the plant cells which is the main reason for the growth [17]. In the other side the shortening of plant height under less soil moisture stress may be associated due to the closure of stomata to conserve soil moisture evaporation, this leads to reduce uptake of $CO_2$ and nutrient. Therefore, photosynthesis and other biochemical reactions are hindred, eventually affecting plant growth [18]. This study outcome is in line with the research that has been done by [19], indicated that soil water supply is directly proportional with plant height growth.

### Leaf number

The number of leave per plant ranged from 6 to 8. The highest leaf number was recorded from treatment receiving 90% ETc. This was significantly different to all other treatments at p<0.05 level and had no significant difference with the control at P<0.01 level. Treatment receiving 60% ETc was inferior to treatment receiving 100 to 80% ETc and had no significant difference with treatment receiving 70%

| | Soil moisture content/(SMC (mm) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Depth (cm) | | | | | | | | |
| Treatment | 0-30 | | | 30-45 | | | 45-60 | | |
| | Before irrig. | After irrig. | Net irrigation | Before irrig. | After irrig. | Net irrigation | Before irrig. | After Irrig. | Net irrigation |
| 100% ETc | 89.3 | 102 | 12.4 | 129.1 | 146.1 | 17 | 167.3 | 189 | 21.6 |
| 90% ETc | 89.3 | 101 | 11.2 | 129.1 | 144.4 | 15.3 | 167.3 | 187 | 19.4 |
| 80% ETc | 89.3 | 99 | 9.9 | 129.1 | 142.7 | 13.6 | 167.3 | 185 | 17.3 |
| 70% ETc | 89.3 | 98 | 8.7 | 129.1 | 141 | 11.9 | 167.3 | 182 | 15.1 |
| 60% ETc | 89.3 | 97 | 7.4 | 129.1 | 139.3 | 10.2 | 167.3 | 180 | 12.9 |
| 50% ETc | 89.3 | 96 | 6.2 | 129.1 | 137.6 | 8.5 | 167.3 | 178 | 10.8 |
| Source: Own data, 2015 | | | | | | | | | |

**Table 1:** Soil moisture content before and after irrigation events and net irrigation requirements.

| Treatment | Plant height (cm) | Leaf number |
|---|---|---|
| 100% ETc | 41.2 | 7.33 |
| 90% ETc | 46.3 | 8 |
| 80% Etc | 41.7 | 7 |
| 70% Etc | 43.8 | 6.67 |
| 60% Etc | 42.9 | 6.33 |
| 50% Etc | 38.2 | 6.67 |
| Mean | 42.3 | 7 |
| LSD0.05 | NS | 0.66 |
| 0.01 | NS | 0.94 |
| SE + | 2.78 | 0.21 |
| CV (%) | 11.38 | 5.22 |
| Source: Own data, 2015 | | |

**Table 2:** Plant height and leaf number as influenced by DI.

| Treatment | Bulb diameter (cm) | Bulb yield (kg ha$^{-1}$) | Marketable bulb yield (kg ha$^{-1}$) | Unmarketable bulb yield (kg ha$^{-1}$) | Percent unmarketable yield |
|---|---|---|---|---|---|
| 100% ETc | 6.01 | 15694.4 | 10902.8 | 4791.7 | 31 |
| 90% Etc | 5.6 | 13958.3 | 9687.5 | 4270.8 | 31 |
| 80% Etc | 5.4 | 12604.2 | 7923.6 | 4680.5 | 37 |
| 70% Etc | 5.21 | 12395.8 | 8263.9 | 4131.9 | 33 |
| 60% Etc | 4.95 | 11041.7 | 6847.2 | 4194.4 | 38 |
| 50% Etc | 4.97 | 10034.7 | 6076.4 | 3958.3 | 39 |
| Mean | 5.4 | 12621.5 | 8283.6 | 4337.9 | 35 |
| LSD0.05 | 0.15 | 1933 | 2171 | NS | |
| 0.01 | 0.22 | 2749 | 3087 | NS | |
| CV (%) | 1.6 | 8.42 | 14.4 | 11.85 | |
| SE + | 0.05 | 613.4 | 688.8 | 296.8 | |

**Table 3:** Bulb diameter, bulb yield, marketable and unmarketable bulb yield as influenced by DI.

and 50% ETc. From the result, it can be observed that up to 20% water deficit was tolerable to obtain at least seven leaf number per plant.

## Bulb diameter

The DI water applications affected the size of onion bulb. The highest bulb diameter was recorded from the control treatment and this was significantly different to all other treatments. The least bulb diameter was recorded from treatment receiving 60% ETc and this was not significantly different to treatment receiving 50% ETc. Water deficit up to 20% gave bulb diameter above the mean value of 5.4 cm. This result is in agreement with that of a study conducted by [20], high amount of soil moisture application leads to large photosynthesis area (plant height and large number of leaves), results to large bulb diameter.

## Total bulb yield, marketable and unmarketable bulb yield

The total bulb yield was highest for the control treatment and this was not significantly different to treatment receiving 90% ETc. The least bulb yield was recorded from treatment receiving 50% ETc and had no significant difference with treatments receiving 60% ETc at $p<0.05$ level and with treatment receiving 60% to 80% at $p<0.01$ level. From this finding, it can be observed that with 10% water deficit to result 11% yield reduction and above 10% water deficit to result total bulb yield below mean value. A study done by [20] also presented similar findings with this result.

Highest marketable bulb yield was recorded from the control treatment and had no significant difference with 90% ETc at $p<0.05$ level and with 70% to 90% ETc at $p<0.01$ level. The lowest marketable bulb yield was observed from treatment receiving 50% ETc and had no significant difference with 60% and 80% ETc at $p<0.05$ level and with 60% to 80% ETc

at $p<0.01$ level. Here too the finding indicated that with 10% water deficit to result 11% marketable yield reduction and above 10% water deficit to result marketable bulb yield below mean value.

The highest and lowest unmarketable onion bulb yieldswere recorded from the control and 50% ETc treatments, respectively. However, the control and 90% ETc treatment gave the lowest percentage (31%) of unmarketable bulb yield and while 50% ETc treatment gave the highest percentage (39%) of unmarketable bulb yield. From the result, it can be observed that up to 30% water deficit was marginal to obtain the least unmarketable bulb yield. The results presented in this study is inclusive and similar with previous research done by [21], high soil moisture application attributes to vegetation growth and increases plant metabolic activities, which leads to marketable bulb yield increment.

## Water use efficiency (WUE)

Table 4 shows the water-use efficiency, applied Water (AW), water saved for onion bulb yield. Treatment receiving 70% ETc resulted in higher WUE and saved 182.5 mm of water (Table 4). The control treatment gave practically similar WUE with 50% and 60% ETc treatments. The lowest WUE was from treatment receiving 90% and 80% ETc. However, 10% water deficit resulted 11% yield reduction and above 10% water deficit resulted bulb yields below mean value for the treatments. The difference in WUE among treatments is very small and considering the yield reduction is a limiting factor, 70% ETc application seems marginal. A study conducted by [22,23] also indicated that WUE is maximum at medium soil moisture level compare to high moisture level treatment.

## Yield response factor (Ky)

Observed yield response factors (Ky) for onion bulb production ranged between 0.8 and 1.7, the lowest and highest being for 70% and 90% ETc applications, respectively. The Ky observed was decreasing as irrigation water application decreasing. Treatments receiving 60% and 50% Etc water application showed almost similar yield response factor (Table 5).

The higher Ky values indicate that the crop will have a greater yield loss when the crop water requirements are not met. Generally, the result indicates the sensitivity of the crop to soil moisture deficit. Therefore, DI practices should be avoided for Ky values that are less than unity. This conclusion is in line with a statement given by [24], the decrease in yield is proportionally greater with increase in water deficit. Considering Ky is limiting factor, 80% ETc application was a marginal and beyond that yield losses are intolerable [25]. With DI application up 20%, hence, saved 45 to 108 mm depth of water from the gross IWR of 678 mm depth of water.

## Conclusion

Water is scarce resource in Central Rift Valley of Ethiopia and

| Treatment | AW (mm) | Bulb yield (Kg ha$^{-1}$) | WUE (kg mm$^{-1}$) | Water saved (mm) | Yield reduction (%) |
|---|---|---|---|---|---|
| 100%ETc | 677.85 | 15694.4 | 23.2 | 0 | 0 |
| 90% ETc | 632.74 | 13958.3 | 22.1 | 45.1 | 11.1 |
| 80% ETc | 570.07 | 12604.2 | 22.1 | 107.8 | 19.7 |
| 70% ETc | 495.4 | 12395.8 | 25 | 182.5 | 21 |
| 60% ETc | 469.34 | 11041.7 | 23.5 | 208.5 | 29.6 |
| 50% ETc | 429.18 | 10034.7 | 23.4 | 248.7 | 36.1 |

**Table 4:** Applied water, water use efficiency, water saved and percent yield reduction under the control and DI practices.

| Treatments | ETc (mm) | Bulb yield (Kg/ha) | Yield response factor (ky) |
|---|---|---|---|
| 100% Etc | 677.85 | 15694.4 | - |
| 90% Etc | 632.74 | 13958.3 | 1.7 |
| 80% Etc | 570.07 | 12604.2 | 1.2 |
| 70% Etc | 495.4 | 12395.8 | 0.8 |
| 60% ETc | 469.34 | 11041.7 | 1 |
| 50% ETc | 429.18 | 10034.7 | 1 |

**Table 5:** Crop water use and yield response factor under control and DI.

is major limiting factor for crop production. The DI practice under drip irrigation is a suitable and most efficient practice for sustainable production in water scarce area. In this study, DI application of 90% ETc gave highest plant height and leaf number. The maximum bulb diameter, total bulb yield and marketable bulb yield were observed when 100% ETc irrigation water was applied. Drip irrigation with 10% water deficit resulted about 11% yield reduction and above 10% water deficit resulted bulb yields below mean value for the treatments. The highest water productivity of onion was observed at 70% ETc water deficit irrigation application.

The yield response factor of onion ranged between 0.8 and 1.7 and the higher Ky value indicated that onion will have a greater yield loss when the critical water requirements are not met. Thus, DI practices should be avoided for Ky values that are less than unity. Considering Ky is limiting factor, 80% ETc application was a marginal and beyond that yield losses are intolerable. With DI application up 20% saved 45 to 108 mm depth of water from the gross IWR (Irrigation Water Requirement) of 678 mm depth of water.

## Recommendation

Water scarcity is the major limiting factor for increased production and productivity. Water is scarce resource in Central Rift Valley of Ethiopia and is major limiting factor for crop production. Onion is one of the major economically important vegetable crops grown in this region. Therefore, DI practice under drip irrigation is a suitable and most efficient practice for sustainable production in water scarce area like Central Rift Valley of Ethiopia.

The maximum bulb diameter, total bulb yield and marketable bulb yield associated with application of 100% ETc irrigation water. However, to obtain the highest water productivity of onion, can be obtained when 70% ETc water deficit irrigation application. If yield response factor (Ky) is considered, 80% ETc application should be a marginal and beyond that yield losses are intolerable. With DI application up to 20%, 45 to 108 mm depth of irrigation water can be saved from the gross irrigation water applied as in the case of no deficit. Deficit irrigation (DI) improves water productivity and irrigation management practices resulting in water saving by maintaining soil moisture content below optimum level throughout growth season.

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