Plant
2022; 10(1): 26-35
http://www.sciencepublishinggroup.com/j/plant
doi: 10.11648/j.plant.20221001.14
ISSN: 2331-0669 (Print); ISSN: 2331-0677 (Online)

Effects of Deficit Irrigation and Mulch Levels on Growth, Yield and Water Productivity of Onion (*Allium cepa* L.) at Werer, Middle Awash Valley, Ethiopia

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To cite this article:
Kebede Nanesa Tufa, Yibekal Alemayehu Abebe, Fentaw Abegaz Ahmed. Effects of Deficit Irrigation and Mulch Levels on Growth, Yield and Water Productivity of Onion (*Allium cepa* L.) at Werer, Middle Awash Valley, Ethiopia. *Plant*. Vol. 10, No. 1, 2022, pp. 26-35. doi: 10.11648/j.plant.20221001.14

Received: December 31, 2021; **Accepted**: January 18, 2022; **Published**: January 28, 2022

Abstract: Enhancing water productivity of irrigated crops through Agricultural water management is a vital option in water scarce areas, such as, Rift valley. Accordingly, a field experiment was conducted at Werer Agricultural Research Center to evaluate the effects of deficit irrigation and straw mulching levels on growth, yield and water productivity of onion (*Allium cepa* L.). The experiment was laid out in a randomized complete block design in factorial arrangement of three levels of irrigation (100, 80 and 60% of Crop Evapotranspiration and four levels of straw mulch (0, 3, 6 and 9ton wheat straw per ha) in three replications. The output of Cropwat model indicated that the highest seasonal water requirement of onion was 422.5 mm at 100% ETc while; the lowest was 253.5 mm at 60% ETc. The analysis of variance revealed that there was significant ($p<0.05$) difference in growth parameters and yield parameters were highly significant ($p<0.01$) influenced by the interaction effects of deficit irrigation and straw mulch levels. The highest marketable bulb yield (33.47 t/ha) was obtained from an experimental plot treated with combined application of 100% of ETc and 6 t/ha straw mulch, while the lowest (21.10 t/ha) was obtained from plots treated with 60% ETc irrigation level and no mulch treatment. Water productivity was also highly significant ($p<0.01$) influenced by the interaction effects of deficit irrigation and straw mulching levels; the highest (10.22 kg/m^3) and the lowest (6.11 kg/m^3) were recorded from the plots treated with 60% ETc and 9 t/ha straw mulch, and 100% ETc and no mulch treatments, respectively. Therefore, in terms of marketable bulb yield and water productivity, irrigating with 80% ETc with 6 t/ha straw mulch would be recommended for production of onion in the study area.

Keywords: Deficit Irrigation, Evapotranspiration, Marketable Yield, Straw Mulching

1. Introduction

Onion (*Allium cepa* L.) is the most widely cultivated species of the genus Allium, and belongs to the family Alliaceae [12]. It is one of the monocotyledonous, cross-pollinated and ranked as the second in production of all vegetable crops next to tomato [5]. Pests and diseases, coupled with a low level of improved agricultural technology, recurrent droughts, and decreases in soil fertility levels are some of the major contributors to the low and unstable crop yields in Ethiopia [11].

In 2016/17, the total area under onion production in Ethiopia is about 31,673.21 ha with an average yield of about 9.279 tons per ha, which is low compared to 2015/16 with average yield 9.745 tons per ha [8]. According to survey work conducted on small-scale irrigation users of 500 agro-pastorals households at Amibara and Fentale districts of the Awash basin, onion cultivar Bombay Red yielded on average 19.3 tons per ha at an increasing rate of returns to production where the household generated to income in profitability rate [19]. In Ethiopia, the crop is one of the most important vegetables produced by smallholder farmers mainly as a source of cash income and for flavoring the local stew ‘wot’ [10].

Improving water productivity represents a major challenge for agricultural water management and consequently sustainable crop production. Water productivity (also known as evapotranspiration water use efficiency) is the relationship between crop yield and crop evapotranspiration (ETc). Water productivity is typically used to identify the environments or management strategies by which the yield per unit water can be maximized. This type of performance indicator is very useful under conditions of scarcity of water resources. So, adaptation of economically sound and scientifically proven techniques is a feasible tool for improving Water productivity. Deficit irrigation (DI) with mulching could be one of the most desirable management practices to meet water scarcity and its consequences. Deficit irrigation and straw mulch are known to individually save scarce water but, there has not been a study made to use surface irrigation in conjunction with surface covering for different climate and crop under moisture stress in Ethiopia. Therefore, in view of the existing low productivity and water shortage, this study needed to be carried out.

Objectives

To investigate the effects of deficit irrigation and straw mulch levels of onion on a) growth b) yield c) yield components d) water productivity.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted at Werer Agricultural Research Center (WARC) experimental site during 2018/19 off-season (September to March). Werer is located in Gabiresu Zone of Afar Regional State and found at 280 km from Addis Ababa in the eastern direction. The center is located at 9° 16'8" N and 40° 09'41" E, and an altitude of 740 m.a.s.l.

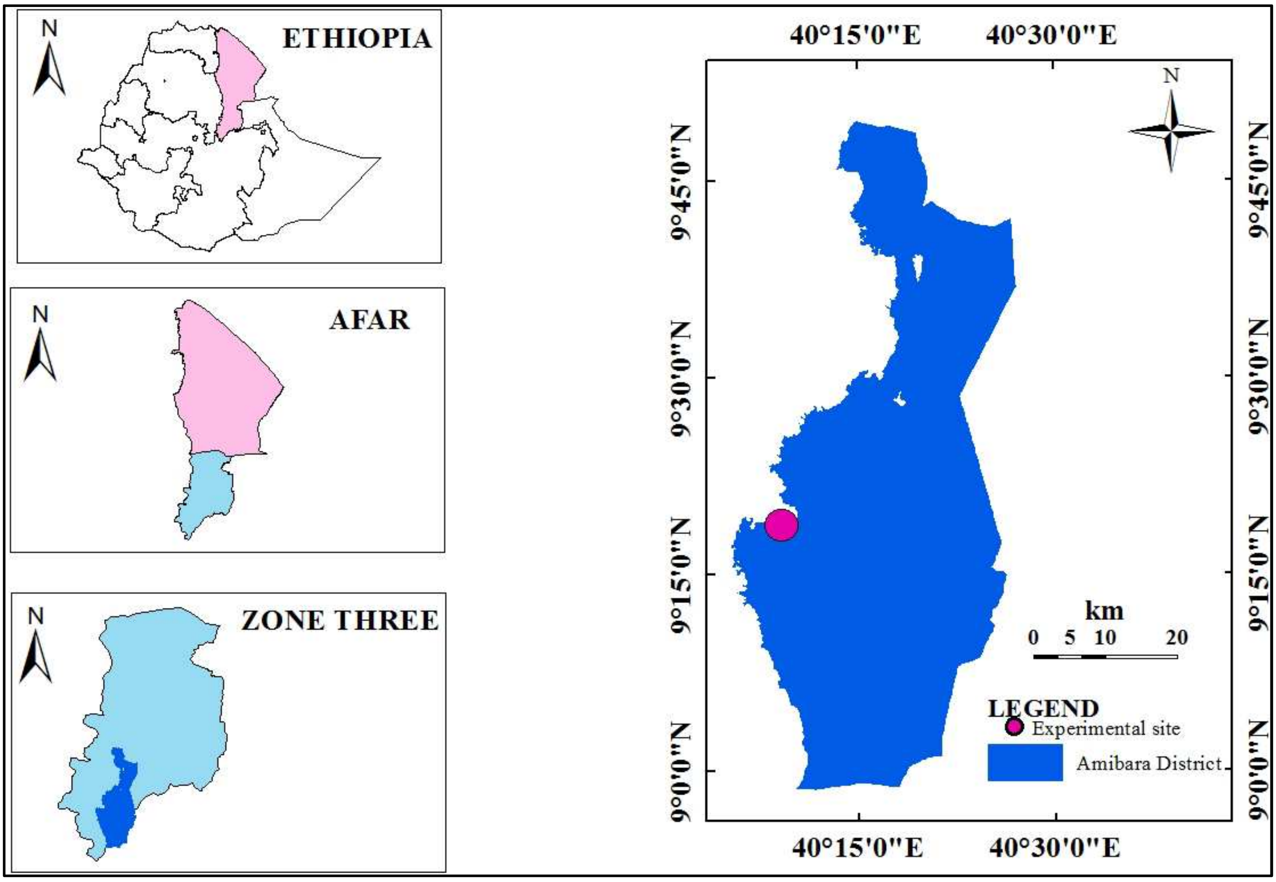

Figure 1. *Study Area Map.*

2.2. Data Collection, Computations and Analyses

2.2.1. Soil Sampling and Analysis

Before transplanting the crop, composite soil samples were taken at random from the experimental field. The soil samples were collected, air-dried on the ground, mixed, and passed through 2 mm sieve and was analyzed for different physical and chemical characteristics. Soil samples were taken in Zigzag way across the experimental plot at a depth of (0-20 cm, 20-40 cm and 40-60 cm) from four points. The soil samples were taken at these depths because of the root system of onion goes up to 60 cm. The collected samples were taken to Werer Agricultural Research Center for determination of soil texture, initial soil moisture content, bulk density, total available water and organic matter, pH.

Moisture content at field capacity (FC) and permanent welting point (PWP) were determined at Oromia Water Works Enterprise Soil laboratory (REF of the method).

Soil texture was determined by the Boycouos hydrometer method (REF) for analyzing soil particle size distribution [3] and the textural class was assigned using USDA textural triangle.

Bulk density: To determine bulk density, undisturbed soil sample of known volume was taken using core-sampler from four representative places in the trial plot at three different depths (0-20 cm, 20-40 cm and 40-60 cm). The sampled soil was oven dried at 105°C for 24 hours to a constant weight and weighed to determine the dry weight fraction. Then, the bulk density was calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume [14].

$$Bd = Ms/Vt \tag{1}$$

Where, Bd = bulk density (g/cm^3), Ms = dry weight of the soil (g) and Vt = total volume of the soil (cm^3).

Field capacity and permanent wilting point: Moisture contents at field capacity and permanent wilting point were determined after samples are saturated for one day (24 hrs) and extracting water from the saturated soil using the pressure plate apparatus at 0.33 and 15 bars, respectively. Then, the total available water (TAW in mm) of the experimental field was determined using the following equation.

$$TAW = (FC - PWP) * Bd * Drz\rho \tag{2}$$

where; FC and PWP in % on weight basis, Bd is the bulk density of the soil in g/cm^3, and Drz is the maximum effective root zone depth in mm, ρ (rho of water) is density of water which is g/cm^3.

2.2.2. Determination of Crop Water Requirement Reference Evapotranspiration (ETo)

Long term (1988-2017) daily weather data was used to calculate ETo. Climatic parameters that were used are maximum temperature (Tmax), minimum temperature (Tmin), relative humidity (H), wind speed (at two meter) and sunshine hour (hrs). The ETo was estimated by the CROPWAT software (FAO, version 8.0) using the FAO Penman Monteith approach (Allen *et al*., 1998). Crop coefficient was collected from FAO Irrigation and Drainage Paper 56 for onion (Allen *et al*., 1998). The crop coefficient values for respective growth stages are 0.7, 1.05 and 0.75 for initial, mid and end stage, respectively. Based on the KC values of the crop and length of each growth stages, daily crop coefficient was interpolated for development and late season. Length of growth stages of 15, 30, 40 and 25 days for initial, development, mid-season and late season, respectively, were considered (Allen *et al*., 1998).

$$ETc = ETo*Kc \tag{3}$$

where, ETc is crop evapotranspiration in mm per day, Kc is crop factor in fraction and ETo is reference crop evapotranspiration in mm per day. The Net irrigation requirement was calculated using the following equation.

$$NIR = ETc - Pe \tag{4}$$

where, NIR = net irrigation water requirement (mm) ETc = crop water requirement (crop evapotranspiration in mm), Pe = effective rainfall (mm).

Effective Rainfall based on analysis carried out for different arid and sub-humid climates, an empirical formula was developed in the Water Service of FAO to estimate dependable rainfall, the combined effect of dependable rainfall (80% probability of exceedance) and estimated losses due to runoff and deep percolation. Determination of effective rainfall was computed based on equation (5) and (6) of 'dependable rainfall' (FAO/AGLW formula) using daily rainfall data.

$$Pe = 0.8 * P - 24 \text{ for month} \geq 70mm \tag{5}$$

$$Pe = 0.6 * P - 10 \text{ for month} \leq 70mm \tag{6}$$

Where, Pe is the effective rainfall (mm/day) and P is total rainfall (mm/day).

The gross irrigation requirement was obtained from the following equation:

$$GIR = NIR/Ea * 100 \tag{7}$$

where; GIR = Gross irrigation requirement (mm), NIR = Net irrigation requirement (mm), Ea = Application efficiency (%). Application efficiency of 60% was used to estimate the gross irrigation requirement using equation (7). Furrow irrigation application efficiencies in general vary from 45-60% (Allen *et al*., 1998). Irrigation water applied to each experimental plot was measured by 3-inch Parshall flume made from metal sheet and installed 10 m away from the nearest plot along main canal. Leveling in all direction of converging section was checked. Leveling for the diverging section was checked only across the waterway, as the base of the diverging part of Parshall flume is slightly slope upward. The entrance section was set at 4 cm above the canal bed to avoid submergence flow and stone riprap was put in the downstream side on canal bed to minimize down streams curing. Only one measurement was required to determine flow rate of free flow condition. Volume of water applied for every treatment was determined from plot area and depth of gross irrigation requirement. Time required to irrigate each treatment was calculated from the ratio of volume of applied water to the discharge-head relation of 3-inch Parshall flume. The time required to deliver the desired depth of water into each furrow was calculated using equation (8). The time required to deliver the desired depth of water into each plot was calculated using the equation:

$$T = A*d/6q \tag{8}$$

where; d = gross irrigation depth of water to be applied (cm), A = Area of the experimental plot (m^2), T= application time (min) and q = flow rate of discharge (l/s).

2.3. Treatment and Experimental Design

The treatments include three levels of irrigation (100, 80 and 60% of ETc) and four levels of straw mulch (0, 3, 6 and 9ton wheat straw per ha). The experimental arrangement was factorial resulting in-to 12 treatment combinations. The 100% of ETc irrigation implies the amount of irrigation water applied in accordance with the computed crop water requirement with the aid of CROPWAT software. The 80% ETc and 60% ET irrigation depths meant 80% and 60% of full irrigation requirement. The experiment was laid out as randomized complete block design (RCBD) in three replications. The mulching treatment was applied after establishment. The experimental field plot layout was made by dividing the field in to 36 plots (Table 1) and each experimental plot had plot size of 5.4 m by 5 m to contain eight furrows of 5 m length with spacing of 60 cm between ridges and the middle six furrows were considered as net plot from which the data collection was under taken. The spacing between plots and replications was 1.6 m and 3.6 m, respectively to eliminate influence of lateral sub-surface water movement. The spacing between plants and between rows was 10 cm and 30 cm, respectively.

Table 1. *Description of treatments.*

Treatment No.	Treatment label	Description
T - 1.	DI100M0t	100% of ETc, No mulch
T - 2.	DI100M3t	100% of ETc, 3 t/ha straw mulch
T - 3.	DI100M6t	100% of ETc, 6 t/ha straw mulch
T - 4.	DI100M9t	100% of ETc, 9 t/ha straw mulch
T - 5.	DI80M0	80% of ETc, No mulch
T - 6.	DI80M3t	80% of ETc, 3 t/ha straw mulch
T - 7.	DI80M6t	80% of ETc, 6 t/ha straw mulch
T - 8.	DI80M9t	80% of ETc, 9 t/ha straw mulch
T - 9.	DI60M0	60% of ETc, No mulch
T - 10.	DI60M3t	60% of ETc, 3 t/ha straw mulch
T - 11.	DI60M6t	60% of ETc, 6 t/ha straw mulch
T - 12.	DI60M9t	60% of ETc, 9 t/ha straw mulch

T = treatments, ETc = Crop evapotranspiration, DI = deficit irrigation, M = straw mulch levels.

Figure 2. *Field layout of the experiment.*

2.4. Data Analysis

The collected data were statistically analyzed appropriate for RCBD using statistical analysis system (SAS) version 9.0 statistical package using procedure of general linear model (SAS, 2002) for the variance analysis. Mean comparisons were executed using least significant difference (LSD), when treatments show significant difference to compare difference among treatments mean.

3. Results and Discussion

3.1. Preliminary Field Investigation Results

3.1.1. Soil Physical Properties

Laboratory analysis indicated that the particle size distribution of the soil was clay dominant at each soil depth as shown in table 2.

Table 2. *Analysis soil physical properties.*

Soil physical property		Soil depth		
		0-20 cm	20-40 cm	40-60 cm
Texture (Particle size distribution)	Sand (%)	13	12	11
	Silt (%)	38	38	38
	Clay (%)	49	50	51
Textural class		Clay	Clay	Clay
Field Capacity (%) (Weight basis)		40	39.5	39
Permanent Wilting Point (%) (Weight basis)		24	23	22
Bulk density (g/cm^3)		1.29	1.30	1.31
Total Available Water (mm/m)		206.4	214.5	222.7

3.1.2. Soil and Water Chemical Properties

Table 3. *Analysis of chemical properties of soil and Irrigation water.*

Soil depth (cm)	Soil chemical properties			
	pH	**EC (dS/m)**	**TOC (%)**	**TN (%)**
0-20	8.51	1.71	1.11	0.05
20-40	8.31	1.35	0.90	0.04
40-60	7.96	0.92	0.70	0.05
Average	8.26	1.33	0.90	0.046
Irrigation Water chemical properties				
		[Ca]+ [Mg] (meq/l)	[Na] (meq/l)	SAR
	8.2	0.95 5.90	5.70	3.32

TN = Total Nitrogen, TOC = Total organic carbon.

3.2. Crop Water Requirement of Onion

Seasonal crop water requirement of onion was determined based on the seasonal water application depth from transplanting to harvest and varied based on treatments. The highest net irrigation water application was 422.5 mm obtained from the control treatment (100% ETc) and the minimum was 253.5 mm from the highly stressed treatment (60% ETc). The highest gross irrigation seasonal water requirement that was calculated by applying 60% field application efficiency was obtained from 100% ETc as 704.12 mm and the lowest was 422.5 mm from 60% ETc. The result of onion seasonal water demands of 422.1 mm that was obtained from optimal irrigation is in agreement with Gobena *et al.* [11].

3.3. Effect of Deficit Irrigation and Straw Mulch Levels on Onion Growth Parameters

3.3.1. Days to Maturity

Statistically, there were significant difference in days to maturity in the interaction of irrigation levels with straw mulching levels at 5% probability level. The Longest days to maturity (132.33 days) were recorded in the experimental plots that received 100% ETc with 9t/ha straw mulch. The possible reason for days to maturity, longer under higher rates of irrigation and straw mulching levels were that optimal irrigation and higher rates of straw mulching helped to create a more conducive soil micro-environment for vegetative growth of onion plant development over extended time. The finding is in line with [1, 13] who reported that, the length of days to maturity of tomato became longer as the frequency and amount of water application increased. Similarly, the findings of [22, 2] also showed significant decrease in the number of days to flowering of haricot and faba beans under water stress. Mulching with organic material, such as straw, clearly prolonged days to maturity in onion production in the two cycles of production as to [22].

The shortest days to maturity (116.0 days) were recorded from plots that received 60 ETc with no mulch treatments. This could be due to the fact that plants under water deficit tend to complete their life cycle, which enables them escape from the unfavorable conditions by ending lifecycle few days earlier than those under normal or high soil moisture conditions, thereby ensuring perpetuation of the species (Al-Suhaibani, 2009).

3.3.2. Number of Leaves Per Plant

Analysis of variance revealed that there was highly significant ($P < 0.01$) difference among deficit irrigation and straw mulching levels in leaf number per plant at 1% probability level. The interaction effects of deficit irrigation and straw mulching levels (SML) had significant ($P<0.05$) effect on number of leaves per plant (Table 4). The highest number of leaves per plant (14.89) was recorded from the experimental plots treated by 100% of ETc and 9 t/ha straw mulch. However, there were non-significant difference with 100% of ETc and 6 t/ha (Trt 3), 80% of ETc and 6 t/ha straw mulch, and the lowest number of leaves per plant (9.1) was obtained from 60% of ETc and no mulch. As the level of straw mulch increases from 3, 6 and to 9t/ha irrespective of increasing irrigation levels, for instance at 80% ETc, the number of leaves per plant increases by 15.25, 29.62 and 19.35%, over non-mulch treatment, respectively.

The number of leaves per plant was decreasing with decreasing irrigation and straw mulching levels. This might be due to the fact that plants respond to water stress by closing their stomata to slow down water loss by transpiration, gas exchange within the leaf is limited, consequently, photosynthesis and growth was slow down. The result of this study agreed with the findings of Singh and Singh (2018), who reported that the number of leaves per plant was increased with increasing irrigation depth, and straw mulching also increased the number of leaves per plant by 22.8 and 17 percent at 75 and 90 DAT, respectively.

This result is also related to that of [7] who reported that onion bulbs of irrigated treatments gave the highest leaves number per plant than the non-irrigated one, whereas onion grown without supplemental irrigation gave lower number of leaves.

Table 4. *Effects of deficit irrigation and straw mulching levels on days to maturity and number of leaves per plant of onion.*

Deficit Irrigation	Days to maturity evels (t/ha) Straw mulching levels (t/ha)				Number of leaves per plant			
	0	3	6	9	0	3	6	9
100% ETc	120.67^{ghi}	124.00^{def}	127.67^{b}	132.33^{a}	11.67^{d}	12.39^{bcd}	14.56^{a}	14.89^{a}
80% ETc	118.33^{ij}	121.67^{ghi}	125.00^{cde}	127.33^{bc}	10.17^{e}	12.00^{bcd}	14.45^{a}	12.61^{bc}
60% ETc	116.00^{j}	120.00^{hi}	122.67^{efg}	125.67^{bcd}	9.17^{f}	10.67^{e}	11.83^{cd}	12.89^{b}
LSD (5%)	1.26				0.90			
CV (%)	2.63				4.32			

Means followed by the same letter are not significantly different at 5% level of significance.

3.3.3. Plant Height and Leaf Length

Analysis of variance showed a highly significant (P<0.01*)* difference in plant heights amongst the deficit irrigation and straw mulching levels. The interaction effects of deficit irrigation and straw mulching levels had significant (P<0.05) effect on plant height (Table 5). The highest plant height (55.92 cm) was recorded from the application of 100% ETc with 9t/ha straw mulching, and the shortest (45.20 cm) plant height measured from the experimental plots that received 60% ETc without mulch. This might be due to the availability of moisture since mulching conserves moisture than un-mulched plots. With straw mulch plant received more soil moisture and temperature which might promote the vegetative growth resulting in the maximum plant height. It indicated that more soil moisture was conserved under mulch over un-mulched plots thereby providing more water availability to the crop throughout the growing period. In general, plant height under all deficit irrigation treatments with mulch produced the taller plants than their respective deficit irrigation treatment without mulch. [4] also revealed similar results of onion plant height under mulch and un-mulched treatment. The mean value of plant height had shown decreasing trend in plant height with decreasing water application and straw mulching level indicating that direct relationship between vegetative growth and water use.

The increase in plant height with increase in irrigation water could be mainly due to better availability of soil moisture that has enhancing effects on the vegetative growth of plants by increasing cell division and elongation. The increasing plant height with adequate depth of irrigation application also indicate the favorable effect of water in maintaining the turgor pressure of the cell which is the major prerequisite for growth [21]. On the contrary, shortening of plant height under soil moisture stress might be due to stomata closure and reduced CO_2 and nutrient uptake by the plants and hence, photosynthesis and other biochemical process hampered, affecting plant growth [9]. In similar experiments (Karasu *et al*, 2015), plant heights were reported to be higher with full irrigation (100% ETc) and slightly deficit irrigation throughout the crop growing season, which agreed with the results of the current study.

The interaction of deficit irrigation and straw mulching levels had significant (p<0.05) effect on onion leaf length. The effects of deficit irrigation and straw mulching levels had a highly significant (P< 0.01) effect on onion leaf length (Table 5). The longest leaf length (48.42 cm) was recorded from the experimental plots that were treated with 100% ETc and 9t/ha straw mulch, and the shortest (39.29 cm) leaf length was recorded from the application of 60% ETc without mulch. The leaf length has shown a decreasing trend with decreasing deficit and straw mulch levels.

This result is supported by observations of [17, 5] who reported longer leaves at 100% crop water requirement compared to treatments of deficit irrigation level. According to [7], deficit irrigation and mulch exerted significant positive impacts on some growth parameters like plant height, scape length and diameter, and umbel diameter. Leaf length under all deficit irrigated treatments with mulch produced the longer leaf length than their respective deficit irrigation treatment without mulch. During water deficit, stomata closed to conserve water then close the exchange of water, carbon dioxide and oxygen resulting in reduced leaf area and decrease in photosynthesis. This means that light interception is reduced, carbon assimilation is reduced and therefore, the rate of leaf growth is reduced. It has been demonstrated that the decrease in available water under moisture stress first affects leaf expansion and then stomata conductance and gas exchange [2].

Table 5. *The Effects of deficit irrigation and straw mulching levels on plant height and leaf length of onion.*

Deficit Irrigation	Plant height (cm) Straw mulching levels (t/ha)				Leaf length (cm)			
	0	3	6	9	0	3	6	9
100% ETc	47.92^{fg}	50.9^{d}	54.73^{ab}	55.92^{a}	41.61^{ef}	44.00^{bcd}	45.86^{ab}	48.42^{a}
80% ETc	46.71^{gh}	50.86^{d}	52.73^{c}	53.41^{bc}	40.25^{fg}	44.1^{bcd}	45.61^{bc}	45.44^{bc}
60% ETc	45.2^{h}	48.55^{ef}	49.79^{de}	52.96^{c}	39.29^{g}	42.2^{def}	43.29^{cde}	45.54^{bc}
LSD (5%)	1.62				2.33			
CV (%)	1.87				3.14			

Means followed by the same letter are not significantly different at 5% level of significance.

3.4. Effect of Deficit Irrigation and Straw Mulch Levels on Onion Yield Parameters

3.4.1. Bulb Length

Statistical analysis made on yield components indicated that the interaction effect of deficit irrigation and straw mulching levels had a significant ($p < 0.05$) influence on bulb length of onion. The longest (4.28 cm) onion bulb length was obtained from experimental plots treated with 80% ETc and 9 t/ha straw mulching and it had non-significant difference with the combination of 100% ETc with 3, 6, 9 t/ha straw mulching, 80% ETc and 6, 9t/ha, and 60% ETc with 3 and 9t/ha. The shortest (2.98 cm) were obtained from plots treated with 60% ETc and no mulch treatment, had no significant difference with 80% ETc and no mulch (6). This is an indication that larger onion sizes can be produced when the applied water is optimum and the moisture stress affect the size of the onion negatively.

The result indicated that the lower irrigation depth might have reduced transpiration and photosynthesis and assimilate available for growth of the crop, which thus caused to produce small bulbs. This result is in line with that of [20] who observed smaller sized bulbs in mild water-stressed onion plants. Similarly, [18] reported that higher level of irrigation 1.2 IW: CPE resulted in maximum bulb length.

3.4.2. Average Bulb Weight

Statistical analysis made on yield components indicated that the interaction effect of deficit irrigation and straw mulching levels highly significantly ($p<0.01$) affected average bulb weight of onion with a coefficient of determination of 0.97 which suggests a direct relationship between deficit irrigation and straw mulching levels and the average bulb weight. The highest average weight of bulbs of 106.69 g was obtained from treatment which received the highest supply of water (100% ETc) and 6 t/ha straw mulch while that received the lowest quantity water (60% ETc) and no mulch treatments produced minimum average bulb weight of 78.91 g (Table 6).

In general, weight was reduced significantly with decreasing applied irrigation, which might be due to water shortage. This shows response of crop to deficit irrigation and as applied water increased the average weight of onion bulbs increased. The increment in bulb weight due to increase in irrigation and straw mulch levels might be due to the growth of taller plants with higher number of leaves causing better synthesis and transportation of assimilates from source to sinks [7]. The result is in conformity with those obtained by [23, 15].

Table 6. *Effects of deficit irrigation and straw mulching levels on bulb length and average bulb weight of onion.*

Deficit Irrigation	Bulb length (cm)				Average bulb weight (g)			
	evels (t/ha)							
	Straw mulching levels (t/ha)							
	0	3	6	9	0	3	6	9
100% ETc	3.54^{d}	4.06^{ab}	4.20^{ab}	4.03^{ab}	85.89^{ef}	90.09^{d}	106.69^{a}	97.11b^{c}
80% ETc	3.20^{e}	3.77^{cd}	4.08^{ab}	4.28^{a}	81.79^{gh}	87.92d^{e}	98.68^{b}	97.77^{cb}
60% ETc	2.98^{e}	4.03^{ab}	4.00^{cb}	4.26^{a}	78.91^{h}	83.51^{fg}	84.42^{fg}	95.25c
LSD (5%)	0.25				2.95			
CV (%)	3.85				1.92			

Means followed by the same letter are not significantly different at 5% level of significance.

3.4.3. Marketable Bulb Yield

Analysis of variance showed that the interaction effect of deficit irrigation by straw mulching levels exhibited a highly significant ($P<0.01$) influence on the marketable yield. The highest marketable yield of onion (33.47 t/ha) was obtained from combined application of 100% ETc irrigation and 6 t/ha straw mulch and not statistically different with 80% ETc and 6t/ha straw mulch. The lowest marketable yield (21.10 t/ha) was obtained from treatment received 60% ETc and no mulch. As the level straw mulch increases from 3, 6 and 9t/ha irrespective increasing irrigation levels, for instance at 80% ETc, marketable bulb yield increases by 11%, 26% and 14%, over non-mulch treatment, respectively. Higher marketable bulbs of onion at higher irrigation levels might be due to the increase in the formation of growth measurements causing faster synthesis and transportation of photosynthates from source to descends. Similarly, the finding of [15] indicated that onion bulb yield (t/ha) increase significantly with increase in irrigation regimes and using residue mulching.

Among deficit irrigation and straw mulch levels, treating the experimental plots with 80% ETc and 6 t/ha straw mulching gave the next higher marketable bulb yield (31.57 t/ha). But this treatment saved water by 20% (84.5 mm) compared to 100% ETc with 6t/ha straw mulch and the yield reduction due to water deficit was 5.67% (1.90 t/ha) (Table 7). However, with 20% (84.5 mm) saved water, 0.2 ha of land would be irrigated from which 6.69 t/ha of marketable bulb yield can be produced, which is greater than the maximum marketable yield (33.47 t/ha) obtained by application of 100% ETc with the same level of mulch. Thus, where water scarce and land is available deficit irrigation is an alternative option to increase production per unit of water applied. This might be due to the conducive environment for growth of onion plants maintained by application of optimum straw mulch along with the increased irrigation levels may have contributed to the production of highest marketable yield.

The trend to imply marketable yield shows that was significantly higher as the soil moisture stress decreases. This could be due to the difference in depth of irrigation water applied. The increment of marketable yield as the amount of irrigation levels increased is similar with the previous work of [13] which indicated that yield reduction was associated with increase in soil moisture tension which when allowed continuing resulted in loss of turgidity, cessation of growth and yield reduction. The highest marketable yield of onion bulbs applying water depth corresponding to 100% ETc, compared with 75% ETc, performing irrigation management with Class A pan and without using mulch. In conformity to the current results, [12] reported that the bulb yield of onion was highly decreased through regulated deficit irrigation. The improvement of water productivity is closely related to the irrigation practice of regulated deficit irrigation and has a direct effect on marketable bulb yield that is, if the amount of water applied decreases intentionally the crop yield will decrease. Moreover, the increment in marketable bulb yield due to application of straw and irrigation water could be attributed to the increment in vegetative growth and increased production of assimilate, which is associated with increment in leaf area index, bulb diameter and average bulb weight.

3.4.4. Total Bulb Yield

Analysis of variance showed that there was highly significantly (P<0.01) difference in total yield of onion due to the interaction effect of deficit irrigation and straw mulching levels. Accordingly, the maximum total yield (34.71 t/ha) was obtained from the experimental plot that received 100% ETc and 6 t/ha straw mulch, followed (32.52 t/ha) by plots that were grown with 80% ETc and 6 t/ha straw mulch (Table 7). The minimum total bulb yield (21.99 t/ha) was recorded from the treatment combination of 60% ETc and no mulch. The highest marketable and unmarketable yield were achieved from plots received 100% ETc and 6 t/ha straw mulch which contributed to total yield. This result is in line with [15], who indicated that the relationship between the total bulb yield and irrigation level (as a percentage of ETc) was linear within the tested range of irrigation levels (R^2 = 0.999 under mulch and R^2 = 0.988 with no-mulch; p<0.01).

The increment in onion total bulb yield might be attributed to large size of onion bulb due to application of high level of irrigation. This is because it encourages cell elongation, above ground vegetative growth and imparts dark green color of leaves, which is important for more assimilate production and partition that favors onion bulb growth. The increased total bulb yield by applying full (no deficit) irrigation could have better performance on vegetative growth like plant height, number of leaves and leaf length which increase photosynthetic capacity of the plant, which in turn can improve bulb weight and contribute to increment in total bulb yield. As the irrigation level increased from 60% ETc to 100% ETc, the total bulb yields increased.

The high total bulb yield produced due to straw mulch application and higher irrigation water depth might be also because of increased photosynthetic area of the plant (height of plants and number of leaves) which increased the amount of assimilate that could be partitioned to the storage organs (increased bulb diameter and mean bulb weight) which consequently increased the total bulb yield.

Table 7. *Effects of deficit irrigation and straw mulching levels on marketable bulb yield and total bulb yield of onion.*

Deficit Irrigation	Marketable bulb yield (t/ha)				Total bulb yield (t/ha)			
	evels (t/ha)							
	Straw mulching levels (t/ha)							
	0	3	6	9	0	3	6	9
100% ETc	25.80^{cd}	26.77^{c}	33.47^{a}	29.64^{b}	27.08^{cd}	28.41^{c}	34.71^{a}	30.72^{b}
80% ETc	23.36^{e}	26.37^{cd}	31.57^{ab}	27.19^{c}	24.46^{e}	27.23^{c}	32.52^{b}	28.11^{c}
60% ETc	21.10^{f}	23.23^{e}	24.53^{de}	25.90^{cd}	21.99^{f}	24.47^{e}	25.33^{de}	26.90^{cd}
LSD (5%)	1.94				1.88			
CV (%)	4.32				4.02			

Means followed by the same letter are not significantly different at 5% level of significance.

3.5. Effects of Deficit Irrigation and Straw Mulch Levels on Water Productivity

The analysis of variance has shown that the interaction of deficit irrigation and straw mulching levels significantly (P<0.05) affected water productivity (WP) and whilst a highly significant (P<0.01) effect was observed from deficit irrigation and straw mulching levels on WP of onion (Table 8). The highest WP (10.22 kg/m^3) was recorded from application of 60% ETc deficit irrigation and 9 t/ha straw mulch, but it is not significantly different from application of 60% ETc and 6 t/ha straw mulch. The experimental plot treated with 60% ETc gave best WP (9.34 kg/m^3) compared to the others deficit irrigation, among straw mulching levels, application of 6 t/ha provided the highest WP (8.93 kg/m^3). The lowest irrigation WP (6.11 kg/m^3) was obtained from the application of 100% ETc with no mulch and had non-significant difference with 100% ETc and 3 t/ha straw mulch application.

In general, higher water productivity was obtained from treatments with higher deficit irrigations. This finding is in agreement with [6], who reported that deficit irrigation increased the water productivity of onion. The mean values of WP indicated that WP was significantly greater for straw mulching levels at each irrigation levels. For instance, application of 60% ETc with 0, 3, 6 and 9 t/ha straw mulching shown an increasing value of WP that were 8.32, 9.16, 9.68, 10.22 kg/m^3, respectively, and also the same for the others deficit levels. As presented in Table 8, if in-sufficient water is applied during the crop cycle the crop was not fully develop resulting in low yield and higher water productivity. And crop yield and water productivity can be increased if a considerable amount of water is added. Also, as the irrigation depth and straw mulching levels differ, the yield and water production also vary.

This result current finding was in line with [15], who reported that WP was significantly greater for mulched than no mulched treatments even at full irrigation (100% ETc). This suggests that increasing the irrigated areas with the saved water could compensate for any yield loss due to deficit irrigation. Herein, crop water requirement under (100% ETc) was about 422.5 mm; and that under 60% ETc was about 253.5 mm, on an average. The water saved which was about 169 mm (422.5 − 253.5 = 169 mm) could be used to irrigate 0.4ha onion cropped land or similar crop and 13.388 t/ha extra yield that might be produced as a result of saved water.

Table 8. *Water productivity and irrigation water saved of deficit irrigation and straw mulching levels of onion.*

Treatments	WP, kg/m^3	Water saved, %	Yield reduction, %	Additional area to be cultivated (ha) by saved water	Additional yield (t/ha) that can be produced as result of saved water
T – 1	6.11^{f}	0	22.90	0	0
T – 2	6.34^{e}	0	20.01	0	0
T – 3	7.92^{c}	0	0	0	0
T – 4	7.01^{d}	0	11.45	0	0
T – 5	6.91^{de}	20	30.20	0.2	6.994
T – 6	7.80^{c}	20	21.20	0.2	6.994
T – 7	9.34^{b}	20	5.67	0.2	6.994
T – 8	8.04^{c}	20	18.76	0.2	6.994
T – 9	8.32^{c}	40	36.95	0.4	13.388
T – 10	9.16^{b}	40	30.60	0.4	13.388
T – 11	9.68^{ab}	40	26.69	0.4	13.388
T – 12	10.22^{a}	40	22.62	0.4	13.388
LSD (0.05)	0.59				
CV (%)	4.33				

Means within a column followed by the same letter are not significantly different at 5% level of significance. T= Treatments, WP= Water productivity.

4. Conclusion

This study is concluded that the deficit irrigation and straw mulch levels exerted significant positive effects on growth, yield, some of yield components and crop water productivities of onion crop. Mulching with 3 and 6 t/ha gave a yield increase of about 3.633 and 22.9% compared to non-mulched treatment under higher irrigation (100% ETc). A greater bulb yield reduction of 30.6 and 36.95% occurred by application of 80% and 60% ETc with no mulch treatments, respectively. Deficit irrigation with straw mulch levels gave better water productivity compared to non-mulched condition. The water productivity was found to be the highest (10.22 kg/m^3) in 60% ETc with 9 t/ha straw mulched treatment, however, higher yield reduction (22.62%) was obtained corresponding to this treatment. Therefore, in terms of marketable bulb yield, water productivity and economic importance, irrigating with 80% ETc with 6 t/ha straw mulch can be suggested for production of onion.

References

[1] Adey Nigatu. 2006. Water use and yield response of drip-irrigated tomato to soil water depletion and mulching. M.Sc. Thesis, Haramaya University, Haramaya, Ethiopia.

[2] Ahmed, Z. I., M. Ansar, M. Iqbal and M. N. Minhas. 2007. Effect of planting geometry and mulching on moisture conservation, weed control and wheat growth under rainfed conditions. *Pakistan Journal of Botany*, 39 (4): 1189-1195.

[3] Allen, R., Pereira, L. A., Raes, D., Smith, M. 1998. Crop evapotranspiration guidelines for computing crop water requirements. *Irrigation and Drainage Paper* No. 56. FAO, Rome.

[4] Anissuzzaman. M., Ashrafuzzaman, M., Ismail, M. R., Uddin, M. K. and Rahim, M. A. 2009. Planting time and mulching effect on onion development and seed production. *African Journal of Biotech,* 8: 412-13.

[5] Bagali, A. N. 2012. Effect of scheduling of drip irrigation on growth, yield and water use efficiency of onion (*Allium cepa* L.). Indian Karnataka, *Journal of Agricultural Science*, 25 (1): 116-119.

[6] Bekele Samson and Tilahun Ketema. 2007. Regulated deficit irrigation scheduling of onion in a semi-arid region of Ethiopia. *Journal of Agricultural Water Management*, 89: 148-152.

[7] Biswas, S. K., P. K., Sarker, A. K. M., Mazharulislam, M. A., Bhuyan., B. C. Kundu. 2003. Effect of irrigation onion production. *Pakistan Journal Biology Science*, 6 (20): 1725-1728.

[8] CSA (Central Statistical Agency). 2018. Agriculture sample survey. Central Statistical Agency. Report on Area and production of major Crops. vol. 1, Addis Ababa, Ethiopia.

[9] El-Noemani, A. A., Aboamera, A. A. and Dewedar, O. M. 2009. Growth, yield, quality and water use efficiency of pea plant as affected by evapotranspiration and sprinkler height. *Journal of Agricultural Research*, 34: 1445-1466.

[10] Fekadu Marame and Dandena Gelmesa. 2006. Review of the status of vegetable crops production and marketing in Ethiopia. *Uganda Journal of Agricultural Sciences* 12 (2): 26-30.

[11] Gobena Dirirsa, Abraham Woldemichael and Tilahun Hordofa, 2017. Effect of Deficit Irrigation at Different Growth Stages on Onion (*Allium Cepa* L.) Production and Water Productivity at Melkassa, Central Rift Valley of Ethiopia. A*cademic Research Journal of Agricultural Science,* 5 (5): 358-365.

[12] Habtamu Gudisa, M. 2017. Onion (*Allium cepa* L.) Yield Improvement Progress in Ethiopia: A Review. *International Journal of Agriculture and Biosciences*, 6 (5): 265-271.

[13] Habtie Honelign, 2007. Comparison of different Irrigation Scheduling Methods for Tomato (*Lycopersicum esculentum* L.) Production in Libo kemkem Woreda south Gondar Zone. MSc Thesis, Haramaya University, Haramaya, Ethiopia.

[14] Hillel, D. 2004. Introduction to Environmental Soil Physics: Elsevier Academic Press, USA.

[15] Ibrahim Mubarak and Altayeb Hamdan. 2018. Onion Crop response to regulated deficit irrigation under mulching in dry Mediterranean region. *Journal of Horticultural Research*, 26 (1): 87–94. DOI: 10.2478/johr-2018-0010.

[16] Igbadun, H. E., A. A. Ramalan and E. Oiganji. 2012. Effects of regulated deficit irrigation and mulch on yield, water use and crop water productivity of onion in Samaru, Nigeria. *Journal of Agricultural Water Management*, 109: 162–169.

[17] Kumar, S., Imtiyaz, M., Kumar, A., Singh, R. 2007a. Response of onion (*Allium cepa* L.) to different levels of irrigation water. *Agricultural Water Management,* 88: 161- 166.

[18] Neeraja, G., K. M. Reddy, I. P. Reddy and Y. N. Reddy. 1999. Effect of irrigation and nitrogen on growth, yield and yield attributes of rabi onion (*Allium cepa* L.) in Andhra Pradesh. Vegetable Science, 26 (1): 64-68.

[19] Nigussie, A., Kuma, Y., Adisu, A., Alemu, T., Desalegn, K., 2015. Onion production for Income generation in Small Scale Irrigation users Agro-pastoral Households of Ethiopia. *Journal of Horticulture*: 1-5. Nkansah, G. O., Owusu, E. O., Bonsu, K. O. and Dennis, E. A. 2003. Effect of mulch type on the growth, yield and fruit quality of tomato (*Lycopersicon esculentum* Mill). *Ghana Journal of Horticulture*. 3: 55-64.

[20] Olalla, F. S., A. D. Padilla and R. Lopez. 2004. Production and quality of the onion crop (*Allium cepa* L.) cultivated under controlled deficit irrigation conditions in a semi-arid climate. Agricultural Water Management, 68: 77-89.

[21] Ramada, S. and Ramanathan, S. P. 2017. Evaluation of Drip Fertigation in Aerobic Rice-Onion Cropping System. *International Journal of Current Microbiology and Applied Sciences,* 6 (4): 2623-2628.

[22] Solomon Abate. 2004. Effects of irrigation frequency and plant population density on growth, yield components and yield of haricot bean in Dire Dawa area, MSc. Thesis, Department of Irrigation Engineering, Haramaya University, Ethiopia.

[23] Zayton, A. M. 2007. Effect of soil water stress on onion yield and quality in sandy soil. *Journal of Agricultural Engineering*, 24 (1): 141-160.