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Research Article

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Effect of Deficit Irrigation on Yield and Yield Components of Onion (*Allium cepa l.*) Cultivars in Horo District, Western Ethiopia

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Abstract

Onion crop is widely is grown under irrigation by the small and large scale farming in Ethiopia However, its yield performance is limited due to scarcity of water resources and varietal influences. Hence, Deficit Irrigation (DI) improves water productivity and irrigation management practices resulting in water saving. Thus, an experiment was conducted using three onion cultivars (Bombay red, Red Creole and Adama red) as the main plot and four types of DI were applied at 3, 5, 7, and 9 days irrigation interval as a subplot and arranged in Split Plot Design with three replications at Horo District, Western Ethiopia. This study aimed to investigate the effects of deficit irrigation on the growth, yield, and yield components of onion cultivars, identify the sensitive onion variety(s) to the deficit irrigation and identify irrigation water use efficiency for onion cultivars. Analysis of variance showed highly significant ($p<0.01$) difference for the interaction effects of varieties (main plot) and deficit irrigation level (subplot) on plant height, leaf length, number of leaves per plant, pseudo-stem diameter, average bulb weight, marketable bulb yield, unmarketable bulb yield and total bulb yield except for day to maturity and bulb size. The result showed that the highest total bulb yield of 21.2 t/ha and crop water productivity of 44.8/kg/m^3/ha at three days deficit irrigation interval. The yield response factor (Ky) except for three days of DI interval ranged between 0.08 and 0.63. Considering the yield response factors (Ky) with water saved for varieties Bombay red, Red Creole and Adama red (Ky) values were 0.35, 0.08, and 0.33 at five days of DI, respectively, by saving 3244 mm of irrigation water.

Keywords: Bulb yield; Deficit irrigation; Yield response; Water productivity

Introduction

Onion (*Allium cepa* L.) belongs to the genus Allium of the family Alliaceae which was believed to be originated in southwestern Asia, being the center of domestication and variability, from where it was spread first across the world and has been cultivated for over 4700 years as annuals for bulb production purposes [1]. Globally, China, Mali, Niger, Japan, Republic of Korea, Tunisia, New Zeland, Nigeria, Turk, and Thailand are the top producers of Onion [2]. And, the average productivity of onion in Ethiopia has been reported of 7.74 ton ha^{-1} which is very low compared to the world average yield of 19.7 tons of bulbs ha^{-1} [3].

Agriculture is one of the main industries which utilize freshwater resources and in many parts of the world, irrigation water has been over-exploited and over-used and the freshwater shortage is becoming critical in the world due to more irrigation to the crops [4,5]. About 60-80% of total consumptive water use is consumed for irrigation in the agriculture sector so far [6]. A recent innovative approach that has been adopted to save agricultural water is the conventional Deficit Irrigation (DI) pattern. Deficit Irrigation is defined as an irrigation practice whereby a crop is irrigated with a less amount of water below the full requirement of water for optimal plant growth; this is to reduce the amount of water used for irrigating crops [7]. Deficit irrigation is a new water-saving strategy under which crops are exposed to a certain level of a limit of water stress throughout the whole growing period and season [8].

In Ethiopia Allium is for home use in the flavoring of local dishes; it is a vital ingredient of the traditional sauce or "wot" [9]. Generally, onion consumption is much higher than most other vegetables and that's why it has a significant contribution to the national economy directly [10]. The area under onion is increasing from time to time mainly due to its high profitability per unit area and the increases in small scale irrigation areas [11]. However, the expansion of irrigable land is highly constrained by a shortage of irrigation water. Irrigation water is a crucial resource for sustainable agricultural development worldwide, increasing competition for water among agricultural, industrial, and urban consumers [12,13]. Agriculture is the largest user of water worldwide, accounting for approximately 69% of the total consumption of fresh water [14].

The increases in irrigation costs and water scarcity have increased interest in improving water productivity for irrigated agriculture, which can be achieved by both efficient irrigation design and appropriate irrigation management [15-17]. Water is a very vital factor but its scarceness can lead as a resource for agricultural development and globally this resource is decreasing in a pattern [18]. Proper water management practices during different crop cultivation practices and also in the coming time is the need of the day. Because water is one of the most important natural resource which has a direct influence on our social life. Besides the increasing demand for water for other purposes (industry and domestic use), degradation of water quality will also limit the water availability for the agriculture sector in the coming future [19].

Under conditions of scarcity of water supply, the application of deficit irrigation could provide a greater economic return to the farmers than maximizing yields per unit of water to the cultivated land [20,21]. The DI has been considered worldwide as a way of maximizing Water Use Efficiency (WUE) [22]. Smallholder irrigation schemes in Ethiopia are generally characterized by poor on-farm water management practices and hence poor performances [23]. The poor on-farm water management comes out from both excesses and insufficient allocation of resources that enable optimum and timely water supply. Farmers lack sound knowledge on on-farm water management, particularly on how much to irrigate and when to irrigate (as they tend to over-irrigate as long as the water is available) results in water shortages and conflicts in other parts of the schemes [24].

Therefore, deficit irrigation strategy is a sustainable practice of applying irrigation levels that are below the optimum crop water requirements improving water productivity [25]. Plants respond differently to water reductions applied at deferent development stages; therefore, their yield responses vary depending on their sensitivity at each growth stage [26]. Regulated Deficit Irrigation (RDI) is a stage-based DI and consists of imposing water deficits at particular phonological stages when the crop is less sensitive to water stress. And to apply the RDI approach effectively, identifying the most critical growth stages for a specific crop species and cultivar is needed [7]. The world population is increasing which is going to pose a serious threat to future agriculture cultivation and production. Therefore, water resources should be used with higher efficiency or productivity. To achieve this, improvement in agricultural water productivity is highly essential.

Currently, onion production in Ethiopia is about 262,478.3 tons from 28,185 hectares area of cultivated land [27]. Horo-Guduru area is a highland area naturally with little streams and rivers on the other hand there have been widespread irrigation activities by small scale farmers who grow vegetables. Due to increasing demand for irrigation water and water resource is becoming a scarce resource that limits the productivity of the onion crop. The crop response to deficit irrigation also varies with cultivars which necessitate the selection of appropriate onion cultivars to deficit irrigation at a particular area Therefore, alternatives need to be explored for effective and efficient use of the existing water resources. Thus, this study aimed to investigate the effects of deficit irrigation on the growth, yield, and yield components of onion cultivars, identify the sensitive onion variety(s) to the deficit irrigation and identify irrigation water use efficiency for onion cultivars.

4. Materials and Methods

4.1 Description of the experimental site

The study was conducted at Horo District, Horo Guduru Wollega province of Gitilo center, Western Ethiopia (Figure 1). The study site is located 314 Km from Addis Ababa nearby Shambu town. Geographically the experimental site is located at 9°34'0" North latitude and 37°6'0" East longitude at an altitude of 2558 m.a.s.l. The site generally receives an annual average rainfall of 1784 mm rainfall with an average minimum and maximum temperatures found in the whole year are 9°C and 24°C, respectively.

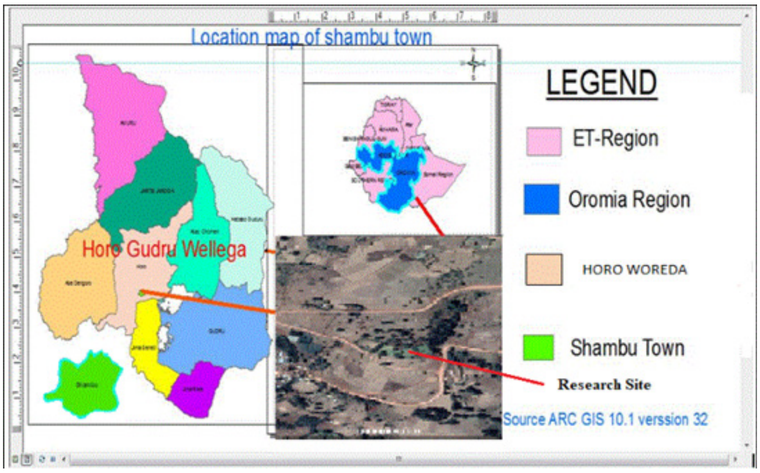

Figure 1: Map of the study area showing Ethiopia, HGW, and Sambu (study site).

4.2 Experimental materials

Three onion improved cultivars such as Bombay red, Red Creole, and Adama red which are under cultivation by the farmers in the study area were used as experimental material. Bombay red onion variety is imported from India and adopted by Melkasa Agricultural Research Center in Ethiopia. Bombay red cultivar is characterized by thick flat shape, dark red color, with medium size and high pungent variety. Bombay red is the most widely grown onion variety under irrigation water in the country due to its higher bulb yield, earliness, and susceptible to the rotting disease under a rain-fed condition at maturity stage [28]. Adama red cultivar is a selection from onion materials imported from Sudan in 1970 which is dark red color and firm, very pungent, and flat glob shaped.

Moreover, the Red Creole onion was originally developed by the Dessert Seed Company in El Centro, California. It was released to the market in 1962. Since then it has become a popular onion over the world and it is not as sweet as other onions and has a more pungent flavor. They are well accepted by both producer and consumer and successfully produces by small farmers and commercial growers scattered in most regions of the country. The seeds of these three improved cultivars were obtained and collected from Bako Agricultural Research Center. The above-mentioned varieties are also even selected by most of the farmers due to their well adaptive and suitable for ecological conditions. It is successfully produced by small farmers and commercial growers in most regions of the country. The yield potential of these varieties is reported in the range of 15-30 th-1 [29].

4.3 Treatments and experimental design

The experiment was conducted in the farmer's field and laid out in the split-plot design. The three onion cultivars were sown as the main plot (Factor A) and the different four deficit irrigation levels were applied at the duration of 3, 5, 7, and 9 days of the interval were arranged as subplots (Factor B) and were replicated three times. 45 days age-old seedlings uprooted from the nursery beds prepared for all three onion varieties grown separately were transplanted in the main and subplots arranged for this particular experiment on the irrigation deficit. There were 12 treatments (3 onion cultivars and 4 DI levels) and each net plot was with 5.72 m^2 area was plotted and prepared with the four constant furrows and double row planting of 20 plants with the spacing of 20 cm and a total number of 80 plants/plot were maintained in each net plot (Table 1).

Factor A (Variety)	Factor B (DI interval)
Bombay red (V1)	1. 3 days after the transplanting deficit irrigation was applied
	2. 5 days after the transplanting deficit irrigation was applied
	3. 7 days after the transplanting deficit irrigation was applied
	4. 9 days after the transplanting deficit irrigation was applied
Red creole (V2)	5. 3 days after the transplanting deficit irrigation was applied
	6. 5 days after the transplanting deficit irrigation was applied
	7. 7 days after the transplanting deficit irrigation was applied
	8. 9 days after the transplanting deficit irrigation was applied
Adama red (V3)	9. 3 days after the transplanting deficit irrigation was applied
	10. 5 days after the transplanting deficit irrigation was applied
	11. 7 days after the transplanting deficit irrigation was applied
	12. 9 days after the transplanting deficit irrigation was applied

Table 1: Treatment combinations as the main plot and sub-plot.

4.4 Field management

Planting and crop management: Seeds of three onion varieties were sown at the rate of 3 kg ha^{-1} on separate three seed beds with the dimensions of 1 m × 5 m to raise the optimum seedlings required for the transplanting to a nursery site close to study site. Nursery bed management was done according to the recommendations and with the packages practices of the crop. After 45 days of sowing when the seedlings were reached about 10-15 cm high above the ground and at three true leaves, they were transplanted to 40 cm wide planting furrow and inter-row spacing of 20 cm to an open field when the plants had reached the two-leaf stage.

Before transplanting, soil moisture content at the depths of 30 cm was maintained by applying irrigation one day before the transplanting to a field where the seedlings were transplanted. Transplanting was done as per the work plan of the research. After transplanting the matured seedlings in the field, full irrigation was applied to restore soil moisture content to field capacity, based on effective rooting depth and was given to all treatment plots for 3-5 days to recover in the new field. Gap filling (re-planting) was carried out within one week to replace those seedlings which were damaged. Urea fertilizer at the rate of 100 kg ha^{-1} was applied between rows in half doses at the time of transplanting as basal dose and half-dose was applied after 4 weeks later the transplanting as top dressing according to the recommendations for this crop. A uniform dose of NPS at the rate of 150 kg ha^{-1} was also applied and incorporated in the soil before transplanting done. Weeding and hoeing were done twice in a nursery and on the main field. The crop was harvested when the tips of more than 50% of leaves of plants in the field appeared in yellow as an indicator of crop maturity.

Irrigation scheduling for deficit irrigation strategies: The daily climatic data such as maximum and minimum temperatures, rainfall, wind speed, relative humidity, and sunshine duration were obtained from Shambu meteorological station during the whole crop growth period. The data was used to compute reference evapotranspiration from CROPWAT windows version 8. The crop coefficient for the different growth stages, critical depletion levels, and yield response factor of onion were taken from the JICA irrigation manual. According to Bako Agricultural Research Centers recommendation irrigation schedule of 3-5 days interval was adopted to all the three onion cultivars and this was considered planning this study and similarly, after transplanting, 3, 5, 7 and 9 days of deficit irrigation interval was applied in a crop growth period for the three cultivars in all three replications through furrow irrigation methods by measuring water to be applied at the gate of a field and supplied to every plot which was considered as treatments to get better-established plant stand of onion crop.

4.5 Data collection and analysis

Growth parameters: Important morphological, phonological, yield, and yield components data for the three onion cultivars were from middle rows of a net plot area. Plant height (cm) was measured from five pre-tagged plants from the net plot for each replication from the middle rows. It was measured using by measuring scale from the soil surface up to the tip of the leaves of each selected plant at the bulb final development stage and the mean was considered. The leaf length (cm) was recorded on five plants from each net plot and was pre-tagged to collect data of leaf length. Different 15 leaves were considered from five selected plants to measure the leaf length. It was measured from base to the tip of each leaf with measuring scale and mean was considered. And many leaves per plant were collected and counted from the five randomly selected plants from the plot and the mean average was considered at maturity of the crop. The pseudo-stem diameter (cm) was taken from the five randomly selected plants from the said plot and the diameter of the basal portion of the stem will be measured with the vernier calipers or electronic calipers and mean average was considered. Days to maturity (days) is the actual number of days from seedling transplanting to the field up to days at which the 50% plants in a plot were showing yellowing of leaves were recorded to determine the days to physiological maturity.

Bulb yield and yield components: Average bulb weight (g) was taken five plants from the net plot area were pre-tagged to collect data of average bulb weight and expressed in gram and mean was recorded. Bulb size (cm) was measured from five plants from the net plot area and was pre-tagged to collect data of average bulb size with the help of vernier calipers and expressed in centimeter and mean was recorded. Marketable bulb yield (MBY) (t ha-1) was recorded by taking the total weight of clean, disease, and damage-free bulbs per net plot and converted to t ha-1. Unmarketable bulb yield (UMBY) (t ha-1) was the total weight of decay, physiological disorder bulbs such as thick-necked, split, bolters, and too small-sized was measured per net plot and converted to t/ha-1. Finally, total bulb yield (TBY) (t ha-1) was measured by taking the total weight of marketable and unmarketable bulbs per net plot and converted to t/ha-1. Harvesting stage was determined and considered when about 50% of the leaves fall in the whole plot and it was noted and considered that bulbs were properly matured. The data was collected from middle rows of a net plot area; the two outermost rows of each treatment were left as border effects.

Data analysis: All data were subjected to the Analysis of Variance

(ANOVA) and mean separation test by using the SAS (9.1) software computer package [30]. And significance difference among the treatment means was computed using LSD at 5% probability level.

5. Results and Discussion

5.1 Analysis of variance

Analysis of variance showed highly significant (P<0.01) for the interaction effects of varieties (main plot) and deficit irrigation level (subplot) on plant height, leaf length, number of leaves per plant, pseudo-stem diameter, average bulb weight, marketable bulb yield, unmarketable bulb yield and total bulb yield except for day to maturity and bulb size. Moreover, Moreover, the main effects of varieties and deficit irrigation levels also showed significant differences (p<0.01) for all of the characters studied (Table 2). This result revealed that onion varieties showed high variability to the deficit irrigation applied for growth and yield parameters except for days to maturity and bulb size.

SV	Rep	Var	Error A	Irr	Var*Irr	Error B	CV A	CV B
DF	2	2	4	3	6	18	-	-
PH	1.9	50.1**	3.6	325.6**	22.8**	1.92	3.67	2.68
PSD	0.15	1.65*	0.09	11.55**	0.28*	0.08	5.52	5.03
DM	7.2	834.5**	10.6	42.9**	1.8NS	1.03	2.28	0.71
BS	1.5	35.9**	1.2	75.8**	0.33NS	0.78	5.46	4.4
ABW	21.6	4651.6**	11.89	4951.9**	245.12**	15.4	3.5	3.9
LL	2.9	31.4**	0.24	192.3**	13.3**	1.7	2.94	1.12
NLP	7.4	10.3**	0.48	26.02**	2.3**	0.64	6.79	7.79
MBYTPHA	0.1	60.9**	0.02	82.6**	3.1**	0.3	3.93	1.07
UMBYTHA	0	0.01**	0.5	0.02**	0.00**	0	10.2	12.74
TBY	0.11	59.1**	0.02	84.45**	3.03**	0.29	3.81	1.15

Note: *Significance at 5% level of probability level and NS is non-significant on 5% of probability level, DF=Degrees of Freedom. Rep=Replication, VAR=Varieties IRR=deficit irrigation interval (level) PH=Plant Height, LP=Leaves per Plant, LL=Leaf Length, PSD=Pseudo Stem Diameter, ABW=Average Bulb Weight, BS=Bulb Size, MBY=Marketable Bulb Yield, UMBY=Unmarketable Bulb Yield TBY=Total Bulb Yield.

Table 2: Mean square values for growth, yield and yield-related characters of onion as affected by onion varieties, and deficit irrigation at Gitilo site during 2019, Ethiopia.

Plant height (cm): The Analysis of Variance (ANOVA) showed that the plant height of onion was highly significantly (p ≤ 0.01) affected by the main effects of varieties and deficit irrigation interval. And the result of the interaction effects of varieties and deficit irrigation interval was highly significant (p ≤ 0.01) (Table 2). Thus, the highest plant height was recorded from Adama red (61.4 cm) followed by Bombay red variety (61.9 cm) at three days deficit irrigation interval while the lowest was recorded on Adama red (42.8 cm) followed by the same variety at nine days deficit irrigation interval (43.3 cm) at seven days irrigation deficit interval (Table 3). This might be due to the increase 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. Plant height is a good indicator for determining water stress. Sammis et al. reported that 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 [31]. Some authors emphasized that deficit irrigation shortens plant height [32].

Number of leaves per plant: The number of onion leaves per plant was highly significant (p ≤ 0.01) affected by the main effects of varieties and deficit irrigation interval. Moreover, the result of the interaction of varieties and deficit irrigation interval was significant at (p ≤ 0.05) (Table 2). By the interaction effects onion varieties and Deficit irrigation interval, a higher number of leaves per plant was observed by Bombay red (14.3) at three days of deficit irrigation interval whereas a lower number of leaves per plant was recorded by Red Creole with 9 days deficit irrigation interval with (7.7) leaves per plant (Table 3). This result agrees with Biswas et al. who reported that onion fully irrigated treatments gave the highest leaves number per plant than the treated with deficit irrigated one, whereas onion grown with deficit irrigation gave the lower number of leaves [33]. This indicates that when 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 [34]. Besides this, the result conforms to Yemane et al. finding who reported leaves number had a linear correlation with the availability of soil moisture [35].

Deficit	Varieties											
Irrigation	Ph./cm			NL/P			LL/cm			PSD/cm		
Level	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
3 days	60.9^{a}	54^{c}	61.4^{a}	14.30^{a}	10.90^{bcd}	10.6^{cde}	51.50^{a}	46.50^{bc}	51.90^{a}	7.5^{a}	6.7^{b}	6.8^{b}
5 days	54.1^{c}	48.9^{e}	57.4^{b}	12.10^{b}	11.7^{bcd}	10^{def}	47.30^{b}	42.40^{ef}	48.00^{b}	6.6^{b}	6.2^{c}	5.7^{d}
7 days	52.3^{cd}	50.4^{bc}	42.8^{e}	10^{df}	9.7^{def}	9.3^{efg}	45.80^{cd}	43.90^{de}	41.40^{fg}	5.4^{d}	5.6^{c}	4.6^{e}
9 days	54.4^{f}	44.4^{f}	43.3^{f}	8.70^{fgh}	7.7^{h}	8.0^{gh}	39.90^{gh}	38.38^{fh}	38.00^{h}	4.7^{e}	4.2^{e}	4.3^{e}
Mean	51.8			10.3			44.6			5.7		

LSD (5%)	2.94	1.41	2.02	0.54
CV	2.68	7.79	2.94	5.03
Note: Means followed by the same letter within a column are not significantly different at 5% of significance. PH-Plant Height LP-Leaf per Plant LL-Leaf Length PSD-Pseudo				

Table 3: The Mean interaction effects of onion varieties and different levels of deficit irrigation on growth parameter and treatment combination at Horo experimental area.

Pseudo-stem diameter (cm): Analysis of variance result showed that plant pseudo-stem diameter of onion was significantly ($p \leq 0.05$) affected by the main effects of varieties and highly significant ($p \leq 0.01$) affected deficit irrigation interval (Table 2). The interaction effect of varieties and deficit irrigation intervals was significant at ($p \leq 0.05$) (Table 3). The highest pseudostem diameter was recorded when Bombay red (7.5 cm) at three days deficit irrigation interval and the lowest pseudostem diameter was recorded from Red Creole variety (4.2 cm) and V3=Adama red (4.3 cm) at nine days deficit irrigation interval. Sammis et al. reported that the pseudo-stem diameter could decrease at an increasing level of water deficiency [31]. Some authors emphasized that deficit irrigation decreases the thickness of the stem diameter to overcome water stress [32]. Thick neck in onion is caused by the active onion growth that the neck did not become dormant and resulted in undifferentiated scales with high thickness at wider intra-row spacing. Tesfalegn this finding is in agreement with the results because wide space increases the chance of onion root to consume more water [36].

Bulb size (cm): The analysis of variance results showed that the onion bulb size was highly significant ($p<0.01$) affected by the main effects of varieties and deficit irrigation interval (Table 2). The interaction an effect of onion varieties and deficit irrigation interval was not significantly affected (Table 2). The highest bulb size of the main factors that are varieties was showed by Bombay red (21.6 cm) which was statistically not significantly different from Red Creole varieties. The lowest bulb size was recorded by Adama red variety (18.2 cm) (data are not shown). The reason for this variation could be due to genetic similarities and differences between the varieties. Tibebu et al. reported that Bombay Red and Red Creole had a higher bulb size than Adama Red [37]. The highest bulb size was showed by deficit irrigation levels of three days deficit irrigation interval with (23.4 cm) and the lowest bulb size was recorded by nine days deficit irrigation interval by (16.7 cm) bulb size. The bulb size decreased with the increase in deficit Irrigation levels. This is due to water stresses and the insolubility of nutrients.

Average bulb weight (g): The result showed a highly significant ($p<0.01$) effect of the main effect of onion varieties and deficit irrigation interval on bulb weight (Table 2). Besides this, the interaction effects of varieties under various deficit irrigation intervals also showed highly significant ($p<0.01$) (Tables 2 and 4). Bombay red receiving irrigation water at three days irrigation interval gave the heaviest onion bulb weight of 154.70 (g) and this was significantly different to remain varieties receiving other deficit irrigation intervals. In contrast to this, the lightest onion bulb was obtained from Adama red receiving 9 days irrigation interval with a bulb weight of 58.20 (g) (Table 4). The study is in agreement with the findings of Habtamu [38]. These findings are also similar in Beniam et al. and Sharda et al. stating deficit irrigation showed a significant effect on the average onion bulb weight [39,40].

Unmarketable bulb yield (tha-1): The unmarketable bulb yield was highly significant ($p<0.01$) affected due to the main effect of varietal and sub-plot factor of deficit irrigation interval. The interaction effect of variety and irrigation intervals also showed highly significantly influence unmarketable bulb yield at ($p<0.01$) (Tables 2 and 4). The maximum unmarketable bulb yield of 0.26 t ha^{-1} was obtained from the interaction of Adama Red with 5 days irrigation interval and the least unmarketable bulb yield was obtained from the interaction of Red Creole with nine days deficit irrigation interval by (0.05 t/ha) which was statistically at par with the interaction of Bombay red with nine days deficit irrigation interval (Table 4). In contrast least unmarketable bulb yield was recorded by Red Creole varieties at 9 days deficit irrigation interval.

Deficit	**Varieties**											
Irriga-tion	ABW/g			MBY/t/ha			UMBY/t/ha			TBY/t/ha		
Level	V1	V2	V3	V1	V2	V3	V1	V2	V3	V1	V2	V3
3 days	154.7^{a}	127.2^{b}	98.13^{d}	21.07^{a}	16.2^{c}	15.2^{d}	0.12^{de}	0.17^{c}	0.15^{cd}	21.2^{a}	16.4^{c}	15.3^{d}
5 days	115.13^{c}	116.93^{c}	94.47^{d}	18.07^{b}	15.6^{cd}	13.0^{fg}	0.12^{de}	0.22^{b}	0.26^{a}	18.2^{b}	15.8^{cd}	13.3^{e}
7 days	111.0^{c}	92.00e	61.00g	14.00e	13.6ef	10.3h	0.11e	0.15cd	0.17^{c}	14.1^{e}	13.8^{e}	10.5^{g}
9 days	86.53^{e}	74.80f	58.20g	12.2g	11.1h	8.7i	0.07f	0.05f	0.13^{de}	12.3^{f}	11.2^{g}	8.8^{h}
Mean	99.1			14.1			0.2			14.2		
LSD	6.97			0.83			0.03			0.82		
CV	4.4			3.93			12.74			3.81		
Note: Means followed by the same letter within a column are not significantly different at 5% of significance. ABW=Average Bulb Weight MBY=Marketable Bulb Yield UMBY=Unmarketable Bulb Yield TBY=Total Bulb Yield, V1=Bombay red, V2=Red Creole, V3=Adama red.												

Table 4: The Mean interaction effects of Onion varieties and under levels of deficit irrigation interval on Yield and yield attributes in 2019 at the Gitilo site.

Marketable bulb yield (t/h): The main effect of variety and deficit irrigation interval had highly significant (p<0.01) different. The interaction effect of both the main plot and subplot factors had also highly significant difference at (p<0.01) for marketable bulb yield (Table 2). The highest marketable bulb yield was obtained from Bombay red variety (21.1 t/h) at the application of three days deficit irrigation interval. On the other hand, the lowest yield was obtained from Adama red variety (8.7 t/h) at nine days of deficit irrigation interval treatment (Table 4). As the irrigation interval increase from three days to nine days, marketable bulb yield was decreased from 21.1 to 8.7 t ha (Table 4). Similar to these finding earlier reports by Tibebu et al. and Yemane et al. [37,41]. Moreover, Sammis et al. reported that marketable yield was significantly decreased with increment of deficit irrigation level [31]. Optimum irrigation gave significantly higher yield and yield components over the deficit treatments [42].

Total bulb yield (t/ha-1): The main factor varieties and sub-plot factor of deficit irrigation interval had shown a highly significant (p ≤ 0.01) effect on the total yield of the onion bulb; as well as it had revealed a highly significant difference (p ≤ 0.01) due to the interaction effects of both factors on total onion bulb yield (Table 2). The highest total bulb yield obtained from Bombay red variety (21.2 t/ha) at three days deficit irrigation level and the lowest total bulb yield was obtained from the interaction of Adama red (8.8 t/ha) with nine days deficit irrigation interval (Table 4). The higher yield was obtained in full irrigated and reduced significantly from full irrigation to deficit irrigation level. But the highest yield reduction was occurred due to long deficit irrigation practices at nine days interval or three times a month. The significant increase in yield with short interval deficit attributed to sufficient moisture in the rhizosphere which did not show any visual stress on various physiological processes resulting in better uptake of moisture and finally increased plant growth, yield, and yield attributes [43]. This finding is similar to Sharda et al. and Spehia et al. [40,44]. Similarly, this study confirms with those earlier reports by Zayton Kumar et al. and Owusu-Sekyre et al. [45-47].

5.2 Irrigation water used

The crop water requirements of onion crops are similar for all treatments in the studied plots. For the uniform seedling establishment, a common irrigation depth of 20 mm was maintained irrespective of treatments after transplantation for normal establishment of seedlings in the used plots for the study of deficit irrigation intervals. After transplanting seedlings in the treatment plots, after a week in the transplanted plots those seedlings which were not established and appeared dried were substituted with fresh seedlings and deficit irrigation application was applied according to schedule. The highest and minimum seasonal crop water requirement obtained was 48 mm in March and 0.0 mm in May, respectively (Tables 5 and 6).

Month	Decad	Stage	Kc	ETc	ETc	Eff. RF	IR. req
			coefficient	Mm/day	Mm/deca	Mm/deca	Mm/deca
Dec	2	Init	0.4	0.53	1.6	0	1.6
Dec	3	Init	0.4	0.58	6.4	0	6.4
Jan	1	Deve	0.53	0.85	7.3	0	7.3
Jan	2	Deve	0.83	1.42	12.7	0	12.7
Jan	3	Mid	1.1	2.21	23	0	23
Feb	1	Mid	1.14	2.63	26.3	0	26.3
Feb	2	Mid	1.14	2.97	29.7	0	29.7
Feb	3	Mid	1.14	3.37	37.8	0	37.8
Mar	1	Mid	1.14	3.78	41.8	0	41.8
Mar	2	Mid	1.14	4.18	48.4	0	48.4
Mar	3	Mid	1.14	4.4	47	0	47
Apr	1	Mid	1.14	4.7	47.9	0	47
Apr	2	Late	1.06	4.61	39.1	0	39.1
Apr	3	Late	0.88	3.69	36.9	0.1	36.8
May	1	Late	0.071	2.81	30.2	30.1	0.1
May	2	Late	0.53	2.04	22.4	22.4	0
May	3	Late	0.39	1.48	14.2	14.2	0
					472.7	66.8	405
Note: Kc=Crop coefficient, ETc=Crop Evapotranspiration, Eff. RF=Effective Rainfall, IR. req=Irrigation Requirement.							

Table 5: Crop water requirement and irrigation needed.

Month	Stage	Irrn. efficiency (50%)	ETc	Eff. RF	N. Irrn	Field. Irrn
			mm/month	mm/month	mm/month	mm/month
Dec	Init	50	1.6	-	1.6	3.2
Dec	Init	50	6.4	-	6.4	12.8
Jan	Deve	50	7.3	-	7.3	14.6
Jan	Deve	50	12.7	-	12.7	25.4
Jan	Mid	50	23	-	23	46
Feb	Mid	50	26.3	-	26.3	52.6
Feb	Mid	50	29.7	-	29.7	59.4
Feb	Mid	50	37.8	-	37.8	75.6
Mar	Mid	50	41.8	-	41.8	83.6
Mar	Mid	50	48.4	-	48.4	96.8
Mar	Mid	50	47	-	47	94
Apr	Late	50	47.9	-	47.9	95.8
Apr	Late	50	39.1	0.1	39.1	78.2
Apr	Late	50	36.9	30.1	36.8	73.6
May	Late	50	30.2	22.4	0	0.2
May	Late	50	22.2	14.8	0	0
May	Late	50	14.2	66.8	0	0
-			472.7	66.8	405.9	811.8

Note: ETc=Crop Evapotranspiration, Eff. RF=Effective Rainfall, N. Irrn=Net Irrigation Requirement, F. Irrn=Field Irrigation Requirement. The field irrigation requirement is the net irrigation requirement divided by irrigation efficiency. Therefore if for total field irrigation requirement 405.9/0.5=811.8 mm/growing season.

Table 6: Field (net) irrigation Requirements of the study field.

Water productivity: According to FAO irrigation and drainage manual 1 mm of irrigation water height is equals to 10 m^3 water per hectare, therefore if onion irrigation requirement is 791.4 mm to convert these to hectare 811.80 × 10 m^3=8118 m^3/ha water was needed starting from these water productivity was estimated as a ratio of a bulb yield to the total ETc through the growing season and it was calculated using the following Zwart and Bastiaanssen equations [48].

$$CWP = (Y / \mathrm{ETc})$$

Where, CWP is crop water productivity (kg m-3), Y crop yield (kg ha-1), ETc is the seasonal crop water consumption by evapotranspiration (m^3 ha-1). As showed in (Table 7) crop water productivity was high under long deficit irrigation water supply level by nine days irrigation interval with Bombay red varieties by 78.7 kg m^3/ha and least crop water productivity was recorded under three days deficit irrigation level by Adama Red varieties (32.5 kg/m^3). Yemane et al. and Nikus et al. reported that crop water productivity was decreased with full crop water requirement and increased as deficit irrigation interval increase [28,41].

Treatment	ETc/mm/ha	Yield/kg/ha	Yield. redu/kg/ha	Yield red%	CWp/kg/m^3/ha	Wc/m^3/ha	Ws/m^3/a	Ws/%
V1*3 days	472.7	21187	0	0	44.8	8118	0	0
V1*5 days	283.6	18193	2994	14	64.1	4874	3244	40
V1*7 days	203.3	14080	7107	33	69.3	3488	4630	57
V1*9 days	156	12270	8917	42	78.7	2711	5407	67
V2*3 days	472.7	16370	0	0	34.6	8118	0	0
V2*5 days	283.6	15820	550	3.4	55.8	4874	3244	40
V2*7 days	203.3	13780	2590	16	67.8	3488	4630	57
V2*9 days	156	11153	5217	32	71.5	2711	5407	67
V3*3 days	472.7	15343	0	0	32.5	8118	0	0
V3*5 days	283.6	13297	2046	13	46.9	4874	3244	40
V3*7 days	203.3	10503	4840	32	51.7	3488	4630	57

V3*9 days	156	8827	6516	42	56.6	2711	5407	67
Note: ETc is a crop used for evaporation and transpiration, CWp is crop water productivity, Wc is water consumed per season, and Ws water saved by different deficit irrigation level, V1=Bombay red, V2=Red Creole and V3=Adama ted.								

Table 7: Crop water productivity with treatment and their interactions.

Yield response factor (Ky): The relationship between the evapotranspiration deficit (1-(ETa/ETc)) and yield depression (1-(Ya/Ym)) is always linear. The slope of this linear relationship is always called a yield response factor or crop response factor (Ky) [49]. Ky is the yield response factor that is defined as the decrease in yield per unit decrease in ET [50]. This relationship is expressed by the following equation:

$$[1-(\mathrm{Ya}/\ \mathrm{Ym})] = Ky[1-\left(\frac{ETa}{ETm}\right)]$$

Where, Ym (kg ha-1), and Ya (kg ha-1) are the maximum (from a fully irrigated treatment) and actual yields, respectively. The ETm (m^3 ha-1) and ETa (m^3 ha-1) are the maximum (from a fully irrigated treatment) and actual evapotranspiration, respectively, while Ky is the yield response factor.

The observed yield response factors (Ky) for onion bulb production of Bombay red ranged between 0.35 and 0.63 for Red Creole 0.08 and 0.48 and Adama red 0.33 and 0.63. The lowest Ky value was recorded at 5 days DI level of Red Creole (0.08) and highest being recorded by Bombay red and Adama red at 9 days DI level with (0.63), for both varieties (Table 8). Ky observed was increasing as irrigation water application decreasing as shown in (Table 8). The higher Ky values indicate that the crop will have a greater yield loss when the crop water requirements are not meet the available requirements. Generally, the result indicated that the sensitivity of the crop to soil moisture deficit. Therefore, DI practices should be avoided for Ky values that are above unity. This conclusion is in line with a statement given by Sarkar, et al. the decrease in yield is proportionally greater with an increase in water deficit [51]. Considering Ky is limiting factor, for DI application 5 days and 7 days DI levels are nearest to the unit to a tolerable range by 0.08 to 0.6. With saved 40% and 52% mm depth of water from the Field IWR of 811.8 mm depth of water.

Treatment	ETc./Mm	Yield/Kg/ha	Yield response factor
V1*3 days	472.7	21187	0
V1*5 days	283.6	18193	0.35
V1*7 days	203.3	14080	0.6
V1*9 days	156	12270	0.63
V2*3 days	472.7	16370	0
V2*5 days	283.6	15820	0.08
V2*7 days	203.3	13720	0.28
V2*9 days	156	11153	0.48
V3*3 days	472.7	15343	0
V3*5 days	283.6	13297	0.33
V3*7 days	203.3	10503	0.56
V3*9 days	156	8827	0.63

Table 8: Yield response factor (Ky) value with treatment and treatment interaction.

6. Conclusion

The study revealed significant effects due to the deficit irrigation levels and onion cultivars on plant height, the number of leaves per plant, leaf length pseudostem diameter, average bulb weight, marketable bulb yield unmarketable bulb yield and total bulb yield characters. The three days deficit irrigation interval effectively enhanced maximum plant growth and yield parameters in onion followed by the imposed irrigation deficit of five days, seven days, and nine days of deficit irrigation intervals respectively. The lowest water application scored the highest water productivity value, whereas the normal application records the least water productivity value. Therefore, it is recommended that for no water shortage scenario onion could be irrigated at full irrigation application of the 3rd day of deficit irrigation interval. On the other hand, for the limited water resource situation, it is advisable to irrigate the available water using 5 days and 7 days deficit irrigation levels to obtain a high yield of onion per unit of water. Bombay red cultivar showed maximum yield performance followed by Red Creole and Adama red. Finally, the study indicates the highest yield performance was obtained from Bombay red onion cultivar at three days deficit irrigation interval.

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