Effect of deficit irrigation on yield of onion using furrow irrigation methods in Kobo Girrana Valley, Ethiopia

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Abstract

Deficit irrigation (DI) is very essential in water scarce areas. Efficiency of irrigation can be improved by making the right decision regarding to irrigation scheduling and irrigation application techniques. This experiment was conducted to determine the most sensitive growth stages of onion to water stress so as to maximize water use efficiency and yield of onion. The study was carried out for two consecutive years (2011 and 2012). Four growth stages (Initial (I), Development (D), Mid (M) and Late (L) stages) and four water application depths (100% application depth, 25% deficit, 50% stress and 75% deficit) were studied in factorial experiment. Irrigation was applied through calibrated siphons with an irrigation interval of six days under furrow irrigation methods. All relevant data were collected and analyzed and significant treatment means were separated using least significant difference at 5%. The result showed that effect of treatments on bulb diameter and bulb weight, marketable yield and total yield was significant. The highest marketable yield (20.96 t ha^{-1}) was obtained from 25% stress at initial stage followed by (20.77 t ha^{-1}) 50% stress at initial stage while the lowest marketable yield (13.94 t ha^{-1}) was obtained from 75% stress at all stages. Full application of 40mm irrigation depth especially at the late stage had resulted in the highest unmarketable yield while stressing by 50% at the initial stage gave the highest marketable yield with a seasonal irrigation requirement of 540mm in the growing season. Therefore, it is recommendable to apply irrigation water at 50% stress (20 mm irrigation depth) at initial, development and mid stages and 40 mm at late stages every six days for onion.

Key words*:* deficit irrigation, growth stage, stress, water use efficiency, yield

Introduction

Agriculture in eastern Amhara of Kobo Girana valley is rainfall dependent. However, the rainfall is erratic and unreliable in its distribution and amount. As a result, recurrent drought and crop failure are common phenomena. Irrigation agriculture is essential to sustain food production in this part of the region. When practicing irrigation, it is quite important to utilize the scarce water resource efficiently, which can be achieved by deficit irrigation practice. Regulated deficit irrigation is the practice of irrigating below crop water requirement. Deficit (regulated deficit) irrigation is one way of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied. It can be carried out by either withholding or skipping irrigation event or reducing the amount of water applied per irrigation at some growth stages of the crop known to be less critical to moisture stress. This practice, although leads to reduction in crop yields in many instances, it saves water, labor and in some cases energy.

Research evidences has shown that higher crop water productivities are sometimes recorded with deficit irrigation practice, especially if the moisture stress resulting from the deficit is not so severe. Different works showed that under conditions of scarce water supply, deficit irrigation can provide greater economic returns that maximizing yields per unit of area (Teferi G., 2015, Nagaz. et al., 2012, Geerts and Raes, 2009, English and Raja, 1996; Kirda et al., 1999). There is no doubt that there is a growing interest in deficit irrigation as a means of improving water productivity. However, there are reports elsewhere showing onion is very responsive to water. According to Anisuzzaman et al. (2009), onion requires frequent irrigations because most of the crop water requirement is extracted from the top 300 mm depth of soil, and very little water from depths below 600 mm; thus the upper soil areas must be kept moist to stimulate root growth and provide adequate water for the plant. Shock et al. (2000) reported that onion yield and grade were very responsive to careful irrigation scheduling and maintenance of optimum soil moisture and that any soil moisture stressed even below field capacity caused yield reduction. Bekele and Tilahun (2007) in Ethiopia, found that water deficit at first and fourth growth stages, gave no significant different yield from the optimum irrigation application. Furthermore, when water stress was imposed 30 days after transplanting for a period of 15 days, leaf area and bulb growth were considerably decreased with a reduction of 17-26% in one yield (Batta et al., 2006).

In practicing DI, the irrigator aims to increase water use efficiency by reducing the amount of water at irrigation or by reducing the number of irrigations. Therefore, the irrigator must decide what deficit level to allow, what level has been reached, when not to allow a deficit to occur and when to apply water at a lower level of adequacy to achieve the highest water use efficiency at minimum cost. Deficit irrigation is quiet essential in water scarce areas like in eastern Amhara but no study have been carried out earlier in this regard. A recent study conducted in Kenya showed that DI at vegetative and late growth stages influence yields in a positive linear trend with increasing quantity of irrigation water and decreasing water stress reaching optimum yield of 32.0 t ha^{-1} at 20% water stress (T80) thereby saving 10.7% irrigation water on onion bulb yield (Tsegaye et al., 2016).

Furthermore, the actual evaluation of stress related to the yield due to soil water deficit during the onion-growing season can be obtained by the estimation of the yield response factor (Ky) that represents the relationship between a relative yield decrease (1-Ya/Ym) and a relative evaporation deficit (1–ETa/ETm). Doorenbos and Kassam (1986) estimated the average values of Ky is 1.5 during the onion-growing season. Vaux and Pruitt (1983) suggest that it is highly important to know not only the Ky values from literature but also those determined for a particular crop species under specific climatic and soil conditions. This is because Ky may be affected by other factors besides soil water deficiency, namely soil properties, climate (environmental requirements in terms of evapotranspiration), growing season length and inappropriate growing technology. Water deficit effect on crops yield can be presented in two ways, for individual growth periods or for the total growing season. Kobossi and Kaveh (2010) suggested Ky values for the total growing period instead for individual growth stages as the decrease in yield due to water stress during specific periods, such as vegetative and ripening periods, is relatively small compared with the yield formation period, which is relatively large.

Conclusively, DI during vegetative development and late season stages, which are considered to be water stress tolerant stages of onion, some water would be saved (David et. al, 2016). The specific objectives of this study were: (i) to determine onion yield in response to various water deficit application levels and during stress tolerance stages and (ii) to determine irrigation water use efficiency of the onion

Materials and methods

Location of experimental site

The field experiment was conducted in the irrigation season of 2011 and 2012 for two consecutive years at kobo irrigation scheme. The site is located at about 50 kilometers from Woldiya town to the North-east direction and situated at 12.08^0 N latitude and 39.28^0 E longitudes with an altitude of 1470 m.a.s.l. The rainfall is about 630 mm with average daily reference evapo-transpiration rate of 5.94 mm. The soil type in the experimental site is silty clay loam with average field capacity (FC) and permanent wilting point (PWP) of 38% and 21.0% on volume basis respectively. And the soil has average infiltration rate of 8 mm hr^{-1} and 7.8 pH value. It contains total N of 0.1% and available P of 10.86 mg of P_2O_5 kg^{-1} of soil.

Experimental set up

The study consisted of 16 treatments composed of four growth stages and four water application depths. The growth stages were Initial (I), Development (D), Mid (M) and Late (L) stages and the water levels were 100% application depth (40mm), 25% stress (10mm), 50% stress (20mm) and 75% stress (30mm). Treatments were arranged in RCBD designs with four replications. The reference crop evapotranspiration was determined based on the Penman-Monteith method and the crop water requirement was determined by a CROPWAT 8.1 computer program software based on the reference crop evapotranspiration and crop coefficient factors at various growth stages.

Seedlings were transplanted from nursery station after 30 days of emergence. Transplantation was carried out with proper agronomic spacing of 40 cm bed including furrow, 20cm between rows on the bed and 10 cm between plants. After transplanting for the first five days irrigation were applied every day to establish the seedlings and followed by six day scheduling. The variety Bombay red of onion was used as a test variety. The recommended rate of phosphorus and nitrogen was used. Di-ammonium phosphate (DAP) was the source of phosphorus and used at transplanting while urea was used as sources of nitrogen and applied half at transplanting and the remaining half after 45 days of transplanting. The rate of DAP was 100 kg ha^{-1}. .

Irrigation water application method

Full optimal crop water requirement (100%) was determined based on CROPWAT 8.1 software program. The irrigation interval was six days for all treatments and the amount of water at each irrigation time was measured by siphons in furrow irrigations (Table 1 and Table 2).

Table 1. Number of irrigation cycles

Growth stages	Initial	Development	Mid	Late
Day length	18	30	30	12
Irrigation cycle	3	5	5	2

Totally there were 15 irrigation cycles in the growing season of onion crop (Bombe red variety) with a total growing length is about 95 days. A seasonal net irrigation requirement was also estimated based on depths of irrigation and growing day lengths.

Table 2. Treatments

Treatments	Irrigation amount and growth stages	Irrigation depths (mm)	Water applied (mm)
1	Full irrigation (optimal watering)	40	600
2	25% deficit @ all stage	30	450
3	25% deficit @ I stage	30	570
4	25% deficit @ D stage	30	550
5	25% deficit @ M stage	30	550
6	25% deficit @ L stage	30	580
7	50% deficit @ all stage	20	300
8	50% deficit @ I stage	20	540
9	50% deficit @ D stage	20	500
10	50% deficit @ M stage	20	500
11	50% deficit @ L stage	20	540
12	75% deficit @ all stage	10	150
13	75% deficit @ I stage	10	510
14	75% deficit @ D stage	10	450
15	75% deficit @ M stage	10	450
16	75% deficit @ L stage	10	540

Data Analysis

Data collected were subjected statistical analysis using SAS version 9 computer software. Mean comparison was done y using least significant difference test at 5% probability level. Correlation among the parameters was computed using Pearson's simple correlation coefficient.

Computation of water productivity

For each treatment, the water productivity (kg m^{-3}) was calculated using the following formula as described by Michael (1997). The water productivity simply referred to the output (crop yield, economic returns) with respect to the water input in crop production. In this study, crop water productivity is defined with respect to yield and seasonal water supply, and the expression is given as:

$$\mathrm{CWP}\left(\frac{\mathrm{Kg}}{\mathrm{M}^3}\right) = \left(\frac{\text{Bulb yield (kg ha}^{-1})}{\text{Waterapplied (M}^3}\right)$$

Results and discussion

Yield and yield components

The finding of the research showed that the interaction effect of treatments on bulb diameter, bulb weight, marketable yield and total yield was insignificant (Table 3). Deficit irrigation to 75% at all growth stages or received only 25% of the ideal full irrigation water throughout the growing season produced the lowest marketable yield (13.94 t ha^{-1}). On the other hand, the highest marketable yield (20.96 t ha^{-1}) was obtained from only 25% deficit at initial stage. Singh and Sharma (1991) reported that more frequent irrigation produced higher yield of onion (17 to 27.t ha^{-1}) in the sandy loam soil of many areas. It was expected that irrigation with 75% deficit at all stage will produce the lowest bulb yield while fully irrigated treatment (100% of CROPWAT 8.1 generated depth) will produce the highest bulb yield. While full irrigation water application in all growth stages was highly affected the marketable yield of onion.

Table 3. Analysis of variance (ANOVA) result

		Mean square				
Source of variation	DF	Bulb diameter	Bulb weight	Marketable yield	Total yield	Water productivity
Replication	3	0.20	240.1	21.349	35.03	1.86
Treatment	15	0.17	281.0	23.04	36.46	17.94
F Treatment		1.29	2.1	3.72	5.82	5.56
treatment*year	15	0.09	205.9	7.46	4.39	0.52
Error	45	0.13	133.9	6.20	6.27	3.23
F interaction		0.71	1.54	1.22	0.70	0.16

The experimental treatments showed significant effects on bulb diameter and bulb weight and a high significant difference in marketable yield and total yield (Table 4).

Table 4. Treatments effect on marketable yield and yield components

Treatment	Bulb diameter (cm)	Bulb weight (gm)	Marketable yield (t ha^{-1})	Total yield (t ha^{-1})
(Full irrigation optimal watering)	5.45	100.5	18.47	21.08
25% deficit @ all stage	5.49	102.8	18.55	18.80
25% deficit @ I stage	5.75	110.5	20.96	21.77
25% deficit @ D stage	5.73	108.0	18.31	19.24
25% deficit @ M stage	5.64	108.1	19.32	20.09
25% deficit @ L stage	5.61	108.3	18.58	19.01
50% deficit @ all stage	5.60	101.1	16.96	17.05
50% deficit @ I stage	5.71	108.3	20.77	22.02
50% deficit @ D stage	5.75	106.9	20.59	20.40
50% deficit @ M stage	5.77	116.0	18.83	19.87
50% deficit @ L stage	5.66	105.7	20.23	20.74
75% deficit @ all stage	5.32	92.5	13.94	14.08
75% deficit @ I stage	5.47	100.3	18.32	18.07
75% deficit @ D stage	5.48	97.5	17.69	16.80
75% deficit @ M stage	5.52	98.5	18.32	16.74
75% deficit @ L stage	5.82	108.8	19.20	20.31
CV (%)	5.4	11.1	13.3	11.00
LSD (0.05)	0.30	11.49	2.471	2.08

Treatment of deficit irrigation to 75% at all growth stages that received only one-fourth of the ideal full irrigation water throughout the growing season produced the lowest marketable yield of 13.94 t ha^{-1}. On the other hand, the highest marketable yield of 20.96 t ha^{-1} was obtained from the treatment with 25% deficit at initial stage. Singh and Sharma (1991) reported that more frequent irrigation produced higher yield of 17 to 27.4 t ha^{-1} in the sandy loam soil of many areas. It was expected that least irrigation treatment (75% deficit at all stage) will produce the lowest bulb yield while fully irrigated treatment (100% of CROPWAT 8.1 generated depth) will produce the highest bulb yield. While full irrigation water application in all growth stages was highly affects marketable yield of onion.

Many studies have been reported on irrigation of onions (Doorenbos and Kassam (1986). These studies gave clear proof that the bulb and dry matter production are highly dependent on appropriate water supply. Onion crop is known to be very responsive to irrigated water. For optimum yield, it is necessary to prevent the crop from experiencing water deficit, especially during the bulbing stage. During the early vegetative growth periods the crop appears to be less sensitive to water deficit; excessive irrigation during this period can lead to a delayed start of bulbing and a reduced bulb development (Doorenboset al, 1979). Deficit irrigation occurring during the last or late growing stage in each deficit level couldn't affect the marketable yield and the yield reduction was experimentally non-significant. This yield reduction would have been much greater had the crop been subjected to water stress during any of the previous stages. It should be noted at this point that in the study area, many farmers withhold irrigation during this last stage, as well as providing inadequate water throughout the growing season. This situation causes major yield reductions. For optimum yield, it is necessary to prevent the crop from experiencing water deficit, especially during the bulbing stage. During the early vegetative growth periods the crop appears to be less sensitive to water deficit. Excessive irrigation during this period can lead to a delayed start of bulbing and a reduced bulb development (Nigus, 2013). There was no significant difference between treatments of stressed 25% at first (I) stage, stressed 50% at first (I) stage, development stage (D) and late (L) stage. Deficit to 75% and 50% at all growth stages affects marketable yield. Deficit to 25% and 50% at I stage didn't affect the marketable yield. But deficit to 25% and to 50% at I stage saves 30mm and 60mm; respectively seasonal water requirement compared to the full application.

During the time interval between two consecutive irrigation applications, soil water storage for full application and actual evapotranspiration is assumed to be equal to maximum evapotranspiration (Nigus, 2013). Hence, the testing crop (onion) was not imposed to water stress and therefore Ya =Ym (actual yield equals maximum yield). Hence, it is possible to derive the relationship between relative yield reduction and relative evapotranspiration deficits. Water stress for all stages (75%), resulted in the highest yield penalty (Table 5). The negative value (Table 5) indicates the yield gained from above the optimum application and the positive one is the yield lose or penalty from the optimum application. Stressed to 75% at all growth stages gave the highest yield reduction 4.53 t ha^{-1} (22.4%). The highest additional yield gain from the optimum irrigation water application was obtained due to deficit effects of 25% and 50% at initial stage. Full application especially at initial and late stage leads to occurrence of unmarketable yield or yield reduction.

Table 5. Relative yield reduction in the experimental area

Treatments	Actual yield (t ha^{-1})	Yield reduction (t ha^{-1})	%yield reduced	Rank
(Full irrigation optimal watering)	18.47	0	0.0	10
25% deficit @ all stage	18.55	-0.08	-0.4	9
25% deficit @ I stage	20.96	-2.41	-13.0	2
25% deficit @ D stage	18.31	0.16	0.8	12
25% deficit @ M stage	19.32	-1.01	-5.5	5
25% deficit @ L stage	18.58	-0.11	-0.6	8
50% deficit @ all stage	16.96	1.51	8.1	15
50% deficit @ I stage	20.77	-2.3	-13.6	1
50% deficit @ D stage	20.59	-2.12	-10.2	3
50% deficit @ M stage	18.83	-0.36	-1.7	7
50% deficit @ L stage	20.23	-1.4	-7.4	4
75% deficit @ all stage	13.94	4.53	22.4	16
75% deficit @ I stage	18.32	0.15	1.1	13
75% deficit @ D stage	17.69	0.63	3.4	14
75% deficit @ M stage	18.32	0.15	0.8	12
75% deficit @ L stage	19.2	-0.73	-4.0	6

As it was observed in Table 6, there was a significant difference between treatments in water productivity. Water productivity value ranges from 3.392 kg m^{-3} due to 25% deficit at late stage to 9.613 kg m^{-3} due to 75% deficit at all stages. In areas where water is the most limiting resource to production, maximizing WP may be more profitable to the farmer than maximizing crop yield. This is because the water saved by applying deficit irrigation becomes available to irrigate more land since the latter is not the limiting factor. In northern Syria it was found by applying 50% of full supplemental irrigation requirements would reduce yield by 10 to 15% while applying the saved water to lands otherwise rain-Ribfed increased the total farm production by 38% (Oweis, unpublished work).

Table-6: Effects of deficit irrigation on water productivity

Treatment	Water productivity (kg m^{-3})		
	First year	Second year	combined
(Full irrigation optimal watering)	3.58	3.87	3.72
25% deficit@ all stage	3.70	4.96	4.33
25% deficit @ I stage	3.31	4.81	4.06
25% deficit @ D stage	2.67	4.64	3.65
25% deficit @ M stage	3.20	4.57	3.89
25% deficit @ L stage	2.55	4.24	3.39
50% deficit @ all stage	4.38	7.59	5.98
50% deficit @ I stage	3.58	5.11	4.34
50% deficit @ D stage	3.50	5.16	4.33
50% deficit @ M stage	3.23	4.92	4.08
50% deficit @ L stage	3.10	4.71	3.90
75% deficit @ all stage	6.53	12.70	9.61
75% deficit @ I stage	2.89	4.50	3.70
75% deficit @ D stage	2.80	4.95	3.87
75% deficit @ M stage	2.83	4.99	3.91
75% deficit @ L stage	3.35	4.66	4.01
CV (%)	9.8	16.2	16.3
LSD (0.05)	0.48	1.25	0.72

Conclusion and recommendation

One of the irrigation management practices which could result in water saving is deficit irrigation. By maintaining the moisture content of the soil below the optimum level during specific growth stages of the season or throughout the growing season, it is possible to identify the periods during which water deficit would have a limited effect on crop production. Our experimental research result revealed that when deficit irrigation water was forced in the early and late growing stages, high yield could be easily obtained while provided adequate watering in the remaining two growing stages. The most critical growing stages for maximum onion production and water productivity are development and mid growth stages. Meeting the full water requirement during the first two stages is not advisable if water shortage can’t be avoided during the remaining of the season and full irrigation water application particularly at initial and late stages leads to occurrence of highest unmarketable yield. Good watering early in the season allows the crop to develop an important cover and a limited root system. Deficit water application to 75% for all growing stages resulted in high yield penalty per unit of irrigation water deficit. Deficit to 50% at initial growth stage gave the highest marketable yield with a seasonal irrigation requirement of 540 mm in the growing season that saves about 60 mm water (10% additional water saving). It is also advisable irrigating onion at 6 days interval with 20 mm irrigation depth at initial, development and late stages while 40 mm at mid stage to achieve high yield for the study area.

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