Response of Onion (*Allium cepa L.* ) to Soil Moisture Stress Conditions at Different Growth Stages under Semi-Arid Area of Ethiopia

Gobena Dirirs*a, Tilahun Hordofa, Ketema Tezera, Adera Tesfaye, Tatek Wendimu

Melkassa Agricultural Research Center, P.O.Box 436, Adama, Ethiopia

Abstract

Soil moisture stress condition is the most critical factor affecting crop yield and water productivity. Under changing climate and increasing human population the evaluation of effect of soil moisture stress on crop production is critical issue for the increasing water scarcity. An experiment was conducted for three consecutive seasons to investigate the effect of water stress imposed at different growth stages on bulb yield and water productivity of onion (*Allium cepa L.*). Sixteen treatments were used depriving irrigation at different combinations of the four growth stages: at each growth stages, at two growth stages, at three growth stages, irrigated at establishment only and full irrigation (control). The treatments were replicated three times in a randomized complete block design. The study result indicated that onion bulb yield and water productivity were significantly (p<0.05) affected with soil moisture stress imposed at different growth stages. The maximum bulb yield (31.50 t/ha) was obtained from fully irrigated onion at all stages (the control). Water stress imposed at combinations of initial and late season stage didn’t affect bulb yield, but soil moisture stress imposed at combinations of development and bulb formation stage decreased bulb yield highly. Withholding irrigation at initial and late season stage increased onion water productivity and reduced yield response factor by saving 29.3% water. While withholding irrigation at development stage followed by bulb formation stage decreased water productivity to 3.41 Kg/m3 causing higher yield response factor of 1.19. Thus, moisture stress at mid-season stage should be avoided especially when combined with moisture stress imposed at development stage for higher bulb yield. Moreover, moisture stress imposed at initial and late season stages enhance water productivity without significantly reducing the yield from the control.

Keywords: Depriving irrigation • Growth stages • Onion • Moisture stress • Water productivity

Introduction

Fresh water scarcity is a main problem for agricultural crop production specially, in arid and semi-arid regions. Population increase and climatic change are aggravating the problem. Thus, achieving food security in the future while using water resources in a sustainable manner will be a major challenge in the future.

Many recent studies have tied water scarcity to agricultural water consumption. Irrigation agriculture is the largest freshwater consumer, using 70% of the total renewable freshwater resources (WWAP, 2014).

In Central Rift Valley of Ethiopia, water shortage is getting severe during dry season as the irrigation farms are expanding from time to time. Under scarce water condition adopting appropriate water saving practices to produce more food per drop of water will be a crucial strategy to address the challenge. Deficit irrigation and soil moisture stress can be used as alternate strategies to reduce irrigation water use as well as improve irrigation efficiency. In deficit irrigation, water applied at an irrigation time is less than the crop’s actual need [1]. In soil moisture stress which is the main concern of this study irrigation water is deprived at respective growth stages. As a result of the two techniques, less water is used and more land can be cover by producing optimum yield [2].

Onion (*Allium cepa L.*) is one of the most important irrigable vegetable crops grown in Ethiopia. The area under onion production was about 48,443.36 hectares with a production of 3.75 million tons (CSA, 2018). The bulk of onion produced in the county comes from the central rift valley area where irrigated land under vegetables and other irrigated crops by state and private farms is expanding leading to water shortage. The great challenge of onion producers is achieving optimal yield with less water use. Most of the water saving studies conducted on onion is attached on evaluating effects of different deficit levels on yield and water productivity [3], but much study has not been done to evaluate the effect of depriving irrigation at some growth stages of crops, particularly for onion.

Therefore, this study aimed to evaluate the effect of soil moisture stress occurred at different onion growth stages on bulb yield and water productivity.

Materials and Methods

Description of the experimental area

Field experiments were carried out for three consecutive years on dry season of 2014/15, 2015/16 and 2016/2017 at Gidara Research Sub-station of Melkassa Agricultural Research Center. The study site is found in the central rift valley of Ethiopia in Oromia Region, East Shoa Zone, in Fentale Woreda. Geographically the site is located at 08°44'55"N and 39°47'49" E with altitude of 1112m above sea level.

The long-term weather data collected from nearby meteorological station, Nura Era, shows that the maximum and minimum monthly average temperature are 31.70°C and 16.80°C, respectively. July to September is the main rainy season whereas the mean annual rainfall is 615mm. The climate water balance (Figure 1) shows that there is Evapotranspiration deficit for longer duration which makes irrigation mandatory to the area.

The soil texture at the study site is sandy loam with pH of 8.4.

Treatment and experimental design

The experiment consisted 16 treatments randomized in blocks with three replications. The treatments are: 1) irrigated all stages (control-no stress), 2) depriving irrigation at initial stage only (DMdMt), 3) depriving irrigation...
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The time required to deliver the desired depth of water into each plot was calculated using the equation below.

\[ t = \frac{I_g \times A}{60 \times q} \]

Where: \( I_g \) = gross depth of water applied (mm), \( t \) = application time (min), \( A \) = plot area, \( q \) = flow rate (l/s) at specific Parshall flume head and 60 (sixty) is unit adjusting figure.

**Data collection**

From the total of five both side plated rows the interior three rows were harvested. Data on onion bulb yield and other parameters were collected.

**Water Productivity**

Water productivity (WP) in this study was determined by dividing the marketable onion bulb yield to the net amount of irrigation water used by the crop as indicated by the following equation [5]:

\[ WP = \frac{Y}{ET} \]

Where, WP is water productivity (kg/m³), Y crop yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m³/ha).

**Water Productivity**

The yield response factor was calculated according to the procedure mentioned by Vaus and Pruitt (1983) as follows:

\[ 1 - \frac{Y_a}{Y_m} = Ky \left[ 1 - \frac{ET_a}{ET_m} \right] \]

Where: \( Ky \) = yield response factor, \( Y_a \) is the marketable bulb yield obtained from each deficit treatments (t/ha), \( Y_m \) is marketable bulb yield obtained from the control treatment with full irrigation (t/ha), \( ET_a \) is the net depth of irrigation applied for each deficit treatments (mm), \( ET_m \) is the net depth of irrigation water applied for the control treatment with full irrigation (mm), \( 1 - \frac{Y_a}{Y_m} \) is the decrease in relative yield due to deficit water application and \( 1 - \frac{ET_a}{ET_m} \) is the relative water saved (decrease in relative crop water consumptive) due to deficit irrigation.
Results and Discussion

Effect of soil moisture stress on onion bulb yield and water productivity

Onion bulb yield

The analysis of pooled mean indicated that soil moisture stress imposed at different growth stages of onion had a significant effect (p<0.05) on bulb yield as indicated in Table 3. The result showed that the maximum bulb yield of 31.50 t/ha was obtained from the control (fully irrigated plot) with no significant difference from the treatment for which irrigation was withheld either at initial or maturity or both. The minimum bulb yield of 1.29 t/ha was obtained from treatment with no irrigation except during establishment. Depriving water at bulb formation stage was noticed to result in lower bulb yield compared with the other stages. The result is in agreement with Zayton finding, where depriving irrigation at bulb formation stage is observed to reduce bulb yield significantly.

Water productivity (WP)

Soil moisture stress occurred at different growth stages of onion had a significant (p<0.05) impact on onion water productivity as indicated in Table 3. Higher water productivity with a value of 8.80 Kg/m³, was attained when moisture stress was occurred at both initial and maturity stages. The minimum water productivity was observed by Gobena et al. given during establishment and bulb formation stage as a result the residual moisture could have helped the plant to skip the stage without irrigation and WUE was increased consequently. Similar effect of soil moisture stress on water productivity was observed by Gobena et al.

Yield response factor (Ky)

The analysis of yield response factor is presented in Table 3. The highest Ky was 1.19 attained at T9 (irrigated at initial and late season only) and the lowest Ky obtained was 0.05 for T2, followed by 0.08 obtained from T5 and T8, respectively. The result revealed that reduction in water applied at development and bulb formation stage resulted in pronounced decrease in yield compared to the other stages. Irrigating onion at two stages only (development and bulb formation stages) resulted in 29.3% water saving with 2.5% yield reduction with minimum yield reduction. Moreover, depriving irrigation at initial and late season stage had no significant impact on bulb yield (Table2).

Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test.

Conclusion and Recommendation

The results of the study revealed that soil moisture stress imposed at some growth stages enhance water productivity of onion without significantly reducing the yield. Stressing onion at development and middle-season crop growth stage while irrigating the rest of growth stages will lead to wastage of water decreasing the productivity of water in relation with the yield obtained. To enhance onion crop productivity in water limited areas, application of the available irrigation water at bulb formation stage is very important. Moisture availability at development stage has great influence on water productivity. Keeping optimal moisture at development and bulb formation stage while depriving irrigation at initial and late stage results in higher water saving with invisible yield reduction. Moreover, combined moisture stress at development and bulb formation stage critically reduces onion bulb yield and water productivity but increases yield response factor. In generally, it can be concluded that the critical sensitive stages are the combined development and mid-season stages. Moreover, to enhance the water productivity without affecting the bulb yield, irrigation could be deprived at initial and late season stage.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Bulb yield (ton/ha)</th>
<th>WP (kg/m³)</th>
<th>Relative yield reduction (%)</th>
<th>Relative ETc deficit/ water saved (%)</th>
<th>Yield response factor (Ky)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fully irrigated (IDMdMt)</td>
<td>31.50¹</td>
<td>8.80a</td>
<td>0.0</td>
<td>0.0</td>
<td>1.19</td>
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<td>DMdMt</td>
<td>31.32¹</td>
<td>7.24d</td>
<td>0.6</td>
<td>12.3</td>
<td>0.05</td>
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<tr>
<td>IMdMt</td>
<td>25.02²</td>
<td>7.08b</td>
<td>20.6</td>
<td>28.4</td>
<td>0.72</td>
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<tr>
<td>IDMt</td>
<td>23.84³</td>
<td>8.29a</td>
<td>25.0</td>
<td>42.2</td>
<td>0.59</td>
</tr>
<tr>
<td>IDMd</td>
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<td>7.58³</td>
<td>1.4</td>
<td>17.0</td>
<td>0.08</td>
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<tr>
<td>MdMt</td>
<td>18.67⁴</td>
<td>6.38c</td>
<td>40.7</td>
<td>40.8</td>
<td>1.00</td>
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<td>DM</td>
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<td>42.6</td>
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<td>DMd</td>
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<td>2.5</td>
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<tr>
<td>IM</td>
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<tr>
<td>IMd</td>
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<td>46.8</td>
<td>46.4</td>
<td>1.03</td>
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<tr>
<td>ID</td>
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<td>5.68⁴</td>
<td>63.6</td>
<td>59.2</td>
<td>1.07</td>
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<tr>
<td>Mt</td>
<td>1.81⁴</td>
<td>2.16⁴</td>
<td>94.3</td>
<td>83.0</td>
<td>1.14</td>
</tr>
<tr>
<td>Md</td>
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<td>5.39⁴</td>
<td>64.3</td>
<td>57.8</td>
<td>1.11</td>
</tr>
<tr>
<td>D</td>
<td>10.86⁴</td>
<td>7.73⁴</td>
<td>65.5</td>
<td>71.6</td>
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<tr>
<td>I</td>
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<tr>
<td>No-irr</td>
<td>1.29⁴</td>
<td>-</td>
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<tr>
<td>CV (%)</td>
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<td>13.5</td>
<td></td>
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<td>LSD0.05</td>
<td>0.81</td>
<td>0.37</td>
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Table 2. Bulb yield, water productivity and yield response factor analysis.
References


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