Onion (*Allium cepa* L.) Response to Soil Moisture Stress Condition at Different Growth Stages at Raya Valley, Northern Ethiopia

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Abstract

In the context of improving Water Use Efficiency, there is interest identify onion sensitive stages, which provides a means of reducing water consumption while minimizing adverse effects on yield. A Field study was carried out at experimental site of Mehoni Agricultural Research Center aimed to identify onion growth stages sensitive to soil moisture stress, to determine critical time for irrigation application for a limited water resources and to determine productivity of water over all growing season. Treatments which were consisted of fourteen soil moisture stress levels and a check which irrigated at all growth stages and laid out in RCBD design with three replications. The three years combined result indicated that there were a significant ($P<0.05$) variation among treatments for bulb yield, total bulb yield, plant height and water productivity. The bulb yield of onion was highly significantly ($P<0.01$) affected due to moisture stress imposed at different growth stages. Accordingly, the highest bulb yield was obtained from irrigating all growth stage treatment (27.74 ton/ha) followed by irrigating all stage except initial stage (24.07 ton/ha). In other hand, irrigated only at maturity stage was recorded the lower yield relatively, which followed by irrigating only at initial. The lowest water productivity was recorded (5.77, 5.94 and 6.1 kg/m^3) from irrigated at all stage, irrigated at all stages except at initial stage and irrigated at all stage except at maturity respectively. The highest (14.73 kg/m^3) at stress at initial, development and late season stage. Therefore, moisture stress during the mid-season growing stage treatments had significantly reduced the bulb yield of onion but stressing t i,Tm( )]T(r)3(in)-49d3.81 C BT/ 8z C B>BDCnifican

productivity and thus relieving water scarcity (Mekonnen and Hoekstra, 2014; Zhuo *et al*., 2016; Zwart *et al*., 2010).

In Ethiopia, irrigation development is increasingly implemented more than ever to supplement the rain-fed agriculture. It aims to increase agricultural productivity and diversify the production of food and raw materials for agro-industry as well as to ensure the agriculture to play a pivot for driving the economic development of the country (Mekonen, 2011).

In the context of improving water productivity, there is a growing interest in deficit irrigation, an irrigation practice whereby water supply is reduced below maximum levels and mild stress is allowed with minimal effects on yield. Under conditions of scarce water supply and drought, deficit irrigation can lead to greater economic gains than maximizing yields per unit of water for a given crop; farmers are more inclined to use water more efficiently, and more water efficient cash crop selection helps optimize returns. However, this approach requires precise knowledge of crop response to water as drought tolerance varies considerably by species, cultivar and stage of growth (FAO, 2002).

Under scarce water condition for irrigation, limited irrigation is an efficient strategy for sustainable vegetable production. It improves crop water use efficiency by reducing amount and frequency of irrigation. It improves crop water use efficiency by reducing amount and frequency of irrigation. This could be result through the identification of sensitive and critical growth stages to water stress and the use of soil moisture stress irrigation practices by maintaining the moisture content of the soil below the optimum level or missing irrigation during specific growth stages of the season.

Soil-water stress is considered as one of the most important factors affecting onions yield and quality, which is not considered obviously in many of the previous research works. Therefore, this study aimed to identify onion growth stages sensitive to soil moisture stress, to determine critical time for irrigation application for limited water resources and to determine productivity of water over all growing season.

Materials and Methods

Description of the experimental site

This study was conducted at the research station of Mehoni Agricultural Research Centre (MehARC) in the Raya Valley, Northern Ethiopia, located 668 Km from the capital Addis Ababa and about 120 Km south of Mekelle, the capital city of Tigray regional state. Geographically, the experimental site is located at 12° 51'50"

North Latitude and 39° 68'08" East Longitude with an altitude of 1578 m.a.s.l. The site receives a mean annual rainfall of 300 mm with an average minimum and maximum temperature of 18 and 32°C, respectively. The soil textural class of the experimental area is clay with pH of 7.1 to 8.1 (MehARC, 2015).

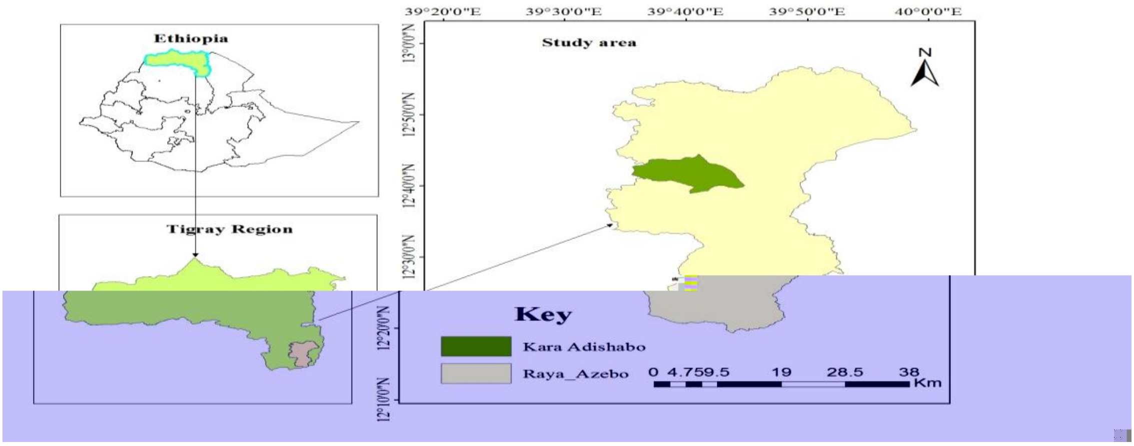

Figure 1. Map of the study area

Climatic characteristics

The average climatic data (Maximum and minimum temperature, relative humidity, wind speed, and sun shine hours) on monthly basis of the study area were collected from the near meteorological station. The potential evapotranspiration ETo was estimated using CROPWAT software version 8.

Experimental treatments and design

A field experiment was carried out for three non-consecutive years. This experiment was laid out in RCBD with three replications. The treatments which are presented in table 1 consisted of fourteen soil moisture stress levels and a check which irrigated at all growth stages.

Experimental procedure and management practice

The size of each individual plots had kept at 2.8 m*3 m. The spacing between plots and blocks were 2 m and 3 m, respectively. The spacing between onion plants and rows was kept at 10 cm and 20 cm, respectively. Each plot has 8 rows of onion plants with double row and 30 plants in each row with a total plant population of 400 in each plot. Each experimental treatment was fertilized with recommended fertilizer application, that was 100kg/ha and 100kg/ha of DAP and Urea respectively. The full dose of DAP was applied at transplanting, whereas Urea was applied by splittinginto two parts, half first three week after transplanting and the rest just at mid-stage. All cultural practices were done to all treatments in accordance to the recommendation made for the area. Irrigation water was applied as per the treatment to refill the crop root zone depth close to field capacity.

Table 1: Treatments combination

Number	Treatments
1	Irrigate all growth stages
2	Irrigate all stages except initial stage
3	Irrigate all stages except development stage
4	Irrigate all stages except mid-season stage
5	Irrigate all stages except maturity stage
6	Irrigate all stages except initial and development stages
7	Irrigate all stages except initial and mid-season stage
8	Irrigate all stages except initial and maturity stages
9	Irrigate all stages except development and mid-season stages
10	Irrigate all stages except development and maturity stages
11	Irrigate all stages except mid-season and maturity stages
12	Irrigate only at maturity stage
13	Irrigate only at mid-season stage
14	Irrigate only at development stage
15	Irrigate only at initial stage

Pre-irrigation and common irrigation

Pre-irrigation and common irrigation were applied for all plots uniformly without considering the treatments variation for transplanting and enhance better establishment of transplanted onion. Pre-irrigation was done before one day of transplanting. Common irrigation during transplanting and after transplanting was applied to refill the moisture to field capacity of the effective root depth.

Irrigation water was applied as per the treatment to refill the crop root zone depth close to field capacity. The amount of irrigation water applied at each irrigation application was measured using Parshall flume.

Data Collected

Agronomic data were recorded during the route of the experiment such as date of transplanting, plant height and other relevant agronomic parameters, number of leaves per plant, and onion bulb yield and other relevant yield parameter. Plant height and number of leaves per plant was taken from the central six rows of each plot at the end of each growth stages. Ten random plants per plot excluding the border rows and border plants in the central four rows were taken as a sample to record plant height. Measurements were carried out by tapping the main stem height from the ground level up to the tip of the leaf with the help of a ruler expressed in centimetre. For number of leaves, all completely developed leaflets was counted and recorded per plant. The amount of bulb produced was collected and weighed from the four central rows of each to avoid boarder effects. The harvested bulb yield was graded into marketable and non-marketable categories of onion bulb according to the size and degree of damage. Onion bulbs with less than 2 cm diameter were categorized under non-marketable (Lemma and Shimels, 2003).

Data on growth parameters and bulb characters were recorded at physiological maturity and harvesting, respectively and expressed as average of eight randomly taken plants in each experimental plot. Maturity and yield data were determined on net plot basis. Date of irrigation (irrigation amount applied at every event and rainfall were record) and the crop water productivity was calculated by the ratio of harvested yield per total water used.

$$\mathrm{WP} = \frac{\text{harvested bulb yield}}{\text{total water used}}$$

Where, WP is crop water productivity (kg/m^3), harvested bulb yield (kg/ha) and total water used is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Statistical analysis

The collected data were statistically analyzed 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) at 5% probability level when treatments show significant difference to compare difference among treatments mean.

Results and Discussion

Crop water requirement of onion

The water requirement of onion was computed for the growing season using the CROPWAT 8 computer program with climate, soil and crop input data from the study area The values of ETo estimated using CROPWAT model based on climate parameters need to be adjusted for actual crop ET. The crop water requirement of the tested crop is calculated by multiplying the ETc with crop coefficient (Kc).

Pre-irrigation and common irrigation were applied for all plots uniformly without considering the treatments variation for transplanting and enhance better establishment of transplanted onion. Pre-irrigation was done before one day of transplanting. Two common irrigation after transplanting was applied to refill the moisture to field capacity of the effective root depth.

The amount of irrigation water applied to each treatment during the experimental period is shown in (Table 2).

According the seasonal irrigation water requirement of onion was in the study area 418.3 mm. This amount of water was needed for the treatment of irrigated at all growth stages which irrigated at four growth stages (full irrigation). The lowest amount of irrigation water was applied in the treatment irrigates only at initial stage. From the four growth stages, the maximum amount of irrigation water was applied during the mid- season stage whereas, the minimum amount of water applied from the treatment of irrigated only at initial stage (Table 2).

Table 2: Number of Days and net irrigation depth applied at each treatments (mm)

Treatments	Irrigation application stages	Number of Days after transplanting	Total net irrigation applied (mm)
1	Irrigate all growth stages	110	418.3
2	Irrigate all stages except initial stage	90	391.4
3	Irrigate all stages except development stage	80	359.07
4	Irrigate all stages except mid-season stage	70	258.04
5	Irrigate all stages except maturity stage	90	369.29
6	Irrigate all stages except initial and development stages	50	299.98
7	Irrigate all stages except initial and mid-season stage	60	208.03
8	Irrigate all stages except initial and maturity stages	70	319.35
9	Irrigate all stages except development and mid-season stages	40	148.63
10	Irrigate all stages except development and maturity stages	60	260.04
11	Irrigate all stages except mid-season and maturity stages	50	159.03
12	Irrigate only at maturity stage	20	98.86
13	Irrigate only mid-season stage	40	210.20
14	Irrigate only development stage	30	109.16
15	Irrigate only initial stage	20	74.94

Crop Growth and Physiology Parameters

Plant height

Analysis of variance has shown highly significant ($P < 0.01$) difference in plant heights among the different treatments due to moisture stress at different growth stage (Table 3). The highest plant height of (50.3 cm) was recorded from the treatment of irrigated at all growth stages followed by irrigated at all stages except at initial stage**.** The shortest plant height of (35.7 cm) was recorded from irrigated only at maturity and irrigated only at initial stage with the value of 35.7 and 36.5 cm respectively. Statistically there were no significances differences among the treatment of irrigated only at maturity, initial, development and irrigate all stages except development and mid-season stages**.**

Generally, the mean had shown decreasing trend in plant height with increasingmoisture stress level indicating that direct relationship between vegetative growth and wateruse. The result of the experiment was also in agreement with the findings of (Bozkurt *et al.*, 2006; Cakir, 2004; Istanbulluoglu *et al.*, 2002) who reported that, plant heights were reported to be higher with full irrigation and slightly deficit irrigation throughout the crop growing season.

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 is in agreement with the results of the current

This result is in line with that of (Olalla *et al*. 2004) who observed smaller sized bulbs in mild water-stressed onion plants. Similarly, (Neeraja *et al*. 1999) have also found a similar effect of irrigation levels on the height of the onion bulb.

Bulb Diameter

Onion bulb diameter was determined as an indicator of size and it was found to be significantly influenced by applied irrigation water stress levels at 5% probability (Tables 3). The largest mean diameter (6.04 and 6.01 cm) was recorded from irrigate all growth stages and irrigate all stages except initial stage respectively while irrigated only at maturity stage gave the smallest diameter (3.6 cm) having received the least amount of water at. Results indicated that bulb diameter varied proportionally with the quantity of irrigation water applied. There is therefore a linear relationship between bulb size and quantity of irrigation water applied.

A similar effect of various irrigation water levels on size of onion bulb was observed by Olalla *et al*. (2004) under drip irrigation. (Leskovar, 2010) reported that it would be possible to adjust water conservation practices to a 75 percent ETc rate, as a means to targeting high-price bulb sizes without reducing quality. These results emphasize that adequate soil moisture content along the growing period encouraged the vegetative growth of the plant and enhanced the development of large and medium bulb size which is considered to be marketable.

Table 3. Effects of Moisture Stress at different growth stages on Plant height (cm), Number of leaf per plant, Bulb height (cm) and Bulb diameter (cm) of onion

Treatment	PH(cm)	NL	BH	BD
Irrigate all growth stages	50.3^{a}	11.8^{a}	5.87^{a}	6.04^{a}
Irrigate all stages except initial stage	46.9^{ab}	11.2^{ab}	5.6^{ab}	6.01^{ab}
Irrigate all stages except development stage	45.4^{bc}	9.2^{def}	5.2^{cd}	5.4^{bcd}
Irrigate all stages except mid-season stage	41.2^{def}	9.1^{def}	5.1^{cd}	4.9^{de}
Irrigate all stages except maturity stage	45.8^{bc}	9.03^{efg}	5.5^{abc}	5.3^{cd}
Irrigate all stages except initial and development stages	43.2^{bcde}	10.18^{bcd}	5.2^{cd}	5.3^{cd}
Irrigate all stages except initial and mid-season stage	38.8^{fg}	9.02^{fg}	4.9^{de}	5.09^{cde}
Irrigate all stages except initial and maturity stages	44.8^{bcd}	10.8^{ab}	5.1^{cde}	5.7^{abc}
Irrigate all stages except development and mid-season stages	39^{fg}	8.87^{efg}	4.8^{de}	4.45^{cd}
Irrigate all stages except development and maturity stages	43.1^{bcde}	9.03^{efg}	4.4^{ef}	5.01^{de}
Irrigate all stages except mid-season and maturity stages	40.95^{ef}	9.05^{efg}	4.3^{ef}	4.45^{de}
Irrigate only at maturity stage	35.7^{g}	7.9^{h}	4.12^{f}	3.6^{g}
Irrigate only at mid-season stage	43.1^{bcde}	10.6^{bc}	5.07^{cd}	5.1^{bc}
Irrigate only at development stage	38^{gh}	8.4^{fgh}	4.3^{ef}	4.5^{ef}
Irrigate only at initial stage	36.5^{g}	8.05^{gh}	4.2^{f}	4.3^{fg}
$LSD_{0.05}$	3.7	1.06	0.57	0.7
CV (%)	5.3	6.6	6.9	9.5

*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at P < 0.05; LSD= least significant difference; CV = Coefficient of variation.

Marketable Bulb Yield

Marketable bulb yield of onion was high significant affected ($P < 0.01$) by the different treatments of soil moisture stress at different growth stage (Table 4).

Highest marketable bulb onion yield was recorded from irrigated all growth stages and followed by irrigate all stages except initial stage (Table 4). From the analysis of the ANOVA was indicated that irrigation missed at mid-season stages more sensitive than the other stages on onion marketable bulb yield. The lowest marketable onion bulb yield was observed from treatment irrigated only at maturity stage and had no significant deference with irrigated only at initial stage.

The increment in marketable bulb yield due to application of irrigation water could be attributed to the increment in vegetative growth and increased production, which is associated with increment in leaf area index, bulb diameter and average bulb weight (Neeraja *et al*., 2007).

Similar results of (Yemane *et al*. 2018, Neeraja *et al*. 1999), and (Bosch sera and Currah 2002) also showed that marketable bulb yield of onion increased with increase in amount of irrigation water.

Similarly, (Shoke *et al*. 2000) indicated that the bulb and dry matter production of onion is highly dependent on appropriate water supply. Similar results were also reported by (Kloss *et al*. 2012) who showed that dealing with improvement of water productivity is closely related to the irrigation practice of regulated deficit irrigation and has a direct effect on yield.

Unmarketable bulb yield

The analysis of variance has shown that unmarketable bulb yield of onion was not significantly affected due to treatments of soil moisture stress condition at different growth stages (Table 4).

The highest unmarketable onion bulb yields were recorded from irrigated all stages except initial and development stages followed by irrigate all stages except maturity stage. However, the control and irrigated only at mid-season stage treatment gave the lowest percentage of unmarketable bulb yield onion. The results presented in this study is inclusive and similar with previous research done by (Kumar *et al*. 2007), high soil moisture application attributes to vegetation growth and increases plant metabolic activities, which leads to marketable bulb.

Total bulb yield

Analysis of variance has shown a high significant ($P < 0.01$) difference in onion total bulb yield among the different treatments due to moisture stress condition at different growth stage (Table 4).

The total bulb yield was highest for the control treatment (30.83 ton/ha) followed by irrigated at all stages except initial stage, irrigated at all stages except initial stage, irrigated at all stages except maturity stage and irrigate all stages except development stage. Among the treatment of irrigated at all stages except initial stage, irrigated at all stages except initial stage, irrigated at all stages except maturity stage and irrigate all stages except development stage statically were not significant differences. The least total bulb yield of onion was recorded from treatment of irrigated at all stages except maturity stage and had no significant deference with treatments of irrigated only at initial stage, irrigated only at development stage, irrigated all stages except development and mid-season stages and irrigated all stages except development and maturity stages at ($p < 0.01$). A study done by (Al Moshileh 2007) also presented similar findings with this result.

Effect of moisture stress on onion water productivity

Effect of moisture stress at different growth stages had high significant ($p < 0.01$) influence during both years on water productivity. Higher water productivity was recorded for moisture stress only at initial stage with the value of 14.73 kg/m^3 and followed by irrigated only at development stage and irrigated only at maturity stage. The minimum water productivity was observed when irrigated at all growth stages, irrigated all stages except initial stage, irrigated all stages except development stage and irrigated all stages except mid-season stage respectively. The study revealed that pooled mean of WP of onion was maximized when moisture stress happens at three growth stages due to minimum water applied. As application water becomes reduced the water use productivity significantly increased. Irrigating all growth stages had recorded the lowest water productivity as compare the other treatments due to maximum irrigation application.

(Yensew and Tilahun 2009) noted that practicing deficit irrigation by reducing the amount of water per irrigation results in a decline of grain yield, increase in irrigated area and high-water use efficiency.

Similarly, (Shock *et al*., 1998), Kebede 2003, Kirnak *et al.* 2005 and Sarkar *et al*. 2008) reported that crop water use efficiency was higher at lower levels of available soil moisture.

Table 4. Effects of Moisture Stress at different growth stages on Marketable bulb yield (ton/ha), Unmarketable bulb yield (ton/ha), Total bulb yield (ton/ha) and Water productivity (kg/m^3) of onion

Treatment	**MBY**	**UMBY**	**TBY**	**WP**
Irrigate all growth stages	27.74^{a}	3.13	30.83^{a}	5.77^{f}
Irrigate all stages except initial stage	24.07^{b}	3.3	27.37^{b}	5.94^{f}
Irrigate all stages except development stage	21.83^{cd}	3.55	25.38^{bcd}	6.1^{f}
Irrigate all stages except mid-season stage	18.62^{efg}	3.46	22.08^{ef}	7.26^{ef}
Irrigate all stages except maturity stage	22.66^{bc}	3.83	26.49^{bc}	6.15^{f}
Irrigate all stages except initial and development stages	20.11^{de}	3.88	24^{de}	6.8^{ef}
Irrigate all stages except initial and mid-season stage	16.63^{gh}	2.94	19.57^{gh}	8.03^{de}
Irrigate all stages except initial and maturity stages	21.33^{cd}	3.16	24.48^{cd}	6.7^{ef}
Irrigate all stages except development and mid-season stages	14.79^{hi}	3.27	18.05^{hi}	10.09^{c}
Irrigate all stages except development and maturity stages	18.72^{ef}	3.2	21.91^{ef}	7.2^{ef}
Irrigate all stages except mid-season and maturity stages	15.05^{hi}	3.25	18.3^{ghi}	9.45^{cd}
Irrigate only at maturity stage	11.01^{k}	3.6	14.45^{k}	$12..14^{b}$
Irrigate only at mid-season stage	17.4^{fg}	3.06	20.45^{fg}	8.27^{de}
Irrigate only at development stage	13.5^{ij}	3.5	16.99^{ij}	12.41^{b}
Irrigate only at initial stage	11.89^{jk}	3.44	14.48^{jk}	14.73^{a}
$LSD_{0.05}$	2.07	NS	2.18	1.77
CV (%)	6.7	17.3	6	12.5

*Means followed by different letters in a column differ significantly and those followed by the same letter are not significantly different at $P < 0.05$; LSD= least significant difference; CV = Coefficient of variation.

Table 5: Bulb yield, Water used, Water saved, Yield reduction, Rank on yield reduction and water saved under the different moisture stress treatments

Treatment	BY (tone/ha)	WU (m^3/ha)	WS (m^3/ha)	YR (%)	YR (ton/ha)	Rank on YR	Rank on WS
Irrigate all growth stages	27.74	4183	0	0	0	1	15
Irrigate all stages except initial stage	24.07	3914	269	13.2	3.67	2	14
Irrigate all stages except development stage	21.83	3591	592.3	21.3	5.91	4	12
Irrigate all stages except mid-season stage	18.62	2580	1602.6	32.9	9.12	9	8
Irrigate all stages except maturity stage	22.66	3693	490.1	18.3	5.08	3	13
Irrigate all stages except initial and development stages	20.11	2999	1183.2	27.5	7.63	6	10
Irrigate all stages except initial and mid-season stage	16.63	2080	2102.7	40.1	11.11	11	6
Irrigate all stages except initial and maturity stages	21.33	3194	989.5	23.1	6.41	5	11
Irrigate all stages except development and mid-season stages	14.79	1486	2696.7	46.7	12.95	12	4
Irrigate all stages except development and maturity stages	18.72	2600	1582.6	32.5	9.02	8	9
Irrigate all stages except mid-season and maturity stages	15.05	1590	2592.7	45.7	12.69	12	5
Irrigate only at maturity stage	11.01	988.6	3194.4	60.3	16.73	15	2
Irrigate only mid-season stage	17.4	2102	2081	37.3	10.34	10	7
Irrigate only development stage	13.5	1091.6	3091.4	51.3	14.24	13	3
Irrigate only initial stage	11.89	749.4	3433.6	57.1	15.85	14	1

BY= Bulb yield (ton/ha), WU= Water Used (m^3/ha), WS= Water saved (m^3/ha), YR=Yield reduction (%), YR=Yield reduction (ton/ha)

Recommendation

Water scarcity is the major limiting factor for increased production and productivity in the study area. Onion is one of the major economically important vegetable crops grown in this region. The maximum onion marketable bulb yield was obtained from full irrigation (irrigated at all growth stages) followed by irrigating all stage except initial stage. In the other hand, the minimum marketable bulb yield was recorded from irrigated only at maturity stage and irrigated only at initial stage. For water productivity the maximum water productivity obtained from irrigating only at initial stage, but the minimum water productivity was obtained from full irrigation (irrigated at all growth stages). Stressing of onion at development and mid-season stage resulted in high yield reduction as compare the other stages. Therefore, it can be concluded that, in the study area enhance the water productivity stress at initial and maturity (late) stages helps to save considerable amount of water.

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