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Water productivity under deficit irrigation using onion as indicator crop

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Abstract

Improving water productivity (*WP*) through deficit irrigation is crucial in water-scarce areas. To practice deficit irrigation, the optimum level of water deficit that maximizes *WP* must be investigated. In this study, a field experiment was conducted to examine WP of the three treatments at available soil water depletion percentage (P_i) of 25% (reference), 45% and 65% using a drip irrigation system. Treatments were arranged in a randomized complete block design. The water deficit was allowed throughout the growth stages after transplanting except for the first 15 days of equal amounts of irrigations during the initial growth stage and 20 days enough spring season rainfall during bulb enlargement periods. Physical *WP* in terms of water use efficiency (WUE_f) for treatments T1, T2, and T3 was 9.44 $kg\cdot m^{-3}$, 11 $kg\cdot m^{-3}$ and 10.6 $kg\cdot m^{-3}$ for marketable yields. The WUE_f and economic water productivity were significantly improved by T2 and T3. The WUE_f difference between T2 and T3 was insignificant. However, T2 can be selected as an optimal irrigation level. Hence, deficit irrigation scheduling is an important approach for maximizing *WP* in areas where water is the main constraint for crop production. The planting dates should be scheduled such that the peak water requirement periods coincide with the rainy system.

Key words: *drip irrigation, effective rainfall, real evapotranspiration, soil water, water quality, water use efficiency*

INTRODUCTION

Improvement of irrigation water productivity (*WP*) is ever more advocated due to the increasing scarcity of water in many areas of the world and projections that indicate the need to increase agricultural production. As agriculture is the largest water consumer, and widely perceived as inefficient in its water use, even its small *WP* improvements are thought to have large inferences for local and global water budgets [SCHEIERLING, TRÉGUER 2018]. Hence, in areas where water is the limiting resource, the productivity of the irrigation water must be improved.

Water productivity is the amount or value of the product over the volume or value of water depleted or diverted [SECKLER *et al.* 2003]. Agricultural and water management practices that increase water productivity must be identified and adopted, thereby easing the pressures of water scarcity and reducing the need for construction of additional water storages [MCCORNICK *et al.* 2003]. Hence, innovations that are economically and technologically feasible to smallholder farmers for more effective and rational uses of limited supplies of water are crucial. Deficit irrigation practices and drip irrigation technologies are among several possible strategies that would enable farmers to apply limited amounts of water to their crops in the time and amount that help realize optimum water productivity.

In deficit irrigation (*DI*), water is applied deliberately to create a prescribed water deficit, which results in a small yield reduction that is less than the associated reduction in transpiration, and possible lower production costs if one or more irrigation can be eliminated [COSTA *et al.* 2007; FERERES, SORIANO 2007; KIJNE *et al.* 2003]. *DI* is a common practice in dry areas of the world where it can be more profitable to maximize crop water productivity; the saved water can be used for other purposes or to irrigate extra units of land [CAPRA *et al.* 2008; GEERTS, RAES 2009; RUIZ-SÁNCHEZ *et al.* 2010].

Many researchers studied *DI* in different areas of the world to improve water productivity of crops [HASHEM *et al.* 2018; JAT *et al.* 2018; MUBARAK, HAMDAN 2018; NAKAWUKA *et al.* 2017; NORELDIN *et al.* 2015; SHAREEF *et al.* 2018; WAKCHAURE *et al.* 2018; XUE *et al.* 2018; YANG *et al.* 2018]. However, studies on strategic scheduling of *DI* by aligning water-sensitive growth stages of a crop with short rainfall seasons on heavy clay soils (vertisols) were very limited. Hence, synchronization of *DI* with rainfall season on vertisols can help maximize water and rainfall productivity in water deficit areas.

To schedule *DI*, the level of water deficit that maximizes water productivity, must be identified scientifically. Therefore, the objective of the research was to evaluate the effects of water deficit levels on physical water productivity of onion and to identify the levels of water deficit that maximizes the economic benefit.

MATERIALS AND METHODS

STUDY AREA

Several household water-harvesting structures have been constructed since 2001 in drought-prone areas of Ethiopia including North Wollo for the attainment of food security. However, only small portions of the command areas were being cultivated. This was due to the low capacity of the storage structures and inadequate farm water management practices, which encourage water losses. As a result, the productivity of the scarce water and land was low and often accompanied with high risks of crop failure. Hence, in these areas, water rather than land is a major constraint for crop production.

The experiment was conducted in 2015/2016 at Mersa Agricultural Technical Vocational Education and Training College (ATVET) in Habru district, North Wollo, Ethiopia. Mersa is located at a latitude of 11°35’N, and longitude of 39°38’E and an elevation of 1557 m a.s.l. Long-term average meteorological data for Mersa (rainfall in mm from 1981–2014 and temperature in °C from 1994–2014) was collected from National Meteorological Agency, Kombolcha Branch, Ethiopia. Figure 1 shows the pattern of rainfall and potential evapotranspiration (*PET*) of the study area estimated by using the Hargreaves method [HARGREAVES, SAMANI 1985]. The mean minimum and the maximum daily temperature range from 12.4 to 28.8°C with an average of 20.6°C. The mean annual rainfall is 979.5 mm. The area has a bimodal type of rainfall. The first rainfall season is March to May and the second is July to September.

The annual total potential evapotranspiration of the area is 1863 mm. The highest mean monthly potential evapotranspiration occurs in June 1986 (189 mm) and the lowest in January 1986 (129 mm). Based on Figure 1, the potential evapotranspiration exceeds the rainfall for about 10 successive months from September to July. Hence, irrigation is required in the area for crop production.

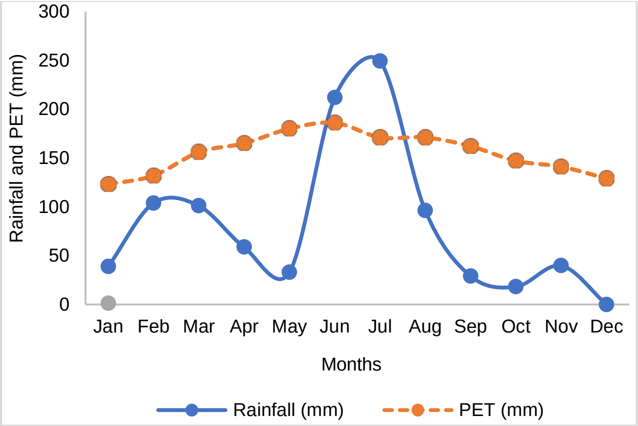

Fig. 1. Long-term average rainfall (mm) (1981–2014) and potential evapotranspiration – *PET* (mm) (1994–2014)

EXPERIMENTAL DESIGN

Three experimental treatments T1, T2, and T3 were set based on different available water depletion levels (P_i). The crops at T1, T2, and T3 were irrigated at P_i = 25%, 45%, and 65%, respectively. The P_i = 0.25 is the management allowed depletion (*MAD*) for onion [FAO undated]. Hence, T1 was set as a reference treatment. The treatments were laid in a randomized complete block design (RCBD) in which each treatment was replicated three times. Crops had been exposed to water stress throughout the growth periods except for the first 15 days of equal amounts of irrigation after transplanting onion seedlings during initial growth stages and 20 days in rapid bulb enlargement periods during which the crop had met full water requirement from spring season rainfall.

The onion (*Allium cepa* var. Adama red), which is the most commonly grown variety under irrigation in the study area, was selected as an indicator crop for water productivity study. The onion was sown on 8 December 2015 and transplanted on 22 January 2016 to 1.5 m wide and 10 m long experimental plots of level beds. Fertilizer UREA 100 kg·ha^{-1} was applied one month after transplanting in the vegetative growth stage. The total experimental area of the nine plots was 215 m^2. The space between plots and between blocks was 0.5 m and 1.0 m, respectively. The net total area without paths was 135 m^2. Numbers of rows per plot were six (three double rows with a spacing of 0.5 m × 0.2 m × 0.1 m). The number of seedlings was 600 per plot and a total of 5400 from all plots.

INSTRUMENTATION

The instrument used for soil water measurement was HydroSense (HS) [Campbell Scientific Inc. 2001]. Only one HS was utilized in this study. HS has 12 and 20 cm long probe rods for soil water monitoring in the upper 20 cm soil profile. Since HS needs calibration on clay soils, calibration equations were developed by curve fitting techniques as shown in Figure 2.

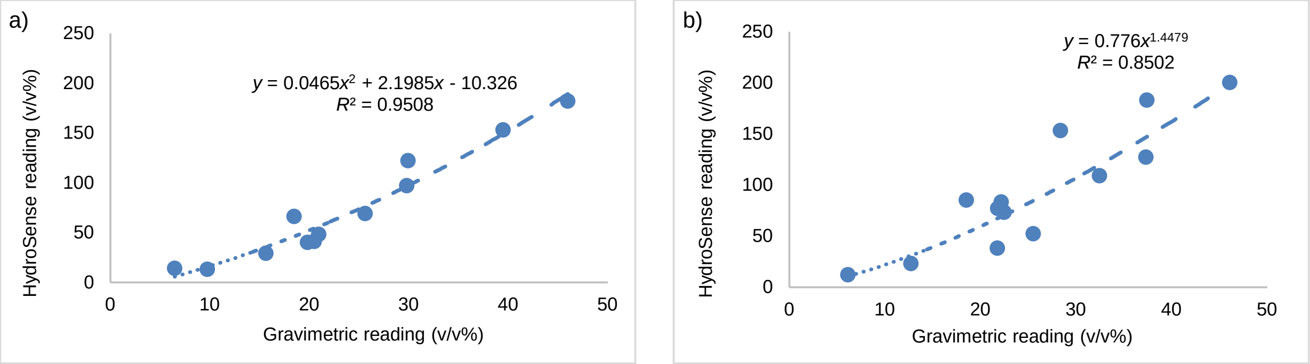

Fig. 2. HydroSense calibration equations for two soil depths: a) 0–12 cm, (b) 0–20 cm; R^2 = coefficient of determination, V = volume; source: own study

SOIL CHEMICAL AND PHYSICAL PROPERTIES

The soil in the experimental area is homogeneous Eutric Vertisols [BECH, WAVEREN 2002]. Hence, only one representative soil profile of 130 cm deep and 100 cm by 120 cm wide was opened and the soil samples were collected from each 20 cm interval layers. Soil physical and chemical properties were analysed following standard procedures.

- Soil chemical properties

The soil chemical properties of the experimental site: organic matter (OM), soil pH (pH), saturation extract (ECe), sodium absorption ratio (SAR) are shown in Table 1. As all the values of *ECe* in each soil profile layers were in the range of 0–2 dS·m^{-1}, the soil was non-saline with negligible salinity effects on crop yield [RICHARDS 1954]. Moreover, the salinity of these soil layers was below the threshold salinity level (1.2 dS·m^{-1}) for onion (*Allium cepa*) which will not result in yield loss [SHAHID, RAHMAN 2011]. The organic matter content was medium [WALKLEY 1947] and the soil pH was alkaline. Using *ECe*, *SAR* characteristics and soil pH, the soil was classified as normal soil [RICHARDS (ed.) 1954]. Therefore, the soil was suitable for the onion and other sodium-sensitive plants.

Table 1. Soil chemical properties of the experimental site

Soil profile depth (cm)	Organic matter (%)	pH	*ECe* (dS·m^{-1})	*SAR*
0–20	3.77	7.91	0.85	0.38
0–40	3.72	7.97	0.10	0.61
40–60	3.78	7.09	0.70	0.66
60–80	3.81	7.84	0.95	0.63
80–100	3.78	8.05	0.71	0.79
100–120	0.54	7.03	0.89	0.58

Source: own study.

- Soil physical properties

Soil physical properties of the experimental site were shown in Table 2. Four undisturbed soil samples, taken by core sampler from each soil layers (20 cm interval) within 80 cm soil depth, were saturated with water and put in pressure plate apparatus (at 20, 33.33, 100 kPa suctions) to determine the soil moisture content at each suction pressures. The soil moisture content at 33.33 kPa was taken as moisture content at field capacity (θ_{FC}). Moisture contents for suction pressures less than 10 kPa (water column heights of 1.0 cm, 1.5 cm, 1.837 cm, and 2.0 cm) were determined using sandbox apparatus utilizing a hanging water column. For the determination of suctions higher than 100 kPa (500 and 1500 kPa suction), disturbed samples were used. The disturbed samples were put on pressure plates (wetted ceramics) and exposed to high suction pressures up to 1500 kPa. The moisture contents calculated at 1500 kPa was taken as moisture content at the permanent wilting point (θ_{PWP}).

The soil water contents were determined at pressure heads of 20, 33.33, 100, 500, 1500 kPa and 1.0, 1.5, 1.837, and 2 cm water heights, and converted to the logarithms of the absolute values of these pressure heads (in cm water height), i.e. pF. These pF values were plotted against their corresponding volume fractions of soil water content θ (cm^3·cm^{-3}) to develop soil-water characteristic curve (Fig. 3) for the upper four soil layers. Once these pF curves were developed for a field, volumetric soil water contents can be easily estimated from the curves by using pressure

Table 2. Soil physical properties of the experimental site

Soil depth (cm)	ρ_b (g·cm^3)	θ_{FC} % (cm^3·cm^{-3})	θ_{PWP} (cm^3·cm^{-3})	*AW* (mm)	Clay (%)	Silt (%)	Sand (%)	Texture
0–20	1.26	39.30	31.19	16.22	56.89	31.47	11.65	clay
20–40	1.45	43.41	37.16	12.50	54.46	35.11	10.42	clay
40–60	1.41	47.52	36.50	22.04	54.72	34.23	11.05	clay
60–80	1.38	48.80	39.07	19.46	51.97	34.49	13.54	clay
80–100					58.02	27.31	14.67	clay
100–120					28.57	18.13	53.30	SCL

Explanations: ρ_b = bulk density, θ_{FC} = soil water content at field capacity, θ_{PWP} = soil water content at permanent wilting point, *AW* = available soil water SCL = sandy clay loam.
Source: own study.

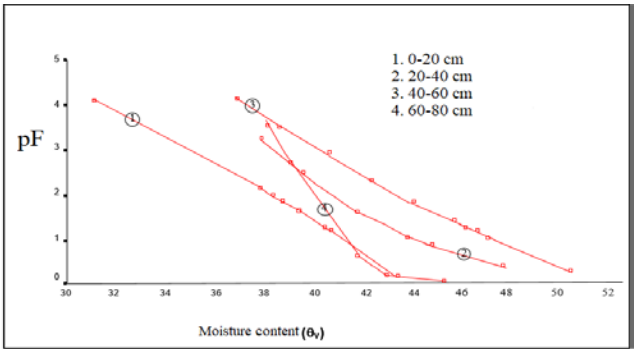

Fig. 3. Soil moisture characteristic curve (pF versus θ %); source: own study

head readings of tensiometer in the absence of other volumetric soil moisture measuring instruments such Hydro-Sense probe or time-domain refractometer (TDR).

Physical properties of the soil including moisture content at field capacity (θ_{FC}), moisture content at the permanent wilting point (θ_{PWP}) and soil bulk densities are presented in Table 2. The available soil water (*AW*) for each soil depth interval or plant root depth (D_r) was estimated using Equation (1). The available soil water depletion was determined using Equation (2). These values are expressed in mm. The θ_{FC} and θ_{PWP} can also be estimated from the four soil water characteristics curves (Fig. 3) at pF values of 2.52 and 4.2, respectively. The value of D_r is 20 cm for each soil layer. Hence, the *AW* of the soil within 80 cm soil depth was 70.22 mm.

$$AW = \frac{(\theta_{FC}\% - \theta_{PWP}\%)\, D_r(\mathrm{cm})}{10} \tag{1}$$

$$AW_{Pi} = P_i\, AW \tag{2}$$

Where: AW_{Pi} = available water depletion for treatment i, P_i = percentage of *AW*.

P_i = 0.25, 0.45, and 0.65 for T1, T2 and T3, respectively. The soil textures were analyzed by the pipette method following the standard procedures. The soil texture is clay in the upper 100 cm depth and sandy clay loam at 100–120 cm depths (Tab. 2). The soil is vertisol as it has 30% or more clay content to a depth of 100 cm or more. The soil bulk densities were estimated from the ratio of dry soil weight to the volume of the soil sample.

IRRIGATION WATER QUALITY

Knowledge of irrigation water quality is crucial to devise important management practices for long-term productivity. A water sample taken from groundwater was analyzed following the standard procedures [APHA 1917]. Then, the suitability of water for onion irrigation was evaluated according to AYERS and WESTCOT [1985] and RICHARDS (ed.) [1954]. The results for electrical conductivity – *EC* (dS·m), pH, sodium adsorption ratio (*SAR*), and residual sodium carbonate (*RSC*) were 0.74, 7.95, 2.26 and 6.48, respectively. The total dissolved solids (*TDS*) was 471.04 $\mathrm{mg{\cdot}dm^{-3}}$. The salinity in terms of *EC* or *TDS* was found to be within the usual range of irrigation water [AYERS, WESTCOT 1985].

Based on *EC* value, the irrigation water was classified as C2 (medium salinity) [RICHARDS (ed.) 1954]. However, as onion crop is moderately tolerant to salinity, the potential of its yield reduction from measured *EC* was none. Based on *SAR*, the water was classified as S1 (low sodium hazard) which can be used on almost all soils with little likelihood of soil salinity development. Generally, the water was classified as C2S1 (medium salinity and low sodium hazard). The degree of restriction of the water for irrigation use was slight in terms of *EC* and *SAR* content [AYERS, WESTCOT 1985]. Hence, irrigation water could be used for onion production. The pH of the water sample was 7.95, which was within the normal range of 6.5 to 8.4 for irrigation water.

IRRIGATION SYSTEM AND SCHEDULING

The irrigation system was bucket gravity drip irrigation as it was shown in a photograph taken at the late season stage (Fig. 4). The bucket system consisted of three drip lines, each 10 m long, and bucket of 40 $\mathrm{dm^3}$ for water storage. Each bucket drip irrigation system has a control

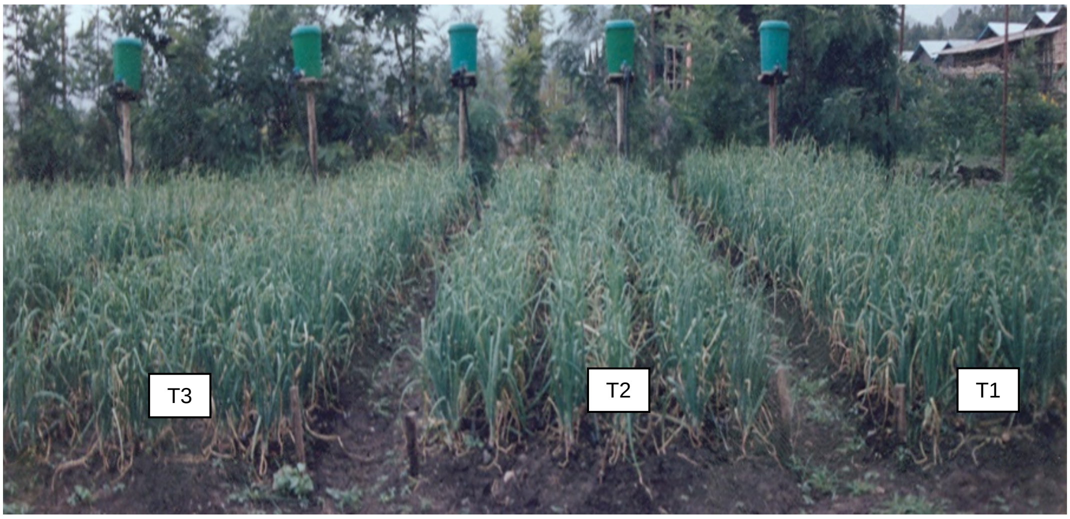

Fig. 4. Experimental plot under drip irrigation system; T1–T3 = treatments; source: own elaboration

and filter. The buckets were supported by bucket stands, with the bottom of the buckets seated at 1.25 m above the planting surface. Each bucket system has three drip lines in which one drip line was irrigating two rows of onion.

All treatments were irrigated from initially set volumetric soil water contents (θ_p) at available soil water depletion levels (p) to volumetric soil water content at field capacity (θ_{FC}) with the help of HydroSense soil water sensor. The volume of irrigation water was estimated using Equation (3).

$$V_{Irr} = \frac{(\theta_{FC}\% - \theta_p\%) D_r A_e}{100} \tag{3}$$

Where: V_{Irr} = irrigation water applied (m^3), D_r = depth of root zone which is equal to the length of HydroSense probe road (m), A_e = wetted area under drip irrigation (m^2).

From field observation and measurement, maximum A_e of a single plot under drip irrigation was 9 m^2 which is 60% of 15 m^2 plot area. Besides, V_{Irr} was measured using bucket calibrated to its equivalent depth. As the available climatic data in the experimental site were only temperature and rainfall amount, Hargreaves and Samani [1985] temperature method (Eq. 4) was used to estimate reference evapotranspiration (ET_o) for its simplicity and the accuracy of the estimates.

$$ET_O = 0.0023 Ra\, Td^{0.5} (T + 17.8) \tag{4}$$

Where: Ra = evaporation equivalent of extraterrestrial solar radiation (mm·day^{-1}), Td = difference between daily $T_{\max}$ and $T_{\min}$ (°C), T = average temperature (°C) for the period.

Ra for the experimental area was interpolated from extraterrestrial radiation – Ra (mm·day^{-1}) for northern hemisphere which is available in paper by Allen and Pruitt [1991].

Real evapotranspiration (ET_r) in mm·day^{-1} during a period of t days (irrigation interval) was computed using the following formula [Aboukhaled *et al.* 1975].

$$ETr = \frac{M_O}{t}\left[1 - ae^{-\left(\frac{E_{max}t}{aM_O} - \frac{1-a}{a}\right)}\right], \text{ provided } t \geq \frac{(1-a)M_O}{E_{\max}} \tag{5}$$

Where: M_o = the maximum available soil moisture (mm·m^{-1}), a = the fraction of the remaining soil moisture at which the reduction in transpiration starts, $E_{\max}$ = maximum atmospheric evaporative demand (mm). In this study, reference evapotranspiration was used as $E_{\max}$.

Effective rainfall (P_e) was computed from monthly total rainfall (P_{tot}) and monthly real evapotranspiration (ETr) of the crop using USDA soil conservation service method [Dastane 1974].

$$P_e = P_{tot}^2 \left[\left(\frac{0.025}{E_{re}}\right) - 0.001\right] + P_{tot}(0.6 + 0.0016 E_{re}) \tag{6}$$

The numbers of irrigations after transplanting were 51, 33, and 26 in treatments T1, T2, and T3, respectively. About 300 dm^3 of water was used on each bed before transplanting to prepare planting beds and to determine the maximum area wetted (A_e) by a single emitter irrigating the soil to field capacity. The spacing of transplants was decided based on the size of A_e.

The volume of water applied in the growing season was 3.194, 2.260, and 1.935 m^3 for T1, T2, and T3, respectively. The corresponding total amount of water applied to the treatments, including 300 dm^3 used before transplanting was 3.494, 2.560 and 2.235 m^3. Considering the A_e of 9 m^2, the volume of water applied to each treatment from the 89.36 mm of effective rainfall would be 0.804 m^3. The total amount of water supplied to the crop (irrigation plus effective rainfall) was 4.3, 3.36 and 3.04 m^3 for T1, T2 and T3, respectively (Tab. 3).

ONION BULB YIELD

Samples of every 10th tagged onion bulbs from four inner rows in each treatment plots were harvested, graded to marketable and unmarketable based on disease, insect damage, and size of bulbs. Bulb weight measurement was taken using a sensitive balance. Onion bulbs below 20 g were considered as unmarketable [Desalegne, Aklilu 2003].

WATER PRODUCTIVITY (WP)

- Physical water productivity in terms of field water use efficiency

Physical water productivity in terms of field water use efficiency – WUE_f (kg·m^{-3}) was determined from the ratio of crop yield (Y) in kg to the amount of water supplied – V (m^3). V is the sum of irrigation water (V_{Irr}) and effective rainfall (P_e).

$$WUE_f = \frac{Y}{V} \tag{7}$$

- Combined physical and economic water productivity

A combined physical and economic water productivity (WP_{pe}) was estimated by dividing the gross revenue (R) of the onion bulb yield in Ethiopian birr (ETB) (ETB = 0.029 USD) by the amount of irrigation water applied – V_{Irr} (m^3).

Table 3. The water used, marketable yield and water productivity of onion

Treatment	V_{Irr} (mm)	P_e (mm)	$(V_{Irr} + P_e)$ (m^3) (a)	W_p (b)	C_{Irr} (c)	Y (kg) (d)	Y_p (e)	R (f) = (d·e)	WUE_f (d/a)	WP_{pe} (f/a)	WP_e (f/c)
T1	388.22	89.36	4.30	2	6.988	40.6^a	2	81.2	9.4^a	23.24^a	11.6^a
T2	284.44	89.36	3.36	2	5.112	37.0^b	2	74.0	11.0^{bc}	28.95^{bc}	14.5^{bc}
T3	248.33	89.36	3.04	2	4.470	32.2^c	2	64.4	10.6^{bc}	28.81^{bc}	14.4^{bc}

Explanations:: V_{Irr} = irrigation water (m^3); P_e = effective rainfall (mm); W_p = water price (ETB·m^{-3}); C_{Irr}= cost of irrigation water (ETB·m^{-3}); Y = marketable onion bulb yield; Y_P = onion price (ETB·kg^{-1}); R = revenue (ETB·m^{-3}); WUE_f = water productivity in terms of field water use efficiency (kg·m^{-3}); WP_{pe} = combined physical and economic water productivity (ETB·m^{-3}); WP_e = economic water productivity (ETB:ETB); levels connected by different letters are significantly different at 0.05 level.

Source: own study.

The farm gate price of 2 ETB·kg^{-1} of onion at harvest time was used to estimate the revenue.

$$WP_{pe} = \frac{R}{V_{Irr}} \quad (8)$$

- Pure economic water productivity

Pure economic water productivity (WP_e) was estimated by dividing the gross revenue of the onion bulb yield (ETB) by the value of irrigation water applied (ETB·m^{-3}). Since irrigation water charge had not been started in the locality, domestic water supply charge from the office of Mersa Municipality Water Supply Service was used to evaluate the WP_e. As irrigation water applied to each plot of treatments per month was less than 5 m^3 (Tab. 3), the water charge of 2.00 ETB·m^{-3} of water was used for estimation of the cost of irrigation water (C_{Irr}) only to show how deficit irrigation improves WP_e.

$$WP_e = \frac{R}{C_{Irr}} \quad (9)$$

DATA ANALYSIS

The mean onion bulb yield and water productivity values were analyzed by One-Way ANOVA: multiple comparison tests at a significance level of 0.05 using IBM SPSS statistics version 25 (Windows).

RESULTS AND DISCUSSION

THE EFFECT OF DEFICIT IRRIGATION ON ONION BULB YIELD

Mean weight of onion bulb yield for each treatment was presented in Table 3. The reference treatment T1 had the highest mean marketable onion yield of 27 083.3 kg·ha^{-1} whereas treatment T2 had the lowest yield of 21 471 kg·ha^{-1}. Based on the mean comparison, yields from deficit treatments were significantly smaller than that of T1 at the 0.05 level. Onion bulb yield was increased at higher levels of water applications and decreased at lower levels. Hence, deficit irrigation resulted in crop water stress and reduced onion bulb yields. However, deficit irrigation saved 26.73% and 36% of the irrigation water applied under T2 and T3, respectively as compared to T1.

WATER PRODUCTIVITY

Physical water productivity

Physical water productivity in terms of field water use efficiency (WUE_f) of treatments T1, T2 and T3 were 9.4 kg·m^{-3}, 11 kg·m^{-3} and 10.6 kg·m^{-3} for marketable bulb yields, respectively (Tab. 3). The WUE_f values are the indicators of the quantity of onion yield produced from every cubic meter of water applied (m^3) to the crop in the field. This means, for example, in treatment T2, 11 kg of marketable onion bulb yield was produced from every cubic meter of irrigation water and effective rainfall supplied to the crop.

Therefore, the WUE_f values can help those who engaged in irrigation agriculture in the selection of the irrigation system they use and the irrigation management system they apply when making irrigation decisions. Treatment T2 recorded the highest WUE_f and T1 the lowest value. The WUE_f of marketable bulb yield obtained from T2 was 17% and 3.8% higher than that of T1 and T3. The difference in water productivity was attributed to the difference in irrigation water applied, as other production factors were constant for all treatments. In T3, the decrease in water productivity was due to reduced yield, which is, in turn, the result of below optimal irrigation water applications. The lowest water productivity of T1 was due to the lower rate of production at above the optimal rate of irrigation water applications.

The mean WUE_f difference between T1 and deficit treatments (T2 and T3) was significant for marketable onion yield. However, there was no significant WUE_f difference between T2 and T3. Hence, in water deficit areas where the land and labour are not a limiting factor of production, water saved by treatment T2 and T3 could be used to produce extra yield by allocating the saved water to additional cultivated land. As there was no significant difference in WUE_f between T3 and T2, T3 (with available water depletion 65%) can be taken as the best irrigation practice in terms of WUE_f in areas where water scarcity is severe. However, to minimize the chances of crop failure and maximize the onion bulb yield, it would be more advantageous to practice deficit irrigation at available water depletion of 45% (T2).

Economic water productivity

Deficit treatments significantly improved both pure economic water productivity (WP_e) and combined physical and economic water productivity (WP_{pe}) at 0.05 levels (Tab. 3) in comparison to the reference treatment. However, there is no significant difference betweenT2 and T3 in both WP_{pe} and WP_e. The highest WP_{pe} was 28.95 ETB·m^{-3} for treatment T2 and the lowest was 23.24 for treatment T1. The highest and the lowest WP_e were 14.5 ETB:ETB and 11.6 ETB:ETB for treatment T2 and T1, respectively.

The WP_{pe} and WP_e of T2 were greater than that of T1 by 24.57% and 25%, respectively. Whereas, the WP_{pe} and WP_e of T3 were greater than that of T1 by 23.97% and 24.14%, respectively. In general, economic water productivity was highest under deficit irrigation and its value was improved by about 25%.

CONCLUSIONS

This research evaluated the deficit irrigation management strategy for the objective of improving water productivity of drip-irrigated onion (*Allium cepa* var. Adama red) bulb yield production. It was concluded that deficit irrigation significantly decreased crop yield but improved both physical and economic water productivity by about 25% and saved a significant amount of irrigation water (27% to 36%). Among all treatments, deficit irrigation at available water depletion percentage (P_i) of 45% (T2) can be selected for irrigation scheduling in the study area as its water productivity in terms of field water use efficiency and economic water productivity are significantly greater than that of T1, and greater than that of the other deficit treatment (T3). In general, deficit irrigation is the main approach in increasing water productivity in areas where water is a major constraint for crop production. Therefore, deficit irrigation was recommended to be practiced in water deficit areas for maximizing water productivity. In this case, the planting dates should be scheduled such that the critical growth periods of the onion crop, for example, onion bulb formation and enlargement stages, coinciding with the rainy system.

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