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Determination of Optimal Irrigation using Soil Moisture Depletion on Yield, Yield Component and Water Productivity of Onion at Odo Shakiso District, Guji zone, Southern Ethiopia

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Abstract

Irrigation scheduling is the use of water management strategies to prevent over application of water while minimizing yield loss due to water shortage or drought stress. The experiment was performed at Odo shakiso District on farm in the 2020/21 and 2021/22 irrigation seasons, with the objective of determining the optimum irrigation schedule on Yield, yield component and water productivity of Onion based on the available soil moisture depletion levels. The experiment was carried out in RCBD with three replications, randomly assigned to the experimental plots with treatments. Five available soil moisture depletion levels (20% ASMDL, 40% ASMDL, 60% ASMDL, 80% ASMDL and FAO recommended ASMDL) were used as treatment. The results obtained of two years of research showed that different of levels of soil moisture available had a significant effect ($P< 0.05$) on bulb diameter, bulb weight, unmarketable bulb yield, marketable bulb yield, and water productivity. However, different soil moisture depletion levels showed no significant difference on plant height. The highest bulb diameter (4.25 cm) and marketable bulb yield (363.9 qt/ha) were recorded at 60%ASMDL. The highest efficiency of water use on marketable onion yield (9.487 kg/m^3) was also attained at 60%ASMDL, which was statistically similar with FAO recommended ASMDL treatment. On the other hand the minimum efficiency of water use (6.234 kg/m^3) was recorded at 40 per cent ASMDL. Therefore, based on the findings of the current experiment, it is recommended that using 60%ASMDL under furrow irrigation system for onion to be grown in areas around Shakiso and similar agro-ecology as best options to increase yield and water use efficiency for the production of onion.

Keywords: ASMDL • Onion • Irrigation • Water use

Introduction

In Ethiopia, the population is growing rapidly and is expected to continuously increasing, which unsurprisingly leads to increased food demand. To sustain self-sufficiency in the food supply, one feasible option is to raise the production and productivity per unit of land through irrigation. Water is essential for crop production and best use of the available water must be made for efficient crop production and high yields. The problem of irrigation consists of when to irrigate, and how much to irrigate. Appropriate amount and timing of irrigation water applications is a central decision for a farm manager to meet the water needs of the crop to avoid yield loss and maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources. Determining crop yield response to irrigation is crucial for crop selection, economic analysis and for practicing effective irrigation management strategies. Furthermore, this enables to know the time of irrigation as well as to optimize yield, water use efficiency and ultimate profit Under limited irrigation water supply, Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas. Irrigation scheduling is the technique of applying water on a timely and accurate basis to the crop, and is the key to conserving water and improving irrigation performance and sustainability of irrigated agriculture (Lopez, 2009). The aim of irrigation scheduling is to keep soil moisture within a desired range, usually between field capacity (full point) and a predetermined refill point for optimal growth. Onion is one of the most important cultivated vegetable crops commercially grown and has economically important role in Ethiopia. The country has enormous potential to produce the crop throughout the year both for domestic use and export market. Ever since the crop is distributed to different parts of the country, it is widely cultivated as a source of income by many farmers in many parts of the country as a whole. Onion production also contributes to commercialization of the rural economy and creates many off-farm jobs. Onion yield is reduced by both over- and under-irrigation. A mere 10 percent deviation from optimum water application for the growing season may begin to decrease yield. Yield reductions due to over irrigation can be attributed to poor soil aeration, increased disease problems, and leaching of nitrogen [1,2].

Even though, irrigation practiced has been long time, farmers experience in irrigation water management was very limited in the study area. Recently with the development and expansion of modern irrigation infrastructure in the country, improvement of irrigation water management is very important to address the on-farm water management. Therefore, monitoring on farm available soil moister depletion levels and irrigation scheduling are efficient technology which help to improve irrigation water management and increase irrigation water use at field condition. Traditional irrigation practices are being used for cultivating onion crops in different areas. However, irrigation water requirement including irrigation scheduling are not known. The soil moisture depletion level for onion should be 0.25. However, the recommendations are needed to be verified on the operational environment since the crop water requirement is dependent on the type of soil and climatic condition. Crop water requirements vary in time and space due to climate, management, phonological stage of the crop, and cultivar, then, their assessment must be local for effective use of available water resource, it is relevant to determine the amount of water need by the crop and the right time of water application (irrigation scheduling). The general objective of this study was therefore, to evaluate the responses of onion to irrigation regime (when and how much) and to identify WP under optimal irrigation regime [3-6].

Materials and Methods

Description of the study area: The experiment was carried out in 2020

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and 2021 at Odo Shakiso District under Bore Agricultural Research Center for two consecutive years. The area is characterized by bimodal rainfall pattern with longest rain season (locally known as Hagayya) and a short rainy season (locally known as Ganna). The District has geographical location of 5º2'29" - 5º58'24" northing latitudes and 38º35'0" - 39º13'38" easting longitudes. The district is characterized by three agro- climatic zones, namely highland (Bada), accounting for about 33%, midland (Bada dare), accounting for about 47% and lowland (Gamoji), accounting for about 20% district area coverage. Most of the earth surface of the district is ups and down of the land surface with an elevation ranging 1500-2000 m a.s.l. in the larger southern portion of North Western part. Plains, dissected hill plateau and mountain as well as valleys and gorges characterized the relief of the district. The mean annual rain fall about 900mm and the mean annual temperature of the district is 22.50C. The soil textural class of the experimental area is clay with pH of 6.95. The most widely cultivated crops in the district are wheat, barley, maize, teff, Haricot bean, chick peas, Linseed, rapeseed, fruits, and Vegetable (District statistical abstract of 2014/15) (Figure 1).

Soil sampling and analysis: Soil samples were collected from two 0-30 cm and 30-60 depths along the diagonal of the experimental field to determine Soil texture, pH, Electrical conductivity (EC), Organic Carbon (OC), Bulk density (BD), Field capacity (FC) and permanent wilting point (PWP). The particle size distributions in the soil profiles were determined using hydrometric method. Soil pH was measured in 1:2.5 soil: water mixture by using a pH meter. Organic carbon content was determined by titration method using chromic acid (potassium dichromate + H_2SO_4) digestion according to Walkley and Black (1934) method. Field capacity and permanent wilting point of the soil were analyzed through ceramic plate apparatus in the laboratory with a pressure of 1 bar (for field capacity) and 5 bars (for permanent wilting point). The soil was also assessed for infiltration using the Double Ring Infiltrometers. Bulk density of the soil was determined using undisturbed soil samples using core sampler having the dimension of 2.5 cm diameter and height of 2.5cm (12.27 cm³). Then the bulk density was calculated as the ratio of dry weight of the soil to known cylindrical core sampler volume [7,8].

$$pb = \frac{M_c}{V_t} \quad (1)$$

Where, p_b : Bulk density (g/cm³), M_c : Dry weight of soil (g), V_t : Volume of core sampler (cm³).

Experimental design and treatment application: The experiments were included five levels of soil moisture depletion depending on FAO soil moisture depletion level. The five level of ASMDL were (20% ASMDL, 40% ASMDL, 60% ASMDL, 80% ASMDL and 100%ASMDL (FAO recommended ASMDL)). Predetermined amount of irrigation water were applied to each plot using Partial flume. Irrigation scheduling were based on the percentage depletion of available soil water in the root zone. The experimental treatments were laid out in Randomized Complete Block Design (RCBD) with three replications, in which the soil moisture depletion levels (SMDL) were randomly assigned to the experimental plots. The experiment was tested on Bombay Red onion variety with experimental plot area of 3 x 4 m (12m²). The space between plots and replications were 1m and 1.5m respectively. Onion seedling was transplanted on ten rows with eight harvestable rows. Plant row spacing across furrow, across ridge and along the ridge was 40cm, 20cm and 10cm respectively. All agronomic practices were implemented as a time of requirements (Table 1). Where: *ASMDL- available soil moisture depletion level according to FAO (33). **Table 1.**Treatment setting for field experiment.

Table 1. Treatment setting for field experiment.

Treatment	Description
ASMDL1	20% ASMDL
ASMDL2	40% ASMDL
ASMDL3	60%ASMDL
ASMDL4	80% ASMDL
ASMDL5	100% ASMDL*(Control)

Crop water requirement: Primarily 15 years (2004-2018) climatic data includes monthly maximum and minimum temperature relative humidity, wind speed, sunshine hour's data was collected. Daily ETo (mm/day) values were computed from the collected data using FAO CropWat 8.0 windows model. Besides, the effective rainfall was calculated with this model. The Kc-values was obtained from FAO Irrigation and Drainage Paper No. 56 then, crop water requirement was calculated from FAO, 2010.

$$ETc\ (mm/day) = ETo \times Kc \quad (2)$$

Where:

ETc=crop water requirement

ETo=estimation of reference crop evapotranspiration in mm/day and

Kc=crop coefficient

Soil moisture determination: The soil sample was collected using soil auger based on the root depth of the crop (0-15 cm, 15-30 cm and 30-60 cm) for monitoring the moisture content of the soil and oven dried at 105°C until the change in weight is constant. Then the oven-dried sample was weighed to determine the water content of the soil. The water content in the soil was determined in weight basis using the following equation. Then, the gravimetric water content was converted to volumetric water content by multiplying with the soil bulk density and root depth of onion to get available field/current moisture at the time of irrigation [9].

$$\phi dW = \frac{W_{ws} - W_{ds}}{W_{ds}} * 100 \quad (3)$$

Where Wws=weight of wet soil (g), ϴdw=water content expressed on weight basis in (%) and Wds=weight of dry soil (g)

Infiltration capacity of soil: The soil infiltration capacity was measured

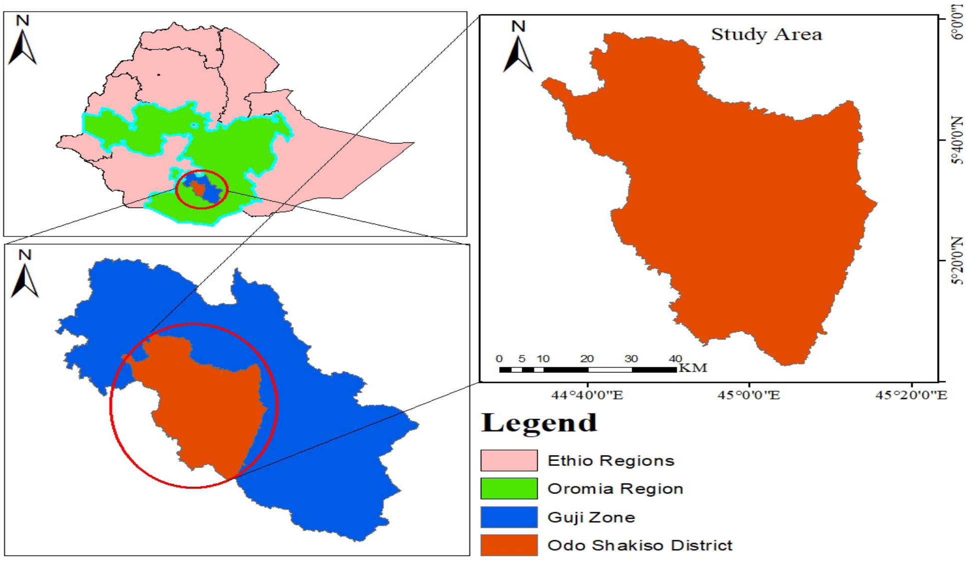

Figure 1. Location Map of the study area.

using the double ring Infiltrometers.

Determination of irrigation requirement and irrigation scheduling: The total available water (TAW) for crop use in the root zone was calculated from field capacity and permanent wilting point using following expression.

$$TAW = 1000 \sum (\phi FC - \phi PWP) * BD * Zr \quad (4)$$

Where: TAW: volumetric total available water in the root zone (mm/m) FC: volumetric moisture content at field capacity (m^3/m^3) and PWP: volumetric moisture content at permanent wilting point (m^3/m^3). BD: bulk density (gm. /cm^3)

Then, RAW (mm) which is equal to net irrigation depth (dnet) was computed from total available water using the following equation:

$$RAW = TAW * p \quad (5)$$

Where: RAW in mm which is equal to net irrigation depth (mm) TAW: Total available water ρ: water depletion fraction/management allowable depletion (%), for onion (ρ =0.25). Then, irrigation interval was computed from the expression FAO, 2010:

$$Interval(days) = \frac{RAW}{Etc} \quad (6)$$

Where, RAW in mm which is equal to net irrigation depth (dnet) and ETc in mm/day is crop evapotranspiration

Then, gross irrigation requirement (dg):

$$dg = \frac{dnet}{Ea} \quad (7)$$

Where, dg in mm and Ea is the field irrigation application efficiency of a short, end diked furrow was taken as 60%. The amount of water applied to the experimental field was measured by 3-inch Parshall flume. The time required to deliver the desired depth of water into each plot was calculated using the equation.

$$t = \frac{dg \times A}{6 \times Q} \quad (8)$$

Where: dg=gross depth of water applied (cm) t=application time (min) A=Area of experimental plot (m^2) and Q=flow rate (discharge) (l/s).

Irrigation water application: The values of ETo estimated using the CROPWAT model based on climatological parameters need to be adjusted for the actual crop. A 3-inch standard Parshall flume was installed near the upstream of the experimental field to measure irrigation water applied to individual plots. An average discharge was diverted into the experimental field from a canal. This discharge was allowed to flow into one plot at a time. With the aid of a calculator and a stopwatch, the flow discharge into each plot and the time required to apply the desired depth of water was immediately calculated as soon as water was introduced into the plot. Water was allowed into the plot and each furrow for the time calculated. Immediately after the desired depth, applied plots were closed with the channel banks to stop water from entering the plots.

Water productivity: Water productivity was estimated as a ratio of fruit yield of onion to the total crop water consumption by evapotranspiration (Etc) through the growing season and it was calculated using the following equation.

$$Cwp = \frac{Y}{ET} \quad (9)$$

Where, CWP is crop water productivity (kg/m^3), Y Onion yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Data collection

Plant height: Plant height (cm) was computed for five randomly selected plants using measuring tape from the ground level up to the tip of the leaf in the experimental plot at physiological maturity.

Bulb weight: Bulb weight (gm $plant^{-1}$) was measured on five randomly selected single onion bulbs and their average weight were computed.

Bulb Diameter: Bulb diameter (cm) was measured at the widest circumstance of the bulb of five sample plants in each experimental unit. Bulb diameter was determined as one of the parameters of crop quality.

Marketable yield (QT/ha): Marketable yield (QT/ha) is healthy and non-diseased average to large-sized Bombay Red onion bulbs were recorded from central three harvestable rows. The marketable onion was sorted out of the total onion bulb depending on the color of the bulb, absence of surface defects on onion (due to insect, disease, or physiological disorders), and firmness [9,10].

Unmarketable onion (kg/ha): Bombay Red onion bulbs were recorded as the weight of unmarketable onion from central three harvestable rows. Unmarketable onions were sorted out of marketable onion yield depending on the disease on the bulb, discoloration, cracks, damage by insect, the smallness of size, and avoiding unwanted onion by the consumer.

Data analysis

All necessary data collected were managed properly using the Genstat software 18th edition. When the treatment effect was found significant, the mean separation was tested using least significant difference (LSD) at 5% probability level.

Table 2. Soil physical properties of experimental site.

Soil Depth (cm)	BD (g/cm^3)	FC mass base(%)	PWP mass base(%)	TAW (mm)	Textural Class			
					%Sand	%Silt	%Clay	
0-30	1.34	25.8	18.0	31.4	38	36	26	Loam
30-60	1.37	25.4	17.9	31.0	32	28	40	Clay
Total available water in 60 cm				62.4				

Table 3. Soil Chemical properties of experimental site.

Soil Depth (cm)	pH(H_2O)	ECe(dS/m)	%OC	%OM
0-30	6.5	0.430	1.97	3.40
30-60	7.4	0.192	1.30	2.24
Average	6.95	0.311	1.64	2.82
Where: EC: Electrical conductivity, OC-Organic carbon and OM- organic matter				

Table 4. Bulb weight significant different with different irrigation water application of available soil moisture level.

Treatments	PH (cm)	BD (cm)	BW(g)	MBY(Qt/ha)	UMBY(Qt/ha)	WUE (Kgm^{-3}
ASMDL 1	39.07	4.162^{ab}	50.00^{ab}	249.9^{ab}	10.76^{b}	6.515^{ab}
ASMDL 2	40.37	3.835^{bc}	41.73^{b}	239.1^{b}	10.70^{b}	6.234^{b}
ASMDL 3	42.83	4.250^{a}	65.27^{a}	363.9^{a}	12.50^{b}	9.487^{a}
ASMDL 4	41.97	3.560^{c}	46.40^{ab}	310.0^{ab}	18.33^{a}	8.082^{ab}
ASMDL 5*(Control)	39.93	3.985^{ab}	53.83^{ab}	333.9^{ab}	9.72^{b}	8.704^{ab}
LSD (5%)	4.028	0.383	18.940	105.69	5.57	1.329
CV (%)	8.2	8.1	30.7	29.5	37.5	29.5

Results and Discussion

Physical and water properties of soil in the study area

The soil result of the study area showed that the average composition of sand, silt, and clay percentages was 35% 32% and 33%, respectively. Thus, according to the USDA soil textural classification, the percent particle size determination for the experimental site revealed that the soil texture could be classified as clay loam soil. The result of bulk density of the soil in the experimental field has a small variation with its depth. It varied between 1.34 (g/cm^3) and 1.37 (g/cm^3) from the top to the sub surface layer of the soil. The subsurface soil has slightly higher compaction than the top soil layer. It may be due to different reasons. The average bulk density of the soil in experimental field was found was 1.36g/cm^3, which is below the critical threshold level 1.45 g/cm^3, and it was suitable for crop root growth. The average moisture content at field capacity of the experimental site soils were 25.8% and at the permanent wilting point had 18%. As indicated in (Table 2) the average total available water was 106 mm/m.

Chemical properties of soil in the study area: The average pH value of the experimental site through the analyzed soil profile was found to be in recommended range with average value of 6.95% (Table 3). The average Organic Carbon content and Organic Matter content of the soil was an average value of 1.64%, 2.82% respectively over 90 cm depth of soil profile. An average electrical conductivity of an experimental soil is 0.089 ds/m. Generally, according to USDA soil classification, a soil with electrical conductivity of less than 2.0 dS/m at 25°C and pH less than 8.5 are classified as normal. Therefore, the soils of the study area are normal soils. The infiltration rate of the study site soil was 6mm/hours. According to Fikire and Olani (2010), onion plants can grow from neutral to a slightly alkaline conditions. The experimental site, therefore, had a favorable soil pH (almost neutral) for onion growth. The ECe of the soil, which ranged from 0.43 at a depth of 0–30 cm to 0.192 at lower depths (30–60 cm), indicate that the soil is non-saline and non-sodic crops not tolerate saline above (>4dS/m).

Yield and yield-related effects

Plant height: The study result revealed that, the variation of soil moisture depletion level from 20% to 100% of the FAO recommendation had no effect on plant heights (Table 4). Numerically among the treatments the highest plant height (42.83 cm) was recorded under irrigation water application at 60% whereas the shortest plant height (39.07 cm) was obtained under treatment with irrigation at 20% ASMDL (Table 4). who reported that irrigation application treatments with different available soil moisture depletion level had no significant different among all treatments regarding to plant height. This result was also in lined with the findings who reported that variation in irrigation depletion level had non-significant difference on plant height of wheat crop.

Bulb diameter: The onion bulb diameter was determined as an indicator of the size and it was found to be significantly influenced ($p < 0.05$) by different irrigation water treatments. The highest bulb diameter was obtained from 60% without significance difference with 20% ASMDL and 100% ASMDL (FAO recommended ASMDL). The lowest bulb diameter was recorded under irrigation water application at 80% available soil moisture depletion level (Table 4) and this was in lined with thr findings in which the highest onion bulb diameter was obtained from 60% of ASMDL.

Bulb weight: The analysis of ANOVA indicates that, there was significant ($P < 0.05$) difference on the different treatment of available soil moisture depletion level (ASMDL) on onion weight. The heaviest bulb weight (65.27 gm) was obtained from treatments which received 60% ASMDL followed by FAO recommended ASMDL (53.83 gm). However, there is no statistically significant different between treatment application 20% ASMDL, 60% ASMDL, 80% ASMDL and 100% FAO recommended ASMDL regarding to average bulb weight. The lightest bulb weight was recorded from the irrigation water application under treatment 40% ASMDL (Table 4). who reported that the average bulb weight significant different with different irrigation water application of available soil moisture level.

Marketable onion yield: From analyzed result, the highest marketable yield (363.9 qt/ha) was obtained from 60% ASMDL followed by (333.9 qt/ha) under treatment with 100% ASMDL whereas the lowest marketable yield (239.1 qt/ha) was obtained from treatment of 80% of ASMDL (Table 4). But statistically, there was no significant difference among four treatments (60% ASMDL, 80% ASMDL, 100% ASMDL and 20% ASMDL) except with treatment of 40% ASMDL, who reported that maximum onion bulb yield and water use efficiency were obtained from 60% of available soil moisture depletion level. 2021 findings in which the highest onion bulb yield was obtained from 60% of available soil moisture depletion level.

Unmarketable onion yield: The analysis of variance indicated that the unmarketable onion yield of onion was significantly ($P < 0.05$) affected by irrigation regime. Based on the result, the highest unmarketable onion yield (18.33 qt/ha) was recorded from 80% ASMDL irrigated plot while the low yield of unmarketable onion yield was obtained from FAO recommended ASMDL received plot who reported that 80%ASMDL under furrow irrigation system provide maximum unmarketable yield of onion. This might be due to very small bulbs increased with inappropriate application of available soil moisture depletion level that contributes to increment of the Unmarketable onion yield.

Water use efficiency: As shown in (Table 4) the highest water use efficiency (9.487 kg m^{-3}) was obtained from 60% ASMDL followed by (8.704 kg m^{-3}) under treatment with 100% ASMDL whereas the lowest marketable yield (6.234 kg m^{-3}) was obtained from treatment of 40% of ASMDL but statistically, there was no significant difference among four treatments (100% ASMDL, 80% ASMDL, 60% ASMDL and 20% ASMDL) except with treatment of 40% ASMDL. According to the water utilization efficiency for harvested yield for bulbs containing 85 to 90% moisture is 8 to 10 kg/m^3. The results obtained from this experiment are within the recommended range of FAO 33. The highest water use efficiency of onion was obtained under irrigation water application of 60% ASMDL.

Conclusions and Recommendations

Irrigation water management is the most critical constraint for the development of irrigation agriculture. Hence, effective use of available water with optimal irrigation scheduling has a significant implication on irrigated agriculture. Onion (*Allium cepa L.*) is a widely recognized cash crop and most successfully produced under irrigated conditions in different parts of Ethiopia, but due to information and Irrigation systems the productivity of the crop is much lower. The objective of this study was, to study the effect of irrigation regime on yield, yield component and WUE of anion. Five available soil moisture depletion levels (20% AMADL, 40% AMADL, 60% AMADL, 80% AMADL and FAO recommended AMADL) were used as treatment under Completely Randomized Block Design (RCBD). The effect of irrigation treatments was evaluated through growth parameters, yield, and water productivity like plant height, average bulb weight, bulb diameter, unmarketable yield, and marketable yields at ($p < 0.05$) significance level. Based on this study, the highest plant height (42.83 cm) was recorded under irrigation water application at 60% ASMDL. Maximum bulb diameter (4.25 cm) and average bulb weight (65.27 g) were also obtained from treatments which received 60% ASMDL. The highest marketable yield (363.9 qt/ha) was obtained from 60% ASMDL followed by (333.9 qt/ha) under treatment with 100% ASMDL whereas the lowest marketable yield (239.1 qt/ha) was obtained from treatment of 80% of ASMDL. But statistically, there was no significant difference among four treatments (60% ASMDL, 80% ASMDL, 100% ASMDL and 20% ASMDL) except with treatment of 40% ASMDL. The analysis of variance indicated that the unmarketable onion yield of onion was significantly ($P < 0.05$) affected by irrigation regime. The highest water use efficiency (9.487 kg m^{-3}) was obtained from 60% ASMDL followed by (8.704 kg m^{-3}) under treatment with 100% ASMDL whereas the lowest marketable yield (6.234 kg m^{-3}) was obtained from treatment of 40% of ASMDL. Generally, the application of different % ASMDL responds differently for the productivity of onion. Therefore, based on the findings of the current experiment, it is recommended to use 60% allowable soil moisture level with shorter irrigation interval under furrow irrigation system for onion production at the study area in similar agro-ecology and soil type.

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