Optimal Irrigation Scheduling of Garlic (Allium *sativum L.*) using Allowable Soil Moisture Depletion for Water Scarce Areas of Ethiopia

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ABSTRACT

The main objective of this study was to evaluate the responses of garlic to the irrigation regime (when and how much) to irrigate. The field experiment was conducted at the main station of Debre Zeit Agricultural Research Center in 2016 and 2017. Five treatments for allowable soil moisture depletion levels (ASMDL) of irrigation at 60%, 80%, 100%, 120%, and 140% were used. Application of irrigation water for garlic was scheduled when 30% of the total water available in the soil profile was depleted. Treatments' were laid out in RCBD experimental design with three replications for each treatment. In the study, it was observed that there was a significant difference in marketable yield and water use efficiency (WUE) between treatments. The maximum marketable bulb yield (7.5 t/ha) and WUE were observed by applying irrigation water at 20% more than the recommended ASMDL and the lowest (4.68 t/ha) was recorded at 40% less than the recommended ASMDL. Reducing the allowable soil moisture depletion level by 40% and also by 20% from the recommended fraction (0.30) has significantly increased the water use efficiency. Generally, from this study it has been observed that irrigating garlic at a shorter frequency enhance yield and water productivity. Therefore, managing the soil moisture content above the allowable depletion level (i.e 60% ASMDL and 80% ASMDL) was better than using the recommended allowable depletion and the other lower levels. Hence, to have a higher yield and maximum water productivity, it was recommended to irrigate garlic frequently.

Keywords: Depletion, Flume; Irrigation scheduling, Water demand; Water use efficiency.

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1. INTRODUCTION

Ethiopia has irrigation of 5.3 million hectares (Awulachew *et al.,* 2010). Of the potential 3.7 million ha is from surface water (small, medium and large scale), while the remaining 1.6 million ha is from rain water harvesting technologies and ground water. Although Ethiopia has abundant rainfall and water resources, its agricultural system is not fully benefitting from the technologies. However, only about 12% (about 857,933 ha) was irrigated in 2015 (FDRE, 2016). Hence, irrigation is a means by which agricultural production can be increased to meet the growing food demand. Increasing food demand can be met in one or a combination of three ways: increasing agricultural yield, increasing the area of arable land and increasing cropping intensity. Expansion of the area under cultivation seems to be the only option, especially because of the marginal and vulnerable characteristics of large parts of the country's land and increasing population. Increasing yields in both rain-fed and irrigated agriculture and cropping intensity in irrigated areas through various methods and technologies are therefore the most viable options for achieving food security (Chartres *et al.,* 2011). Therefore, irrigation is expected to contribute to the national economy in several ways. At the micro-level, irrigation can lead to an increase in yield per hectare and subsequent increment in income, consumption and food security (Lipton *et al.,* 2003). Irrigation enables small-scale farmers to adopt a more diversified cropping pattern, and to switch from low value subsistence production to high-value market-oriented production (Hagos *et al.,* 2007). Introducing modern irrigation methods and improved water management practices empowers farmers to enhance the efficiency of irrigated water use and bring more area under irrigation through available water resources.

The agriculture sector is facing increasing challenges in the face of changing climate, rapid population growth, increasing salinity accumulation, land degradation, decreasing availability of land, and competition for scarce water resources (FAO, 2011). One of the most important considerations in increasing and stabilizing agricultural production is through increasing yields in both rain-fed and irrigated agriculture. This can be done through crop intensification in irrigated areas using various methods and technologies are those from viable options for achieving food security (Chen *et al.,* 2010, Mintesinot *et al.,* 2004 and Seckler *et al.,* 1998). Besides, the development of irrigation and agricultural water management has significant potential to improve productivity and reduce vulnerability to climactic volatility in any country (Heydari, 2014).

In worldwide, garlic (Allium sativum L.) is the second most used crop from cultivated Alliums probably after the onion. Garlic is a shallow-rooted and water-stress sensitive crop throughout the growing season especially during blubbing. The amount of irrigation varies depending on the soil type and weather conditions. However, in most soils, 2.5 cm of water per week is required during the growing season; however, about 5 cm of water is required for sandy soils during hot and dry weather. To obtain uniform and rapid sprouting, irrigation should be done twice a week until more than 80% of planted cloves sprout Then after, the frequency can be reduced to once a week. Fluctuation of soil moisture between dry and wet conditions may result in irregular growth and development of distorted bulbs. Irrigation should be stopped three weeks before harvest or at physiological maturity when leaves start senescing or turning yellow and necks become soft. For fresh market crops, irrigation should cease three weeks before harvest.

Water use efficiency in agriculture is poor with more than 50% water loss, making it possible to save enormous water quantities in the agricultural sector when compared to the use of water by other sectors (Dennis Wichelns, 2014). Irrigation scheduling is becoming more important because of concerns for water quality and possible shortages of water in the future (Laura *et al.*, 2017, Zhang & Oweis, 1999). However, knowledge of soil water status, crop water requirements, crop water stress status, and potential yield reduction under water-stressed conditions is a prerequisite to maximize profits and optimize the use of water and energy (Ahmed *et al.*, 2007). This experimental study, therefore, aims at investigating the response of Garlic (Allium sativum L.) to different levels of optimal irrigation water scheduling (when and how much) options for multifaceted water problems of irrigated agriculture on vertisol of the study area.

2. MATERIALS AND METHODS

2.1. Description of the study area

The field experiment was conducted at Debre Zeit Agricultural Research Center, located in the Oromia Region, East Shoa Zone, and also in the central highlands of Ethiopia. Its geographical location is 08°45’51” Northern latitude and 39°00’29” Eastern longitude. It has a low relief difference with an altitude ranging from 1610 to 1908 meters above the sea level. The soil at the experimental site was heavy clay in textures with field capacity and permanent wilting point values of 35% and 19%, respectively. The area receives an annual mean rainfall of about 810.3 mm with a medium annual variability and bimodal pattern. Seasonal variations and atmospheric pressure systems contribute to the creation of three distinct seasons in Ethiopia: Kiremt (June to September), Bega (October to February), and Belg (March to May).

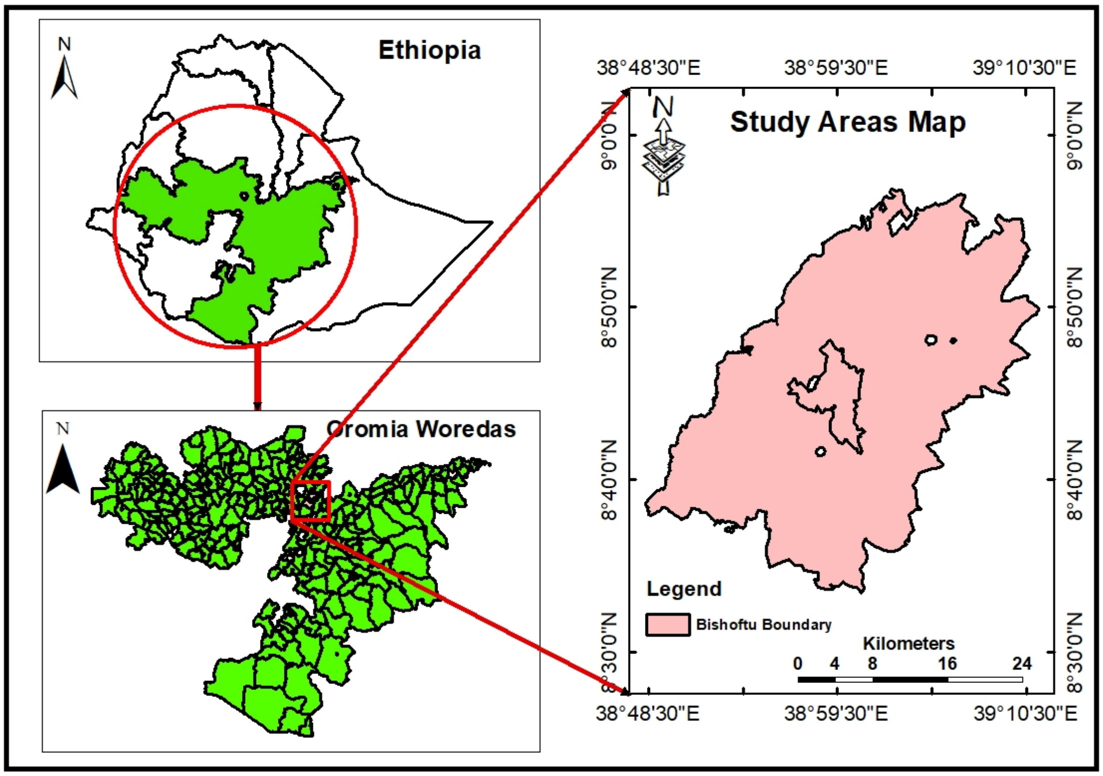

Figure-1. Map of the study area

According to (Seleshi and Zanke, 2004) and (Tessema and Lamb, 2003), the Kiremt (June-August) is the main rainy season and Tseday (September-November) is the spring season sometimes known as the harvest season. Belg (March-May) is the autumn season with occasional showers but it is the short-lasting. The dry season is attributed to Bega (December- February) is the dry season Belg in the study area receives quite small rainfall to support crop production whereas Kiremt is known for long rainy season. About 76 % of the total rainfall of the area falls in Kiremt or wet season, about 15% in Belg, and the rest is the Bega or dry season which needs full irrigation in the area. The mean maximum temperature varies from 23.7 to 27.70C while the mean minimum temperature varies from 7.4 to 12.10C (Table-1 and figure-2). However; maximum and minimum reference Evapotranspiration (ETo) was recorded as 4.9 and 3.3 mm/day in May and July respectively (Table-1 and figure-2).

Table-1: The climate data of 42 years (1975 – 2017) for the study area

Month	T max (^{O}C)	T min (^{O}C)	Humidity (%)	Wind (m/s)	Sunshine (hrs)	Rad. (MJ/m^2/day)	ETo (mm/day)	Rainfall (mm)	Eff. Rainfall (mm)
January	25.2	8.9	63.0	1.3	9.8	22.0	4.0	9.4	0.0
February	26.3	10.2	46.4	1.4	8.5	21.4	4.4	24.8	4.9
March	27.0	11.3	46.4	1.5	8.1	21.8	4.7	31.5	8.9
April	27.1	11.9	47.7	1.5	7.1	20.4	4.6	44.2	16.5
May	27.7	11.6	46.5	1.6	8.6	22.2	4.9	41.3	14.8
June	26.4	11.4	54.9	1.0	6.3	18.4	3.9	88.9	47.1
July	23.7	12.1	66.4	0.9	4.9	16.4	3.3	235.1	164.1
August	23.9	12.1	67.8	0.9	5.5	17.7	3.5	208.2	142.6
September	24.1	11.5	63.3	0.8	6.7	19.6	3.7	83.6	42.9
October	25.0	9.5	49.9	1.4	8.6	21.7	4.3	25.9	5.5
November	24.6	8.0	47.0	1.3	9.3	21.4	4.1	7.4	0.0
December	24.8	7.4	46.9	1.4	9.4	20.9	4.0	1.0	0.0
Total								**810.3**	**447.3**
Average	**25.5**	**10.5**	**53.9**	**1.2**	**7.7**	**20.3**	**4.1**		

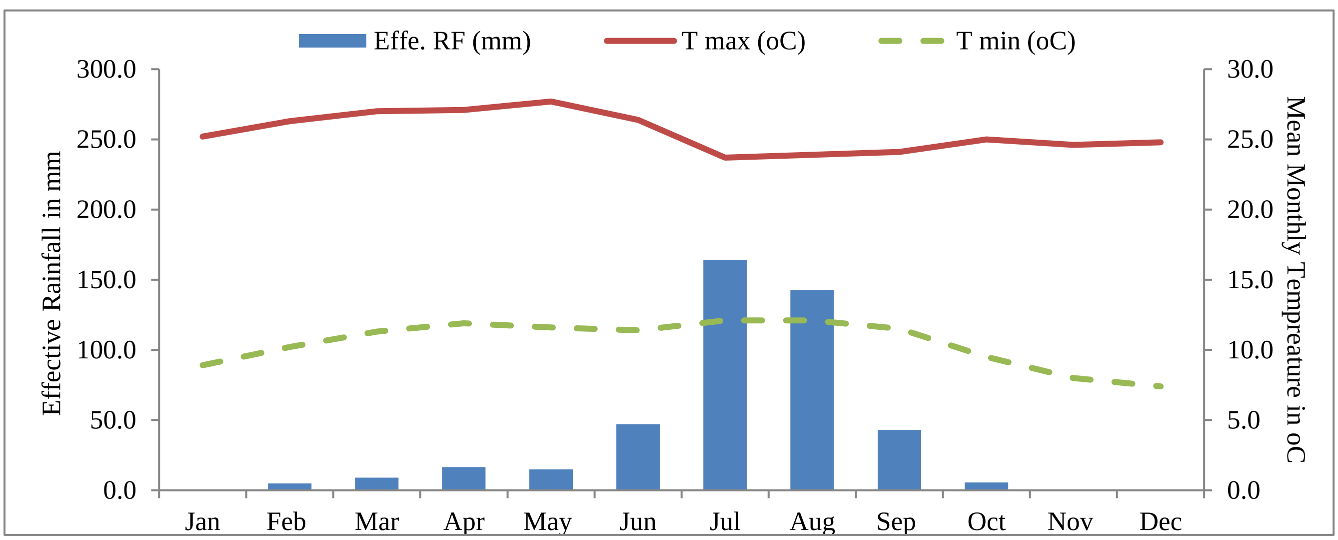

Figure-2. The weather characteristics of the study area

2.2. Experimental design and treatment combinations

The experiment included five levels of allowable soil moisture depletion levels (ASMDL) as a treatment (60% FAO recommended ASMDL, 80% FAO recommended ASMDL, FAO recommended ASMDL for garlic is 30% (Alllen et.al., 1998), 120% FAO recommended ASMDL and 140% FAO recommended ASMDL). The experiment was designed as a single factor experiment and laid out in randomized complete block design (RCBD) arrangement with three replications. For garlic crop recommended allowable soil moisture depletion level was 30% and the other treatments allowable soil moisture depletion levels were calculated based on this value in the study area.

Table 2: Treatments and it discretion

Treatment	Description
ASMDL 1	60% of ASMDL
ASMDL 2	80% of ASMDL
ASMDL 3	ASMDL* (control)
ASMDL 4	120% of ASMDL
ASMDL 5	140% of ASMD

N.B: ASMDL (allowable soil moisture depletion level) for garlic is 0.3.

2.3. Experimental procedure and management practice

Garlic (tseday) genotype was released from Debre Zeit Agricultural Research Center was used for the study. It was planted by furrow space of 40cm with a ridge bed accommodating two rows of 20cm spacing and plant spacing was 10cm. Garlic has such short roots and sparse canopy that it cannot compete with weeds especially at an early stage of growth. Good land preparation before planting is used to reduce the need for cultivation. Hand weeding is used once every month to control weeds with shallow cultivation. Garlic is a heavy feeder of nutrients 200 kg DAP and 150 kg Urea per ha Nitrogen is applied in split one third at planting and two-third after three weeks of planting.

2.4. Reference Evapotranspiration (ETo)

The reference evapotranspiration ETo was calculated by FAO Penman-Monteith method, using decision support software CROPWAT8 developed by FAO, based on FAO Irrigation and Drainage Paper 56 (Allen *et.al,* 1998). FAO56 adopted the Penman-Montieth method as a global standard to estimate ETo from meteorological data. The Penman-Monteith equation integrated into the CROPWAT program is expressed by the following equation.

Equation 1: $$ET_0 = \frac{0.408\,\Delta(Rn - G) + \gamma \frac{900}{T+273} U2(es - ea)}{\Delta + \gamma(1 + 0.34u2)}$$

Where ET_0 is reference evapotranspiration (mm day^{-1}), T, G, and Rn are daily mean temperature ^oC at 2 m height, soil heat flux density (MJ m^{-2} day^{-1}) and net radiation value at crop surface (MJ m^{-2} day^{-1}) respectively. Also, u2, e_s e_a, (es–ea), D and c represent wind speed at 2 m height (m s^{-1}), saturated vapor pressure at the given temperature (kPa), actual vapor pressure (kPa), saturation vapor pressure deficit (kPa), the slope of the saturation vapor pressure curve (Pa/^{o}C) and psychometric constant (kPa/^{o}C), respectively (Alllen et.al., 1998).

2.5. Crop data and characteristics

Crop data for garlic crop characteristics used as input parameters referred mainly to the length of the growth cycle, crop factors, rooting depth, critical depilation factor, and yield response factor for each growth stages.

Table-3. Crop characteristic of garlic

Kc and Yield Factors	Scientific name	Growth Stages			
	Garlic	Initial season	Develop ment	Mid-season	Late-season
Growing Period		30	40	50	25
Kc values		0.7	0.95	1.0	0.7
Critical depletion fraction.		0.30	NA	0.45	0.50
Yield response fraction		0.8	0.4	1.2	1.0
Maximum crop height (m)		0.3			
Maximum root depth (m)		0.3-05			

Source: (Alllen *et.al.,* 1998).

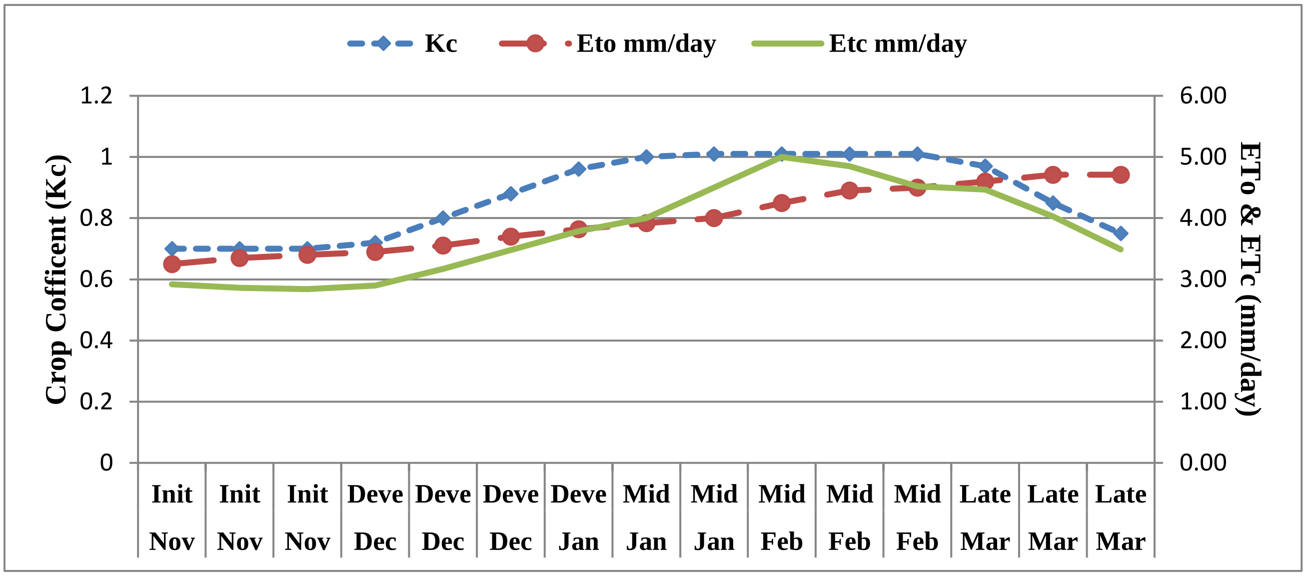

Figure-3. Relationship of Reference Evapotranspiration (ETo), crop coefficient (Kc) and Crop water demand (ETc)) to the growth stage

2.6. Irrigation management

The amount of irrigation varies depending on the soil type and weather conditions. The depth of irrigation water applied was estimated using CROPWAT 8 model from daily climate data. Calculations of irrigation requirements and scheduling utilize inputs of climatic, crop, and soil data, as well as irrigation and precipitation data. The simulations were based on the daily water balance (Allen *et al.*, 1998). Daily climatic data (maximum and minimum temperatures, humidity, wind speed, and actual sunshine hours), and geographical information (coordinates and altitude of the location) were used by CROPWAT to calculate ETo according to the FAO Penman-Montieth equation (Allen *et al.*, 1998). ETc was therefore estimated by using the crop coefficient (Kc). The amount of water applied at each irrigation interval was determined following the respective depletion level of each treatment. Accordingly, the average irrigation intervals and depth of irrigation were used for treatment at each growth stage.

2.6.1. Determination of irrigation requirement and irrigation scheduling

Crop water use (ETc) was determined by multiplying ETo by the crop coefficient (Allen *et al.*, 1998) for initial, development, mid-season, and late stages. Irrigation water to be applied to garlic was determined by at an allowable constant soil moisture depletion fraction (p = 0.3) of the total available soil water (TAW) and readily available water (RAW), where TAW and RAW were determined from the permanent wilting point, field capacity, root depth, and bulk density variables (Equation 6 & 7). The depth of water applied during each irrigation event was the net irrigation requirement between irrigation events, plus that needed for inefficiencies in the irrigation system. In this experiment, considering application losses, an irrigation efficiency of 60% was assumed and added to each plot.

The optimal irrigation schedule was worked out using CropWat for windows that permit to selection of the different irrigation scheduling criteria. The computation method used was irrigation to be given at a fixed interval per growth stage with a depth of irrigation that would refill the root zone to its field capacity. Irrigation Requirement (IR) computation of IR requires long-term rainfall data from study sites.

Equation 2. CWR = ETo * Kc

Equation 3. IR = CWR – Effective rainfall

Equation 4. Effective rainfall (mm) = 0.6 * RF (mm) – 10 for RF < 70 mm

Equation 5. Effective rainfall (mm) = 0.8 * RF (mm) – 24 for RF > 70 mm

Where CWR is crop water requirement in mm, Kc is crop coefficient; IR is irrigation requirement in mm, and effective rainfall in mm. RF is actual monthly rainfall and the equations represent combined effect of dependable rainfall (80% probability of exceedence) and estimated losses because of Runoff (RO) and Deep Percolation (DP).

The p-value was assumed to be 0.3 as given in Allen *et al.*, (1998) for cereal crops and TAW was computed from the soil moisture content at field capacity (FC) and permanent wilting point (PWP) using equation sex: Considering the daily CWR, TAW, Dz, and p, the irrigation interval was computed from the expression equation 6. The optimal irrigation schedule was worked out using CROPWAT 8.0 for windows and assumed the irrigation regime applied at 100 % readily available soil moisture. The RAW was the amount of water that crops could extract from the root zone without experiencing any water stress. The RAW was computed from the expression in equation 7.

Equation 6. $\mathbf{TAW} = \frac{(\mathbf{FC-PWP})}{\mathbf{100}} * \mathbf{BD} * \mathbf{Dz}$

Equation 7. $\mathbf{RAW} = \mathbf{p} * \mathbf{RAW}$

Where; FC and PWP in % on a weight basis, BD is the bulk density of the soil in gm cm^{-3}, and Dz is the maximum effective root zone depth in mm. RAW in mm, p is soil water depletion fraction for no stress in fraction and TAW is the total available soil water of the root zone in mm per root depth.

Equation 8. $\mathbf{Interval\ (Days)} = \frac{\mathbf{RAW}}{\mathbf{CWR}}$

Equation 9. $\mathbf{IRg} = \frac{\mathbf{Interva*CWR}}{\mathbf{Ea}}$

Where RAW in mm and CWR in mm day^{-1}, IRg is gross irrigation requirement in mm, an interval in days and Ea is the Irrigation water application efficiency as a fraction. Field application efficiency in this study was assumed as 60%.

Data collection and analysis

The selected variety of garlic varity tsedey was planted in November for consecutive three years in Debre Zeit Agricultural Research Center of the main station. During the implementation period, all agronomic & yield parameters and data of irrigation water were collected following the data sheet including date of 50% emergency, days of 95% maturity, stand count at harvesting, fresh biomass yield, marketable yield, bulb diameter, and weight was measured after the sample was sun-dried for three days. Water use efficiency was calculated using the following formula as indicated in equation 10 below.

Equation-10: Water Use Efficiency of Irrigated Garlic.

$$\text{Water use efficiency (WUE)} = \frac{\text{Marketable Bulb yield } \left(\frac{\text{kg}}{\text{ha}}\right)}{\text{Net irrigation water applied} \left(\frac{\text{m}^3}{\text{ha}}\right)}$$

Where; Water use efficiency (kg/m^3), Marketable bulb yield (kg/ha), and Net irrigation water applied (m^3/ha).

The collected data were analyzed and presented using analysis of variance (ANOVA) after checking the normality. All the results shown in tables and figures were means of treatment plots. Mean values were compared for any significant differences using the least significant difference (LSD) method by Fisher's least significant difference (LSD) at a 5% probability level ($\alpha = 0.05$).

3. RESULTS AND DISCUSSION

3.1. Crop water demand and Irrigation interval

The cumulative reference evapotranspiration (ETo) for the period from planting (1st of November) to the beginning of the irrigation experiment was 77.5mm for the initial stage, 136.9mm, 208mm, and 112.9mm for development, mid and late stages of net crop water demand though out the cropping season of garlic. As indicated the highest crop water demand was observed during the mid-stage as indicated in Table 4.

Table-4. Crop ware demand of Garlic under Debre Zeit climatic and soil conditions

Month	**Decade**	**Stage**	**Kc** coeff	**ETc** mm/day	**ETc** mm/dec	**Eff rain** mm/dec	**Irr. Req.** mm/dec	**Stage** CWR
Nov	1	Init	0.7	2.92	20.5	0.1	20.4	
Nov	2	Init	0.7	2.86	28.6	0	28.6	
Nov	3	Init	0.7	2.84	28.4	0	28.4	77.5
Dec	1	Deve	0.72	2.9	29	0	29	
Dec	2	Deve	0.8	3.17	31.7	0	31.7	
Dec	3	Deve	0.88	3.48	38.3	0	38.3	
Jan	1	Deve	0.96	3.79	37.9	0	37.9	136.9
Jan	2	Mid	1	3.97	39.7	0	39.7	
Jan	3	Mid	1.01	4.12	45.3	0.1	45.2	
Feb	1	Mid	1.01	4.27	42.7	1.1	41.6	
Feb	2	Mid	1.01	4.41	44.1	1.6	42.5	
Feb	3	Mid	1.01	4.52	36.2	2.1	34.1	208
Mar	1	Late	0.97	4.47	44.7	2.4	42.3	
Mar	2	Late	0.85	4.03	40.3	2.8	37.5	
Mar	3	Late	0.75	3.49	27.9	2.7	24.2	112.9
					535.4	12.9	521.5	

The total amount of water applied in different irrigation treatments was presented in Table 5. The irrigation water applied for 140% of ASMD was maximum (140.94 mm) but minimum when 60% of ASMDL (72.05 mm) was applied in the first year and also the second year of experimentation.

Table-5. Crop ware demand of Garlic under Debre Zeit climatic and soil conditions

Growth stage	60% of ASMDL		80% of ASMDL		100% of ASMDL		120% of ASMDL		140% of ASMDL	
	Interval (day)	Depth (mm)	Interval (day)	Depth (mm)	Interval (day)	Depth (mm)	Interval (day)	Depth (mm)	Interval (day)	Depth (mm)
Initial	3	10.78	4	12.07	5	15.09	6	19.95	7	21.12
Development	4	17.68	6	19.48	7	24.35	9	32.00	11	34.08
Mid	5	27.61	6	30.61	7	38.26	8	42.85	9	53.56
Maturity	3	15.99	4	18.39	6	22.98	9	43.12	10	32.18
Sum	15	72.05	20	80.54	25	100.67	32	137.92	37	140.94
Average	3.75	18.01	5	20.13	6.25	25.17	8	34.48	9.25	35.23
Interval (Days)	4		5		6		8		9	

The interval of irrigation events of the irrigation treatments was determined to be 4-5-6-8-9 days (Table 5). The irrigation application events or interval was short for 60%of ASMADL but long for 140% of ASMDL of garlic. The result revealed a decreasing trend with the increasing of irrigation interval. It might be due to the availability of water at the root zone. This was attributed to 4 days irrigation interval, increased the mobility of nutrients in the soil that consequently increased the minerals uptake by the plant and this increased carbohydrate assimilation, photosynthetic, and other physiological activity that are necessary for different growth processes that lead to increased bulb yield (Sankar *et al*. 2008). Irrigation interval had a significant effect on bulb yield in both seasons. As regard the data, an increase in irrigation interval significantly decreased the bulb yield from 4 to 9-day interval. The fifth days' irrigation interval showed a significantly higher bulb yield (7.45 t/ha) than the remaining irrigation intervals (Table 7). However, an irrigation interval of 9 days gave the lowest bulb yield (4.68 t/ha). Similar findings were reported by Rahim *et al.* (2003), Singh and Chand (2003), and Singh *et al*. (2010) in garlic crop.

Table-6. Yearly effects of soil moisture depletion level on garlic bulb yield

	2016					2017				
Treatments	**PH (cm)**	**D (cm)**	**FBM (t/ha)**	**Yield (t/ha)**	**WUE (Kg/m^3)**	**PH (cm)**	**D (cm)**	**FBM (t/ha)**	**Yield (t/ha)**	**WUE (Kg/m^3)**
-40 % ASMDL	52.17^{b}	4.14^{b}	8.67^{a}	7.08^{a}	3.08^{b}	54.57^{a}	4.14^{ab}	8.82^{a}	6.26^{b}	1.83^{a}
-20 % ASMDL	55.77^{a}	5.07^{a}	8.83^{a}	7.44^{a}	3.17^{a}	57.00^{a}	4.93^{a}	8.12^{a}	7.44^{a}	1.90^{a}
ASMDL	51.00^{b}	4.12^{b}	8.63^{a}	7.04^{a}	2.76^{c}	50.00^{b}	4.12^{b}	7.11^{ab}	5.94^{b}	1.73^{a}
+20% ASMDL	45.53^{c}	3.95^{bc}	8.62^{a}	6.35^{a}	2.71^{d}	43.33^{c}	3.95^{bc}	6.96^{ab}	5.86^{b}	1.33^{b}
+40 % ASMDL	43.00^{d}	3.70^{c}	6.92^{b}	5.02^{b}	2.70^{e}	41.00^{c}	3.70^{c}	6.11^{b}	4.34^{c}	0.73^{c}
CV (%)	1.60	4.33	4.10	10.42	7.23	4.32	13.26	9.90	7.91	10.27
$LSD_{0.05}$	1.49	0.34	0.64	1.29	0.24	4.00	1.01	1.35	0.89	0.28

N.B. ASMDL=Allowable Soil Moisture Depilation Level, PH=Plant height, D= Diameter, FBM=Fresh Biomass, BY= Bulb yield and WUE=Water Use Efficiency.* Means followed by different superscripts are statistically different.

Table-7. Combined analysis effects of soil moisture depletion level on garlic bulb yield

Treatments	**Over year analysis**				
	PH (cm)	**D (cm)**	**FBM (t/ha)**	**BY (t/ha)**	**WUE (Kg/m^3)**
-40 % ASMDL	53.36^{b}	4.13^{b}	8.25^{a}	6.67^{ab}	1.90^{b}
-20 % ASMDL	56.38^{a}	5.00^{a}	8.48^{a}	7.45^{a}	2.42^{a}
ASMDL	50.50^{c}	4.02^{b}	7.87^{a}	6.49^{b}	1.70^{b}
+20% ASMDL	44.43^{d}	4.00^{b}	7.79^{a}	6.11^{b}	1.22^{c}
+40 % ASMDL	42.00^{e}	3.44^{c}	6.51^{b}	4.68^{c}	0.78^{d}
CV (%)	3.65	9.39	10.91	10.38	19.69
$LSD_{0.05}$	2.16	0.46	1.02	0.78	0.38

N.B. ASMDL=Allowable Soil Moisture Depilation Level, PH=Plant height, D= Diameter, FBM=Fresh Biomass, BY= Bulb yield and WUE=Water Use Efficiency.* Means followed by different superscripts are statistically different.

Bulb Yield

The production of garlic with different irrigation at different depletion levels significantly affected the bulb yield in the consecutive year of experimentation and thus consistent results were recorded over the year. Accordingly, the highest marketable bulb yield of 7.45 t/ha was recorded in the frequently irrigated plot. The lowest yield (4.68 t/ha) was recorded in the treatment irrigated with a wider interval which is 40% plus of allowable soil moisture of depletion level of garlic. These findings are in close agreement with other workers like Singh *et al.* (2007), Doro (2012), and Dorcas *et al.,* (2012).

Water use efficiency (WUE)

The water use efficiency of garlic was significantly influenced (P<0.01) under different levels of allowable soil moisture depletion. The water use efficiency of garlic yield as a function of the amount of applied water is presented in Table 7. The highest water use efficiency (2.42 kg/m^3) of yield was obtained under 80% allowable soil moisture depilation level whereas the lowest water productivity (0.78 kg/m^3) was obtained under 140% allowable soil moisture depilation level.

4. CONCLUSIONS

Water use, crop yield, soil moisture depletion, and irrigation water use efficiency were compared for irrigated garlic. The results of the study revealed that irrigating in a shorter frequency with a smaller amount enhances garlic yield and water productivity. This study showed that managing the soil moisture content above the allowable depletion level of 60% and 80% was better than the recommended or control allowable depletion and other lower levels. Therefore, for higher yield and maximum water use efficiency, and better water productivity, it is better was recommended to irrigate garlic frequently.

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