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Optimal Irrigation Scheduling for Garlic (Allium *sativum L.*) in the Central Highland Vertisols Areas of Ethiopia

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Abstract

For sustainable utilization of limited available water resources in irrigated agriculture, accurate estimation of crop water requirements and irrigation scheduling is crucial to improve irrigation water management and crop productivity. Therefore, the objective of this activity 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 during 2016, 2017, and 2018. 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. From the study, it has been observed that there was a significant difference in marketable yield and water use efficiency (WUE) among treatments. The maximum marketable bulb yield (7.5 t/ha) and WUE were observed from applying irrigation water at 20% more of recommended ASMDL and followed by 40% more of ASMDL (6.7 t/ha) but the lowest (4.68 t/ha) was recorded at 40% less of recommended ASMDL. Reducing the soil moisture depletion level by 40% and 20% from the recommended fraction (0.25) has significantly increased the water use efficiency. Under irrigated Garlic a shorter frequency with a smaller amount improve yield and water productivity than irrigating with wider interval but a larger amount. Therefore, managing the soil moisture content above the allowable depletion level like 60% ASMDL and 80% ASMDL was better than the recommended allowable depletion and the other lower levels. Hence it is recommended that for higher yield and maximum water productivity it is better to irrigate Garlic frequently.

Keywords

Water demand, Depletion, Irrigation scheduling, Water use efficiency, Flume

1. Introduction

Ethiopia has a long history of traditional irrigation systems and yet. Simple river diversion still is the dominant irrigation system in Ethiopia [1]. Estimates of the irrigation potential of Ethiopia has estimated that 5.3 million hectares. 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. In terms of utilization, only about 12% (about 857,933 ha) has been irrigated by 2015 [2]**.** So, it is prudent to make efficient use of water and bring more area under irrigate on through available water resources [3, 4]. This can be achieved by introducing advanced methods of irrigation and improved water management practices.

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 [1, 5-7]. 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 [4]**.** One of the most important considerations in increasing and stabilizing agricultural production is through irrigation and drainage development, reclamation of degraded lands and wise use of water resources [5, 8-10]. The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in any country [2]. Although Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of agricultural water management [1, 6].

There is considerable scope for improving water use efficiency of crops by proper irrigation scheduling which is governed by crop evapotranspiration [11, 12]. In Ethiopia, although irrigation has long been practiced at different farm levels, there is no efficient and well managed irrigation water practice. There are very few or no information regarding appropriate management of irrigation water and crop management practices for the rapidly expanding irrigation farms in the country.

Garlic (Allium *sativum L.*) is the second mostly used crop of the cultivated Alliums worldwide probably after the onion [13, 14]. Garlic is shallow rooted and it is sensitive to water-stress throughout the growing season especially during blubbing [15, 16]. 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; whereas in sandy soils during hot and dry weather about 5 cm, water is required [14]. Irrigate twice a week from planting until more than 80% of planted cloves sprout in order to obtain uniform and rapid sprouting. 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 misshapen bulbs [14, 17]. 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.

Irrigation implies the application of water to crops in right amount at the right time [18, 19]. Salient features of any improved method of irrigation is the controlled application of the required amount of water at desired time, which leads to minimization of range of variation of the moisture content in the root zone, thus reducing stress on the plants [20]. Hence, irrigation scheduling is important for developing best management practices for irrigated areas [12, 21]. Therefore, this experimental study investigated the effects of different levels of water supply and application frequency on the water use efficiency of garlic on vertisol of the study area.

2. Materials and Methods

2.1. Description of study area

The field experiment was conducted at Debre Zeit Agricultural Research Center, located in Oromia region, East Shoa zone and also in the central highlands of Ethiopia. Its geographical extent ranges 08°45’51” Northern latitude and 39°00’29” Eastern longitude. It has low relief difference with altitude ranging from 1610 to 1908 meters above the see level. The soil at the experimental site was heavy clay in textures with field capacity and permanent wilting point of 35% and 19%, respectively. The area receives an annual mean rainfall of around 810.3 mm with the 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).

The Kiremt is the main rainy and Belg is the short lasting one while the dry season is attributed to Bega (Selshi and Zanke, 2004). Belg in the study area receives quite small rainfall to support crop production whereas Kiremt is known by 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 Bega or dry season which needs full irrigation in the area. The mean maximum temperature varies from 23.7 + to 27.70C while mean minimum temperature varies from 7.4 to 12.10^{C} (Table 1). However; maximum and minimum reference Evapo-transpiration (ETo) was recorded as 4.9 and 3.3 mm/day in May and July respectively (Table 1).

2.2. Experimental design and treatment combinations

The experiment was designed as a single factor experiment in randomized complete block design (RCBD) arrangement with three replications. The experiment included five levels of soil water depletion levels (ASMDL) as a treatment and the five level of ASMDL are (60% FAO recommended ASMDL, 80% FAO recommended ASMDL, FAO recommended ASMDL, 120% FAO recommended ASMDL and 140% FAO recommended ASMDL). For garlic crop, recommended allowable soil moisture depletion level is 25% and the other treatments allowable soil moisture depletion levels were calculated based on this value.

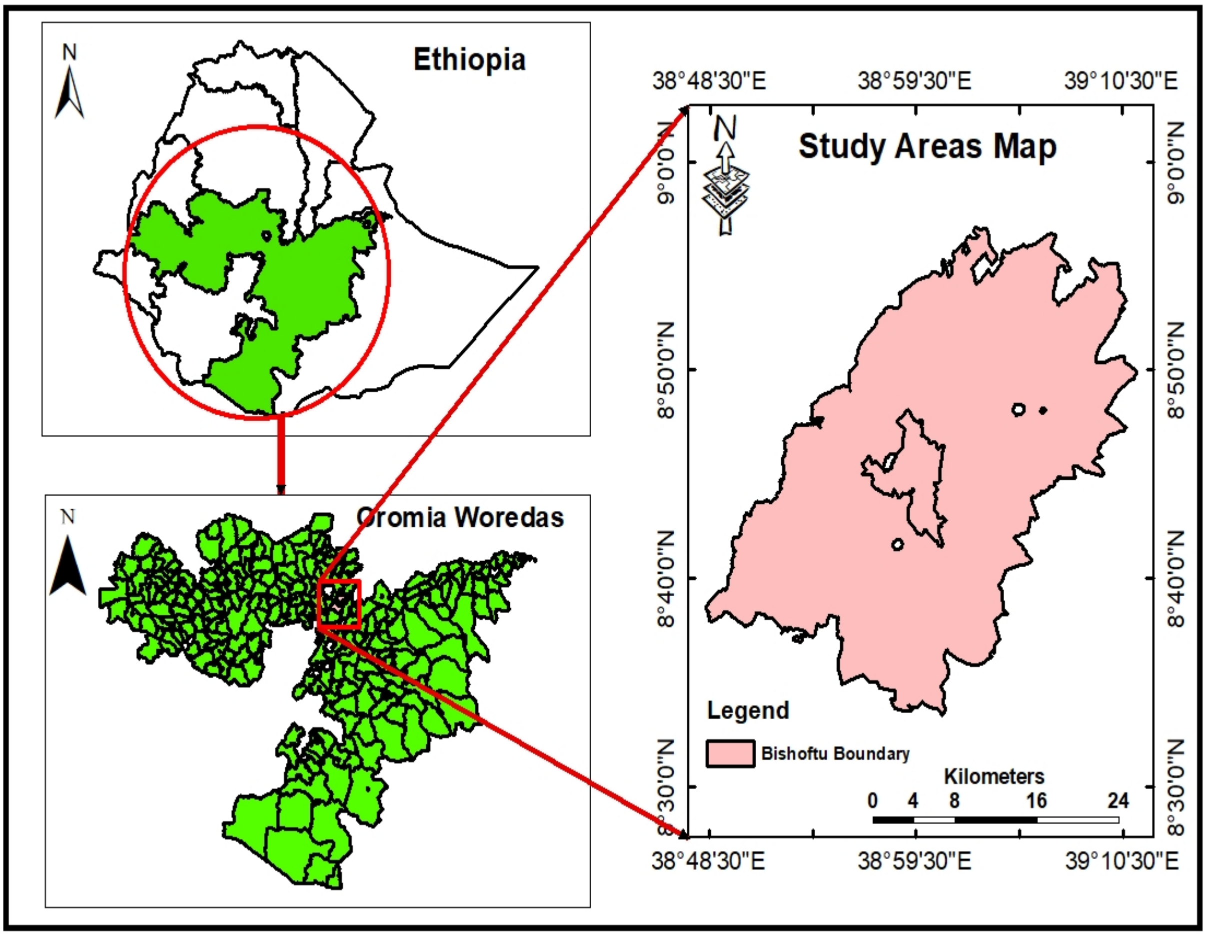
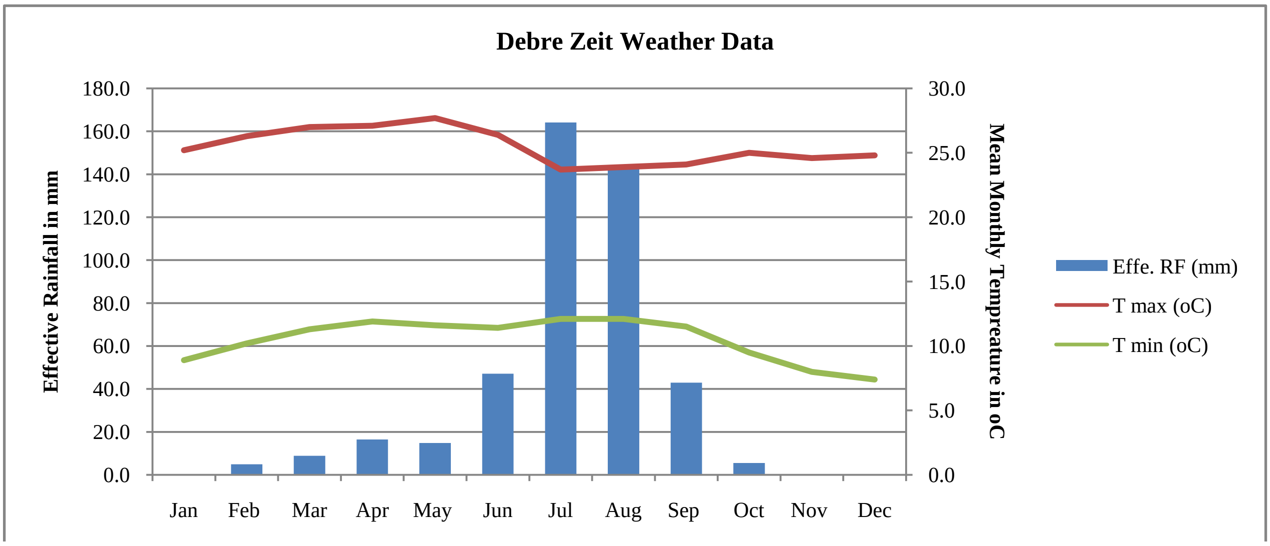


Figure 1. Map of the study area.

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

Month	T max (°C)	T min (°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**		



Graph 1. The weather data analysis of the study area.

Table 2. Treatment combinations

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

2.3. Experimental procedure and management practice

Garlic (Allium *sativum L.*) genotypes in Ethiopia have many (up to 20) small sized cloves per bulb which are difficult to peal. Internationally known cultivars often have six to ten large cloves which can be pealed easily. Garlic bulbs have either white skin color or white with purple tinges. Three garlic cultivars: ***Tsedey*** were released from Debre Zeit Agricultural Research Center (DZARC). The yield is about 7.5 t/ha ' under optimum management with plant population of 333 thousand. Garlic attains maturity within 120-145 days. Garlictsedey variety was used for the experiment planted on a 3 m by 4 m plot in November of 2016 and 2017. After selecting medium sized clovers, it is planted by the space of 40 cm between double rows on the ridge, 20 cm between the rows and 10cm between cloves. Garlic has short roots and sparse canopy that it cannot compete with weeds especially at early stage of growth. Good land preparation prior to planting has been used to reduce the need for cultivation. Hand weeding was used to control weeding with shallow cultivation once every month. Garlic is a heavy feeder of nutrients 200 kg DAP and 150 kg Urea per ha was applied. Application of 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 [22]. FAO56 adopted the Penman-Montieth method as global standard to estimate ETo from meteorological data. The Penman Monteith equation integrated in the CROPWAT program is expressed by the following equation.

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

Where: ET_0 is reference evapotranspiration (mm day^{-1}), T, G and Rn are daily mean temperature ^{o}C 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_se_a, (es–ea), D and c represent wind speed at 2 m height (m s^{-1}), saturated vapour pressure at the given temperature (kPa), actual vapour pressure (kPa), saturation vapour pressure deficit (kPa), slope of the saturation vapour pressure curve

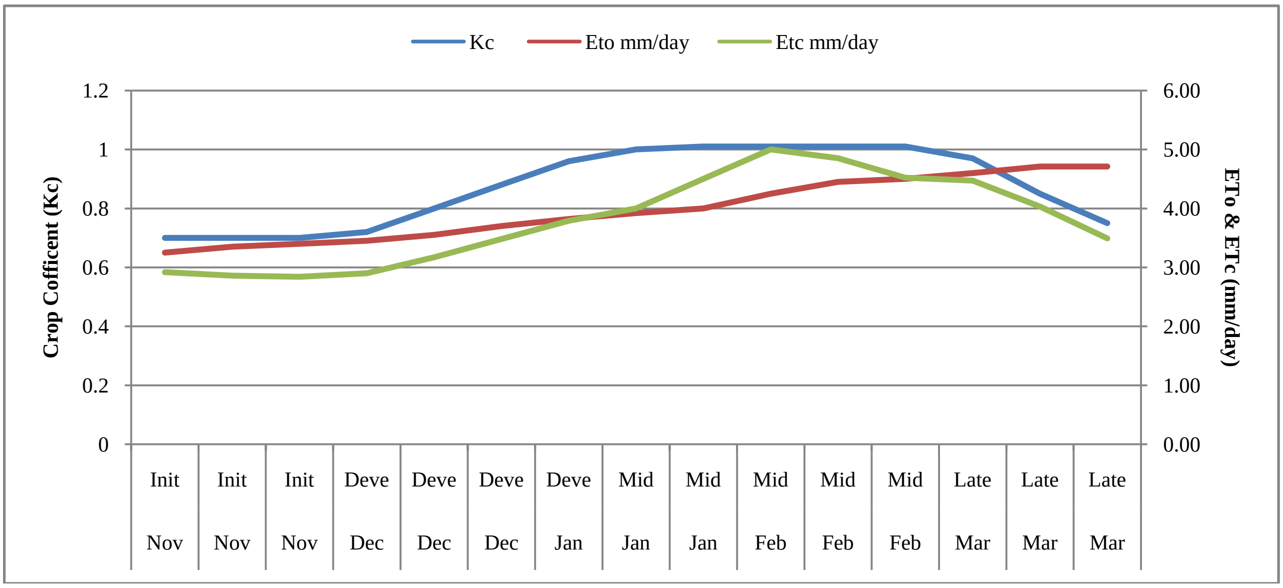
(Pa/°C) and psychometric constant (kPa/°C), respectively [22].

2.5. Crop data and characteristics

Crop data for garlic crop characteristics used as input parameters are mainly length of the growth cycle, crop factors, rooting depth, critical depilation factor, yield response factor for each growth stages are specified in Table 3 below.

Table 3. Kc values, critical depletion and yield response factors for Garlic

Kc and Yield Factors	Scientific name	Growth Stages			
	Garlic	Initial season	Development	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			



Source: *FAO-56 (1998).*

Figure 2. Relationship of Reference Evapotranspiration (ETo), crop coefficient (Kc) and Crop water demand (ETc)) with respect to growth stage.

2.6. Irrigation management

Garlic has a shallow root system and it is sensitive to water-stress throughout the growing season especially during bulbing. The amount of irrigation varies depending on the soil type and weather conditions. 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 are based on the daily water balance [22]. Daily climatic data (maximum and minimum temperatures, humidity, wind speed and actual sunshine hours), and geographical information (coordinates and altitude of the location) are used by CROPWAT to calculate ETo according to the FAO Penman-Montieth equation [22]. ETc is therefore estimated by using 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 used for treatment at each growth stage.

2.7. Determination of irrigation requirement and irrigation scheduling

Crop water use (ETc) was determined by multiplying ETo by the crop coefficient [22] for initial, development, mid-season, and late stages. Irrigation water to be applied to garlic was determined at an allowable constant soil moisture depletion fraction (p = 0.25) of the total available soil water (TAW) and readily available water (RAW), where

TAW and TAW was 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 permits to select the different irrigation scheduling criteria. The computation method used was irrigation to be given at fixed interval per growth stage with 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 exceedance) and estimated losses due to Runoff (RO) and Deep Percolation (DP).

The p-value was assumed 0.25 as given in [22] for cereal crops and TAW is computed from the soil moisture content at field capacity (FC) and permanent wilting point (PWP) using the following expression: Considering the daily CWR, TAW, Dz and p, the irrigation interval was computed from the expression in Equation 5. 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 is the amount of water that crops can extract from the root zone without experiencing any water stress. The RAW was computed from the expression in Equation 6.

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

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

Where, FC and PWP in % on 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. $\mathbf{Interval\ (Days) = \frac{RAW}{CWR}}$

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

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

2.8. Data collection and analysis

The selected variety of garlic varity tsedey was planted in November for the consecutive three years in Debre Zeit Agricultural Research Center of main station. During the implementation period, all agronomic & yield parameters and data of irrigation water was 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.

Equation 10: *Water Use Efficiency of Irrigated Onion.*

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

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. Mean values were compared for any significant differences using the least significant difference (LSD) method using Fisher's least significant difference (LSD) at 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 77.5 mm for the initial stage, 136.9 mm, 208 mm and 112.9 mm 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 as it is confirmed in [11].

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 is presented in Table 5. The irrigation water applied in treatment 140% allowable soil moisture depletion level (ASMDL) was maximum (140.94 mm) followed by 120% ASMDL (137.92 mm) and the minimum crop water applied at 60% ASMDL (72.05 mm) in first year and also 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 shortest for 60%of ASMADL but longest interval for 140% of ASMDL of garlic. The result revealed that the trend showed a decrease with increase of irrigation interval. It might be due could be availability of water at the root zone, which is attributed to 4 days irrigation interval, increased the mobility of nutrients in the soil that consequently increased the minerals uptake by plant and this increased carbohydrate assimilation, photosynthetic and other physiological activity that are necessary for different growth processes that lead to increased bulb yield [23]. Irrigation interval had significant effect on bulb yield in both seasons. As regard the data, increase in irrigation interval significantly decreased bulb yield from 4 to 9 day interval. Fifth days irrigation interval showed the significantly higher bulb yield (7.45 t/ha) followed by fourth days than the remaining irrigation intervals (Table 7). Irrigation interval of 9 days gave the lowest bulb yield (4.68 t/ha). Similar findings have also been reported by [14, 16, 24] in garlic crop.

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

Treatments	2016					2017				
	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 letter of 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 letter of superscripts are statistically different.

3.2. Bulb Yield

The production of garlic with different irrigation at different depletion level significantly affected the bulb yield in consecutive year of experimentation and also consistence result has been recorded during over year analysis. Accordingly, the highest marketable bulb yield of 7.45 t/ha was recorded from the frequently irrigated plot compared to control and the lowest yield (4.68 t/ha) was recorded from the treatment irrigated with 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 [13, 16, 18].

3.3. Water use efficiency (WUE)

Water use efficiency of garlic was significantly influenced ($P<0.01$) different levels of allowable soil moisture depletion. 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. This finding aligned with [25].

4. Conclusions

Water use, crop yield, soil moisture depilation and irrigation water use efficiency were compared for irrigated garlic. The results of the study revealed that, irrigating in a shorter frequency with smaller amount enhance garlic yield and water productivity than irrigating with wider interval but larger amount. 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 the other lower levels. Therefore, for higher yield and maximum water use efficiency and better water productivity, it is better to irrigate garlic frequently.

5. Acknowledgements

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References

[1] Awulachew, S. B., et al. (2010). *Roles, constraints and opportunities of small scale irrigation and water harvesting in Ethiopian agricultural development: Assessment of existing situation*. in *ILRI workshop*. 2010.

[2] Molden, D., et al. (2010). *Improving agricultural water productivity: Between optimism and caution.* Agricultural Water Management, 2010, 97(4): 528-535.

[3] Oki, T. and S. Kanae. (2006). *Global hydrological cycles and world water resources.* Science, 2006, 313(5790): 1068-1072.

[4] Dubois, O. (2011). *The state of the world's land and water resources for food and agriculture: managing systems at risk*. 2011: Earthscan.

[5] De Fraiture, C. and C. Perry. (2007). *Why is agricultural water demand unresponsive at low price ranges.* Irrigation water pricing: The gap between theory and practice, 2007: 94-107.

[6] Diriba-Shiferaw, G. (2016). *Review of management strategies of constraints in garlic (Allium sativum L.) production.* Journal of Agricultural Sciences–Sri Lanka, 2016, 11(3).

[7] Seleshi, Y. and U. Zanke. (2004). *Recent changes in rainfall and rainy days in Ethiopia.* International Journal of Climatology: A Journal of the Royal Meteorological Society, 2004, 24(8): 973-983.

[8] Rosegrant, M. W. and X. Cai. (2002). *Global water demand and supply projections: part 2. Results and prospects to 2025.* Water International, 2002, 27(2): 170-182.

[9] Mintesinot, B., et al. (2004). *Examining traditional irrigation methods, irrigation scheduling and alternate furrows irrigation on vertisols in northern Ethiopia.* Agricultural Water Management, 2004, 64(1): 17-27.

[10] Seckler, D. W. (1998). *World water demand and supply, 1990 to 2025: Scenarios and issues*. Vol. 19. 1998: Iwmi.

[11] Hanson, B., et al. (2003). *Response of garlic to irrigation water.* Agricultural Water Management, 2003, 58(1): 29-43.

[12] Incrocci, L., et al. (2014). *Substrate water status and evapotranspiration irrigation scheduling in heterogenous container nursery crops.* Agricultural Water Management, 2014, 131: 30-40.

[13] Dorcas, A., et al. (2012). *Irrigation scheduling for onion (Allium cepa L.) at various plant densities in a Semi-Arid environment*.

[14] Singh, Y. and R. Chand. (2003). *Performance studies of some garlic (Allium sativum L.) clones.* Himachal J. Agri. Res., 2003, 29(1&2): 35-42.

[15] Silabut, N., et al. (2014). *Response of garlic cultivars to irrigation levels.* Indian Journal of Horticulture, 2014, 71(3): 354-359.

[16] Singh, P., et al. (2010). *Response of garlic (Allium sativum) cultivars to different date of sowing in Malwa region of Madhya Pradesh.* Indian Journal of Agricultural Sciences, 2010, 80(7): 645-648.

[17] Yayeh, S. G., et al. (2017). *Economic and agronomic optimum rates of NPS fertilizer for irrigated garlic (Allium sativum L.) production in the highlands of Ethiopia.* Cogent Food & Agriculture, 2017, 3(1): 1333666.

[18] Doro, A. K. (2012). *Effect of irrigation interval on yield of garlic (Allium sativum L.) at Ajiwa irrigation site of Katsina State–Nigeria.* Jordin, 2012, 10: 30-33.

[19] Ghanbari, M., G.-R. Zaboli, and B. Mir. (2013). *Comparing irrigation methods and weed control on yield of garlic (Allium sativum L.) cultivars.* World of Science Journal, 2013, 3: 78-78.

[20] Ahmed, H., et al. (2007). *Response of garlic (Allium sativum L.) to irrigation interval and clove size in semi-arid Nigeria.* J. Pl. Sci., 2007, 2: 202-208.

[21] Liu, H., et al. (2012). *Irrigation scheduling strategies based on soil matric potential on yield and fruit quality of mulched-drip irrigated chili pepper in Northwest China.* Agricultural Water Management, 2012, 115: 232-241.

[22] Allen, R. G., et al. *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56.* Fao, Rome, 1998, 300(9): D05109.

[23] Sankar, V., K. Lawande, and P. Tripathi. (2008). *Effect of micro irrigation practices on growth and yield of garlic (Allium sativum L.) var. G. 41.* Journal of Spices and Aromatic Crops, 2008, 17(3): 230-234.

[24] Rahim, M., et al., *Effect of planting dates on the growth and yield of garlic germplasm.* Asian Journal of Plant Sciences, 2003.

[25] Chala, M. and S. Quraishi. (2015). *Effect of Deficit Irrigation on Yield and Water Productivity of Garlic (Allium Sativum L.) under Drip Irrigation and Mulching at Wolaita Soddo, Ethiopia.* International J. Life Sciences, 2015, 4(4): 232-239.