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Effect of Water Application Level on Garlic (*Allium sativum* L.) Under Different Furrow Irrigation Systems, in Tiyo District, Central Ethiopia

Abu Dedo Ilmi[1*], Asfaw Kebede[2] & Tilahun Hordofa[3]

[1-3]Oromia Agricultural Research Institute, Jimma Agricultural Engineering Research Center, Jimma, Oromia, Ethiopia.
Corresponding Author (Abu Dedo Ilmi) Email: abuhu2008@gmail.com[*]

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ABSTRACT

The availability of water is increasingly impeding crop productivity and agricultural growth. In the Tiyo area, where water resources are limited, a field experiment was carried out to evaluate furrow irrigation methods and deficit irrigation levels that maximize garlic bulb output and water usage efficiency. Twelve treatments were created using the furrow irrigation systems—CFI, AFI, and FFI—and irrigation levels—100%ETc, 85%ETc, 70%ETc, and 55%ETc—that were arranged in an RCBD with three replications. The outcome showed that while the various degrees of furrow irrigation had no effect on the number of leaves per plant, bulb height, bulb weight, neck diameter, glove number, and glove weight, they did have a significant impact on plant height, leaf length, and garlic bulb diameter.

Keywords: Alternate furrow; Conventional furrow; Deficit irrigation; Fixed furrow; Garlic; Water use efficiency; Irrigation systems; Crop productivity; RCBD; Bulb yield; Furrow irrigation methods; Deficit irrigation levels.

1. Introduction

Given that over 80% of Ethiopians depend on agriculture for their livelihood and that it generates 40% of the nation's gross domestic product (GDP), raising agricultural productivity and output in the country can help to improve both the quality of life for rural residents and the sustainability of the economy (IWMI, 2010). Ethiopia's agricultural system does not yet fully benefit from irrigated agriculture and the technologies of water management and land usage, despite the country's potentially enormous irrigable land and water resources. Ethiopia has extremely low agricultural output as a result (Selesh Belele, 2010). More efficient use of water in both rainfed and irrigated agriculture is necessary to fulfill future needs and intensifying competition for water (Martin Smith, 2000).

Since crop productivity and agricultural growth are increasingly hampered by the scarcity of water, it is imperative to implement effective water management strategies that would eventually increase crop water use efficiency. Higher yields, lower production costs, and eventually maximum investment returns are the results of this. Moreover, effective water management and application methods are necessary for sustainable agricultural growth that maximizes the utilization of natural resources (Kranz et al., 2011).

One of the most significant bulb crops, garlic (*Allium sativum* L.) is used as a spice in a variety of dishes and is the world's second-most popular crop after onions (Voigt, 2004). It is extensively planted and farmed in Ethiopia at elevations between 1800 and 2500 masl, both under irrigation and with rain. Small-scale commercial producers produce the crop for both domestic use and export (Shimelis and Metasebia, 1998). Because the crop has shallow roots and is susceptible to changes in soil moisture, it has to be irrigated sufficiently and frequently. According to Singh et al. (2010) and Silabut et al. (2014), a soil moisture depletion fraction of no more than 30% should be maintained for maximum production.

An irrigation system with a basin and furrow is ideal for this crop. Smallholder farmers most commonly use basin irrigation systems because of their ease of use, low maintenance requirements, and effective water management. The FAO (2001) claimed that the majority of commercial farms in Ethiopia and surface irrigation technologies account for 97.8% of irrigation in Ethiopia, where the furrow irrigation technology is commonly used. Despite being one of the most popular methods of surface irrigation, the technique is reportedly among the least effective when compared to other irrigation systems (Seid and Hasene, 2017).

Therefore, water management and a strategic water application system are crucial to raising food output and maintaining agricultural productivity. Conventional furrow irrigation (CFI), in which each furrow receives irrigation during a series of waterings, is less effective and may result in significant runoff, inadequate irrigation at the lower portion of the furrow, and excessive deep percolation at the upper part of the furrow. This could lead to low application efficiency and distribution. The best use of irrigation water might be achieved using fixed and alternate furrow irrigations. Half of the root is exposed to moist soil conditions and the other half is exposed to dry soil conditions when alternate furrow irrigation is used. The irrigation water application in fixed furrow irrigation is fixed to one of the two nearby furrows (Booher, 1974); (Zhang et al., 2000).

Deficit irrigation is a technique that lowers extra water use and increases water use efficiency (WUE), lowers irrigation costs, and increases irrigation efficiency by allowing the soil water to be depleted beyond a threshold value at which the crop experiences water stress (Capra et al., 2008). In this study, when water is the limiting element to agricultural production, deficit irrigation under different furrow irrigation systems was employed to maximize crop yields and enhance crop water use efficiency (CWUE). Reductions in crop production are anticipated with deficit irrigation in order to achieve the best water use efficiency (WUE). In regions where water is scarce, boosting WUE could be economically more advantageous for farmers than optimizing yields or land productivity (English, 1990).

Thus, the general and particular goals of this study were to measure the impact of furrow and deficit irrigations on garlic productivity and water usage efficiency under the climatic circumstances of the Tiyo area.

1.1. Study Objectives

1. To evaluate the effect of water application level on garlic (*Allium sativum* L.) under different furrow irrigation systems, in Tiyo district, central Ethiopia.

2. To evaluate the effect of furrow irrigation systems on garlic yield and water use efficiency.

3. To assess the interaction effects of irrigation systems and levels on garlic growth parameters.

4. To recommend water management practices for sustainable garlic production.

2. Materials and Methods

2.1. Description of the Study Area

Geographic location

The Experiment was conducted at kulumsa Agricultural Research Center, which is 170 km far from Addis Ababa. Geographically, the center is situated between 8° 0'' to 8° 2'' N latitude and 39° 7'' to 39° 10'' E longitude at an altitude ranging from 1980 to 2230 masl (Figure 2.1) at east Arsi Zone Tiyo woreda.

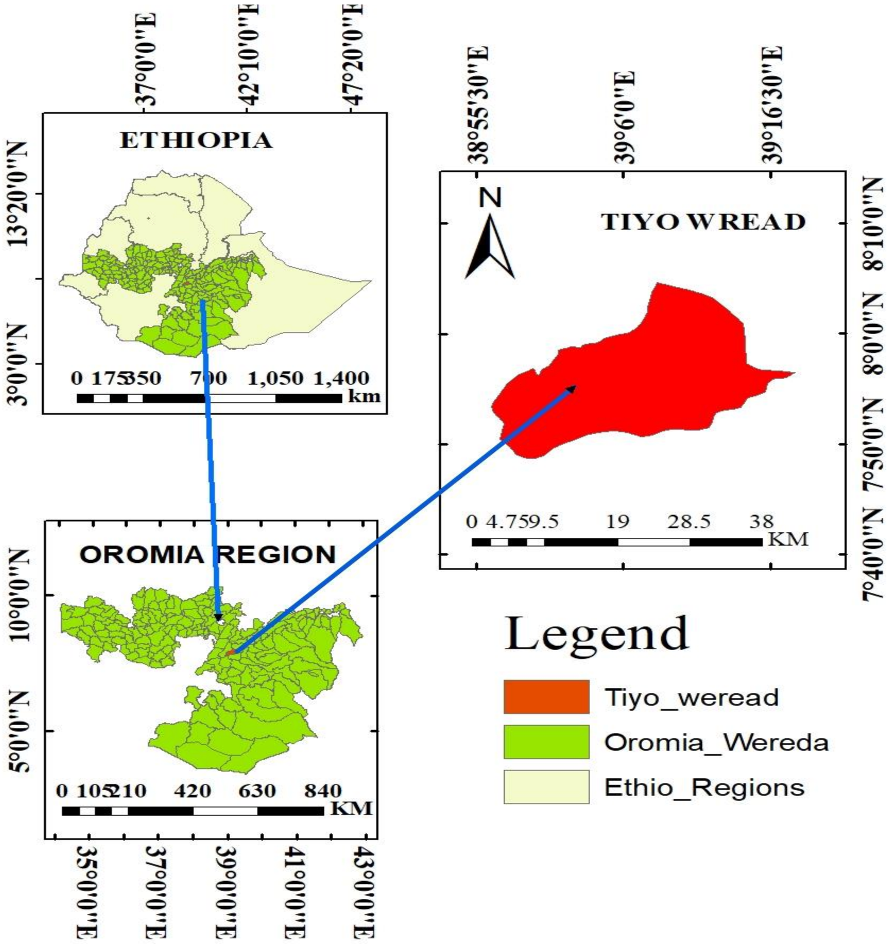

Figure 2.1. Location of the study site

Climatic conditions

The climate condition of the study area is characterized by a sub-humid dry zone with a mean annual rainfall of 820 mm and unimodal rainfall. Most of the rain occurs in the main cropping season in the months from July to September. The mean minimum and maximum temperatures are 7.71°C in December and 25.07°C in March, respectively.

Soil types and topography

Gently undulating topography with a gradient of 0 to 10% slope and agroecological zones are categorized as a sub-humid dry zone. The soil of the area is heavy clay to sandy clay loam (Sertsu et al., 2003).

Water sources and irrigation practices

The water resources system in the experiment area is from the diversion of Kulumsa river, ponds, .and wastewater treated of Asella malt factory. The irrigation systems practiced are conventional furrow irrigation and simple flooding irrigation by cultivating onion, garlic, potato, beetroot, cabbage, and barley around the study area.

Land use system

Mountain chilalo is the highest point in this woreda. Rivers include the Katar, Kulumsa, Gonde, Dosha, and Walkesa. A survey of the land in this woreda shows that 40% is arable or cultivable (32% was planted with cereals), 23.1% pasture, 8.7% forest, and the remaining 28.2% is considered swampy, mountainous, or otherwise unusable. The farmers have one irrigation season from December to May. The major crops cultivated in the irrigation season are onion, garlic, potato, cabbage, barley, and beetroot.

2.2. Materials

Materials used to conduct this experiment were sprouted garlic bulb, fertilizer (DAP and UREA), chemical for pest control, Parshall flume, soil auger and core sampler, dry oven, pressure plate apparatus, hydrometer, double-ring infiltrometer, meter, electronic balance, rope stake, and digital caliper.

Soil sampling analysis

Composite soil samples were collected from the experimental field at 20cm increments (0 – 20 cm, 20 – 40 cm, and 40 – 60 cm) up to 60 cm soil depth from the surface. The soil samples were taken from different plots randomly and diagonally across the experimental field using an auger for each depth of interval. The collected soil samples were composited to one sample per depth. The bulk soil samples collected were air-dried and packed properly, labeled, and transported to the laboratory for further analysis. The analysis was carried out at Debre Zeit Agricultural research center's soil laboratory.

The soil texture was analyzed using the hydrometer method. The soil particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962) to identify the sand silt and clay contents and hence soil texture. The soil samples collected were also analyzed for FC and PWP after preparing the samples following standard procedure ready for the soil moisture content determination at FC and PWP using a pressure plate and pressure membrane apparatus at a pressure of 0.33 bars and 1/5 bars, respectively. The process is said to be completed when no drop of water is observed from saturated soil coming out of the apparatus.

The soil density was determined by taking undisturbed soil samples from the effective root zone at 20 cm intervals up to 60 cm using a core sampler having a volume capacity of 98.125 cm^3.

The soil and water chemical analysis that include, soil pH, ECe and ECw, soil organic matter (OM), and cation-exchange capacity (CEC) parameters were analyzed. The soil pH was determined by measuring soil solution of 1:5 ratios (soil to water) using a pH meter. The Organic carbon (%) was determined following the wet digestion method as described by Walkley and black. (1934). The OM content was then determined by multiplying OC by 1.724 (Nelson, and Sommers,1996) The electrical conductivity of saturated paste (ECe) was determined using electrical conductivity meter.

Treatments and Experimental Design

The experiment has two factors namely furrow irrigation systems and irrigation application levels. The treatments in furrow irrigation systems include a) Alternative Furrow Irrigation, AFI, b) Fixed Furrow Irrigation, FFI, and c)

Conventional Furrow Irrigation, CFI. The treatments in irrigation levels include 100%ETc, 85%ETc, 70%ETc, and 55%ETc. The two factors were combined as shown in Table 2.1 and treatment combinations produced 12 individual treatments as shown in Table 2.2. The experiment was laid out in a Factorial randomized complete block design (RCBD) with three replications (Figure 2.2). The plots and replications had a buffer zone of 2m for canals carrying no irrigation water and 2.5 m for canals carrying irrigation water supply canals between plots to eliminate the influence of lateral water movement and also 1m between plots.

Table 2.1. Treatment combinations

Irrigation Level	**Furrow Irrigation System**		
	AFI	**FFI**	**CFI**
100%Etc	T1	T5	T9
85%Etc	T2	T6	T10
70%Etc	T3	T7	T11
55%Etc	T4	T8	T12

Table 2.2. Experimental treatments

Treatment	**Designation**	**Description**
T1	AFI100%ETc	Alternative furrow irrigation with 100%ETc
T2	AFI85%ETc	Alternative furrow irrigation with 85%ETc
T3	ALI70%ETc	Alternative furrow irrigation with 70%ETc
T4	ALF55%ETc	Alternative furrow irrigation with 55%ETc
T5	FFI100%ETc	Fixed furrow irrigation with 100%ETc
T6	FFI85%ETc	Fixed furrow irrigation with 85%ETc
T7	FFI70%ETc	Fixed furrow irrigation with 70%ETc
T8	FFI55%ETc	Fixed furrow irrigation with 55%ETc
T9	CFI100%ETc	Convectional furrow irrigation with 100%ETc
T10	CFI85%ETc	Conventional irrigation with 85%ETc
T11	CFI70%ETc	Conventional irrigation with 70%ETc
T12	CFI55%ETc	Conventional irrigation with 55%ETc

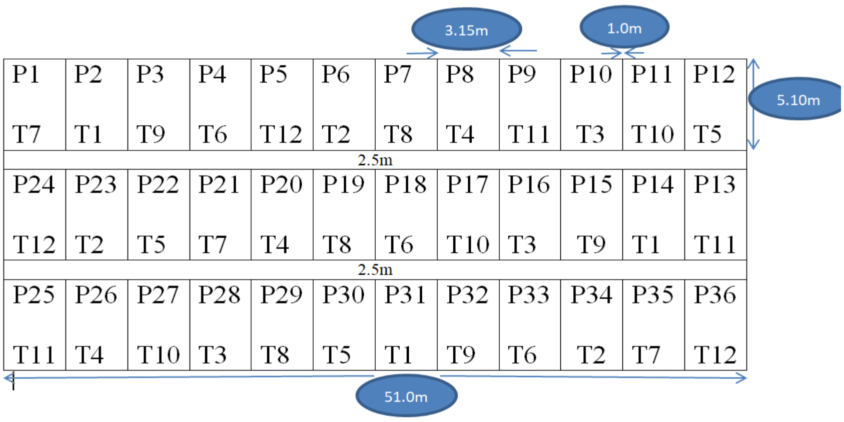

Figure 2.2. Experimental field layout

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2.3. Agronomic Practices

The tractor was used to plow and harrow the trial. The experimental field was leveled, and 45 cm-spacing ridges and furrows were made. Furthermore, thirty-six 3.15 x 5 m plots with seven furrows each were built and arranged. On the elevated bed, the clover/bullets were planted around 50 mm deep. There were 98 garlic cloves in a ridge of the double row, placed 10 cm apart, and there were 6 rows on each plot, spaced 45 cm apart. There were 588 seedlings or cloves in each plot.

In the experimental plots, a fertilizer rate that is generally advised was used. The identical rates of 150 kg/ha of urea and 200 kg/ha of DAP fertilizer were applied to each plot. Based on the suggested irrigation levels, the plots were watered. After planting, two establishing irrigations were provided at intervals of four days, after a common irrigation at planting. Using the Parshall flume, the necessary irrigation water depth was applied to each plot. Half of the garlic leaves dropped off as the crop got closer to maturity, prompting the irrigation to be stopped. Aside from treatment variables, all other cultural activities such as weeding and cultivating were carried out in compliance with the instructions provided for the region.

2.4. Soil Moisture Determination

In experimental plots, the soil moisture content (SMC) was measured gravimetrically both before and after irrigation. Using augers, soil samples were obtained from the center rows of a plot at three different depths (0–20, 20–40, and 40–60 cm) before and after each irrigation session. Only three locations within a plot with convectional furrow irrigation provided samples. The soil samples were dried in an oven set at 1050C for a whole day. The soils' gravimetric water content was then calculated using Eq. (1) and expressed as a percentage by weight.

$$\text{SMC } (\%\text{wt}) = \frac{\text{wet weight of soil(g)} - \text{Dry weight of soil (g)}}{\text{A dry weight of soil (g)}} \quad \ldots(1)$$

Where, SMC is the soil moisture content in percent by weight.

2.5. Crop Water and Irrigation Water Requirements

2.5.1. Determination of crop water requirement

The window computer software application CROPWAT version 8.0 was utilized to predict crop water requirements. The Kulumsa Meteorological Station provided the crop and climate data that were utilized as inputs. Garlic's crop water requirement was calculated by multiplying the crop coefficients by the mean daily reference evapotranspiration (ETo), which was obtained using meteorological data such as temperature (maximum and minimum), relative humidity, sunshine hours, and wind speed.

2.5.2. Determination of net irrigation water requirement

Net irrigation water requirement was determined for the control treatment (100%ETc) based on the crop water requirement and effective rainfall following Equations. The net irrigation requirement for the rest treatments was obtained by multiplying the percentage assigned to each treatment with the net irrigation requirement as obtained from the control treatment.

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Daily effective rainfall (P_e) was determined as given in(Allen et al.,1998) following Eq. (2) and (3):

P_e = 0.6*P - 10/30,31 for P ≤ 70mm/30,31 …(2)

P_e = 0.8*P - 24/30,31 for P > 70mm/30,31 …(3)

Where, P is the total precipitation (mm/day) and P_e is the effective rainfall (mm/day).

The TAW in mm, stored in a unit volume of soil was determined by taking the difference between the water content at FC and PWP and computed following Eq. (4).

Gross irrigation: Irrigation water was applied with a field application efficiency of 60%. Based on the net irrigation depth and irrigation application efficiency, the gross irrigation water requirement was obtained following Eq. (4).

$$GIRg = \frac{NIR}{Ea} \quad \ldots(4)$$

Where, GIR_g is gross irrigation water requirement (mm), **NIR** is net irrigation depth of water (mm) and E_a is irrigation application efficiency.

Irrigation water application

The irrigation interval, (I) was determined for the control treatment (100%ETc) and computed following Eq. (5).

$$I = \frac{NIR}{ETc} \quad \ldots(5)$$

Where, I is irrigation interval (Days); NIR is net irrigation requirement (mm), ETc is the mean daily crop water requirement (mm/day)

Parshall flume was used to apply the desired depth of irrigation water to each experimental plot.

The time require to irrigate a particular plot/treatment will be obtained following Eq. (6).

$$T = \frac{AD}{6q} \quad \ldots(6)$$

Where, T is the time required to irrigate a plot (minutes), A is plotting area (m^2), D is the depth of irrigation to be applied for a plot (cm) and q is the flow discharge at a particular head through a Parshall flume (l/s).

2.6. Agronomic Data Collection

Relevant agronomic data were recorded during the experiment period. Five randomly selected plants from the central three rows per plot excluding the border rows and border plants were taken as a sample.

Plant height (cm) five garlic plants were selected from the interior of three rows in order to avoid the border effect. The height of these five plants was measured from the ground surface to the tip of the plant using a ruler. The mean value of the five-plant height was recorded as the plant height of each plot.

Leaf number pre-plant refers to the mean number of leaves produced by sampled plants at the mid-stage. The number of leaves, all completely developed leaflets were counted and recorded per plant. The sum of the total

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counted number of leaves of sampled plants was divided by the number of plants to get mean leaf numbers per plant.

Leaf length (cm) refers to the measured average length of a leaf by using a ruler in centimeters. The average leaf length was obtained by dividing the sum of measured leaf lengths of the five randomly selected plants at the maturity stage by the number of leaves.

Bulb height (cm) refers to the mean length of randomly selected five bulbs using a digital caliper in centimeters. Then, the average bulb height of five bulbs was recorded as bulb height.

Bulb diameter (cm) refers to the mean diameter of five samples of randomly selected plant bulbs from interior rows and measured at the widest point in the middle portion of the mature bulb using a digital caliper.

Marketable bulb yield: Marketable bulb/ clove (MC) yield was recorded as weight (**kg ha^{-1})** obtained from the central three rows of the experimental field. The marketable clove category includes cloves having one and greater than one gram clove weight (marketable clove size > 2.0 gm; acceptable marketable clove size1.5-1.99 gm and scarcely marketable clove size 1.0 - 1.49 gm) (Teweldebrhan Tadese 2009).

Unmarketable bulb yield (UMC): Unmarketable cloves recorded as weight (**kg ha^{-1}) were obtained** from the central three rows of the experimental field. The unmarketable cloves category includes cloves having less than one gram weight (Teweldebrhan tadese 2009).

Total bulb yield (kg ha^{-1}) was recorded from the net plot area by weighing (**kg ha^{-1})** all bulbs taken from central three rows of a plot that include marketable and unmarketable cloves weight.

Days to maturity: Days to maturity were the actual number of days from the day of transplanting to the time when 70% of plants' foliage fell and when plants show neck fall in the field experiment.

2.7. Water Use Efficiency

Water use efficiency could be determined based on the ratio of yield of marketable yield to the crop depth of water and irrigation depth of water used from germination to harvest. Hence, CWUE and IWUE as expressed were used to obtain the respective values for garlic.

2.8. Yield Response Factor

The yield response factor (Ky) of garlic which relates relative yield decrease to relative ET deficit was estimated following Equation.

2.9. Cost-Benefit and Net Return Analysis

In order to compare the benefits of various irrigation application levels for each treatment, yield and economic data were computed along with a partial analysis of the costs and benefits of each treatment. Operating and variable costs make up the majority of the overall cost. Based on the planted area, operating expenses (labor, seed, fertilizer, and implement costs) were calculated. The quantity of irrigation events, manpower, and the cost of a water unit determined the variable expenses. The study area's farmers do not pay for their crops' irrigation water. As a result,

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an estimate of 30 ETB/m3 was used to represent the cost of the water unit. Irrigating the field cost 50 ETB every man-day Labor Day. The season's total water expenditure was determined by multiplying.

Gross revenue was calculated by multiplying the total yield in kg ha-1 of garlic market price per kilogram. Net return (NR) and benefit-cost ratio (BCR) due to irrigation will be calculated following Eq. (7).

NR = Gross revenue – Total cost …(7)

The benefit-cost ratio (BCR) in ETB measures the increase in net return (NR) which was generated by total cost expenditure (TC) and compared following Eq. (8).

$$BCR = \frac{NR}{TC} \quad \ldots(8)$$

The amount of water saved (WS) per hectare of land will be attained by subtracting from CFI (100% ETc) application level which was used as a control from the treatments. The net return for the additional area (NRA) for harvested marketable yield was calculated as the difference between the sum of the cost of labor for a combination of irrigation Systems and application levels, the cost of water that was saved from application levels, and the revenue lost due to yield decreases resulting from this factor protocol was obtained following Eq. (9).

$$NRA = (G * LS + C * WS) - P * YL \quad \ldots(9)$$

Where, NRA is net returns of additional area (ETB), LS is labor saved from the irrigation system (person per day), WS is the volume of water saved (m^3 ha^{-1}), YL is yield loss (kg ha^{-1}), C is the unit price per m^3 of water, P is the unit price per kilogram of garlic bulb yield and G is the unit cost of labor per irrigation per ha

2.10. Statistical Analysis

The collected data were statistically analyzed appropriately for RCBD. When the data have shown statistical differences among treatments, mean separation was done using the least significant difference (LSD). The R statistical software was used for the analysis of variance. Correlation analysis was performed to obtain the correlation coefficients among the collected data.

3. Results and Discussion

3.1. Soil Sample Analysis

The results of soil sample analyses on soil physical and chemical properties are given in Table 3.1 and Table 3.2

3.1.1. Soil physical characteristics

According to the laboratory study, the experimental plot's particle size distribution ranged between 32% and 69% for the clay content, 17% and 20% for the sand content, and 34% and 44% for the silt content (Table 3.1). As a result, it is discovered that the soil textural classes are clay for soil depths of 20 to 40 cm and silty clay loam for soil depths of 0 to 20 cm and 40 to 60 cm. The experimental site's bulk density varied somewhat and got higher as depth climbed. With a mean bulk density of 1.19 gm/cm3, the bulk density ranged from 1.13 to 1.26 gm/cm3. With a mean value of 187.4 mm/m, the TAW fluctuated within a narrow range of 185.7 to 188.7 mm/m.

Table 3.1. Soil physical properties of the experimental area

Soil depth (cm)	Soil moisture content		Bulk density (gm/cm^3)	TAW (mm/m)	Particle size distribution (%)			Textural class
	FC (%v)	PWP (%v)			Clay	Sand	Silt	
0 - 20	50.83	32.26	1.13	185.7	36.9	19.6	43.5	Silty clay loam
20 - 40	52.21	33.44	1.18	187.7	68.7	17.6	13.7	Clay
40 - 60	51.85	32.98	1.26	188.7	32.4	19.6	48.0	Silty clay loam
Mean	**51.63**	**32.89**	**1.19**	**187.4**	**46.0**	**18.9**	**35.1**	**Clay**

3.1.2. Soil chemical and water quality analysis

The pH of the soil in the experimental field was found to be almost neutral and to range very narrowly between 7.0 and 7.1. An essential metric for determining the acidity or alkalinity of soil is its pH, which expresses the concentration of hydrogen ions in the soil. A pH range of 6.0 to 8.0 is ideal for garlic growth (Olani Nikus and Fikre Mulugeta, 2010). Through a 60 cm soil profile, the soil exhibited a CEC of around 12.1 me/100gm of soil, indicating a poor fertility state and a garlic threshold value of 1.2 dS/m, which is below the typical ECe of 0.27 dS/m (Smith et al,. 2011). The average values of the soil's OM and OC contents were 1.82% and 1.04%, respectively.

The laboratory results of the irrigation water quality indicate that the pH value was 7.5 and the ECw value was 0.69 dS m^{-1} (Table 3.2). According to Bryan et al., (2007), irrigation water is classified in terms of pH as low (below 7), slight to moderate (7-8), and severe (above 8). Based on this classification, the characteristic of the irrigation water in the study area was found slight to moderate (Table 3.2).

Bauder et al., (2014) reported that irrigation water quality in terms of salinity hazard has four categories: ≤ 0.75 dS m^{-1} none; 0.76 - 1.5 dS m^{-1} some; 1.51 - 3.0 dS m^{-1} moderate and ≥3.0 dS m^{-1} severe. Based on the above categories the irrigation water quality of the study area was classified as none

Table 3.2. The soil and water chemical analysis

Soil depth (cm)	pH	ECe (dS/m)	OC (%)	OM (%)	CEC (me/100gm)
0 – 20	7.1	0.28	1.2	2.1	14.6
20 – 40	7.1	0.25	1.1	1.89	11.8
40 – 60	7.0	0.29	0.9	1.6	9.8
Average	**7.1**	**0.27**	**1.1**	**1.82**	**12.1**
Irrigation water	7.5	0.69			

3.2. Garlic water and Irrigation Water Requirements

The daily ETo was generated using CROPWAT 8.0 for windows using the Kc values as derived below (Allen et al., 1998), based on the daily weather data acquired from the Kulumsa meteorological station throughout the growth season from February 23 to July 15, 2022. It was discovered that the seasonal crop water needs were

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374.35 mm and the irrigation water requirements were 298.5 mm, respectively. Table 3.3 displays the net and gross depths of water required for the treatments under full irrigation. Table 3.4 displays the gross depth of irrigation applied for each treatment during the growth season. The gross irrigation need applied under each treatment ranged from 135.45 to 497.52 mm per season, based on a 60% irrigation application efficiency. Under was the least amount of gross irrigation water applied. And hence, the least water used to produce the garlic yield from AFI and FFI treatments was 135.45 mm.

Table 3.3. Crop water and irrigation water requirements for the control treatment

Date	ETc (mm)	RF (mm)	Effective rainfall (mm)	NIR (mm)	GIR (mm)
26-Feb		3.9	2		
8-Mar	26.24			31.1	51.8
18-Mar		49	29.1		
19-Mar		4.7	2.5		
20-Mar		18	10.5		
23-Mar		9.8	5.6		
6-Apr	84.34			40.54	67.57
12-Apr		4.5	2.37		
13-Apr		25.3	14.85		
15-Apr		3.5	1.77		
16-Apr		2.3	1.05		
17-Apr		0.3	0		
23-Apr		3.9	2.01		
24-Apr		3.3	1.65		
25-Apr		4.5	2.37		
26-Apr		0.2	0		
30-Apr	82.33			44.78	74.6
5-May	43.56			44.78	74.6
13-May	44.62			44.78	74.6
22-May	44.82			44.78	74.6
3-Jun	48.43			47.78	79.6
Total	**374.35**	**133.2**	**75.77**	**298.5**	**497.5**

Table 3.4. Depth of irrigation water application (mm)

Date	AFI/FFI 100%ETc	AFI/FFI 85%ETc	AFI/FFI 70%ETc	AFI/FFI 55%ETc	CFI 100%ETc	CFI 85%ETc	CFI 70%ETc	CFI 55%ETc
8-March	25.90	22.01	18.13	14.24	51.80	44.03	36.26	28.49
6-April	33.79	28.72	23.65	18.58	67.57	57.44	47.30	37.17

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30-April	37.32	31.72	26.12	20.52	74.63	63.44	52.24	41.05
5-May	37.32	31.72	26.12	20.52	74.63	63.44	52.24	41.05
13-May	37.32	31.72	26.12	20.52	74.63	63.44	52.24	41.05
22-May	37.32	31.72	26.12	20.52	74.63	63.44	52.24	41.05
3-June	37.32	31.72	26.12	20.52	79.63	63.44	52.24	41.05
Total	246.27	209.33	172.39	135.45	497.52	418.65	344.77	270.89

3.3. Crop Growth and Physiology Parameters

3.3.1. Plant height

A substantial (P<0.05) variation in plant heights has been found by analysis of variance between the application on various furrow irrigation systems and irrigation levels (Table 3.5). With 100% ETc treatment, the greatest plant height of 50.53 cm was reported from CFI; there were no appreciable variations between CFI85%ETc and CFI70%ETc applications. Among the deficit irrigations, the 85%ETc treatment produced the tallest plants, and there was no discernible variation between the CFI70%ETc, AFI100%ETc, and FFI100%ETc applications.

The shortest plant height of 40.80 cm was recorded from deficit irrigation of 55%ETc application under FFI and shows no significant differences with FFI70%ETc, AFI55%ETc, AFI70%ETc, AFI85%ETc, and CFI55%ETc. This result was associated with treatment that received a larger amount of water that showed significantly taller plants compared with plots that received lower amounts at the same date of sampling.

There is a clear correlation between water usage and vegetative development since, on average, the mean plant height decreased as the amount of water applied decreased. Water stress circumstances have been shown to decrease the flexibility of the leaf cell wall, which inhibits leaf development. This finding might help to explain why water-stressed plants exhibit poor development because of significant variations in their relative water content and leaf water potential (Hsiao, 2000). Consistent with the findings of the current study, comparable tests have shown that plant heights increase under full irrigation (100%ETc) and drop under somewhat deficient irrigation over the crop growth season (Karasu et al., 2015). Similar research (Zinabu Akele, 2019) showed that convectional furrow irrigation produced the maximum plant heights.

3.3.2. Number of leaves per plant

Irrigation levels and furrow irrigation schemes had no effect on the number of leaves per plant (Table 3.5). On the other hand, when water delivery levels decreased, the number of leaves per plant decreased as well. With 100%ETc treatments, the maximum number of leaves per plant was measured from CFI. The mean number of leaves above the mean value for the treatment was obtained by applying deficit irrigation at rates of 85%ETc, 70%ETc, and 55%ETc under CFI, 100%ETc and 85%ETc under AFI, and 85%ETc application under FFI. With deficit irrigation of 70%ETc applications, FFI produced the fewest leaves per plant, whereas AFI and FFI with 55%ETc treatments produced about equal numbers of leaves per plant. This result appears to be closely related to that of Yemane Mebrahtu et al. (2018), who reported that the irrigation effect that promotes nutrient availability and photosynthesis for uninterrupted plant growth is responsible for the higher leaf number per plant resulting from the application of CFI with 100%ETc irrigation depth. Similarly, the effects of water stress on cell development may account for the decreased number of leaves per plant at (FFI) 55% ETc of irrigation level (Gebeyehu Tegenu, 2019). According to Zinabu Akele (2019), this showed that in response to water stress, plants close their stomata to reduce water loss through transpiration. This limits gas exchange inside the leaf, which slows down photosynthesis and development.

3.3.3. Leaf length

The length of the garlic leaves was considerably (P<0.05) impacted by the furrow irrigation methods and deficit irrigation levels. As irrigation levels have decreased, there has been a trend toward a decrease in leaf length. The CFI55%ETc treatment yielded the largest leaf length of 44.27 cm, and Table 3.5 indicates that there are no appreciable variations between the CFI100%ETc, CFI85%ETc, and FFI85%ETc applications. However, the lowest leaf length of 36.73 cm was obtained with the deficit irrigation application of 70%ETc under FFI. No significant differences were seen with FFI55%ETc, FFI100%ETc, or with any other deficit irrigations under AFI and CFI70%ETc treatments.

This result is supported by observations of Sandeep Kumar, (2012) and Gangwar et al., (2019) who reported that longer leaves at 100% crop water requirement compared to treatments of deficit irrigation levels. Water deficit leads to retarded plant growth as it results in the closure of stomata and interferes with the photosynthesis ability and nutrient uptake of plants and consequently, reducing cell division and growth and thus resulting in the stunting of leaves.

Table 3.5. Effect of furrow irrigation system and irrigation level on garlic plant growth

Treatments	Plant height (cm)	NLP (Number)	LL (cm)
CF100%ETc	50.53[a]	8.8	43.20[ab]
CFI85%Etc	48.47[ab]	7.9	42.13[abc]
CFI70%ETc	48.07[ab]	8.3	39.73[bcd]
CFI55%ETc	44.07[cdef]	8.1	44.27[a]
AFI100%ETc	46.53[bcd]	8.7	38.60[cd]
AFI85%ETc	43.07[ef]	8.3	38.87[cd]
AFI70%ETc	42.27[ef]	7.6	37.20[d]
AFI55%ETc	41.27[ef]	7.4	36.33[d]
FFI100%ETc	47.20[bc]	7.8	39.67[bcd]
FFI85%ETc	44.53[cde]	8.0	41.93[abc]
FFI70%ETc	43.33[def]	7.3	36.73[d]
FFI55%ETc	40.80[f]	7.5	39.67[bcd]
Mean	**45.01**	**7.9**	**39.86**
CV	**4.32**	**8.17**	**6.34**
LSD (P = 0.05)	**3.29**	**NS**	**4.28**

NB: Figures carrying the same letter are not significantly different from each other.

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During water deficit, stomata close to conserve water, limiting carbon dioxide availability and decrease in photosynthesis. This means that carbon assimilation is reduced and therefore the rate of leaf growth is reduced. It has been demonstrated that the decrease in available water under moisture stress first affects leaf expansion and then stomata conductance and gas exchange (Biniam Yaziz Muktar, 2019), Similarly, (Smith et al., 2011) quoted that the rate of transpiration, photosynthesis, and growth is lowered by even mild water.

3.4. Yield and Yield Parameters

3.4.1. Yield parameters

The yield parameters that include bulb diameter (BD), bulb height (BH), the weight of a single bulb (WSB), neck diameter (ND), number of gloves (GNo), and weight of a glove (WGLo) have shown statistically no significant difference except bulb diameter.

3.4.1.1 Bulb diameter

Garlic bulb diameter was measured to grade the quality of garlic produced. The analysis of variance has shown that furrow irrigation systems and irrigation levels significantly ($P<0.05$) affected bulb diameter (Table 3.6). The maximum bulb diameter of 48.73 mm was recorded from the CFI100%ETc application and shows no significant differences with CFI at 85%ETc and 70%ETc, AFI at 100%ETc, 85%ETc and 70%ETc and FFI at 100%ETc applications. However, the minimum bulb diameter of 40.67 mm was recorded from FFI and shows no significant differences with FFI at 85%ETc and 55%ETc. AFI at 55%ETc and 70%ETc and CFI at 55%ETc and 70%ETC applications.

The outcome was consistent with the findings of Bayu Enchalew et al. (2016) and Yemane Mebrahtu et al. (2018), who reported that high irrigation levels led to the formation of larger photosynthetic areas of the plant, such as plant height and leaf count, which in turn increased the amount of assimilating material partitioned to the bulbs and increased bulb diameter. Furthermore, the outcome is consistent with the findings of Kannan Narayanan and Mulugeta Mohammed Seid (2015), who found that harvests with higher percentages of large-sized bulbs were produced in plots that got the most water, whereas plots with little water yielded smaller-sized bulbs. Furthermore, Gebeyehu Tegenu et al. (2019) reported that greater irrigation led to an increase in bulb diameter. Furthermore, this suggests that transpiration.

3.4.1.2. Bulb height

The analysis of variance has shown that furrow irrigation systems and irrigation levels have no significant impact on bulb height (Table 3.6). The largest bulb height of (38.1mm) was recorded from full irrigation (100%ETc) application. The deficit irrigation levels applied in CFI at 85%ETc and 70%ETc, and in AFI at 100%ETc and 85%ETc gave bulb height above the average bulb height of 35.2mm.

The shortest bulb heights of 33.4mm were recorded from AFI and FFI with deficit irrigation of 55%ETc and 100ETc applications, respectively. The bulb height recorded in CFI55%ETc, FFI85%ETc, and FFI70%ETc applications were within a narrow range with the least bulb height. The result indicated that the 55%ETc deficit

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irrigation level might have reduced transpiration and photosynthesis and assimilated available for growth of the crop, which thus caused the production of small bulbs. This result is in line with that of Gebeyehu Tegenu et at., (2019) who observed smaller-sized bulbs in mild water-stressed plants. Similarly, Habtie Yelma, (2020) reported that a higher level of irrigation in a ratio of 1.2 IW: CPE resulted in maximum bulb length.

3.4.1.3. Bulb weight

The analysis of variance has shown that furrow irrigation systems and irrigation levels have no significant impact on bulb weight (Table 3.6). The maximum bulb weight of 43.13gm was recorded from the CFI100%ETc application (Table 3.6). The bulb weights recorded from CFI85%ETc and CFI70ETc, AFI100%ETc and AFI85%ETc, and FFI100%ETc applications were greater or about equal to the average bulb weight for the treatments. The lowest average bulb weight of 30.2mm was recorded from the FFI55%ETc application and the bulb weight obtained from the AFI55%ETc application was found in a narrow range with the minimum bulb weight obtained in the FFI55%ETc application.

Similarly, Rowell, (1994) reported that average bulb weight was significantly increased at 120%ETC irrigation levels. Average bulb weight responded to an increased level of irrigation water applied. The increment in bulb weight due to an increase in irrigation levels might be because the growth of taller plants is depicted by a higher number of leaves causing better synthesis and transportation that assimilates from source to sinks (Kannan Narayanan and Mulugeta Mohammed Seid, 2015)

3.4.1.4. Neck diameter

The analysis of variance has shown that furrow irrigation systems and irrigation levels have no significant impact on neck diameter. As indicated in Table 3.6, the highest neck diameter of a bulb (0.16cm) was obtained from the control treatment (CFI100%ETc). The neck diameters of a bulb obtain from the CFI85%ETc application were in a narrow range with the AFI100% application. The rest treatments resulted in neck diameters between 0.05 and 0.09cm diameter with the minimum and maximum diameter being from AFI at 100%ETc and 55%ETc applications, respectively. As the coefficient of variation (CV) (at what point accepted) was not within an acceptable range, the result could not be trusted from a statistical point of view.

However, this result is consistent with the findings of Murphy, (1968) and Metwally, (2011) who reported that a higher level of applied water resulted in a significantly thicker neck bulb.

3.4.1.5. Number of Gloves

The analysis of variance has shown that furrow irrigation systems and irrigation levels have no significant impact on number of gloves**.** As indicated in Table 3.6, the highest glove number (17) was obtained from the control treatment (CFI100%ETc). The clove numbers obtained from CFI85%ETc and CFI70%ETc, AFI100%ETc, and FFI100%ETC were above the mean values for the treatments. The lowest glove number (14) was recorded from the FFI55%ETc application and the glove number obtained from CFI55%ETc, AFI85%ETc, AFI55%ETc, FFI100%ETc, and FFI70%ETc were found within a narrow range with the lowest glove number.

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3.4.1.6. Glove weight

The analysis of variance has shown that furrow irrigation systems and irrigation levels have no significant impact on glove weight**. As** indicated in Table 3.6, the highest glove weight of 3.40gm was obtained from the control treatment (CFI100%ETc). The glove weight of CFI85%ETc CFI70%ETc, AFI100%ETc, and CFI100%ETc applications gave nearly above the mean glove weight for the treatment. The lowest glove weight of 2.3gm was obtained from the AFI55%ETc application.

Table 3.6. Effect of furrow irrigation and irrigation level on yield component of garlic

Treatments	BD (mm)	BH (mm)	WB (gm)	ND (cm)	GNo (Number)	WGLo (gm)
CF100%ETc	48.731[a]	38.1	43.1	0.16	16.9	3.40
CFI85%ETc	46.13[abcd]	35.9	41.3	0.14	16.2	2.67
CFI70%ETc	44.20[abcde]	35.2	40.8	0.08	14.7	2.77
CFI55%ETc	43.33[bcde]	34.7	36.0	0.08	13.6	2.60
AFI100%ETc	47.93[ab]	37.1	40.1	0.09	15.3	2.87
AFI85%ETc	46.00[abcd]	36.6	39.9	0.08	13.8	2.73
AFI70%ETc	44.33[abcde]	34.9	32.7	0.06	14.1	2.50
AFI55%ETc	42.73[cde]	33.4	31.1	0.05	13.7	2.33
FFI100%ETc	47.40[abc]	33.4	39.9	0.08	13.7	2.67
FFI85%ETc	42.67[cde]	34.6	34.9	0.08	15.5	2.60
FFI70%ETc	40.67[e]	34.5	33.4	0.08	14.3	2.53
FFI55%ETc	42.00[de]	33.8	30.2	0.08	13.5	2.47
Mean	**44.68**	**35.2**	36.9	**0.08**	**14.4**	**2.68**
CV	**6.61**	**5.75**	**18.04**	**54.21**	**16.86**	**25.37**
LSD (0.05)	**5.00**	**NS**	**NS**	**NS**	**NS**	**NS**

NB: Figures carrying the same letters are not significantly different from each other.

3.5. Total bulb yield

During data collection, the total weight of unmarketable bulbs that are undersized < 20gm diseased, decayed, and bulbs from plants with the physiological disorder could not be obtained. The data collected were all marketable bulbs and hence, total bulb yield. Accordingly, the analysis was carried out only for the total bulb yield of garlic.

The results of the analysis of variance showed that the irrigation levels and furrow irrigation schemes had a significant ($p<0.05$) impact on the overall bulb production of garlic (Table 3.7). The control treatment produced the greatest overall bulb yield of 98.62 qt/ha, which was noticeably greater than that of any other treatment. The CFI85%ETc application produced the greatest overall bulb yield of 82.68 qt/ha among the deficit irrigation treatments; there was no discernible difference between the CFI70%ETc and AFI100%ETc applications. With the exception of AFI100%ETc applications, all AFI and FFI applications show no discernible difference in total bulb yield, with the lowest total bulb yield of 42.75 qt/ha coming from the FFI55%ETc application.

The finding of this study is closely related to that of Yemane Mebrahtu et al., (2018), who reported that the CFI system with 100%ETc irrigation applications gave the highest marketable bulb yield. According to (Neeraja et al., 1999), the increment in marketable bulb yield due to an application of irrigation water could be attributed to the increment in vegetative growth and total bulb yield, which is associated with an increment in bulb diameter and average bulb weight. According to (Yemane Mebrahtu et al., 2018), among the furrow irrigation systems, CFI and AFI produced the best marketable bulb yield while the significantly lowest mean marketable bulb yield was obtained from FFI and 55%ETc application. Similar to the present observation Bhagyawant et al., (2015) also reported that water application with no deficit (100% full Crop water requirements) at any stage of plant growth gave the highest marketable yield. Results of Gebeyehu Tegenu , (2019), Habtie Yelma, (2020), and Bayu Enchalew et al., (2016) also showed that the marketable bulb yield of garlic increased with an increase in irrigation water amount in a linear relationship. Similar results were also reported by Gebeyehu Tegenu, (2020) who showed that dealing with the improvement of water productivity is closely related to the irrigation practice of regulated deficit irrigation and has a direct effect on yield i.e. if the amount of water applied decreases similarly the crop yield will also drop.

3.6. Yield Response to Deficit Irrigation

Table 3.7 provides the yield response factor (Ky)-quantified reaction of garlic yields to the water supply. Based on the findings of the field experiment, the maximum seasonal evapotranspiration (ETm) of 3743 m3, or the complete crop water need, was recorded as the maximum garlic yield (Ym) of 9862.4 kg ha-1. Table 3.7 shows the yield response factor (Ky) of garlic to water deficiency under various furrow irrigation techniques and application amounts. Ky varied from 0.6 to 1.1, with 100% of ETc applications under AFI and 85% of applications under CFI resulting in the lowest and highest Ky values. According to FAO (2002), Ky values larger than unity imply that the relative yield decrease is greater than the water shortage. In light of

According to Klocke et al., (2011), the Ky value for field crops goes from 0.2 to 1.15 which agrees with the reported result. Pershing et al., (1920) reported that the effect of water deficit on crop yield, a deficit occurring for the total growing period, the decrease in yield is proportionally less with the increase in water deficit.

Table 3.7. Garlic yields a response to water

Treatment	ETa (mm ha^{-1})	ETm (mm ha^{-1})	Ya (Kg ha^{-1})	Ym (Kg ha^{-1})	Ya/Ym	ETa/ETm	Ky
CF100%ETc	374.3	374.3	9862.4	9862.4	1	1	-
CFI85%ETc	318.2	374.3	8268.1	9862.4	0.8	0.9	1.1
CFI70%ETc	262.0	374.3	7647.3	9862.4	0.8	0.7	0.7
CFI55%ETc	205.9	374.3	5530.9	9862.4	0.6	0.6	1.0
AFI100%ETc	187.2	374.3	7125.2	9862.4	0.7	0.5	0.6
AFI85%ETc	159.1	374.3	5686.1	9862.4	0.6	0.4	0.7
AFI70%ETc	131.0	374.3	5488.5	9862.4	0.6	0.4	0.7
AFI55%ETc	93.6	374.3	4289.2	9862.4	0.4	0.3	0.8
FFI100%ETc	187.2	374.3	5516.8	9862.4	0.6	0.5	0.9

FFI85%ETc	159.1	374.3	4797.2	9862.4	0.5	0.4	0.9
FFI70%ETc	131.0	374.3	4557.3	9862.4	0.5	0.4	0.8
FFI55%ETc	93.6	374.3	4275.1	9862.4	0.4	0.3	0.8

4. Conclusions and Recommendations

4.1. Conclusions

The research has led to the development of irrigation water management strategies that, in the event of a shortage of water resources, can optimize garlic bulb output and WUE. According to the study, of all the deficit irrigation methods, CFI85%ETc treatments produced the maximum yield of garlic bulbs—82.68 q/ha—while CFI70%ETc and AFI100%ETc applications did not significantly vary from one another. However, taking into account water conserved and the yield of garlic bulbs that may be generated with excess water, AFI100%ETc offered 19.03 kg mm-1 and 28.64 kg mm-1, respectively, as ideal in terms of CWUE and IWUE. According to Ky, the yield response factor, the AFI at 100%, 85%, and 70% ETc applications will be least impacted by the relative yield loss.

4.2. Recommendations

From the findings, it is clear that garlic bulb yield and WUE can be improved from the limited available water resource. For the improved garlic bulb yield and WUE under limited water resource conditions, the following recommendations were made.

- For maximum garlic bulb yield and WUE, the crop should be irrigated under AFI with deficit irrigation of 100%ETc applications. Since we have saved 50% of water to irrigate additional and also the yield and CBR was not significant difference with the second higher yield obtained.
- Farmers should be advised, well trained and monitored by the experts of BoA to acquire knowledge and create awareness on the importance of deficit irrigation in water scare areas in terms of yield advantage and water saving.
- Since this study is a one-season study, should be repeated for one more year to validate the output.
- A similar study should be repeated in other areas under similar agroecological conditions in order to confirm the validity of the present findings and hence garlic bulb production and WUE could be improved under similar agroecology of the region.

Declarations

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Competing Interests Statement

The authors have declared that no competing financial, professional or personal interests exist.

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Availability of Data and Material

Supplementary information is available from the authors upon reasonable request.

Authors' contributions

All the authors took part in literature review, analysis, and manuscript writing equally.

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