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Effect of Irrigation Regimes on Yield and Water Use Efficiencies of Potato at Dorso Scheme, in the Abaya District, Southern Oromia

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Abstract

The use of water management techniques, such as irrigation scheduling, minimizes production losses brought on by drought stress or water scarcity while preventing excessive water application. In order to ascertain the best irrigation schedule for potato yield, yield component, and water productivity based on the available soil moisture depletion levels, the experiment was carried out at the farm level in the Abaya district during the irrigation seasons of 2022 and 2023. Three replications of a randomized full block design were used to lay out the irrigation treatments. Treatment was conducted using the five available soil moisture depletion levels: 60% ASMDL, 80% ASMDL, and 100% ASMDL (FAO recommended ASMDL), 120% ASMDL, and 140% ASMDL. The findings demonstrated that, as compared to other treatments, irrigation regimens with 80% ASMDL produced superior tuber weight, number of tubers per plant, marketable tuber yield, and water use efficiency of potatoes; however, these effects were statistically insignificant when applied with 60% ASMDL. The 80% ASMDL treatment produced the largest tuber weight (94.53 g) and the most tubers per plant (12.107), and the results were statistically comparable to those of the treatment that received 60% ASMDL irrigation. Treatments receiving 80% FAO-recommended ASMDL had the highest marketable tuber production (24.98 tons/ha) and water productivity (5.259 kg/m3), with no discernible difference from treatments receiving 60% FAO-recommended ASMDL. Based on the results of the current experiment, it is advised that potatoes be grown in the Abaya district and in areas with comparable agro-ecology and soil types using a convectional furrow irrigation system with an 80% allowed soil moisture level every five days.

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Introduction

Crop production depends on water, and in order to produce crops efficiently and with high yields, the best use of the water that is available must be made. This necessitates a thorough comprehension of how irrigation and rainfall affect crop development and production in various growing environments (1). Agricultural output is constrained by elements that impact production success, such as soil structure, climate, and water availability. One agricultural input that is essential to agricultural production is water (2). Applying the right amount of water to crops at the right time is essential for crop development efficiently.

There is no effective and well-managed irrigation water practice in Ethiopia, despite the fact that irrigation has been used at various agricultural levels (3). Any better irrigation technique's primary characteristic is the precise timing of the water administration, which minimizes the range of moisture content variations in the root zone and lessens plant stress.

The act of choosing when and how much irrigation water to use is known as irrigation scheduling (4). Irrigation scheduling is one of the most crucial instruments for creating appropriate management practices for irrigated areas when the supply of irrigation water is limited (5). It is essential for increasing irrigation efficiency, conserving water, and ensuring the sustainability of irrigated agriculture (6). Maintaining soil moisture within a specified range usually between field capacity (full point) and a predefined replenishment point for ideal growth is the goal of irrigation scheduling. Farmers in Southern Oromia, most especially in the Abaya district, know very little about the quantity and frequency of water used in irrigated potato farming.

Farmers either over irrigate, which results in soil erosion, water logging, salinity, an increase in the water table, crop disease susceptibility, water loss, and additional pumping energy expenditures. However, because they irrigate their fields at the wrong times and in sufficient quantities, farmers result in strained crops of water for plant physiological activities. This led to a decrease in yield and unfavorable alterations in the chemical characteristics of the soil (7) and (8). The purpose of this study was to ascertain the water consumption efficiency of potatoes under optimal scheduling in the study region and to assess how the potato crop responded to the irrigation regime (when and how much).

Materials and Methods

Description of the Study Area

The study was conducted for two consecutive years of 2022 and 2023 during off-season at Abaya district of west Guji Zone, Oromia regional state, Ethiopia. The district is found at a distance of 110 km from Bule hora, the zonal capital city and 385 km from Finfinne in south west side. The study area lies between 06° 10' 0" to 06° 40' 0" N and 37° 50' 0" to 38° 20' 0" E longitude with average elevation of 1577 m a.s.l.

The Rain fail characteristic of the site is bi-modal rainfall pattern with a total annual rainfall of 1804 mm and maximum rainfall occurs on month of April, May, September and October (table1). The climate of the study area has maximum and minimum air temperature of 24.7 °C and 10.3 and respectively.

In the west Guji zone's Abaya district, there were no reputable weather stations. For this purpose, CLIMWAT was employed to create the requisite climatic data. Long-term monthly mean values of seven climatic parameters—daily maximum and minimum temperatures, relative humidity, wind speed, sunshine hours, solar radiation, monthly effective rainfall, and reference evapotranspiration—are provided by the CLIMWAT climatic database, which is used in conjunction with the computer program CROPWAT (9).

Using the Geographic Positioning System, latitude, longitude, and altitude are recorded on-site and used to retrieve meteorological data from CLIMWAT. The reference evapotranspiration (ET_o) was calculated using the experimental site's minimum and maximum temperatures, relative humidity, wind speed, daylight hours, and solar radiation. CROPWAT software version 8.0 was used to estimate Reference Evapotranspiration (ET_o) using the FAO Penman-Monteith technique (10).

Experimental Design and Treatment Combinations

Three replications and a randomized complete block design (RCBD) were used to create the single factor experiment. Five levels of soil moisture depletion based on the FAO soil moisture depletion level were included in the experiment. According to table 2, those are ASMDL (60%, 80%, 100%, and FAO-recommended ASMDL), 120%, and 140%. The other treatments' permissible moisture depletion levels were computed using the suggested permitted moisture depletion level of 35% for potatoes. The experimental plots were randomly assigned to the treatments.

The experimental plot, which was 3 m broad and 4.2 m long, was planted with the potato zemen variety as the test crop. Plots and blocks were separated by 1 m and 1.5 m, respectively. Plants were spaced 0.3 meters apart and rows were spaced 0.75 meters apart. Half of the 100 kg/ha urea was applied during planting, and the remaining 40 days were spent after planting, using the recommended fertilizer rate of 121 kg/ha NPS at planting. For every treatment, all other agronomic procedures were maintained consistent and routine.

Soil Moisture Determination

Soil moisture content was determined by gravimetric method, i.e. by oven drying of soil samples at 105 °C for 24 hr or until the change in weight is constant. Then, gravimetric water content was converted to volumetric water content by multiplying soil bulk density and root depth of crop to get available field/current moisture at the time of irrigation using the following equation.

$$\theta_{dw} = \frac{w_{ws} - w_{ds}}{w_{ds}} \times 100 \quad (1)$$

Where W_{ws} = weight of wet soil (g), θ_{dw} = water content expressed on weight basis in (%) and W_{ds} = weight of dry soil (g).

Determination of Crop Water Requirement and Irrigation Scheduling

According to (10), the crop coefficient for potatoes was derived from FAO Irrigation and Drainage Paper 56 and was 0.5 for the starting stage, 0.5 < Kc < 1.15 for the developmental stage, 1.15 for the mid-season stage, and 0.95 Kc for the late-season stage. The established Kc value (Eq. 2) was multiplied by the long-term ETo value to predict the seasonal crop water requirements (ETc).

$$ET_C = ET_o * K_c \quad (2)$$

Where, ETc = Crop evapotranspiration (mm/day), Kc = crop coefficient, and ETo = reference crop evapotranspiration (mm/day).

Using (10) (Eq. (3), the difference between the water content at field capacity (FC) and at permanent wilting point (PWP) was used to determine the total accessible water (TAW) of soil.

$$TAW = \frac{(FC - PWP)}{100} * BD * DZ \quad (3)$$

Where: - TAW=Total available Water (%), FC and PWP in % on weight basis, BD= Bulk density of the soil (gm cm^{-3}) and DZ= maximum effective root zone depth (mm).

The amount of water that crops may draw from the root zone without going through any water stress is known as readily available water, or RAW. Equation (10) was used to calculate the RAW.

$$RAW = TAW * p \quad (4)$$

Where: - RAW is the readily available water or net irrigation depth, IRn (mm), p is allowable permissible soil moisture depletion fraction and TAW is total available water in the root depth (mm).

Whenever there is rainfall between irrigation, the IRn was calculated based on(10) as follows:

$$IR_n = ET_c - P_e \quad (5)$$

Where P_e is the amount of rainfall that enters the soil and becomes accessible for crop production, ET_c is the amount of crop evapotranspiration (mm), and IR_n is the amount of net irrigation requirement (mm). The approach described by (10) was used to determine the effective rainfall (p_e).

$$P_e = 0.6 * RF - 10/3 \; for \; RF \; month \leq 70 \; mm \; or$$

$$P_e = 0.8 * RF - 24/3 \; for \; RF \; month > 70 \; mm \quad (6)$$

Where P (mm) is the actual monthly rainfall and Pe (mm) is the effective rainfall. Water losses during transportation and field application are factored into the gross irrigation requirements. When project gross irrigation requirements are calculated from net irrigation requirements, this is expressed in terms of efficiency. The following formula was used to estimate daily gross irrigation (4):

$$IRg = \frac{ET_c}{E_a} \quad (7)$$

Where, IR_g= gross irrigation requirement (mm), ET_c = crop evapotranspiration (mm/day)/net irrigation water requirement and E_a= irrigation efficiency.

Irrigation Water Application

A 3-inch Parshall flume was used to measure the amount of irrigation water applied to each experimental plot, which was placed 10 meters from the first plot in the first block. The plot area and depth of gross irrigation demand were used to calculate the amount of water applied for each treatment. The ratio of the volume of water applied to the discharge-head relation of the 3-inch Parshall flume was used to determine how long it would take to irrigate each treatment. An equation below was used to determine how long it would take to deliver water into each furrow to the specified depth.

$$T = \frac{A*d}{6*q} \quad (8)$$

Where, T= Application time (min), A= Area to be irrigate (m^2), d= gross irrigation depth of water to be applied (cm) q= Flow rate of Discharge (l/s).

Water Productivity

The following formula was used to compute water productivity, which was evaluated as the ratio of marketable potato output to total crop water absorbed by crop during the growing season (11).

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

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

Data Collection

Plant height, number of tubers per plant, tuber weight, and yield of unmarketable and marketable tubers were the data to be collected. A measuring tape was used to measure the height of nine randomly chosen plants in the experimental plot at physiological maturity, starting from ground level and ending at the tip of the leaf.

From nine randomly chosen plant samples, potato tubers were excavated, counted, and recorded from each sampling potato plant to determine the quantity and weight of tubers per plant. In order to determine the yield of marketable and unmarketable tubers, the yield of potato tubers from the middle rows of each plot was manually collected, graded, and their fresh weight quantified. The results were then translated to t ha^{-1} for statistical analysis.

Data Analysis

All necessary data collected were managed properly using the Genstat software 18th edition.

When treatment effect was found significant, mean separation was tested using least significant difference (LSD) at 5% probability level.

Results and Discussion

Soil Physical and Chemical Properties of Experimental Site

The physical and chemical characteristics of the soils at the study location were measured in order to characterize them. Therefore, the particle size of the soil at the experimental location indicated that the subsurface (20–60 cm) and surface (0–20 cm) soil profiles could be categorized as clay and clay loam, respectively, based on the USDA soil textural categorization (table 3).

The experimental field's soil bulk density was 1.36 g/cm3 for soil profiles measuring 0–20 cm and 1.40 g/cm3 for soil profiles measuring 20–40 and 40–60 cm. According to (12), the average bulk density of the soil in the experimental field was 1.39 g/cm3, which is less than the required threshold level for crop root growth (1.45 g/cm3).

And the average soil water values at the experimental site's permanent wilting point (PWP) and field capacity (FC) were 24.2% and 33.0%, respectively. The average amount of water that was available in the soil profile was 97.75 mm, as shown in table 3.

According to the laboratory results, the average pH of the soil at the experimental site was in the somewhat acidic range (table 4). Over a 90-cm depth of soil profile, the average values of the soil's organic matter and organic carbon content were 3.007% and 1.74%, respectively. An experimental soil's average electrical conductivity (ECe) is 0.137 ds/m. In general, a soil is considered normal if its pH is less than 8.5 and its electrical conductivity is less than 2.0 dS/m at 25°C, under USDA soil classification. As a result, the research area's soils can be categorized as typical soils.

Crop Water Requirement and Irrigation Interval

According to an analysis of monthly reference evapotranspiration (ETo) determined by CropWat, the mid-stage, which is in February and March, had the highest ETo of 4.32 mm/day, while the initial crop growth stage, which is in December and January, saw the lowest ETo. For the first, development, mid, and late growth stages, the seasonal crop water requirements are 39.7 mm, 96.3 mm, 244.7 mm, and 115.5 mm, respectively. As a result, the total net crop water demand for potatoes during the cropping season was determined to be 496.2 mm (table 5).

The treatment of 60% ASMDL resulted in the highest total net irrigation application, whereas the treatment of 140% ASMDL produced the lowest total net irrigation application (table 6). For irrigation treatments of 60% ASMDL, 80% ASMDL, 100% ASMDL, 120% ASMDL, and 140% ASMDL, respectively, the average irrigation interval was 4, 5, 6, 7, and 9 days (table 6). The findings indicate that, in comparison to the potato crop treated with 140% ASMDL, irrigation application events or intervals were shorter for the 60% ASMADL treatment. The findings showed that when irrigation intervals grow, tuber production tends to decrease. When compared to other irrigation intervals, the fifth day's interval produced more tubers.

The lowest tuber production was obtained with a 9-day irrigation interval (table 6). This outcome was reported by (13), who found that a garlic crop treated with 80% ASMDL and spaced five days apart from irrigation produced the highest output.

Effect of Irrigation Regimes on Potato Yield and Yield Component

Plant Height

There was no significant difference ($P<0.05$) in the height of potato plants between treatments, according to analysis of variance. The highest plant height (76.72) was achieved with an irrigation application of 60% ASMDL; nonetheless, there were minimal numerical variations between treatments (table 7).

However, the smallest plant height (66.55 cm) was produced by the irrigation water treatment that applied 140% ASMDL. Overall, the findings indicated that the height of the potato plants declined as the degree of depletion increased.

Number of Tuber per Plant

ANOVA revealed that the available soil moisture depletion level (ASMDL) treatments had a significant ($P < 0.05$) effect on the number of tubers per plant. The irrigation that was provided every five days or 80% ASMDL produced the most tubers per plant (12.126). The amount of tubers per plant (11.107) that resulted with 60% ASMDL or watering every four days was statistically equivalent to this. Although it produced less tubers per plant than the 100% ASMDL (FAO recommended) and 120% ASMDL treatments, the 140% ASMDL treatment was statistically equivalent (table 7).

Tuber Weight

Every possible soil moisture depletion level (ASMDL) treatment had a substantial ($P < 0.05$) impact on the mean tuber weight. The treatments of 80% ASMDL and 60% ASMDL produced the largest tuber weight (94.53 g), respectively. However, the potato tuber weight values that were lowest (71.84, 72.34, and 78.88 g) came from treatments that had available soil moisture depletion levels of 140%, 100%, and 100% ASMDL, respectively.

Marketable Tuber Yield

The results of the analysis of variance showed that the marketable tuber production of potatoes was considerably ($P < 0.01$) impacted by irrigation regimes. Treatments that got 80% of the FAO-recommended ASMDL produced the maximum marketable tuber output (24.98 t/ha); there were no statistically significant variations in marketable tuber yield between treatments that received 60% ASMDL during irrigation. However, the application of 140% ASMDL produced the lowest marketable tuber yield of potatoes (17.65 tons/ha), which is statistically comparable to that of 100% and 120% ASMDL (table 7).

This outcome is consistent with the findings of (14), who found that a much larger yield of potato tubers was obtained when 80% of the available soil moisture was depleted by irrigation at shorter intervals.

Comparing the highest garlic output under treatment of 80% available soil moisture depletion with shorter interval irrigation to the control, (13) made a similar claim.

Water Productivity

In terms of water production, there is a significant difference between treatment applications of 80% and 120% ASMDL. Potatoes with 80% ASMDL irrigation applied every five days had the best water productivity (5.506 kg/m3), and all treatments were statistically comparable with the exception of irrigation with 120% ASMDL.

In terms of numbers, treatment with 120% ASMDL had the lowest water productivity (4.212 kg/m3) (table 7). This result was consistent with research by (15),(13), which found that the highest water production of the garlic and onion crops was achieved at a soil moisture depletion level of 80%.

Figure.1 Study area map.

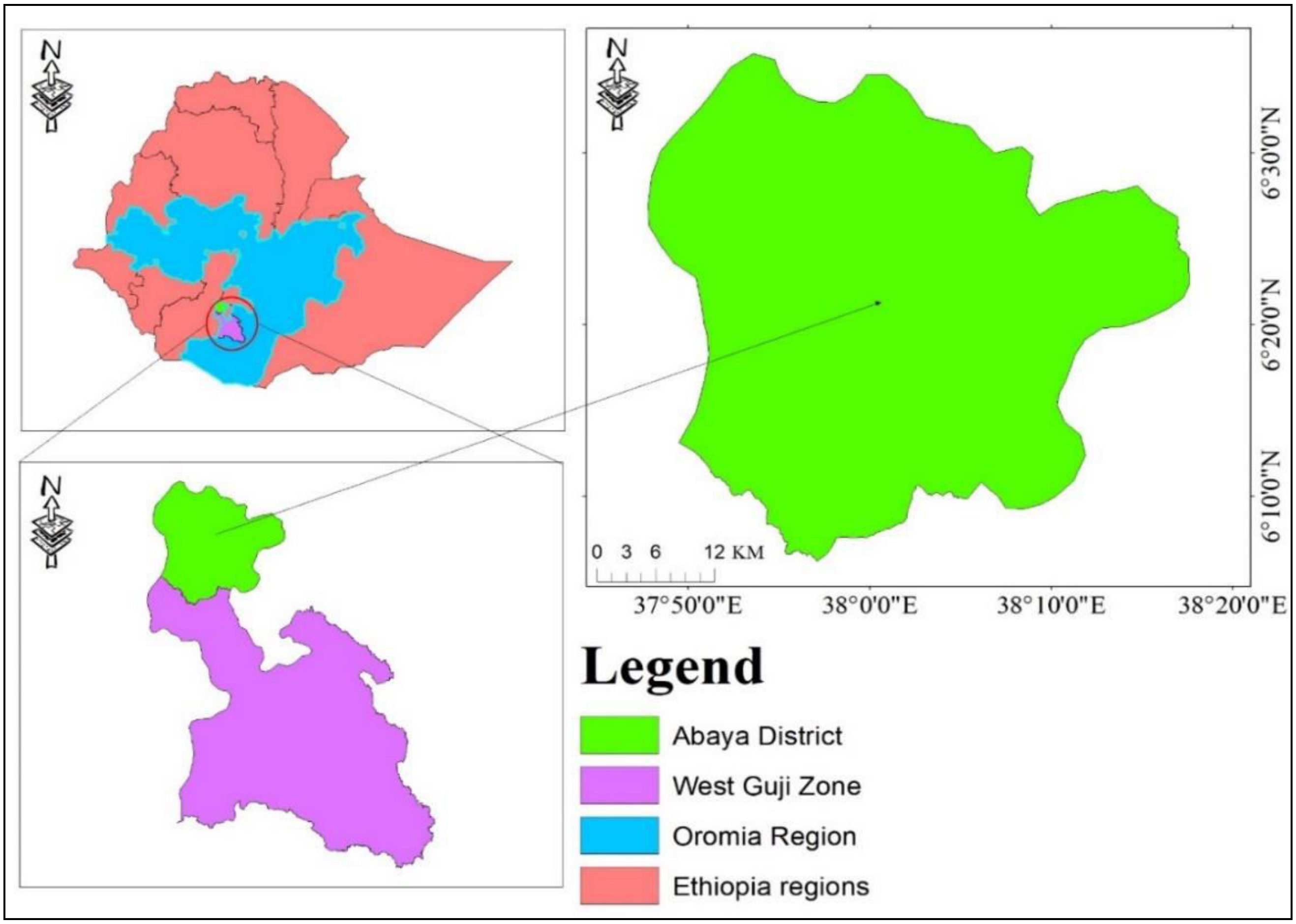

Table.1 Long term monthly average climatic data of the study computed by CLIMWAT.

Month	T_{min} (°C)	T_{max} (°C)	Humidity (%)	Wind speed(m/s)	sunshine hours(hr)	ET_o (mm/day)	Rainfall (mm)
January	7.3	26.6	62	1.5	8.4	4.07	29
February	9.8	26.3	60	1.5	8	4.25	42
March	10.9	26.9	65	1.7	7.3	4.38	123
April	11.3	25.2	75	1.5	7.4	4.05	293
May	11.2	24.1	77	1.5	7.2	3.75	296
June	11.8	23.6	80	1.8	6.7	3.51	136
July	11.8	23.3	80	1.4	4.7	3.1	101
August	11.9	23.3	77	1.4	5	3.3	124
September	11.3	23.4	81	1	6	3.43	243
October	11.4	23.1	71	0.9	7.1	3.61	301
November	8.9	24.7	70	1.1	8.5	3.78	103
December	6.3	26.1	58	1.3	8.2	3.88	13
Average	10.3	24.7	71	1.4	7	3.76	1804

Table.2 Treatment setting for field experiment.

Treatment (T)	Description
T_1	60% of ASMDL
T_2	80% of ASMDL
T_3	100% of ASMDL*(Control)
T_4	120% of ASMDL
T_5	140% of ASMDL

*ASMD is available soil moisture depletion level according to FAO (33)

Table.3 Soil physical properties of experimental site.

Soil depth (cm)	FC (%)	PWP (%)	BD (g/cm^3)	Percent in (%)			Textural Class	TAW (mm)
				Sand	**Silt**	**Clay**		
0-20	30.4	20.8	1.36	34	24	16	Clay	26.88
20-40	32.4	24.7	1.40	35	37	9	Clay loam	21.56
40-60	36.1	27.0	1.40	31	39	75	Clay loam	24.75
Average	33.0	24.2	1.39	33.3	33.3	33.3	Clay loam	97.75

Where: BD- bulk density, FC- field capacity, PWP- permanent wilting point, TAW- total available water

Table.4 Soil chemical properties of experimental site.

Soil depth (cm)	pH (H_20)	EC (dS/m)	%OM
0-20	6.2	0.245	4.44
20-40	6.0	0.091	2.83
40-60	6.0	0.077	1.75
Average	6.07	0.137	3.007

Where: EC: Electrical conductivity and OM- organic matter

Table.5 Crop water requirement of (ET_c) of potato.

Growth stage	Growing Period	ET_o (mm/day)	Kc	ET_c (mm/day)	Effective rain (mm/season)	CWR(mm/stage)
Initial	25	3.98	0.50	1.19	0	39.7
Development	30	4.16	0.75	2.99	0	96.3
Mid	45	4.32	1.16	5.27	15.0	244.7
Late	30	4.21	0.95	3.28	61.5	115.5
Total					76.5	496.2

Table.6 Irrigation interval of potato for each treatment.

Treatments	Initial Stage		Development stage		Mid stage		Late stage		Total net irrigation (mm)	Average Interval (days)
	NIR depth (mm)	**Interval (days)**	**NIR depth (mm)**	**Interval (days)**	**NIR depth (mm)**	**Interval (days)**	**NIR depth (mm)**	**Interval (days)**		
60% of ASMDL	8.40	4	10.90	4	14.99	3	15.10	4	471.8	4
80% of ASMDL	11.13	6	12.38	4	17.99	4	19.23	5	453.7	5
100% of ASMDL	14.96	8	15.46	5	20.00	4	25.80	7	404.9	6
120% of ASMDL	16.98	9	18.90	6	26.20	5	0.00	0	422.1	7
140% of ASMDL	20.93	11	27.38	9	32.52	7	29.40	8	379.9	9

Table.7 Effect of irrigation regimes on potato yield, yield component and water productivity.

Treatment	PH (cm)	NTPP	TW (g)	UMTY(t/ha)	MTY (t/ha)	WP (kg/m^3)
60%ASMDL	76.72	11.107^a	83.38^{ab}	2.291	21.04^{ab}	4.459^{ab}
80%ASMDL	73.16	12.126^a	94.53^a	2.206	24.98^a	5.506^a
100%ASMDL	75.00	7.525^b	72.34^b	2.102	19.69^b	4.862^{ab}
120%ASMDL	72.94	7.915^b	78.88^b	2.017	17.78^b	4.212^b
140%ASMDL	66.55	6.550^b	71.84^b	2.194	17.65^b	4.646^{ab}
$LSD_{0.05}$	9.285	2.122	14.645	0.341	4.526	1.036
CV (%)	10.7	19.6	15.3	13.2	18.7	18.3
Mean	72.87	9.04	80.19	2.16	20.23	4.74

Note: PH-plant height, TW-tuber weight, NTPP-number of tuber per plant, UMTY-unmarketable tuber yield, MTY- marketable tuber yield, WP- water use efficiency, t- tone. Means followed by the same letters in a column are not significantly different from each other at a 5% probability level.

In conclusion, For two years in a row, during the irrigation seasons of 2022–2023 and 2023–2024, an experiment was carried out in the Abaya district in the west Guji zone. The purpose of this study was to ascertain the water consumption efficiency of the potato crop under ideal scheduling in the study area and to assess the crop's responsiveness to irrigation regime (when and how much). Depending on the FAO soil moisture depletion level, the experiment included five different levels of soil moisture depletion. 60% ASMDL, 80% ASMDL, 100% ASMDL (FAO recommended ASMDL), 120% ASMDL, and 140% ASMDL were the five ASMDL levels. Three replications of the experiment were set up using a Randomized Complete Block Design (RCBD). According to the results of the effects of various irrigation schedules, the treatment of 80% ASMD produced the largest tuber weight and number of tubers per plant, followed by the treatment of 60% ASMDL. There was no discernible difference between the two treatments. Furthermore, treatments that got 80% of the FAO-recommended ASMDL had the highest marketable tuber production (24.98 tons/ha) and water productivity (5.259 kg/m3), with no discernible difference from treatments that received 60% ASMDL. Based on the results of the current experiment, it is advised that potatoes be grown in the Abaya district and in areas with comparable agro-ecology and soil types using a convectional furrow irrigation system with an 80% permissible soil moisture level and a five-day irrigation interval.

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Conflicts of Interest

The authors declared no conflicts of interest.

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