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Effect of Water Levels at Different Growth Stages on Yield and Water Productivity of Potato at Ketar Genat Irrigation Scheme

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ABSTRACT

Irrigation is becoming a critical issue in the country so that selected irrigation technologies need to be developed. A field study was carried out at Ketar Genat irrigation scheme for two consecutive years during the dry season with the objective of evaluating water level effects at different growth stages on yield and water productivity and identifying the most delicate phases of potato tuber. The experiment was carried out in split plot design with nine treatment combinations and three replications. The treatments include four growth stages (initial, development, mid and late) as main plot, and two water levels (80% and 60% of ETc), and one control irrigation of 100% ETc as a subplot. The combined result of the experiment analysis indicated that, water level imposed at different growth stages significantly ($P<0.05$) affected potato tuber yield and water productivity. The highest tuber yield (35.62 t/ha) was obtained at control treatments where irrigation was applied at all the growth stage, this result was followed by a treatment 80% ETc during the initial stage (34.18 t/ha) which was statistically non-significant. On the other hand, the lowest tuber yield (18.17 t/ha) was obtained at 60% ETc during the mid-stage. The result tells that initial and late stages of potato tuber were the right time to practice deficit irrigation without significant yield reduction. The highest water productivity of (10.01 kg/m3) was recorded at 80% ETc during the initial stage. The output again revealed that potato tuber yield was most sensitive to water deficit that occurred at development and mid stages. Therefore, in areas where excess irrigation water is available potato tuber should be irrigated with 100% ETc at all growth stages to get high yield, otherwise irrigate potatoes with 80% ETc at initial stages at water scarce areas to maximize water productivity.

Keywords: Additional Area; Deficit Irrigation; Growing Phases; Irrigation Scheme; Opportunity Cost; Tuber Yield; Water Applied; Water Saved; Water Use Efficiency; Yield Penalty.

1. Introduction

Poor on-farm water management techniques and consequently these results are characteristics of Ethiopia's smallholder irrigation practices (Eguavoen et al., 2012). Both surpluses and inadequate resource allocation that permits an optimal and timely water supply are the root causes of poor on-farm water management. On-farm water management is poorly understood by farmers, especially when and how much to irrigate. When water is available, they have a tendency to over irrigate, which leads to conflicts and lack of water in other areas of the schemes. According to Haileslassie et al., (2016) excessive irrigation can also raise the water table and make the soils more salinized.

Water application intervals are regulated and mutually agreed upon by cultivators in many developing nations (FAO, 2016). But this doesn't take into account when and how to apply. However, just 3 to 5% of Ethiopia's 9.85 million hectares of potentially irrigable arable land are currently under irrigation, despite the country having a vast array of irrigation prospects that may account for 3% of total food crop production (WCD, 2000). If all other inputs stay the same, the output from rain-fed land is now only around 50% of that from irrigated land (Amede et al., 2008).

Chai et al., (2016) Claim that by optimizing yield per unit of water, lowering the quantity of irrigation application in irrigated agriculture could result in higher economic gains under drought and limited water supplies. Therefore, it is crucial to determine the exact conditions under which stress should be applied to a crop in regions with water shortages. This could be used, for instance, by choosing a crop's tolerant growth stage, which increases water productivity. Because crop sensitivity at a certain growth stage can affect the yield response, this helps irrigators identify specific crop growth stages and the amount of stress that should be applied to increase water productivity (Yilmaz et al., 2010).

According to Babukani et al., (2024), crop production using deficit irrigation at the level of 80–90% water requirement reduces the negative environmental effects of excessive irrigation and aids in reducing intercommunity conflicts for scarce water resources. Potato production should be watered throughout all growth stages in regions with unrestricted irrigation water; otherwise, irrigation was only permitted during the development stages or midseason to optimize water productivity (Mehiret et al., 2022).

Both the vegetative growth and tuber formation stages of potatoes showed no significant change in final plant height when a water deficit of 0 to 25 days was started at the beginning of the vegetative growth stage and the tuber formation stage. However, a longer duration of the water deficit resulted in a significant delay in flowering and a reduction in total biomass, yield, tuber dry matter content, and the share of large tubers (Li et al., 2023)].

Compared to other stages, potato crops that experienced irrigation water deficits during the tuber start and bulking stages were more vulnerable. The best water crop yield can be achieved by irrigating at 75% water during the vegetative stage when there is an availability of water. To get the maximum crop water production during water scarcity, 50% of the water must be applied during tuber bulking (Taleb et al., 2022).

Kifle and Gebretsadikan, (2016) Suggests that water application stress at the middle stage had a greater impact on potato yield than other treatments. This demonstrated that the crop is responsive to deficit irrigation when stressed during the blossoming or middle stage.

1.1. Objectives of Research

The objective of the research was to evaluate the effect of water levels at different growth stages on yield and water productivity of potato and to identify the most vulnerable phases of potato to different irrigation water levels.

2. Materials and Methods

2.1. Description of the Study Area

The research was conducted at Tiyo district, during dry season (December to May) on Ketar Genat irrigation scheme (Figure 1). The district was located at 7° 46’ 30" - 7° 54’ 0" North and 38° 55’ 30"-39° 4’ 30" East with an altitude of 2430 m above sea level (a.s.l).

The climate of the area is generally warm and temperate. The average annual temperature is 13.8°C at an average 15.1°C. April is the hottest month of the year at an average of 12.7°C and December is the coldest month of the year. The rainfall here is 1118 mm.

Precipitation is the lowest in December, with an average of 12 mm. In July, the precipitation reaches its peak, with an average of 187 mm.

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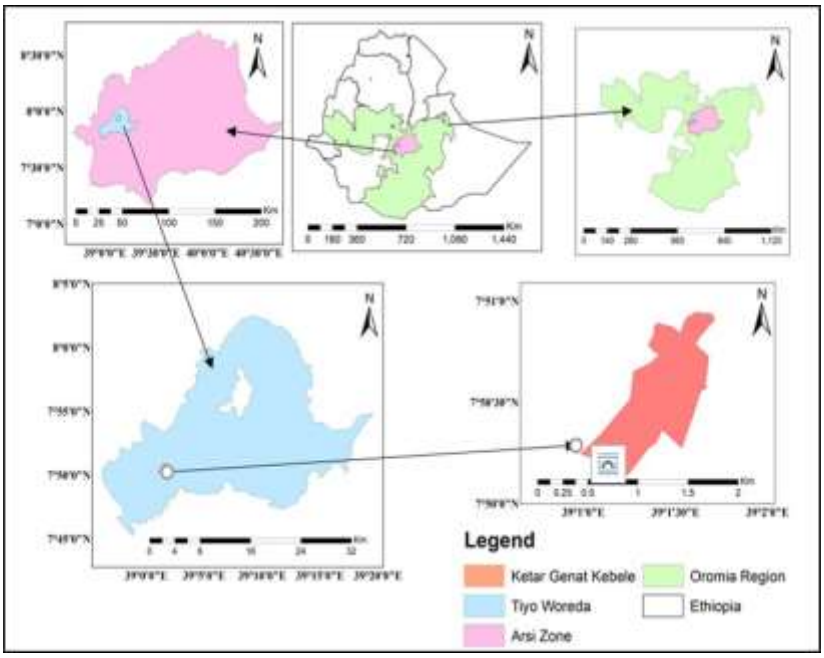

Figure 1. Study area map

2.2. Experimental Treatments and Design

The experimental trial were four crop growing stages, viz., initial, development, mid and late stages and two irrigation water levels (80% ETc and 60 % ETc) and 100% ETc/Control. The design of the experiment was split plot design with three replications. The growing stages were arranged as a main plot and the irrigation water levels as sub-plot (Table 1).

Table 1. Treatment combinations

Main plot	Sub plot	Description	Code
	Control	Irrigated at all growth stage	T_1
Initial	80% ETc	Irrigated at 80% ETc during Initial stage	T_2
	60% ETc	Irrigated at 60% ETc during Initial stage	T_3
Development	80% ETc	Irrigated at 80% ETc during development stage	T_4
	60% ETc	Irrigated at 60% ETc during development stage	T_5
Mid	80% ETc	Irrigated at 80% ETc during mid-stage	T_6
	60% ETc	Irrigated at 60% ETc during mid-stage	T_7
Late	80% ETc	Irrigated at 80% ETc during late stage	T_8
	60% ETc	Irrigated at 60% ETc during late stage	T_9

2.3. Crop Establishment and Management Practices

Following thorough preparation and pre-irrigation, the seeds of a Gudane variety potato tuber were manually planted in a row on a pre-existing research area. Row planting techniques were used, with 70 cm separating rows and 30 cm between potatoes. The experiment was conducted using the necessary management techniques, such as weeding, thinning, cultivation, herbicide, fungicide, and others.

Before planting, a consistent amount of water was applied to each experimental plot to pulverize the soil. Before the treatment was applied, two standard irrigations were given to each plot to guarantee plant establishment. Throughout the crop's growth stage, irrigation water was applied at the permitted soil moisture depletion (p=0.3) of the total available soil moisture. While the recommended rate of urea fertilizer was evenly applied in splits, half at planting and the other half before hilling, NPS fertilizer was applied as a basal dose to all plots at planting.

2.4. Soil Sampling and Analysis

Before plowing the experimental field, undisturbed soil samples were collected to determine bulk density, and samples were collected at random to create three composite samples. The composite soil samples were air-dried, crushed, blended, and put through a 2mm filter before being evaluated for various physical and chemical properties. The soil samples were collected from three depths (0-20, 20-40, and 40-60 cm). The composite soil samples were examined to determine their physical and chemical qualities. Soil texture, organic matter content, bulk density, water retention at field capacity (FC), permanent wilting point (PWP), and pH were all tested.

2.5. Irrigation Scheduling and Management

Using the FAO CROPWAT software version 8.0, the modified FAO Penman-Monteith equation based on the monthly record of meteorological data (Allen et al., 1998) was used to determine the monthly reference evapotranspiration (ETo). The CROPWAT software program uses the following input data: wind speed, daylight duration, relative humidity, altitude, and daily maximum and lowest air temperature values.

2.6. Crop and irrigation water requirement

Using reference evapotranspiration (ETo) and crop coefficient (Kc), the amount of water required (CWR) to balance the amount of water lost through evapotranspiration (ETc) was 0.53, 0.79, 1.05, and 0.88 for the initial, development, mid, and late growth stages, respectively (Allen et al., 1998). ETo values were multiplied by the (Kc) values, the crop water requirements (ETc) were calculated.

$$ET_C = ET_O \ x \ K_c \qquad (1)$$

Total available water was computed from the moisture content at field capacity and permanent wilting point using the following equation.

$$\text{TAW} = (\text{FC} - PWP) \ x \ BD \ x \ Dz \qquad (2)$$

where, TAW is the total available water in the root zone (mm), FC and PWP are moisture content at field capacity and permanent wilting point (%) on weight basis respectively and Dz is the root zone depth of onion at times of each irrigation.

The net irrigation requirement was calculated as follows:

$$\text{IRn} = \text{ETc} - \text{pe} \qquad (3)$$

Where IRn =Net irrigation requirement (mm), ETc in mm and Pe = effective rainfall (mm) which is part of the rainfall that enters into the soil and makes available for crop production. The effective rainfall (Pe) was estimated using the methods.

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$Pe = 0.6 * P - 10 \text{ for month } P \leq 70mm$ (4)

$Pe = 0.8 * P - 24 \text{ for month } P > 70mm$ (5)

Where Pe (mm) = effective rainfall and P (mm) = total rainfall.

The gross irrigation requirements account for losses of water incurred during conveyance and application in the field. The gross irrigation requirement was computed by adopting a field application efficiency of 60 %.

$IR_g = \frac{IR_n}{E_a}$ (6)

2.7. Setting and discharge measurement of parshall flume

A 2-inch Parshall flume (PF) constructed of metal sheet and positioned 10 meters from the closest plot along the main canal was used to measure the amount of irrigation water applied to each plot. The converging section's leveling in all directions was examined. Since the base of the diverging portion of PF slopes somewhat upward, the leveling for the diverging section was only tested across the river. Stone riprap was used on the downstream side of the canal bed to reduce downstream scouring, and the entrance portion was positioned 4 cm above the canal bed to prevent submergence flow.

Based on the proportion of each treatment, calculated gross irrigation was ultimately applied to each plot. The plot area and depth of gross irrigation demand were used to calculate the volume of water applied for each treatment. The amount of time needed to irrigate each treatment was determined by dividing the volume of water applied by the 2-inch PF discharge-head relation. The time needed was estimated using head levels ranging from 5 to 15 cm, although discharge levels may vary depending on field conditions. The time required to deliver the desired depth of water into each furrow was calculated as.

$t = \frac{A \text{ x dgross}}{Q}$ (7)

where: dg - gross depth of water applied (mm), t - Application time (sec), A- Plot Area (m2) and Q - Flow rate (l/s)

2.8. Water productivity and Opportunity Cost

The ratio of potato yield (tuber yield per hectare) to net irrigation depth plus effective rainfall use from establishment to harvest, represented as (kg) of tuber yield per (m3) of water, was used to calculate water productivity.

$WP = \frac{Ya}{Twu}$ (8)

Where: - WP - Water productivity (kg/m^3), Ya - Actual yield (kg/ha), Twu – Total water used (m^3/ha)

Water saving with varied irrigation water level as compared with full irrigation was calculated as:

$Ws(\%) = \frac{TWUfp - TWUip}{TWUfp} * 100$ (9)

Where: - WS - Water saved due to improved irrigation practice

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TWUfp - Total water using farmer practice (mm) and

TWUip - Total water using improved irrigation practice (mm).

Percent of yield increase/decrease in varied irrigation water level (%) as compared to full irrigation was calculated using the following equation.

$$Yadv(\%) = \frac{YIp - Yfp}{YIp} * 100 \qquad (10)$$

Where: - Yadv - Percent of yield advantage

Yfp - Yield in (kg/ha) obtained from farmer practice and

YIp - Yield in (kg/ha) obtained from improved practice.

2.9. Yield response factor

The effect of water stress on yield was quantified by calculating the yield response factor (Ky)

$$(1 - \frac{Y_a}{Y_m}) = \text{ky}(1 - \frac{ET_a}{ET_m}) \qquad (11)$$

where, Ym is maximum yield (kg/ha) from the plot without water stress during the growing season and Ya is actual yields (kg/ha); ETm (mm) and ETa (mm) are the maximum and actual evapotranspiration and Ky is a yield response factor representing the effect of a reduction in ET on yield losses.

2.10. Economic Water Productivity

Using partial budget analysis, economic water productivity analysis was first conducted by taking into account the overall link between crop output per hectare of land and crop water demand for all treatments.

2.11. Statistical Analysis

The collected data were analyzed using R software appropriate for the split plot design. When treatment effect was found significant for a parameter the mean separation was carried out at 5% probability level.

3. Results and Discussion

3.1. Depth of Irrigation Water Applied

Table 2 displays the depth of irrigation water applied to the various treatments throughout the trial. Until the better sprout period (18.24 mm), the total gross irrigation depth applied ranged from 402.56 mm to 498.60 mm without common irrigation. Because the maximum kc value increased, the treatment that received 60% ETc at mid-stage had the lowest total depth of water, while the control treatments, which received 100% ETc at all potato growth stages, had the most.

Table 2. Gross irrigation depth applied at each growth stage (mm)

Treatments		Growth stages				Total
Growth stage	Irrigation Level	Initial	Development	Mid	Late	
	Control	66.60	129.20	240.10	62.70	498.6

Initial	80% ETc	53.28	129.20	240.10	62.70	485.28
	60% ETc	39.96	129.20	240.10	62.70	471.96
Development	80% ETc	66.60	103.36	240.10	62.70	472.76
	60% ETc	66.60	77.52	240.10	62.70	446.92
Mid	80% ETc	66.60	129.20	192.08	62.70	450.58
	60% ETc	66.60	129.20	144.06	62.70	402.56
Late	80% ETc	66.60	129.20	240.10	50.16	486.06
	60% ETc	66.60	129.20	240.10	37.62	473.52

3.2. Soil Physico-chemical Properties of Study Area

Table 3 below displays the laboratory results for the experimental site's soil physicochemical characteristics. Clay loam dominates the soil texture classification. In comparison to the upper root layers, the bulk density at the lower root zone layers is more compacted, contains less organic matter, aggregation, and root penetration, and so has less pore space. The experimental site's weighted average bulk density was 1.25 g/cm3, which falls within the ideal range for the best possible air and water circulation in the soil for crop root growth (Hunt and Gilkes 1992). The soil's weighted average organic matter was around 3.71%.

Table 3. Physico-chemical properties of soils

Depth (cm)	Bulk density (gm/cm^3)	Ph	OM (%)	Texture			
				% Sand	% Silt	% Clay	Class
0 - 20	1.17	5.57	3.84	30	36	34	Clay loam
20 - 40	1.24	6.70	3.71	32	35	33	Clay loam
40 - 60	1.35	7.50	3.58	31	32	37	Clay loam
Average	1.25	6.59	3.71	31	34	35	Clay loam

3.3. Effect of irrigation levels on potato tuber yield and yield components

3.3.1. Number of Tuber per plant and tuber diameter

There was a significant difference ($P < 0.05$) between the four plant growth stages, but not between the initial and late and development and mid stages in terms of the number of potato tubers per plant and their weight per plant (Table 4). However, there was a significant variation ($P < 0.05$) in the number and diameter of potatoes depending on the irrigation water level. Full irrigation water level/control (100% ETc) produced the maximum tuber number per plant and tuber diameter values, whereas 60% ETc irrigation produced the lowest values. This finding is consistent with a research by Yetagesu et al., (2020) that found that tuber diameter reduced during the development and mid-growth phases.

The number of tubers per plant and tuber diameter was significantly ($P < 0.05$) impacted by the analysis of variance on the interaction effect of irrigation level at various growth stages (Table 5). The control treatment had the most tubers (17) and the largest tuber diameter (6.15 cm), which was not statistically significant. Treatments that received irrigation with 80% ETc at the beginning and end of the season had 15 and 14 tubers, respectively, and 5.91 and 6.01 cm in diameter. The minimum number of tubers (8 and 10) and the tuber diameter (5.34 and 5.02) cm, respectively, were produced by treatments that experienced high water stress (60% ETc) during development and mid-stage.

A large photosynthetic area (plant height and leaf count) is caused by high soil moisture application, which results in a big tuber diameter. This suggests that a big tuber diameter was obtained by applying an irrigation level of 80% ETc at either the early or late phases. On the other hand, compared to the control and other treatments, the tuber diameter was noticeably smaller when 60% ETc irrigation was used during the development and mid phases (Mehiret et al., 2022 and Enchalew et al., 2016) had comparable outcomes.

Table 4. Effects of irrigation levels and growth stages on tuber yield and yield components

Growth Stage	**NTPP**	**PWPP (kg)**	**DPT (cm)**	**MY (t/ha)**	**TY (t/ha)**	**WP (kg/m^3)**
Initial	15^{a}	1.51^{a}	5.93^{a}	25.92^{a}	31.97^{a}	9.36^{a}
Development	13^{b}	1.39^{b}	5.71^{b}	23.05^{a}	28.61^{b}	8.38^{b}
Mid	14^{ab}	1.39^{b}	5.54^{c}	23.11^{a}	27.64^{b}	8.08^{b}
Late	14^{a}	1.46^{ab}	5.91^{a}	24.39^{a}	31.40^{a}	9.19^{a}
CV	4.81	3.6	1.37	7.39	2.19	2.34
LSD (5%)	1.33	0.1	1.57	3.56	2.24	1.31
Irrigation Levels						
100% ETc	17^{a}	1.70^{a}	6.15^{a}	27.30^{a}	35.62^{a}	8.09^{c}
80% ETc	14^{b}	1.43^{b}	5.78^{b}	23.81^{b}	32.22^{b}	9.27^{a}
60% ETc	11^{c}	1.19^{c}	5.39^{c}	21.24^{c}	21.89^{c}	8.90^{b}
CV	0.54	3.09	0.37	4.52	1.84	1.50
LSD (5%)	0.55	0.06	0.75	1.87	1.66	0.41

NTPH – Number of Tuber per plant PWPP – Plant weight per plant DPT – Diameter of potato tuber MY – Marketable yield TY – Total yield WP – Water productivity.

3.3.2. Potato tuber yield

The amount of irrigation and the timing of application had a significant ($P < 0.05$) impact on the overall production of potatoes (Table 4). The yield of potato tuber showed a significant difference ($P < 0.05$) between the initial and development and mid and late plant growth stages, but not between the initial and late or development and mid stages. Conversely, the total yield was significantly impacted by the irrigation water level ($P < 0.05$). The highest tuber yield of 35.62 t/ha was observed at full irrigation/control (100% ETc), while the lowest yield of 21.89 t/ha was obtained at 60% ETc irrigation level. The use of irrigation water was responsible for the rise in total yield, which was linked to an increase in tuber diameter and average weight as well as increased production and vegetative growth. Yetagesu et al., (2020) found a similar pattern, with higher irrigation levels yielding more marketable bulbs.

Potato tuber output was significantly ($P<0.05$) impacted by the interaction of irrigation level at all growth stages, according to the analysis of variance (Table 5). The treatments that received irrigation applications of 80% ETc at the beginning of the season (34.18 t/ha) and at the end of the season (33.42 t/ha) were statistically comparable to the control treatment, which yielded the maximum overall tuber yield (35.62 t/ha). Conversely, mid-stage irrigation of potatoes at 60% ETc irrigation level had the lowest tuber production of 18.17 t/ha on average. While allowing moisture stress throughout the growth and mid-stage of potato tubers can alter or diminish production, stressing irrigation water during the early or late-season stages of a crop could not significantly affect its yield.

The crop stage during tuber starts and tuber bulking was more susceptible to deficit irrigation than other stages, according to (Taleb et al., 2022) and (Yilmaz et al., 2010). Stressed watering during the development stage produced a minimum tuber output that was statistically comparable to mid-season production. Compared to the control treatment, the overall yield is reduced by 4.04% and 6.18%, respectively, when irrigation water is applied at 80% ETc in the early and late seasons. However, when 80% ETc is applied during the development and mid-stage phases, the reduction is 15.33% and 18.25%, respectively, compared to the control treatment. The results of this study were comparable to those of Zheng et al., (2013), who found that water stress throughout the development and mid-growth phases considerably decreased yield by 15% and 20%, respectively. Due to their quick growth and expansion, potato tuber production was extremely vulnerable to water stress throughout development and tuber creation. However, they were not responsive during the late phases or during tuber sprouting. Therefore, it can be concluded that producing potato tuber by applying irrigation water at 80% ETc during the initial or late seasons was preferable as compared to 100% ETc irrigation application for the whole growing season. Highest yield reduction was occurred when the stress was applied at the mid and development stage. Thus, mid and developmental phases was taken to be the most sensitive stages to water stress.

Table 5. Interaction effects of irrigation levels and growth stages on tuber yield and yield components

Treatments	NPTPP	PWPP (kg)	DPT (cm)	MY (t/ha)	TY (t/ha)	WP (kg/m^3)
Control	17^{a}	1.70^{a}	6.15^{a}	27.30^{a}	35.62^{a}	8.09^{cd}
I x 80% ETc	15^{b}	1.49^{b}	5.91^{a}	25.99^{ab}	34.18^{ab}	10.01^{a}
I x 60% ETc	13^{c}	1.33^{cd}	5.68^{b}	24.45^{abc}	25.14^{d}	9.98^{a}
D x 80% ETc	13^{c}	1.43^{bc}	5.64^{bc}	23.05^{bcd}	30.16^{c}	8.75^{b}
D x 60% ETc	8^{d}	1.03^{f}	5.34^{d}	18.80^{e}	20.07^{e}	8.29^{bc}
M x 80% ETc	14^{bc}	1.35^{cd}	5.45^{cd}	22.14^{bcde}	29.12^{c}	8.49^{bc}
M x 60% ETc	10^{d}	1.15^{ef}	5.02^{e}	17.89^{de}	18.17^{f}	7.66^{d}
L x 80% ETc	14^{bc}	1.44^{bc}	6.01^{a}	24.07^{abc}	33.42^{b}	9.82^{a}
L x 60% ETc	12^{c}	1.24^{de}	5.54^{bc}	21.81^{cde}	24.18^{d}	9.66^{a}
CV	4.56	4.7	1.5	8.95	2.97	3.01
LSD (5%)	1.09	0.12	1.49	4.14	1.80	1.07

I – Initial D – Development M – Mid L – Late CV- coefficient of variation LSD – Least significance difference.

From figure 2, vertical error bar indicates letter of significance level and total yield of crop was not significantly affected at 80% ETc of the initial and late phase as compared to the control treatment.

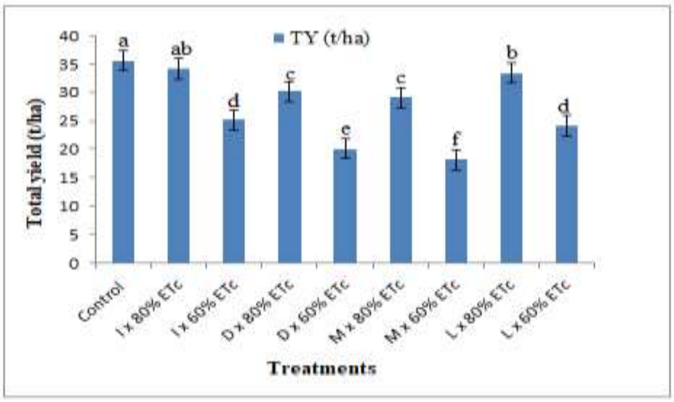

Figure 2. Effect of growth stage on total yield of potato

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3.3.3. Water productivity and Opportunity cost

Table 4 shows that water productivity is considerably ($P \leq 0.05$) affected by the primary effect of deficit irrigation application at various growth stages. The beginning stage reported the highest water productivity of 9.36 kg/m^3, which was statistically comparable to the late-stage value of 9.19 kg/m^3. At development and mid-stage, respectively, the lowest water productivity values of 8.38 and 8.08 kg/m^3 were achieved.

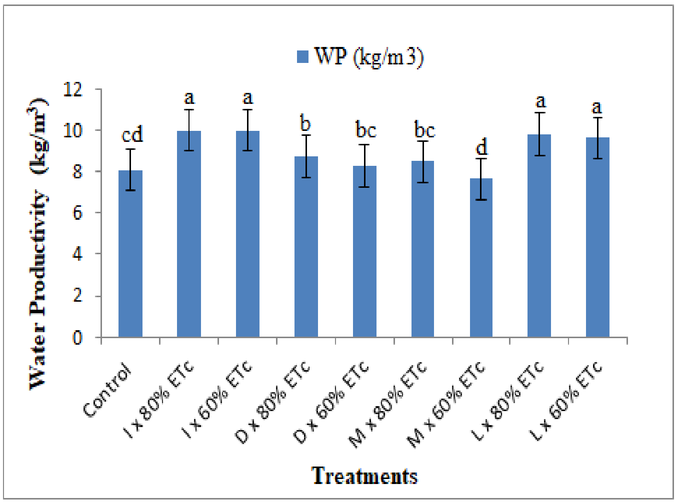

Figure 3. Effect of growth stage on water productivity of potato

Reducing irrigation water level at the initial and late stage of potato tuber could not affect the productivity, and high-water productivity was obtained at the initial and late stage (figure 3).

At each growth stage, the interaction of irrigation level had a significant ($P < 0.05$) impact on potato water productivity (Table 5). In the beginning stage, applying 80% of the complete irrigation produced the maximum water productivity (10.01 kg/m3), which was statistically comparable to the value achieved at the late stage (9.82 kg/m3). In the mid-stage treatment, 60% ETc produced the lowest water productivity (7.66 kg/m3). With a moisture content of roughly 75%, the water productivity for fresh tuber yield is 4–11 kg/m3 (Mehiret et al., 2022). The water productivity at the mid-stage and development stages was statistically comparable to the control treatment. Treatments that were simply irrigated in the beginning had higher water output (Mehiret et al., 2022). Therefore, higher water productivity was obtained from treatments stressed at initial and late stages than development and mid stages.

Table 6. Relative yield reduction of potato and Additional Area irrigated by saved water

Treatments	TY (t/ha)	Igross (m^3/ha)	WS (m^3/ha)	WS (%)	YL (t/ha)	YL (%)	AA Irr. by WS (ha)	YG from AA (t/ha)	YG-YL (t)
T_1	35.62	4986	0	0	0	0	0	0	0.00
T_2	34.18	4852.8	133.2	2.67	1.44	4.04	0.03	0.94	-0.50
T_3	25.14	4719.6	266.4	5.34	10.48	29.42	0.06	1.42	-9.06
T_4	30.16	4727.6	258.4	5.18	5.46	15.33	0.05	1.65	-3.81
T_5	20.07	4469.2	516.8	10.37	15.55	43.66	0.12	2.32	-13.23
T_6	29.12	4505.8	480.2	9.63	6.5	18.25	0.11	3.10	-3.40

T_7	18.17	4025.6	960.4	19.26	17.45	48.99	0.24	4.33	-13.12
T_8	33.42	4860.6	125.4	2.52	2.2	6.18	0.03	0.86	-1.34
T_9	24.18	4735.2	250.8	5.03	11.44	32.12	0.05	1.28	-10.16

TY= total yield, WS= saved water, AA irrig.= additional area irrigated due to saved water, YG= yield gain by additional irrigated area and YL= yield loss due to deficit irrigation.

The quantity of water conserved in terms of extra farmland that could be watered and the output that would result from doing so is expressed as the opportunity cost of deficit irrigation (Table 6). According to the above table, treatment T2 saved 2.67% of the water, which might lower the yield loss compared to the control, which was 0.5 tons, on an extra 0.03 hectares of land. The yield loss was reduced to 1.34 tons on an extra 0.03 ha of land at treatment T8, where the percentage of water saved was 2.52%. Compared to development and mid-stage, the percentage of yield loss was lower for potato tubers that were stressed during the early and late seasons. Mehiret et al., (2022) claims that when moisture stress occurs throughout the development and midseason phases of a crop, the yield drop rate is significantly larger than when the crop is stressed at the beginning and end of the growing season.

3.3.4. Yield response factor (Ky)

From (Table 7), the yield response factor (Ky) of potato tuber ranges from 0 – 6.38. The crop yield response factor gives an indication of whether the crop is tolerant of water stress and subsequent yield decrease. From (Table 7), the highest Ky value obtained were 6.38 and 5.51 at treatments T9 and T3 i.e at 60% ETc at late and initial stage respectively. The higher Ky value, the greater the reduction of yield for a given reduction in evapotranspiration because of water deficits in the specific period (FAO, 2012). Water stress happened at development and mid-season stages, the yield reduction rate is extremely higher than stressed the crop at initial and late stage.

Table 7. Yield response factor of potato tuber

Treatments	Tuber yield (kg/ha)	Water applied (mm)	[1-(Ya/Ym)]	[1-(ETa/ETm)]	Ky
T_1	35.62	498.6	0.00	0.00	0.00
T_2	34.18	485.28	0.04	0.03	1.51
T_3	25.14	471.96	0.29	0.05	5.51
T_4	30.16	472.76	0.15	0.05	2.96
T_5	20.07	446.92	0.44	0.10	4.21
T_6	29.12	450.58	0.18	0.10	1.89
T_7	18.17	402.56	0.49	0.19	2.54
T_8	33.42	486.06	0.06	0.03	2.46
T_9	24.18	473.52	0.32	0.05	6.38

Ya – actual yield Ym – maximum yield ETa – actual evapotranspiration ETm – maximum evapotranspiration Ky – yield response factor.

3.3.5. Economic Water Productivity

The examination of the partial budget showed that the highest net benefit of 1,063,483 ETB was obtained from T1 or control. Benefit cost ratio (B/C) of potato tuber was computed for each treatment combination as the ratio of yield gained to the cost expended. Accordingly, treatments 100% ETc water application or control had the highest B/C of 18.2 and treatment 80% ETc water application at initial and late had the next higher B/C of 17.6 and 17.1 respectively. However, the lowest B/C was recorded under treatments receiving 60% for the period of development and mid stages (Table 8).

Treatment T2 and T8 i.e. water application at 80% ETc during initial and late, with optimum net benefit and benefit-cost ratio next to control. The lowest benefit-cost ratio obtained from T5, T7, T4 and T6 might be attributed to water stress imposed at both developmental and mid stages, which are the critical stages for potato production.

Table 8. B/C of potato production under different growth stage and irrigation levels

Treatments	TC (ETB/ha)	UMY (kg/ha)	AMY (kg/ha)	GB (ETB/ha)	NB (ETB/ha)	B/C ($ETBha^{-1}$)
T_1	58,547	35,620	32,058.00	1122030	1,063,483	18.2
T_2	58,041	34,180	30,762.00	1076670	1,018,629	17.6
T_3	57,534	25,140	22,626.00	791910	734,376	12.8
T_4	57,565	30,160	27,144.00	950040	892,475	15.5
T_5	56,583	20,070	18,063.00	632205	575,622	10.2
T_6	56,722	29,120	26,208.00	917280	860,558	15.2
T_7	54,897	18,170	16,353.00	572355	517,458	9.4
T_8	58,070	33,420	30,078.00	1052730	994,660	17.1
T_9	57,594	24,180	21,762.00	761670	704,076	12.2

TC= Total cost, UTY= Unadjusted total yield, ATY= Adjusted total yield, GB= Gross benefit, NB =Net benefit, B/C = Benefit Cost ratio

4. Conclusion and Recommendation

4.1. Conclusion

From the experiment result, considering the sensitive stage of the irrigated potato tuber, deficit irrigation can increase water production without significantly lowering output. The maximum tuber yield was obtained from full irrigation/control followed by applying irrigation water by 80% ETc at initial stage. The maximum water productivity was obtained from 80% ETc at initial stage. The study showed that, stressing potato at development and mid-season, reduce its yield and the water productivity is also reduced.

4.2. Recommendation

1) It is recommended that under good water resource condition for irrigation, potato could be irrigated at full irrigation application to obtain higher tuber yield.
2) Moreover, irrigation with 80% ETc at initial or late season also gave similar yield and water productivity and therefore it could be practiced when irrigation water is limited.
3) Stressing potato tuber during development and mid stage reduces productivity.

4) The treatment receiving 80% ETc at initial stage has higher benefit and having better cost benefit ratio next to control.

5) Thus, adopting 80% ETc irrigation water applications at initial or late stage are recommended for the study area, similar agro-ecology and soil type.

Declarations

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Competing Interests Statement

The authors have not declared any conflict of interest.

Consent for publication

The authors declare that they consented to the publication of this study.

Authors' contributions

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

Informed Consent

Not applicable for this study.

Availability of data and material

Supplementary information is available from the authors upon request.

Institutional Review Board Statement

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