

Response of Potato Yield to Soil Moisture Stress Condition at Different Crop Growth stages in Wondo Genet, Southern Ethiopia

Aregash Deboch Jelos^{1*} and Sirak Tekleab Gebrekristos²

¹Department of Irrigation and Drainage Research Program, Southern Agricultural Research Institute, Hawassa Agricultural Research Center, Hawassa, Ethiopia

²Department of Water Resources and Irrigation Engineering, Hawassa University, Institute of Technology, Hawassa, Ethiopia

Abstract

Potato is produced in central rift valley of Ethiopia as one of the staple food and the production and productivity is limited by the scarcity of water. A field experiment was conducted to study the influence of soil moisture stress at different growth stages of potato with the objectives of identifying crop growth stages sensitive to soil moisture stress, to determining the critical time for irrigation application under condition of limited water resources. The experiment was conducted on sandy loam soil at Wondo Genet in SNNPRs Southern, Ethiopia during the 2017/18 cropping season. The experimental design was randomized complete block design with three replications seven treatments including the control treatment were devised to represent some possible combinations of water application. The highest and lowest mean tuber yield was obtained from plants grown under non stressed soil moisture (ranging from 10.20 to 29.16 t/ha across treatments). Most of the parameters (dependent variable) that are plant height, branch number, tuber number and total tuber yield showed significant ($p < 0.05$) yield in their values as moisture stress increased at different growth stages. Growth parameters were slightly affected by moisture stress when the stress was imposed during the initial and late season growth stages but they were not significant. Initial and Mid-season growth stage of potato tuber was the most critical stage (causes 65% yield loss) for soil moisture stress followed by development stage (49% yield reduction). The maximum water use efficiency was obtained from T5 ranging from 4.3 kg/m³ to 7.9 kg/m³ across treatments.

Keywords: Deficit irrigation • Potato • Growth stages • Moisture stress

Introduction

Potato (*Solanum tuberosum* L.) is one of the predominant tuber crops in the world, constituting a large percentage of the staple diet in many developing countries [1].

It is the fourth most important food crop after wheat, rice and corn, with a worldwide production of 364 million tons in 2012 [2]. It is also the most important tuber crop, ranking first in volume produced among root and tuber crops; is followed by cassava (*Manihot esculenta* Crantz), sweet potato (*Ipomoea Batatas* L.), and yam (*Dioscorea* spp.).

Root and tuber crops like potato, sweet potato, cassava, and yam will play an important role in feeding the developing world in the coming decades. The growth rates in production are particularly strong for a potato with an annual average increase of 4.5 million tons per year, greater than those of rice and wheat [3]. By 2020, more than

two billion people in Asia, Africa, and Latin America will depend on these crops for food, feed, or income [4].

Ethiopia is among the top potato producers in Africa, with 70% of its arable land in the high altitude areas above 1500 m being suitable for a potato production [5].

In Ethiopia potato productivity is low; it could reach 30 t/ha attainable yield [6]. There are many complicated reasons for this low yield of potato tubers. Water is one of the main factors limiting yield production in arid and semi-arid regions of the world. When water resources are a limiting factor for yield production, irrigation programming is necessary to maximize production per m³ of irrigation water [7].

In arid and semi-arid area, plant production is limited by soil moisture availability and actual evapotranspiration [8]. These two parameters influence the occurrence of water stress in rainfed

*Address for Correspondence: Aregash Deboch Jelos, Department of Irrigation and Drainage Research Program, Southern Agricultural Research Institute, Hawassa Agricultural Research Center, Hawassa, Ethiopia; E-mail: aregashdeboch2@gmail.com

Copyright: © 2025 Jelos AD, et al. This is an open-access article distributed under the terms of the creative commons attribution license which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited.

Received: 04 October, 2023, Manuscript No. IDSE-23-115661; **Editor assigned:** 09 October, 2023, PreQC No. IDSE-23-115661 (PQ); **Reviewed:** 24 October, 2023, QC No. IDSE-23-115661; **Revised:** 15 January, 2025, Manuscript No. IDSE-23-115661 (R); **Published:** 22 January, 2025, DOI: 10.37421/2168-9768.2025.14.468

agricultural systems. Fluctuations in soil moisture often have negative effects on crop productivity [9]. So that the lands soil moisture deficits, soil fertility depletion and soil erosion are major constraints to agricultural crop production [10]. Moisture loss from the soil through evaporation and presence of erratic rainfall in the middle of the cropping season may leads to crop failure.

According to Woldeamlak, in Ethiopia there is a decreasing of rainfall amount and the distribution is erratic especially in arid and semi-arid regions of the country. This want different emphasis since soil moisture stress happens at the main cropping season decrease yield of crops which directly affect the livelihood of the community engaged on agriculture. The country receives sufficient rainfall for crop production if annual rainfall average is considered in most of the areas. However, the production of sustainable and reliable food supply by smallholder farmer is challenged by temporal and spatial variation in rainfall distribution and erratic rainfall [11].

Crop failure due to moisture stress in Ethiopia is common practice especially in moisture stress area of the country which caused by low and erratic rainfall distribution. Different researchers worldwide and in the country also show the diverse effect of moisture stress on the crop production [12]. They have investigated the moisture stress based on decreasing the amount of irrigation water given on few combinations of growth stage especially on the stolonization and tuberization stages [13]. In times when irrigation water is limiting, the farmer may not have enough water to irrigate all the crop fields. In this case, the farmer may decide to spread the available water over a large area rather than depriving irrigation in some growth stages of a crop. Here, it is good to know.

- The crops which mostly suffered by water shortage.
- The growth stages during which the crops mostly suffered by water shortage [14].

The objective of this work is to identify growth stages sensitive to soil moisture stress and to investigate the water productivity under different treatments.

Materials and Methods

Description of the experimental area

The study was conducted under irrigation condition during the 2017/18 cropping season at Wondo Genet districts in Yuhu kebele, in Southern Regional State. The site was selected based on the ideal place for potato production areas in the district. The town is 25 km far from Hawassa and 300 km from Addis Ababa and it is a resort town in Ethiopia located Southeast of Shashemene in the Sidama Zone of the SNNPRs. The site is located at 7° 1' 3"N latitude and 38° 35' 42" E longitudes at an altitude of 1703 meters above sea level.

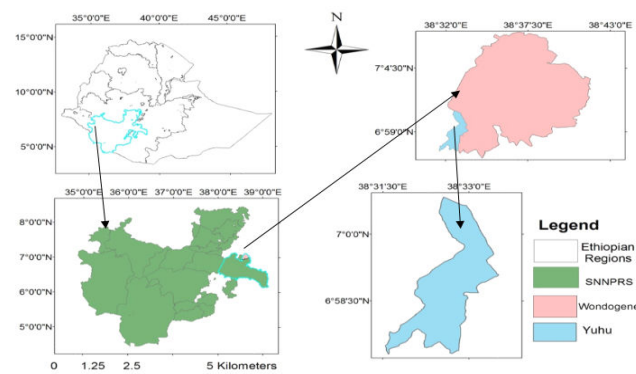


Figure 1. Location map of the study area.

Climate

The climate of the area is semi-arid with total annual precipitation of 180.2 mm of rainfall expected in the rainy season which is characterized by bimodal rainfall pattern. The major season is “kremt”, the long rainy season (July to September), while the short rainy season that extends from March to April is “belg” and mean temperature of 14.86°C during the potato growing season was characterized by a long term meteorological data (Figure 2). Long-term total rainfall exceeded long-term mean temperatures in August, but in the remaining months, including July, long-term mean temperatures exceeded long-term total rainfall.

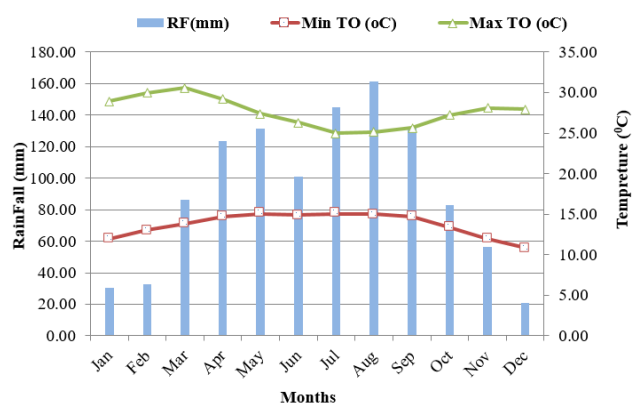


Figure 2. Mean monthly rainfall, maximum and minimum temperature of the study area.

Soil sampling and analysis

Soil samples were collected from 0-30 and 30-60 cm depth to evaluate different soil physical properties. At the beginning of the experiment, 5 samples were randomly collected in zigzag manner by using an auger and composited. Then, the samples were air dried, crushed with mortar and sieved to pass through 2 mm mesh. To analysis of soil texture, soil pH, Field Capacity (FC), and Permanent Wilting Point (PWP) was determined. Moisture contents at FC and PWP measured using a pressure plate and membrane apparatus technique by applying pressures at $-1/3$ bar and -15 bars respectively. Soil pH will be determined by using a pH meter whereas Total

Available Water (TAW) was obtained by subtracting PWP from FC.

$$TAW=(FC-PWP)/100 \times BD \times Drz \quad (1)$$

Where;

TAW=Total Available Water (mm/m), FC=Field Capacity (% on weight basis),

PWP=Permanent Wilting Point (% on weight basis), BD=Bulk Density (g cm⁻³) and

Drz=Depth of root zone (mm).

The soil bulk density is defined as the oven dry heaviness of undisturbed soil in a given volume, as it happens in the field. It was determined by core sampler method. Soil bulk-density data was taken as cores in the field at two depths 0–30 cm and 30–60 cm, oven dried for 24 hrs at 105°C and weighed for dry density using the following formula [15].

$$BD=Ms/Vs \quad (2)$$

Where;

Ms is the weight of oven dry soil, and Vs. is the volume of the same soil in cm³.

Computation of crop water, irrigation water requirement and scheduling

Reference crop evapotranspiration: To calculate the reference evapotranspiration using the CROPWAT model, 10 years (2007-2017) of average monthly maximum and minimum temperature, relative humidity, sunshine hour and wind speed data that was collected from Hawassa meteorology station.

Reference evapotranspiration (ET_o) was determined based on the modified FAO Penman Monteith equation.

$$ET_o=(0.4080\Delta(Rn-G)+\gamma 900/T+273 u_2(e_s-e_a))/\Delta+\gamma(1+0.34u_2) \quad (3)$$

Where,

ET_o=reference evapotranspiration (mm day⁻¹), Rn=net radiation at the crop surface (MJ m⁻² day⁻¹), G=soil heat flux density (MJ m⁻² day⁻¹), T=mean daily air temperature at 2 m height (°C), u₂=wind speed at 2 m height (ms⁻¹), e_s=saturation vapour pressure (kPa), e_a=actual vapour pressure (kPa), e_s-e_a=saturation vapour pressure deficit (kPa), Δ=slope vapour pressure curve (kPa°C⁻¹), γ=psychrometric constant (kPa°C⁻¹).

Crop water requirement: The crop water requirement (ET_c) was determined for potato crop of the study area over the growing season requires the crop coefficient (K_c) values at different crop development stages, planting dates, length of growing season, and length of each crop development stage. The K_c values were determined on the basis of in-field observations of crop phenological stages and using the data. K_c values were fixed at 0.5, 1.15 and 0.75 respectively for the initial crop growth stages (up to the beginning of stem elongation), mid-season (since stem elongation until flowering), and the late season stage (maturity). Maximum root depth was fixed at 0.6 m [15].

The CWR was estimated based on the established procedure given by Allen et al.

$$ET_c=ET_o \times K_c \quad (4)$$

Where;

ET_c is crop evapotranspiration, ET_o is reference evapotranspiration in mm/day and K_c is crop coefficient (dimensionless).

Irrigation Requirement (IR): Computation of IR requires long-term rainfall data from the study sites. Long-term monthly rainfall data was obtained from the study sites. The values attained were used during the computation of CWR. Generally, IR can be estimated from the expression:

$$IR=CWR-P_e \quad (5)$$

Where;

IR is irrigation requirement in mm, CWR is crop water requirement in mm and P_e is effective rainfall which is part of the rainfall that entered into the soil and made available for crop production in mm. but, in this study effective rainfall was taken as zero because it eliminates to see the effects of moisture stress at different crop growth stage [16].

Irrigation scheduling: Considering the daily CWR, TAW and Drz the irrigation interval could be computed from the expression:

$$Irrigation \text{ interval (days)}= RAW/CWR \quad (6)$$

Where;

RAW is readily available water in mm and CWR=Crop Water Requirement in mm day⁻¹

The gross irrigation requirement, IR_g, in a particular event could be computed from the expression:

$$IR_g=Interval \times CWR/Ea \quad (7)$$

Where;

IR_g is gross irrigation in mm, irrigation interval in days, CWR is crop water requirement in mm day⁻¹ and Ea is the Irrigation water application efficiency in fraction.

Method of irrigation was furrow irrigation with furrow spacing, width and depth respectively. And Irrigation water was applied as per the treatment to refill the crop root zone depth close to field capacity. The irrigation scheduling for potato was determined on the basis of predetermined 5 days' irrigation interval, 0 yield loss and field efficiency of 60%. Irrigation water was delivered to this experimental site by water pump from the shallow well which is near to the farm and the 3 inch standard rectangular shaped Parshal flume was set near the up-stream furrows to monitor the rate of inflowing irrigation water. The flume was made at Melkasa Agricultural Research Center based on the calibrated depth and discharge (5 cm and 1.7 l/s respectively), the time required to irrigate each plot were calculated using the following formula [17].

$$t=d \times A/60 \times q \quad (8)$$

Where;

t =application time (min), d =gross depth of water applied (mm), A =net area of the plot (m^2) and q =flow rate (discharge) (l/s).

Experimental set up and treatment randomization

The trial was implemented in a Randomized Complete Block Design (RCBD) with three replications. There were seven treatments made by varying two water regimes (0 and 100%) of crop water requirement (ETC) and imposed at four growth stages of potato crop.

Treatments	Description
T1	Apply irrigation at all growth stages (control)
T2	Miss irrigation application at initial stage only, but apply at all other stages
T3	Miss irrigation application at developmental stage only, but apply at all other stages
T4	Miss irrigation application at midseason stage only, but apply at all other stages
T5	Miss irrigation application at late season stage only, but apply at all other stages
T6	Miss irrigation application at initial and midseason stage only, but apply at both other stages
T7	Miss irrigation application at initial and late season stage only, but apply at both other stages

Table 1. Treatment combination.

RCBD were selected to minimize the effect of slope difference on the treatment following the gradient of experimental site. Treatments were arranged in each of the three blocks randomly based on randomization.

Land preparation and planting

Land preparation was carried out in January 2018. Gudene, an early maturing cultivar of potato medium size and well sprouted tubers were used for planting. It was planted on 19 February 2018 at a spacing of 75 cm between rows and 30 cm between plants. The plot size has a dimension of 4.5 m $\times$ 2 m and the spaces between plot and blocks was 1.0 m and 1.5 m respectively, each plot has five ridges and six end blocked furrows and having 7 plants in each row with a total of 35 plant population in each plot from this the harvested plot area was 3 $\times$ 2 m by avoiding the border furrows. Partial of the N and the full P fertilizer rate was applied during the time of planting; and the remaining half of the N dose was applied during the first earthling-up (30–45 days after planting) as side dressing. Weeds were managed by hoeing and hand weeding. Earthling-up was done three times before flowering to initiate tuber bulking and one time after flowering to prevent exposure of tubers to direct sunlight. All agronomic practices were done to all treatments in harmony to the recommendation made for the area. Potato was harvested manually using hand hoe after three months [18].

Water use efficiency

Physical water productivity or Water Use Efficiency (WUE) was determined by dividing the yield to seasonal evapotranspiration and calculated by the following equation.

The crop growing period was divided into four major growth stages: initial stage, development stage, mid-season stage, and late season stage. The treatments were: Treatment with full irrigation throughout the growing season (no stress), miss irrigation application at initial stage only (I), miss irrigation application at development stage only (D), miss irrigation application at midseason stage only (M), miss irrigation application at late season stage only (L), miss irrigation application at initial and midseason stages (IM) and miss irrigation application at initial and late season stages (IL), respectively (Table 1).

$$WUE (kg/m^3) = \text{Yield/Water} \quad (9)$$

Where;

WUE is water use efficiency (Kg/m^3), Y is actual yield (Kg/ha), and ET_c is seasonal crop evapotranspiration (m^3/ha).

Growth, yield data collection and analysis

In the experiment the agronomic parameters were collected in the study site to know the effect of soil moisture stress on different crop growth stage in days. Five plants were chosen and marked from each plot randomly after 90 days from sowing. Parameters measured included:

Plant height (cm): Five potato plants were randomly selected from the center three rows to avoid border effect then the height of these five plants was measured from the soil surface to the tip of the plant using tape meter. The mean value of the five plant height was recorded as plant height of each plot.

Number of branches per plant: Number of branches was counted from randomly selected five plants per plant. The mean value of the five plant branches was recorded as plant branch number of each plot after 90 days from sowing.

Number of tubers per plant: is the mean number of tuber produced by the sampled plants. Total number of tuber from each of the sampled plant were counted and divided by the number of plants and expressed as number per plant.

$$\text{No. of tubers/plant} = \frac{\text{No. of all tubers from sample (5 plants)}}{\text{No. of plant in sample (5 plants)}} \quad (10)$$

Tubers fresh weight (g): is the mean weight of tubers produced by the five randomly selected plants. The weight of all tubers from the

sampled plants were taken and divided by the number of plants sampled and expressed in gram.

Tuber length (cm): refers to the length of randomly selected five plant tubers were measured using caliper in centimeter. Then, average tuber length was calculated.

Tuber diameter (cm): refers to the diameter of five sample randomly selected plant tuber measured at the widest point in the middle portion of the mature tuber using a caliper.

Yield components: At harvest, the yield of tubers was classified according to sizes and the total marketable and non-marketable tubers were weighed separately and further computed to tons per hectare.

Marketable yield: Tubers classified under extra-large, big, medium and small were considered marketable yields.

Non-marketable yield: Tubers classified as marbles, diseased, physiologically disordered and putrid were considered non-marketable.

Tuber yield (ton/ha): Harvesting was done after 90 days from sowing and the tuber was recorded from net plot by weighed all tuber taken from central three rows and converted in to ton/ha calculated as:

$$\text{Yield (ton/ha)} = \frac{\text{wt. of tuber (g/m}^2\text{)} \times 10000 \text{ (ha)}}{1000 \text{ (ton)} \times 1000 \text{ (kg)}} \quad (11)$$

Water use efficiency (kg/m³): was determined by dividing the tuber yield produced from each treatment to the total water applied for the respective treatments.

Statistical analysis

The collected data has been analyzed by using SAS software 9.0 window versions for analysis of the statistical effect of stress irrigation treatments. The input data was plant height, branch number, tuber number per plant, tuber length, tuber diameter, tuber fresh weight, marketable yield, unmarketable yield, total tuber yield and water use efficiency. Whenever the treatment effects were found significant, at 5% was performed to assess any significant difference among treatments means [19].

Results and Discussion

Soil of the study area

The particle of the study soils possesses sand, silt and clay with 58, 26 and 16% distribution, respectively (Table 2). This could be named as sandy loam textural class based on. The pH of the area is 6.3, which could be grouped as slightly acidic. The bulk density of the experimental plot is 1.34 g/cm³, which is ideal for plant growth for aforementioned sandy loam soils according to USDA-NRCS. The amount of water present in this soil during planting was 156.2 mm/m, which is found in the range of available water (100-175 mm/m) for loam soils according to FAO irrigation and drainage paper. Thus, the soils of the study area are suitable for potato crop production. This is in agreement with Lynn, who elaborated potato as a crop that requires well drained loam or sandy loam soils with slightly acidic pH. Some physical characteristics of soil, at the experimental site are presented in Table 2.

Bulk density (g/cm ³)	pH	Field capacity (%)	Permanent wilting point (%)	Available water holding capacity (mm)	Particle size distribution (%)			Textural class
					Sand	Silt	Clay	
1.39	6.3	22.4	11.5	152.6	58	26	16	Sandy loam

Table 2. Physical characteristics of soil at the experimental site.

Irrigation water requirements and irrigation scheduling on potato

The amount of irrigation water applied to each treatment during the experimental period is shown in Table 3. The highest amount of irrigation water was applied on T1, which was irrigated at all stages while the lowest was applied at treatment T6 which was irrigated at development and late season growth stages only. The total amount of

water used by the crop was in the range of previous report of Pejic et al. who reported that seasonal evapotranspiration rate of potato in irrigated conditions ranged from 491.3 to 498.6 mm. While treatment T1 consumes higher than 450 mm [20]. An ET value of the study was being slightly higher from the above two researchers. This may be attributed to differences in climatic conditions, planting date and total growing season irrigation depth.

Treatment	Irrigation application stage	Rainfall (mm)	Net irrigation (mm/period)	Irrigation requirement (mm/period)
1	IDML	0	272.9	455.3
2	DML	0	251.6	419.5
3	IML	0	207.6	346
4	IDL	0	144.1	240.3

5	IDM	0	215.4	359.2
6	DL	0	122.8	204.8
7	DM	0	194.1	323.7

Note: IDML: At Initial, Developmental, Midseason and Late season stage; DML: At Developmental, Midseason and Late season stage; IML: At Initial, Midseason and Late season stage; IDL: At Initial, Developmental and Late season stage; IDM: At Initial, Developmental and Midseason stage; DL: At Developmental and Late season stage; DM: At Developmental and Midseason stage

Table 3. Rainfall, total amount of water applied (crop water requirements).

From Table 4 as shown below crop water requirement values were low at the beginning of the growing season, but increased gradually to reach a maximum during the plant growth stage of at development to midseason stage then decreased gradually the plant to reach at late season stage of the crop. This result indicates that, the maximum

amount of water was applied around tuber formation of the potato crop which was lined with who reported that water requirement of potato crop increase from planting to tuber formations stage then decrease at harvesting stage because photosynthesis gradually decreases, leaves turn yellow and the vines die.

Date	Day	Crop growth stage	IDML	DML	IML	IDL	IDM	DL	DM
			(T1)	(T2)	(T3)	(T4)	(T5)	(T6)	(T7)
23-Feb	5	Init	3.5	-	3.5	3.5	3.5	-	-
28-Feb	10	Init	7	-	7	7	7	-	-
5-Mar	15	Init	10.7	-	10.7	10.7	10.7	-	-
10-Mar	20	Init	14.3	-	14.3	14.3	14.3	-	-
15-Mar	25	Dev	17.6	17.6	-	17.6	17.6	17.6	17.6
20-Mar	30	Dev	19.4	19.4	-	19.4	19.4	19.4	19.4
25-Mar	35	Dev	21.7	21.7	-	21.7	21.7	21.7	21.7
30-Mar	40	Dev	23.9	23.9	-	23.9	23.9	23.9	23.9
4-Apr	45	Dev	26.4	26.4	-	26.4	26.4	26.4	26.4
9-Apr	50	Mid	28.9	28.9	28.9	-	28.9	-	28.9
14-Apr	55	Mid	32.3	32.3	32.3	-	32.3	-	32.3
19-Apr	60	Mid	35.6	35.6	35.6	-	35.6	-	35.6
24-Apr	65	Mid	37.9	37.9	37.9	-	37.9	-	37.9
29-Apr	70	Mid	42.3	42.3	42.3	-	42.3	-	42.3
4-May	75	Mid	37.7	37.7	37.7	-	37.7	-	37.7
9-May	80	Late	31.5	31.5	31.5	31.5	-	31.5	-
14-May	85	Late	25.8	25.8	25.8	25.8	-	25.8	-
19-May	90	Late	18.7	18.7	18.7	18.7	-	18.7	-
24-May	95	Late	11.9	11.9	11.9	11.9	-	11.9	-
29-May	100	End	7.9	7.9	7.9	7.9	-	7.9	-
Sum			455.3	419.5	346	240.3	359.2	204.8	323.7

Table 4. Irrigation scheduling and amount of water applied for each treatment (mm).

Effect of moisture stress on potato crop growth parameters

Plant height: The statistical analysis showed that the plant height was significantly influenced at ($p < 0.05$) due to soil moisture stress at

different growth stage. The maximum plant height of 92.67 cm and 85.16 cm were recorded from T1 and T5 (no stress and stressing only

at late season) respectively while the minimum plant height of 47.433 cm and 55.53 cm were observed from T3 and T4 (stress only at development stage and stress at initial and midseason stage) respectively (Table 5). The data indicated that plant height for the treatment (T3) was inferior to other treatments. Water stress during the vegetative growth stage decreases plant height and root expansion Haider and Ramana. This confirms that plant height was associated with the water applied at development stage.

Number of branches per plant: The number of branches per plant was different in different soil moisture stress (Table 5). There was a

difference between treatments with control treatment. The treatment (T1) gave the highest number of branches but had no significant difference with treatments except with treatment T2, T3, T4, T6 and T7 while the lowest number of branches was recorded from treatment T3 (stress at development stages). The statistical analysis showed that there was a significant difference between the soil moisture stress at ($p < 0.05$). The results were lined with who reported that Water stress during development growth stage significantly reduced number of main stems produced per plant compared to stress during mid-season stage.

Treatment	Plant height (cm)	Branch number
1	92.67 ^a	8.66 ^a
2	69.66 ^b	6.66 ^b
3	47.433 ^e	3.33 ^d
4	55.53 ^d	4.66 ^c
5	85.16 ^a	8.66 ^a
6	57.467 ^{cd}	5.0 ^c
7	66.50 ^{bc}	6.33 ^b
LSD _(0.05)	9.81	1.01
CV	8.14	9.21

Means followed by the same letter within a column are not significantly different at 5% level of significance. LSD: Least Significant Difference; CV%: Coefficient of Variation.

Table 5. Effect of moisture stress on plant height, and number of branch per plant at harvesting.

Effects of moisture stress on yield and yield components of potato crop

The numbers of tuber per plant: Considering the table of analysis of variance, the attribute of number of tuber per plant of potato was significantly affected ($P < 0.05$) by moisture stress applied at different growth stages. The highest number of tuber per plant was obtained from treatment T1 which received irrigation at all growth stages but had no significance differences with treatments T2 and T5. Whereas the lowest number of tuber was recorded from treatment T6, which was stress in the combination of at initial and mid-season stage but, it has no significant difference with treatment T3 and T4. In general, water stress at development and mid-season growth stage causes a significant reduction in tuber number. Similarly, water stress reduces seed yield in soybean and resulted fewer pods and seeds per unit area. Avoiding soil moisture stress at developmental and mid-season growth stages of the crop leads to higher number of tuber yield. This is in line with that the number of tuber in plant decreases if irrigation is cut at appearing the tuber initiation and beginning of elongation. Missing irrigation at the late season growth stage had no effect on number of tuber yield (Table 6).

Tuber length and tuber diameter: Moisture stress at different potato growth stage had a significant influence at ($p < 0.05$) on tuber length and tuber diameter. Treatment that irrigated at all stages was superior from the other treatments showed 7.76 cm and 5.53 cm on both tuber length and tuber diameter respectively in Table 6. The minimum tuber

length of 2.86 cm was recorded due to treatment that stressed only at mid-season stage and minimum tuber diameter of 2.36 cm and 2.8 cm was recorded by treatment that moisture stresses occur at initial and mid-season stages and only at mid-season stage respectively. This revealed that when soil moisture stress occurred at development and mid-season growth stage, tuber length and tuber diameters were highly affected which have a direct relation with tuber yield. Accordingly, Eldredge et al., extreme water stress conditions at serious growth stages influence the tuber yield, size, and exterior and interior quality of potato crop. Water stress during the tuber bulking stage causes dark stem-end fry color.

Tuber fresh weight per plot: The analysis of variance indicated that the Fresh weight of tuber was significantly difference ($p < 0.05$) between the treatments. The effect of soil moisture stress showed a decrease in fresh weight of the tubers compared with the treatment which received irrigation at all growth stage. Treatment (T1, T2 and T5) gave the highest tuber fresh weight while treatment (T3) gave the lowest one. A statistical analysis of mean showed that high significant differences between treatments (Table 6). These results are in confirmation with those of Fekadu, who reported that Water stress during vegetative and tuber bulking growth stages reduced tuber fresh weight in that, water stress fluctuation caused the highest yield reduction (40%) followed by the stress treatment which stayed for 15 days at vegetative or tuber bulking growth stages, both caused similar yield reduction (18%) from the zero water stress (control) treatment

per plant. In general, tuber number per hill and tuber weight per hill appeared to be the yield component that are affected by deficit water

during tuberization stage, which can reduction tuber yield up to 69% depending on period and strength of moisture stress.

Treatment	Tuber number per plant	Tuber length (cm)	Tuber diameter (cm)	Tuber fresh wt. per plant (g)
1	11.33 ^a	7.76 ^a	5.53 ^a	756.67 ^a
2	10.00 ^b	6.83 ^b	4.73 ^b	693.33 ^b
3	5.33 ^d	3.36 ^d	3.26 ^d	216.67 ^e
4	4.33 ^e	2.86 ^e	2.8 ^{de}	306.67 ^d
5	10.66 ^{ab}	7.7 ^a	5.73 ^a	735.67 ^a
6	3.66 ^e	3.2 ^{de}	2.36 ^e	303.33 ^d
7	6.66 ^c	5.5 ^c	4.06 ^c	570 ^c
LSD (0.05)	0.91	0.466	0.59	21.32
CV (%)	6.88	4.93	8.15	2.34

Note: Means of the same main effect within a column followed by the same letter are not significantly different at 5% of probability level and different letter are significant different at 5%, of probability level.

Table 6. Effect of moisture stress at different growth stage on potato yield components at harvesting.

Marketable and unmarketable tuber yield

Marketable: The ANOVA result showed that marketable tuber yield was significantly affected $p < 0.05$ by moisture stress. The difference in total marketable potato tuber yield for the control and moisture stress occurred at different growth stage was found to be statistically significant. Treatment (T1) that receives irrigation at all growth stage was superior to the others showed 28.93 ton/ha with no significant difference between treatment (T5) which was moisture stress occurs only at late season growth stage recorded 27.83 ton/ha on marketable tuber yield and the minimum marketable tuber yield of 5.86 ton/ha was received by treatment (T6) that stressed at initial and midseason growth stage only with small significant difference of T4.

Unmarketable: The difference in unmarketable tuber yield for the control and moisture stress done at different growth stage was found to be statistically significant. The maximum tuber yield of 4.4 ton/ha was recorded from T3 which had moisture stress occurs only at development stage and but had no significant difference with T6. While the minimum unmarketable tuber yield of 0.23 ton/ha was received by treatment (T1) which received irrigation at all growth stages but no significant difference with T2 and T5 tuber yield (Table 7). These revealed that when moisture stress at development and mid-season growth stage happen, marketable yield of tuber decrease whereas unmarketable tuber yield was increase and highly affected which have a direct relation with tuber yield. At final harvest, the size distribution of the marketable yield represents only a fraction of the harvestable yields. This is because marketable yields exclude tubers with physiological disorders like second growth, growth cracks, damage and diseases. In addition, unmarketable tuber yield, small tubers are also removed from the size distribution; for example, tubers < 10 g.

Total tuber yield: Data presented in Table 7 showed that missing irrigation at any of the studied growth stages significantly ($P < 0.05$) decreased total tuber yield. The application of normal irrigation significantly produced the maximum total tuber yield (29.16 t ha⁻¹)

there were no significant difference but there was simply in number difference with treatment (T5). While the lowest total tuber yield (10.20 t ha⁻¹) was obtained by applying water stress at the combination of initial and mid-season growth stage. These results are in agreement with those of Mauromicale whose reported that water stress causes a significant reduction in total tuber yield and also Wang et al. studied that the effects of full irrigation and deficit soil moisture on yield of potato at tuber initiation stages was highly affected. They showed that potato tuber yield decreased significantly under deficit soil moisture relative to full irrigation.

Bekele and Tilahun indicated that moisture stress at some growth stages had significantly affected the yield as compared to optimum application. This is due to the fact that yield is more dependent on rainfall or well distributed irrigation over the growing season based on demand at each stage than on total water available through the growing season. Water deficit affects nearly all growth processes; however, the stress response depends upon the intensity, rate, and duration of exposure and stage of plant development. The present study also showed that yield reduction was greatly governed by the time of water stress. The total tuber yield was reduced by 13.4%, 12.1% and 10% when the plants were exposed to miss irrigation application at the combination of initial and mid-season, mid-season and development growth stages in comparison to the plants received normal irrigation respectively.

The average yield shows increased potato yield production with additional water. Not only the amount of water applied important, but also the timing, relative to the growth stage of the crop. The present result in line with Jaleel et al, tuber yield decreased with rising of drying in soil. As stated by Vijitha and Mahendra, the final yield of the crop is the result of the combined effects of stress on growth, photosynthesis, respiration, metabolic processes, reproduction and other processes. Water stress can reduce photosynthesis by decrease in chlorophyll content, reduction in leaf area, closure of stomata, decrease in the efficiency of carbon fixation and reduced nutrient uptake by crops finally reduces yield.

Treatment	Mky (ton/ha)	Umy (ton/ha)	Ty (ton/ha)	WUE (kg/m ³)
1	28.93 ^a	0.23 ^e	29.16 ^a	6.4 ^b
2	26.37 ^c	0.70 ^d	27.06 ^b	6.2 ^c
3	10.50 ^e	4.40 ^a	14.96 ^d	4.3 ^e
4	8.36 ^f	3.63 ^b	12.00 ^e	5.0 ^d
5	27.83 ^b	0.56 ^d	28.36 ^a	7.9 ^a
6	5.86 ^g	4.33 ^a	10.20 ^f	5.0 ^d
7	19.70 ^d	1.13 ^c	20.80 ^c	5.0 ^d
LSD _(0.05)	0.84	0.24	0.88	0.23
CV%	2.81	6.51	2.43	2.45

Note: Means followed by the same letter within a column are not significantly different at 5% level of significance.

Table 7. Effect of moisture stress at different growth stage on potato Marketable (Mky), Unmarketable yield (Umy), Tuber yield (Ty), and Water Use Efficiency (WUE).

Water Use Efficiency (WUE)

Moisture stress at different growth stage had a significant difference at ($p < 0.05$) between the treatments. The highest water use efficiency was recorded 7.9 kg/m³ on treatment (T5) While the lowest water use efficiency due to moisture stress happens at development growth stage were measured 4.3 kg/m³ (Table 8). The result of this

study is similar to what is repeated by Tolga et al. Erdem et al. reported that seasonal evapotranspiration of potato, drip irrigated, varied from 459 mm to 524 mm under semiarid conditions. King et al. revealed that potato is highly sensitive to water stress during the vegetative and flowering stage.

Treatment	Tuber yield (kg/ha)	Amount of total irrigation (mm)	Water use efficiency (kg/m ³)
T1	29185	455.3	6.4
T2	26148	419.5	6.2
T3	14963	346	4.3
T4	12000	240.3	5
T5	28370	359.2	7.9
T6	10222	204.8	5
T7	20815	323.7	5

Table 8. Component of water requirement and water productivity in different moisture stress treatments.

Conclusion

The result showed that soil moisture stress at different growth stages of potato had significant effect on potato growth components like plant height, and number of branch per plant and on potato yield and yield components like tuber number, tuber fresh weight, tuber yield, marketable, unmarketable tuber yield, total tuber yield and water use efficiency were also significantly affected by soil moisture stress at different growth stages of potato. The maximum plant height was recorded from T1 and T5, which were irrigated at all stage and irrigated at three consecutive growth stages whereas the shortest was recorded from plants that were under soil moisture stress at development stages (T3).

The maximum tuber yield, number of tuber and tuber fresh weight was recorded from control treatment (T1) whereas the lowest was from T6 (grown under soil moisture stress at initial and mid-season stages). Plants grown at soil moisture stress condition only at initial growth stages showed little yield reduction than the control treatment. Plants grown under soil moisture stress condition at all growth stages except at developmental and mid-season stage provided higher yield than plants grown under soil moisture stress condition only at developmental and mid-season stage (T4). Applying irrigation water only at developmental and mid-season stage provided higher tuber yield than applying irrigation water at initial and late season stages.

The maximum tuber yield was recorded from T1 while, the lowest was from T3 and T6 (grown under soil moisture stress at development and initial and mid-season growth stages respectively). Missing irrigation at developmental and mid-season growth stage reduced tuber yield significantly.

Recommendations

From the study irrigate the crop at initial, development and mid-season growth stages were giving more tuber yield than irrigating the crop at development, midseason and late season growth stages. However, this experiment was conducted at a given site (farm land) in one season. Therefore, conducting the same experiment for one more season, and initiating similar experiments at different environmental conditions and variety is recommended to develop reliable limited irrigation practice based on sensitive crop growth stages for the given potato crop.

References

1. Abdel-Motagally FMF. "Evaluation of water use efficiency under different water regimes in grain sorghum (*Sorghum bicolor*, L. Monech)." *World J Agric Sci* 6 (2010): 499-505.
2. Allen, Richard G, Luis S Pereira, Dirk Raes, and Martin Smith. "Crop Evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56." Fao, Rome 300 (1998): D05109.
3. Awulachew, Seleshi Bekele, Philippe Lempriere, and Taffa Tulu. Training manual on agricultural water management. International Livestock Research Institute, 2009.
4. Barker, Randolph, David Dawe, and Arlene Inocencio. "Economics of water productivity in managing water for agriculture." In *Water productivity in agriculture: Limits and opportunities for improvement*, pp. 19-35. Wallingford UK: CABI Publishing, 2003.
5. Bekele, Samson, and Ketema Tilahun. "Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia." *Agric Water Manag* 89 (2007): 148-152.
6. Biamah, Elijah K. Coping with drought: options for soil and water management in semi-arid Kenya. Wageningen University and Research, 2005.
7. Biamah EK, L Stroosnijder, TC Sharma, and RKK Cherogony. "Effect of conservation tillage on watershed hydrology in semi-arid Kenya." In *13th International Congress on Agricultural Engineering*, pp. 335-357. 1998.
8. Doorenbos J, and AH Kassam. "Yield response to water." *Irrig Drain Paper* 33 (1979): 257.
9. Eldredge EP, ZA Holmes, AR Mosley, and CC Shock, et al. "Effects of transitory water stress on potato tuber stem-end reducing sugar and fry color." *Am Potato J* 73 (1996): 517-530.
10. Erdem, Tolga, Yesim Erdem, Halim Orta, and Hakan Okursoy. "Water-yield relationships of potato under different irrigation methods and regimens." *Scientia Agricola* 63 (2006): 226-231.
11. Cromme, Nicolaus, Adam B. Prakash, N. Litaladio, and Fernando Ezeta. *Strengthening potato value chains: Technical and policy options for developing countries*. 2010.
12. Mengistu, Fekadu Gebretensay. "Yield and quality response of processing potato variety 'Royal' to water stress during vegetative and tuber bulking growth stages." University of Copenhagen, (2009).
13. Gomez, Kwanchai A, and Arturo A. Gomez. *Statistical procedures for agricultural research*. John Wiley and sons, 1984.
14. Abbas, Haider, and Ramanathan Sri Ranjan. "Effect of soil moisture deficit on marketable yield and quality of potatoes." *Can Biosyst Eng J* 57 (2015).
15. Hassan AA, AA Sarkar, MH Ali, and NN Karim. "Effect of deficit irrigation at different growth stages on the yield of potato." *Pak J Biol Sci* 5 (2002): 128-134.
16. Ierna, Anita, Gaetano Pandino, Sara Lombardo, and Giovanni Mauromicale. "Tuber yield, water and fertilizer productivity in early potato as affected by a combination of irrigation and fertilization." *Agric Water Manag* 101 (2011): 35-41.
17. Khalili, Marouf, Mohammad Reza Naghavi, Alireza Pour Aboughadareh, and Houshang Naseri Rad. "Effects of drought stress on yield and yield components in maize cultivars (*Zea mays* L.)." *Intl J Agron Plant Prod* 4 (2013): 809-812.
18. Ierna, Anita, and Giovanni Mauromicale. "Physiological and growth response to moderate water deficit of off-season potatoes in a Mediterranean environment." *Agric Water Manag* 82 (2006): 193-209.
19. Onder, Sermet, Mehmet Emin Caliskan, Derya Onder, and Sevgi Caliskan. "Different irrigation methods and water stress effects on potato yield and yield components." *Agric Water Manag* 73 (2005): 73-86.
20. Pejic, B, M Aksic, K. Mackic, and G. Sekularac. "Response of potato to water stress in Southern Serbia." *Austin J Irrig* 1 (2015): 1-4.

How to cite this article: Jelos, Aregash Deboch and Sirak Tekleab Gebrekristos. "Response of Potato Yield to Soil Moisture Stress Condition at Different Crop Growth stages in Wondo Genet, Southern Ethiopia." *Irrigat Drainage Sys Eng* 14 (2025): 468.