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Evaluation of Potato Responses to Supplementary Irrigation in Rain-Fed Agriculture at Misrak Azernet Berbere Woreda, Ethiopia

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Abstract

In Sub-Saharan countries more than 95% of agricultural practices were laid on rain-fed. Ethiopia is one of the parts of the Sub-Saharan country and its agricultural practice mostly depends on rain-fed farming system. Highly reliance of agriculture on variable rainfall reduces income of farmers which adversely affects economy of the country. The similar climatic variability was happening in the study area in which rain fall doesn't fulfil the needs crop up to maturity. To address this problem, two years field experiment was conducted at 2015 and 2016 in Misrak Azernet Berbere Woreda, Southern Ethiopia to evaluate the effects of different supplementary irrigation (SI) levels on yield of potato. The experiment laid out in randomized complete block design (RCBD) with five treatments replicated three times. The treatments were:- Rain fed, 100% ET_c (crop evapotranspiration) SI throughout season, 75% of ET_c SI throughout season, 50% of ET_c SI throughout season and 100%ET_c SI starting at flowering stage).The combined yield results show that only rain-fed agriculture through season decreased yield of potato significantly. The maximum yield (45.31 t/ha) was obtained from 100% ET_c Supplementary irrigation throughout season while the minimum yield (24.46 t/ha) was obtained from only rain fed treatment. The yield obtained from 100% of ET_c supplementary irrigation starting from flowering stage was 38.98t/ha which has insignificant yield difference with 100% of ET_c throughout the season (45.31 t/ha). The yields of all supplemented treatments are greater than rain-fed treatment. From these result it can be concluded that supplementing rain fed potato production through irrigation increases yield.

Keywords: Potato; Rain-fed agriculture; Crop evapotranspiration; Supplementary irrigation

Introduction

In Sub-Saharan African countries more than 95% of agricultural practices were laid on rain-fed [1]. Ethiopia is one of the countries found in Sub-Saharan and most of its populations were living in high land areas with 85% being rural and dependent on rain-fed agriculture with a low level of productivity [2]. Highly reliance on rain-fed agriculture, during conditions of very variable rainfall and recurrent droughts affects agriculture and has adverse effects on the country economy. Irrigated agriculture is the main focus for the food security of the country by implementing small scale irrigation schemes which reduce dependency on rain-fed agriculture and increase food self-sufficiency of the rapidly increasing population [3].

Water is becoming an economically scare resource even in areas of the world that have relatively plentiful water [4]. Agriculture production under an erratic climatic conditions and limited water resources cannot be profitable investment unless on-farm water management practices were designed to meet the present and future growing demands of water for sustainable food production [5].

Shortage of soil moisture in the dry rain-fed areas often occurs during the most sensitive growth stages (flowering and grain filling) of the crops. As a result, rain-fed crop growth is poor and yield is consequently low. Supplemental irrigation (SI) using a limited amount of water, if applied during the critical crop growth stages can result substantial improvement in yield and water productivity. Therefore, SI is an effective response to alleviate the adverse impact of soil moisture stress during dry spells on the yield of rain-fed crops. SI may be defined as 'the addition of small amounts of water to essentially rain-fed crops during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields'. Since rainfall is the major water supply source for crop growth and production, the amount of water added by SI cannot by itself support economical crop production. In addition to yield increases, SI also stabilizes rain-fed crop production [6]. Supplemental irrigation in rain-fed areas is based on the following three basic aspects [7]:

1. Water is applied to a rain-fed crop that would normally produce some yield without irrigation
2. Since rainfall is the principal source of water for rain-fed crops, SI is only applied when rainfall fails to provide essential moisture for improved and stable production and
3. The amount and timing of SI are scheduled not to provide moisture-stress-free conditions throughout the growing season but to ensure that a minimum amount of water is available during the critical stages of crop growth which would permit optimal instead of maximum yield.

The study area was facing with high rainfall fluctuations during summer season due to high climate variability. The assessment done by AGP-II [8], despite the significance of the problem of water scarcity and inefficient rainfall, studies which can improve the problem were limited in the study area. In the study area farmers are potentially produce potato under irrigation and rainfed condition but they are not familiar with using both irrigation and rainfed agriculture at the same time. This study was conducted in misrak woreda, SNNPR to Evaluation of supplementary irrigation response on potato yield in rain-fed agriculture system.

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Methodology

Description of study area

Study area: The study was conducted at Goda kebele in Misrak Azernet Berbere Woreda, Located 221 km from Hawassa, capital of south regional state. The geographical location of study area was 7.85°N latitude, 38.03°E longitude and an altitude of 2483 m above mean sea level (Own GPS measured data) (Figure 1).

Climate: The average annual rainfall of the area varies from 600 to 1200 mm and seasonal rainfall (RF) pattern at the experimental area shows uni-modal distribution, which extends from half of April to early September with peaks rain fall in July. The mean annual minimum and maximum temperatures of the study area are 11°C and 27°C, respectively.

Agronomic practices: Main Crops grown by irrigation in the study area are onion, potato, tomato, garlic and cabbage. The experimental area was kept weed free by hand digging and pulling three times throughout the cropping season starting from July to November which is being under practices in the study area. The areal recommended NPS (150 kg/ha) fertilizer was applied at transplanting and urea (100 kg/ha) was split applied during planting and 6 weeks after transplanting. Redomil Gold (3 liter/ha) and phenotrotine chemical were used, to safeguard the crop against fungus and harmful insects, respectively (Misrak Azernet Woreda Agricultural office).

Experimental design

Five treatments include: Only rainfed, 100% of ETc SI throughout season, 75% of ETc SI throughout season, 50% of ETc SI throughout season, 100% ETc SI starting at flowering stage was used. Each treatment had three replications made a total of 15 experimental plots that was arranged in a randomized complete block design (RCBD). Each plot had 9 m^2 (2.8 m × 3.2 m) sizes. Total number of plants per plot and per replication were 32 and 160 respectively. The space between plots and blocks were 1m and 1.5m, respectively. As per the recommendation

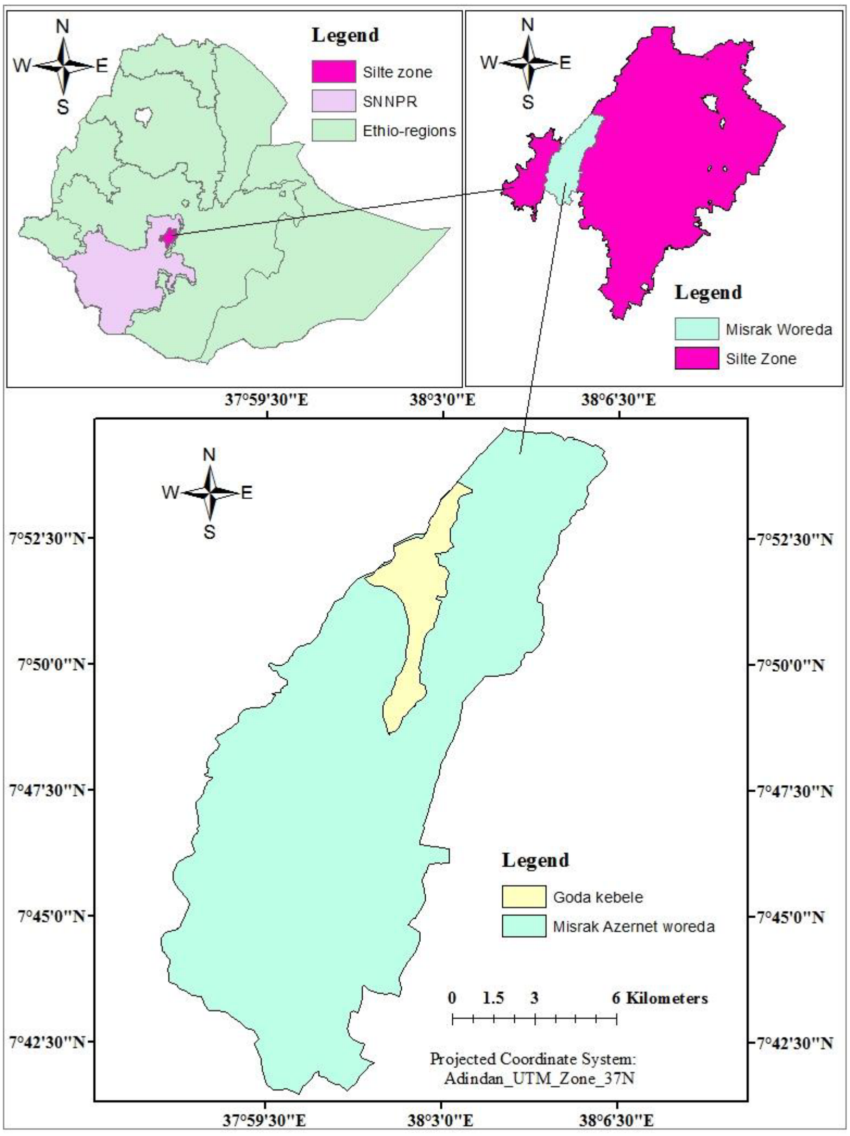

Figure 1: Location map of the study area.

from Agricultural research centers, the spacing between potato plants and rows kept at 40 cm and 70 cm respectively.

Soil sampling

Soil sample was collected from experimental field. Physical and chemical properties of the soil were analyzed. Disturbed mixture of soil samples were taken using auger for the analysis of soil moisture, texture, bulk density, FC and PWP.

Soil textural class was analyzed by using hydrometric method from collected soil samples and it was determined using USDA textural triangle procedure. Bulk density (BD) is an indicator of soil compaction. It is calculated as the dry weight of soil divided by its volume. This volume includes the volume of soil particles and the volume of pores among soil particles. Bulk density is typically expressed in g/cm³:

$$BD = \frac{Weight\ of\ dry\ soil\,(gm)}{Volume\ of\ the\ same\ soil\,(\mathrm{cm}^3)} \tag{1}$$

The water content of the soil at field capacity and permanent wilting point were determined in the laboratory by using a pressure plate apparatus. The pressure plate was adjusted to 0.33 bar to determine field capacity and 15bar to determine permanent wilting point to a saturated soil sample. The soil analysis was carried out at Ethiopian Construction Design Supervision Works Corporation (ECDSWC) Addis Ababa. Total available Water (TAW) in the root zone was computed as the difference in moisture content between FC and PWP. It is computed as follows:

$$TAW = \frac{(FC - PWP) * Dr}{100} * BD \tag{2}$$

Where: TAW=Total Available Water (cm), Fc=Water content at filed capacity (%), PWP=Water content at permanent willing point (%) and Dr=effective depth of root zone (cm).

Readily available water is the portion of the total available water (FC – PWP) which is most easily extracted by the plant roots without creating stress. The water content approaching PWP cannot be easily extracted by the plant roots. Therefore, only part of the TASW is used before the next irrigation. The term Maximum/management Allowable Deficiency, MAD, can be used to compute the amount of water that can be used without adversely affecting the plants and can be expressed as a fraction of the TASW. This value varies with the crop type and could be obtained experimentally. Once the MAD is known, it is possible to compute the net irrigation water requirement, IRn, necessary to restore the main root-zone, Rz, to FC. The factor MAD or p is differs from crop to crop. It is about 0.30 for shallow rooted plants e.g. onion [9].

The infiltration rate of the soil in the experimental field was determined using double ring infiltrometer method before the staring of the experiment. The double ring infiltrometer was set up in the field surface and measured the depth of water levels infiltrated continuously and the rate at which water level lowered was calculated.

Determination of crop water requirement (CWR)

Determination of water required (CWR) to compensate the amount of water lost through evapotranspiration (ETc), requires climatic and crop input data. Crop water reqiurment or ETc over the growing season was calculated from reference evapotranspiration (ETo) and crop coefficient (Kc) for that stage:

$$ET_c = k_c * ET_o \tag{3}$$

Where: ET_c=Crop water requirement (mm), k_c=crop coefficient, ET_o=reference evapotranspairation (mm)

The net irrigation (*IRn*) in each stage was computed from the following expression:

$$IRn = ETc - P\ eff \tag{4}$$

Where: P eff=Effective rain fall (mm)

The gross irrigation requirements (IRg) for each stage were obtained from the expression:

$$IRg = \frac{IRn}{Ea} \tag{5}$$

$$\text{Irrigation interval}\,(\text{days}) = \frac{IRn}{ETc} \tag{6}$$

Climatic data

Maximum and minimum temperature (˚C), humidity (%), wind speed (km/day) and sunshine (hours) and Rainfall (mm) of the experimental site were collected on daily base from New locClim1.10 model since there is no meteorological station near the area. The reference evapotranspiration of each month were computed by incorporating local climate information listed above in to the Cowpat 8.0 model.

Crop data

The irrigation water had applied using furrow irrigation system. Watering can was used for measuring applied water with application efficiency of 95% in first year. In the second year, partial flume was used for measuring applied water with application efficiency of 60. Fixed irrigation intervals of every 5 days in each stage were used as irrigation frequency**.**

Parshall flume was installed in the experimental field to measure the flow rate in to plots. The time of irrigation required in a given head of water through Parshall flume was calculated as:

$$t = \frac{A * dg}{6Q} \tag{7}$$

Where, t=time in minute, A=area of plot (m²), d_g=required depth of water in cm, Q=discharge in l/s. The irrigation interval was based on soil, climatic and crop data (Table 1).

Data collection

The field data such as tuber diameter, number of tuber per plant and yield weight were taken from each plot. Tuber diameter and number of tuber per plant were taken by random selection of plants from each plot by excluding the border rows and border plants. At the end of the season the amount of tuber yield produced was harvested and weighted from each plot. The harvested yield was grouped based on its quality for market according to the size and degree of damage.

Statistical analysis

Data was subjected to ANOVA using SAS 9.0 software based on randomized complete block design. Least Significant Difference (LSD)

Crop data	Growth stage				
	Initial	Dev.t	Mid	Late	Total
Length of growing season (days)	25	30	35	30	120
Crop coefficient (kc)	0.5		1.15	0.75	
Rooting depth (m)	0.30		0.60	60	
Depletion level (p)	0.25		0.15	0.5	
Yield response factor (ky)	0.45	0.80	0.80	0.30	
Source: CWR: crop water requirement, FAO 56 (Allen et al. [9]).					

Table 1: Potato crop data required for CWR determination.

at P=0.05 was employed to identify different level of supplementary irrigation that were significantly different from other treatments.

Result and Discussion

Soil field investigation results

Soil characterized results of study area will be presented in Table 2.

Crop water requirement

In the two growing season the amount of irrigation water applied on each treatment was presented in the following tables. The gross irrigation applied for fully supplemented treatment were 241.3 mm in 2015 and 339.8mm in 2016. These amounts of irrigation water were applied for only full irrigation level treatment. The 181 and 120.6 mm seasonal irrigation water depths were determined for treatments that have 75% and 50% of CWR throughout the season in the 2016 respectively. In the same way 254.85mm and 169.9mm irrigation water applied for treatments that have 75% and 50% of CWR throughout the season in the year 2017, respectively. For treatment having 100% ETc after flowering 128.7mm and 242mm water applied in 2016 and 2017, respectively. The amount of water saved on treatment 3 and 4 also presented. In these two treatments irrigation water was applied as the amount of rainfall unsuccessful to meet the crop water need (Tables 3 and 4).

Soil parameters	2015	2016	Method
Sand (%)	34.85	35.23	Hydrometer
Clay (%)	38.51	36.23	
Silt (%)	30.32	28.54	
Textural class	Clay loam	Clay loam	
Bulk density (gm/cm^3)	1.02	1.01	Oven dry
Field capacity (%) (0.33 bar)	29.73	28.93	Pressure Membrane
Permanent wilting point (%) (15 bar)	15.32	14.02	
Infiltration rate (mm/hr)	7.45	6.5	Double-ring infiltrometer

Table 2: Soil characterized results of study area.

Statistical results

The ANOVA Table 5 below indicated that there is significant difference between treatments means in which the p values in the table below 5%. Similarly, Table 5 below indicated that there is significant difference between treatments means in which the p values in the table below 5% but there is not interaction between years (Tables 5 and 6).

Response of crop parameter

As we have seen in the Table 7 below, the response of potato crop parameters to different levels of supplementary irrigation was varied depending on the types of parameters. The maximum yield was obtained from 100% ET_c Supplementary irrigation throughout season while the minimum yield was obtained from only rain fed treatment. The yield obtained from 100% of ET_c supplementary irrigation starting from flowering stage has insignificant yield difference with 100 % of ET_c throughout the season. The yields of all supplemented treatments are greater than rain-fed treatment. From these result, it can be concluded that supplementing rain fed potato production through irrigation increases yield.

The combined results in the two years indicated that different levels of supplementary irrigation had significant effect on the yield and tuber diameter of potato crop. Markus also showed that different level of supplementary irrigation had significant effect on yield of potato. The tuber diameter of potato showed significant effect on the two year supplementary irrigation. The combined result of number of tuber per plant for the two year was not significant. This might be due to

Treatments	IR_g required (mm)	IR_g applied (mm)	Irrigation water saved (%)	Irrigation water saved (mm)	Total water applied (IR_g+RF) (mm)
Rain fed	-		-	-	376.5
100% ET_c	241.3	241.3	-	-	617.8
75% of ET_c	241.3	181.0	25	60.3	557.5
50% of ET_c	241.3	120.7	50	120.6	497.2
100% ET_c SF	241.3	128.7	46.6	112.6	505.2
NB: SF: starting from flowering.					

Table 3: Irrigation Water supply (mm) under different irrigation treatments in 2015.

Treatments	IR_g required (mm)	IR_g applied (mm)	Irrigation water saved (%)	Irrigation water saved (mm)	Total irrigation Applied (IR_g+RF) (mm)
Rain fed	-	-	-	-	315.95
100% ET_c	339.8	339.8	-	-	655.75
75% of ET_c	339.8	254.85	25	84.95	570.8
50% of ET_c	339.8	169.9	50	169.9	485.85
100% ET_c SF	339.8	242	28.8	97.8	557.95
NB: IR_g: Gross Irrigation, IR_n: Net Irrigation (mm), RF: Rain Fall (mm), ET_c: Crop Evapotranspiration (mm) and AF: starting from flowering.					

Table 4: Water supply (mm) under different irrigation treatments in 2016.

Source	DF	SS	MS	P
Rep	2	7.9527	3.9763	
Trt	4	18.9087	4.7272	0
Yr	1	16.428	16.428	0
Trt*Yr	4	14.2753	3.5688	0.0001
Error	18	5.194	0.2886	
Total	29	62.7587		
NB: Rep: replication, Trt: Treatment, Yr: Year, DF: Degree of Freedom, SS: Sum of Square, MS: Mean Square and p: Probability Level.				

Table 5: Factorial AOV table for TD.

Source	DF	SS	MS	P
Rep	2	2.813E+08	1.41E+08	
Trt	4	1.591E+09	3.98E+08	0.0003
Yr	1	3.557E+09	3.56E+09	0
Trt*Yr	4	2.582E+08	6.45E+07	0.2542
Error	18	7.932E+08	4.41E+07	
Total	29	6.481E+09		

Table 6: Factorial AOV table for yield per hectare.

Treatments	Number of tuber	Tuber diameter (cm)	Total yield (ton/ha)	Applied Water (m^3)	WP (kg/m^3)
Rain fed only	22.63^{b}	5.60^{b}	24.46^{b}	3462.3^{e}	7.37
100% ETc SI	27.8^{a}	7.91^{a}	45.31^{a}	6367.8^{a}	7.04
75% ETc SI	$26.56b^{a}$	6.83^{ab}	32.22^{ab}	5641.5^{b}	5.70
50% ETc SI	$25.36b^{a}$	6.13^{b}	29.72^{ab}	4915.3^{d}	6.06
100% ETc SI SF	27.5^{a}	7.05^{ab}	38.98^{ab}	5315.8^{c}	7.25
CV (%)	8.4	18.63	41.46	4.5	42.2
LSD	4.1	1.5	16.9	0.28	NS
WP: Water Productivity (kg/m^3), letters a, b, c, d and e indicates significance level at ($P \leq 0.05$). Means followed by the same letter in a column are non-significantly different with each other at a 5% probability level in (SAS 9.0).					

Table 7: Combined yield and Water productivity results (2015 and 2016).

sufficiency of rain water for tuber formation in the growing season for all treatments.

Generally, supplementing 100% ET_c throughout the season and 100 % ET_c at starting flowering stage accrued the highest yield of potato in the two growing seasons. The potato yield showed proportional increase with amount of supplementing irrigation water. This indicated that supplementary irrigation stabilizes the growth of potato during low rain fall which enhance potato production.

Conclusion and Recommendation

Because of the climatic variability was happening in Ethiopia in which rain fall doesn't fulfill the needs of crops up to harvesting, especially during crop sensitive stages. To address these problems, two consecutive years experiment was conducted at 2015 and 2016 in Misrak Azernet Berbere Woreda, Silte Zone. The two years combined yield results showed that only rain-fed agriculture through season decreased yield of potato significantly. The maximum yield was obtained from 100% ET_c Supplementary irrigation throughout season while the minimum yield was obtained from only rain fed treatment. The yield obtained from 100% of ET_c supplementary irrigation starting from flowering stage has insignificant yield difference with 100 % of ET_c throughout the season. The yields of all supplemented treatments are greater than rain-fed treatment. From these result, it can be concluded that supplementing rain fed potato production through irrigation increases yield.

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