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Performance evaluation of irrigation scheduling methods on water use efficiency, yield and economic return of potato under furrow irrigation system at Jima Genati and Wayu Tuka Districts, Western Oromia

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ABSTRACT

Aim: The main objective of this study was to evaluate the performance of irrigation scheduling methods on water use efficiency, yield and economic return from Potato under furrow irrigation system**.**

Materials and Methods: The performance of four irrigation scheduling methods; Hand Feel Method, Soil moisture sample method, Calculating evapotranspiration losses and Farmer Practice were evaluated under furrow irrigation. Based on this study Farmer Practice was more frequent (15 irrigation events) than Hand Feel Method (13 irrigation events). However Hand Feel Irrigation scheduling method was more frequent than Soil moisture sample method and Calculating evapotranspiration losses.

Results: The Calculating evapotranspiration losses and Soil moisture sample method irrigation scheduling methods saved water by approximately 36.5% and 22% (two-season means), respectively, as compared to Hand Feel Method. The highest marketable tuber yield (21620 Kg/ha) was obtained from soil moisture sampling method, whereas the lowest marketable tuber yield (13953.4 Kg/ha) was recorded from Farmer Practice. The highest WUE (6.6 kg m^{-3}) was recorded for Evapotranspiration irrigation scheduling method, followed by 5.9 kg m^{-3} for Soil moisture sampling irrigation scheduling method, whereas the lowest WUE (2.1 kg m^{-3}) was recorded for the Farmer practice. From those, two irrigation scheduling methods evapotranspiration losses and Soil moisture sample method were best performed at both locations.

Conclusion: It was concluded that irrigating by using evapotranspiration losses irrigation scheduling method save more irrigation water regardless of minimum yield difference when compared with Soil moisture sample irrigation scheduling method. Key words: irrigation scheduling, Water use efficiency, and potato yield.

Keywords: Furrow irrigation system, Jima Genati and Wayu Tuka, potato, Western Oromia.

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Introduction

Ethiopia has abundant water resources suitable for irrigation but smallholder farmers continue to face challenges of water scarcity leading to low crop productivity (Worqlul,2017).Irrigation has a multi-faceted role in contributing towards food security, self-sufficiency, food production and exports. The traditional and small-scale irrigations cover the lions share in the Ethiopian irrigated agriculture (Yalew *etal*.2011). The main sources of water for irrigation in Ethiopia are diversion from rivers, spring development, and surface reservoirs, whereas the common method of water application is furrow irrigation.

Nearly 90% of the irrigated land of the world is watered using the least efficient traditional methods of irrigation (Koech *et al,* 2014). Among such traditional methods is conventional furrow irrigation (CFI) method, which is widely practiced across Ethiopia for watering row crops.

Irrigation scheduling is one of the factors that influence the agronomic and economic viability of small farms. It is important for both water savings and improved crop yields. The irrigation water is applied to the cultivation according to predetermined schedules based upon the monitoring of the soil water status and the crop water requirements. The type of soil and climatic conditions have a significant effect on the main practical aspects of irrigation, which are the determination of how much water should be applied and when it should be applied to a given crop. Poor management, uniformity and distribution of water have been cited as the most frequent problems of surface irrigation, resulting in water logging, salinization and less water use efficiency (AbouKheira, 2009). Potato (*Solanum tuberosum L.*) is one of the most important vegetable crops grown in the high and mid altitude areas of Ethiopia. It serves as food and cash crop for small scale farmers, occupies the largest area compared to other vegetable crops and produces more food per unit area and time compared to cereal crops.

Thus, the objective of this study was to evaluate the performance of irrigation scheduling methods on water use efficiency, yield and economic return from Potato under furrow irrigation system.

Materials and Methods

Description of the study area

The study was conducted at the farmer's field in the district of Jima Ganati, Horo Guduru Welega Zone (09°21′06.98″ N and 37°06′49.36″ E), and in the district of Wayu Tuka, East Welega (09°01′00.95″ N and 36°40′19.37″ E) which is located in the humid climatic region of western Ethiopia. The experiment was undertaken during the dry season (November–March) in 2019 and 2020.

Climatic Conditions

Climatic Conditionof Jima Ganti site and Wayu Tuka site were recorded (Table 1&2)

Experimental Design

A Complete Randomized Block Design with three replications was implemented for this study in which three irrigation scheduling methods (Hand Feel Method, Soil moisture sample method and Calculating evapotranspiration losses) and Farmer Practice (Irrigation scheduling done by farmer) were included. All experimental plots were planted with germinated potato tuber seeds (Belete) manually by hand on the ridge of furrows and maintaining a 0.30m plant-to-plant distance along the row (ridge) and 0.75m between rows. Thus, there were a total of 8 rows (rides) with in each plot and 33 plants within a row comprising of264 plants per plot. For preventing the lateral movement of water during irrigation from plot to plot, each block and treatment plot was kept 2 and 1 m, respectively, apart.

The recommended rates of UREA (150 kg ha^{-1}) and NPS (100 kg ha^{-1}) for potato in the study area were uniformly applied to all plots. All NPS and half dose of UREA fertilizers were applied at sowing as basal placement while the remaining half of UREA was side dressed 1 month later during hilling (earthing up) operation. The experimental plots were always kept free from weeds by manual clearing and hoeing. The Ridomil gold fungicide was applied against late blight disease of potato. All other agronomic practices were carried out as per the recommendation for potato crop.

Determination of Crop Water and Irrigation Requirements

The reference evapotranspiration (ETo) from the potato field was computed employing FAO Penman–Monteith equation (Allen *et al*, 1998) and implemented in the CROPWAT 8.0 model (Martin, CROPWAT, 1996). The ETo of the experimental sites were computed from minimum and maximum air temperatures, wind speed, relative humidity, sunshine hours, and solar radiation using the FAO CROPWAT 8.0 model. The crop evapotranspiration (ETc) was calculated by multiplying the ETo with crop coefficient (Kc) at each crop growth stage using CROPWAT 8.0 model. Since there were no site specific K_C for potato in the study area, the values set by FAO (Allen *et al*, 1998) for the 4 crop development stages were adopted for this study:

$$ETc = ETo * Kc \qquad 1$$

Where ETc, ETo, and K_C are crop evapotranspiration ($mmday^{-1}$), reference crop evapotranspiration (mm day^{-1}), and crop coefficient (dimensionless), respectively.

The total length of the test crop's growing period in the study area ranged from 120–130 days. The growing period of potato was divided into initial, development, middle, and late stages. Irrigation scheduling was also computed employing CROPWAT 8.0 model by considering the crop, climatic and soil properties of the study area over the growing period. Three irrigation scheduling methods tested in our study differed from each other in the way to estimate the amount of water stored in the soil during the growing season.

Determination of Water Use Efficiency

The field water use efficiency was calculated by dividing the marketable (economic) potato tuber yield with the total amount of irrigation water applied per treatment and per period as shown in the following equation (Bos, 1985).

$$WUE = \frac{Y}{ETc} \qquad 2$$

Where WUE is the water use efficiency (kgm^{-3}), Y is the potato tuber yield ($kgha^{-1}$), and ETc is the total irrigation water supplied during the experimental period (m^3ha^{-1}). The total water included only the supplied irrigation water.

The irrigation water saved with Calculating evapotranspiration losses (ETo), Soil moisture sample (SMS), Hand Feel Method (HF) to Farmer Practice (FP) was calculated using the following equation (Chapagain and Yamaji, 2010):

$$water\ saving\ (\%) = \frac{\theta FP - \theta ETo, SMS\ OR\ \theta HF)}{\theta FP} * 100 \qquad 3$$

Where θFP, θETo , θ SMS and θHF are the total amount of irrigation water (mm) used with the Farmer Practice, Evapotranspiration method, Gravimetric soil moisture sample methods Hand Feel and appearance of soil method respectively.

Data Collection

The data collected (computed) during the experimental period were weight of tuber per plot, plant height, and marketable tuber yield and water use efficiency. The plant height was measured from 20 plant samples from the soil surface to the plant apex at the end of the growing season. Potato tubers were dug out from all plants weighed and recorded from each of the plots potato plants for weight of tubers per plot. The marketable potato tubers from the central 6 rows of each plot (45m²; 4.5 m by 10 m) were harvested manually, the fresh weight was measured for tuber yield determination and the values were converted to $Kgha^{-1}$.Soil samples were collected before planting the crops from both the experimental sites. Collected soil samples were analyzed for Soil texture, bulk density, field capacity and Permanent wilting point.

Data Analysis

Data were analyzed using analysis of variance procedures on the appropriate statistical analysis software (SAS, 2010) version 9.0. Whenever the treatment differences show significance, mean differences was tested by LSD at 5% level of significance.

Table 1. Climatic Condition of Jima Ganti site

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sunshine hours	Radiation MJ/m²/day	ETo mm/day
January	11.2	26.3	47	130	8	19.3	3.88
February	12.1	27.4	43	147	7.6	20	4.36
March	12.8	27.4	45	147	7.1	20.3	4.53
April	12.7	27.2	52	138	7	20.3	4.4
May	12.4	26.5	57	130	6.3	18.8	4.03
June	11.7	24.6	71	95	5.1	16.6	3.3
July	12.2	22	84	104	3.4	14.2	2.68
August	11.9	23.3	84	95	8.1	21.6	3.74
September	11.1	23.5	76	104	5	17	3.2
October	10.7	25	53	156	7.6	20.1	4.09
November	10.2	25.1	43	147	8.7	20.5	4.12
December	10.3	25.5	49	147	8.6	19.7	3.88
Average	11.6	25.3	59	128	6.9	19	3.85

Table 2 Climatic Condition of Wayu Tuka site

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sunshine hours	Radiation MJ/m²/day	ETo mm/day
January	11.7	25.8	46	95	7.9	19.2	3.67
February	12.3	26.7	43	112	7.7	20.1	4.12
March	13	27	52	121	7.4	20.7	4.29
April	13.4	26.7	46	112	7.2	20.6	4.4
May	12.8	24.4	58	78	5.6	17.7	3.61
June	11.5	21.7	75	69	4.3	15.5	2.94
July	11.2	20.7	81	104	3.3	14.1	2.66
August	11	20.7	81	78	3.4	14.5	2.67
September	10.6	21.9	71	78	4.2	15.7	2.95
October	11.4	23.2	62	104	6.7	18.8	3.5
November	12	24.2	56	104	7.3	18.5	3.52
December	11.7	24.8	50	104	7.3	17.9	3.47
Average	11.9	24	60	96	6	17.8	3.48

Table 3 Treatments setting for the field experiment.

No	Treatment Name	Remark
1	Hand Feel Method	Irrigation scheduling by Hand Feel
2	Soil moisture sample method	Irrigation scheduling by Soil sampling
3	Calculating evapotranspiration losses	Irrigation scheduling using ETo
4	Farmer Practice	Irrigation scheduling done by farmer

Results and Discussion

Soil physical characteristics of the experimental sites

The analyzed soil sample showed that bulk density of the experimental site (1.34 g/cm3 and 1.31 g/cm^3 Wayu Tuka and Jima Genati respectively) were ideal for plant growth**.**

Applied irrigation water (Wa)

The number of irrigation events and amount of applied water (Wa) for each treatment were shown (Table 2). The treatment 4 (Farmer Practice) was more frequent (15 irrigation events) than Treatment 1 (Hand Feel Method) (13 irrigation events). However Hand Feel Irrigation scheduling method was more frequent than Soil moisture sample method and Calculating evapotranspiration losses.

The seasonal amount of Wa was the mean of the two seasons at both sites and amounted to 474.1mm (4745 m3 ha^{-1}), 369.8 mm (3698 m^3 ha^{-1}), and300.8 mm (3008 m^{3}ha^{-1}) for Hand Feel Method, Soil moisture sample method, and Calculating evapotranspiration losses, respectively. This indicated that the Calculating evapotranspiration losses and Soil moisture sample method irrigation scheduling methods saved water by approximately 36.5% and 22% (two-season means), respectively, as compared to conventional Hand Feel Method.

Growth Performance and Yield Components

Marketable tuber yield: Marketable was highly significantly ($P<0.005$) affected by different irrigation scheduling methods. The highest marketable tuber yield (21620 Kg/ha and 21236.7 Kg/ha) were obtained from soil moisture sampling method at Jima Genati and Wayu Tuka respectively, whereas the lowest marketable tuber yield (13953.4 Kg/ha and13953.4 Kg/ha) were recorded from Farmer Practice at Jima Genati and Wayu Tuka Sites respectively. These results were in line with other researchers who reported that marketable tuber yield was significantly affected by frequency of irrigation (Elfinesh, 2008; Kumar et al., 2007).

Unmarketable tuber yield: The results showed that no significant difference ($P>0.05$) was observed between soil moisture sample method and Evapotranspiration method at Jima Genati and Wayu Tuka while it was significantly affected by irrigation scheduling methods. The highest unmarketable tuber yield (942.9Kg/ha and 1050.4Kg/ha) were obtained from Framer Practice at Jima Genati and Wayu Tuka sites respectively, whereas the lowest un marketable tuber yield (459.3Kg/ha and 488.9Kg/ha) were recorded from soil moisture sample method at Jima Genati and Wayu Tuka respectively.

Plant height: The results showed that no significance difference ($P>0.05$) between soil moisture sample method and Evapotranspiration method at Jima Genati and Wayu Tuka sites.

Water use efficiency

Crop water use efficiency (WUE) for Evapotranspiration irrigation scheduling method substantially increased as compared with Farmer irrigation scheduling method table 8.The highest WUE values were 6.6 and 6.4 kg m^{-3} recorded for Evapotranspiration irrigation scheduling method, followed by 6 and 5.9 kg m^{-3} for Soil moisture sampling irrigation scheduling method at Jima Ganati and Wayu Tuka sites, respectively, whereas the lowest WUE value was 2.2 and 2.1 kg m^{-3} recorded for the Farmer practice at both sites. These results indicate that both Evapotranspiration method and Gravimetric soil moisture sample method4 achieved high WUE values as compared with Hand Feel and appearance of soil method. This could be due to the high yield obtained with Evapotranspiration method and lower CWU obtained with Hand Feel and appearance of soil method.

Economic Analysis

The purpose of Economic analysis was to evaluate the differences in cost and benefits among different irrigation scheduling methods. In the preparation of economic analysis, all the costs of production and the cost that varied among different irrigation scheduling method were taken into account. Yield of all crops were adjusted downward by 30% to reflect probable lower yields expected by the farmers due to differences in factors like management, plot size, harvest data and harvesting technology (Byerlee *et al.* 1984). The field prices of the crops were calculated by adjusting the average market prices of those crops downward by 10 percent.

Table 4. Soil physical characteristics of the experimental sites

Sampling Depth	Wayu Tuka			Jima Genati		
	Bulk density	Average bulk density g/cm³	Soil texture	Bulk density	Average bulk density g/cm3	Soil texture
0-5cm	1.32	1.34	Clay	1.18	1.31	Sandy clay loam
5-10cm	1.34			1.29		
10-15cm	1.36			1.38		
15-20cm	1.37			1.4		
FC (%)	61.72			52.6		
PWP (%)	50.18			34.87		

Table 5. Number of irrigation events and amount of applied water (Wa) for each treatments at both sites

Jima Genati and Wayu Tuka						
Hand Feel Method		Soil moisture sample method		Calculating evapotranspiration losses		Farmer practice
Date	Net Irr(mm)	Date	Net Irr(mm)	Date	Net Irr(mm)	
15-Nov	18.5	16-Nov	19.5	20-Nov	22.5	
26-Nov	22.4	28-Nov	21.4	7-Dec	24.4	
8-Dec	27.0	11-Dec	26.0	22-Dec	28.0	
18-Dec	30.1	22-Dec	31.1	4-Jan	30.1	
27-Dec	34.7	2-Jan	32.7	16-Jan	35.7	
5-Jan	38.6	12-Jan	39.6	28-Jan	37.6	
14-Jan	40.3	22-Jan	42.3	8-Feb	42.3	
23-Jan	40.9	31-Jan	38.9	21-Feb	40.9	
31-Jan	37.3	9-Feb	39.3	14-Mar	39.3	
8-Feb	38.8	19-Feb	40.8			
16-Feb	39.2	5-Mar	38.2			
26-Feb	46.6					
13-Mar	59.7					
Total	474.1		369.8		300.8	643mm

Table 6. Mean of tuber Yield and plant height for both seasons at Jima Ganati

Treatments	Marketable Yield (kg/ha)	Un Marketable Yield (kg/ha)	Total Yield (kg/ha)	Plant Height (cm)
Hand Feel and appearance of soil method	16406.7c	718.5b	17125.2c	54.5b
Gravimetric soil moisture sample method	21620a	459.3c	22079.3a	61.5a
Evapotranspiration method	19243.4b	518.5c	19761.9b	59.2a
Farmer Practice	13953.4d	942.9a	14896.3d	51.2b
LSD	467.8	83.32	512.53	3.96
CV	11.4	14	15.3	9.4

Table 7. Mean of tuber Yield and plant height for both seasons at Wayu Tuka

Treatments	Marketable Yield (kg/ha)	Un Marketable Yield (kg/ha)	Total Yield (kg/ha)	Plant Height (cm)
Hand Feel and appearance of soil method	15870.0c	762.9b	16633.0c	54.2b
Gravimetric soil moisture sample method	21236.7a	488.9c	21725.6a	60.5a
Evapotranspiration method	18783.3b	533.3c	19316.7b	58.5a
Farmer Practice	13493.3d	1050.4a	14543.7d	50.2a
LSD	490.83	191.7	467.6	3.22
CV	12	14	15	12

Table 8. Mean of Water use efficiency (WUE) for both seasons at Jima Ganati and Wayu sites

Treatments	Water Use Efficiency (Kg/m³)		Water Saved (%)
	Jima Ganati	Wayu Tuka	
Hand Feel and appearance of soil method	3.6	3.5	26.3
Gravimetric soil moisture sample method	6	5.9	42.5
Evapotranspiration method	6.6	6.4	53.2
Farmer practice	2.2	2.1	-

Table 9. Economic analysis for treatments at Jima Ganati and Wayu Tuka sites

	Jima Genati				Wayu Tuka			
Components	Hand Feel Method	Soil moisture sample method	Calculating evapotrans-piration losses	Farmer Practice	Hand Feel Method	Soil moisture sample method	Calculating evapotrans-piration losses	Farmer Practice
Average Mar.Yield	16407	21620	19243	13953	15870	21237	18783	13493
GFB (Eth Birr/ha)	164067	216200	192434	139534	158700	212367	187833	134933
Fertilizer, seed cost and Chemical (Eth Birr/ha)	29450	29450	29450	29450	29450		29450	29450
Labor cost (Eth Birr/ha)	19975	19075	18175	20875	19975	19075	18175	20875
Total costs (Eth Birr/ha)	49425	48525	47625	50325	49425	48525	47625	50325
NB (Eth Birr/ha)	114642	167675	144809	89209	109275	163842	140208	84608

Conclusions

It was concluded that irrigating by using evapotranspiration losses irrigation scheduling method save more irrigation water regardless of minimum yield difference when compared with Soil moisture sample irrigation scheduling method. Adoption of this technique suggests the great potential of doubling the cultivable land and production using the existing irrigation water resource by shifting from the conventional (farmer practice) to water saving irrigation scheduling method. Adoption of the water-saving irrigation scheduling method further helps to minimize the adverse effects of excess irrigation to the environments and the conflicts among the community for the limited water resource.

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