Effect of Irrigation Regimes on Tuber Yield and Water Use Efficiency of Potato in Efratanagidiem District, North Shewa

Introduction

Ethiopia has the greatest potential for potato production as 70% of its arable land mainly in highland areas with altitudes greater than 1,500 m above sea level is considered suitable for potato (Yilma S ,1991). In a natural environment, plants are subjected to many stresses that have a great impact on the growth, development and finally yield of crops. These factors could be drought and nutrients -sub-optimal use, excess water and water stress are major abiotic factors that limit crop production (Reddy AR, *et al,* 2004).

Studies show that water is the most important limiting factor for potato production and it is possible to increase production levels by well-scheduled irrigation programs throughout the growing season for efficient use of water (Panigrahi B, *et al,* 2001). The most important requirmentto avoid water shortage and over-irrigation, which can also affect yields of potato through reducing soil aeration, water and nutrient uptake and increasing essential nutrients leaching is effective water management (Shirie JM, *et al* 2006).

Potato (Solanum tuberosum L.) is one of the most well-known vegetable crops which is grown under temperate conditions and highly produced in Ethiopia. There is a blind faith to which potato production held mostly on high land areas rather than low lands. But potato is also produced in low land areas up to 1500 m.a.s as suggested by many researchers. The main requirment that potato production depends on is soil moisture conditions. On the low lands, to gain satisfactorily tuber yield the application of optimum amount of irrigation water to the right time is just a mandatory.

Sustainable use of resources that make up the agricultural production system is the means to support environmental conservation and assure food security. One of the main problems that has been facing nowadays is the low implementation of advanced technologies for irrigation forecasts in a real time. So, there are still using traditional methods of irrigation practices by which water consumption is higher and the scarce resource is lost. Most vegetables grow in the dry season and are sensitive to water deficit in the soil, thus requiring frequent irrigation and light to ensure soil moisture above 75% of the available taking into account those edaphoclimatic conditions in the period that rainfall is insufficient to satisfy the water demand (Cristina etal., 2011).

Irrigation management is performed according to crop water needs that will allow crops to reach their productive potential. For a rational forecast of water management, knowing the crop evapotranspiration during the development phases is very important. Setting the right amount of water and scheduling in each development phase is the most important factor to improve the quality and quantity of potato yield. This is the most important point to efficient utilization of resources and to improve the food security of a growing population in developing countries.

In Ethiopia, the population is growing rapidly and is expected to continue growing, which inevitably leads to an increase in food demand. To maintain self-sufficiency in food supply, one viable option is to raise the unit yield. Irrigation is the most common means of ensuring sustainable agriculture and copying with periods of inadequate rainfall (Dessalegn, 1999)

Irrigation scheduling is planning when and how much water to apply to maintain healthy plant growth during the growing season. The interval between two irrigations should be possible to save irrigation water without affecting adversely the growth and yield (Dilip, 2000). Irrigation is also an essential daily management practice for a farm manager growing irrigated crops. Apply the right amount of irrigation water at the right time is a crucial decision for a farm manager to meet the water needs of the crop to prevent yield loss due to water stress, maximize the irrigation water use efficiency resulting in beneficial use and conservation of the local water resources and minimize the leaching potential of nitrates and certain pesticides that may impact the quality of the groundwater (Jerry, 2002).

Effective irrigation is possible with regular monitoring of soil water and crop development conditions in the field, and with the forecasting of future crop water needs. Delaying irrigation until crop stress is evident, or applying too little water, can result in substantial yield loss. Therefore, this research activity was conducted to determine the appropriate frequency and amount of irrigation water for improving the productivity and water use efficiency of potato .

Materials and method

Description of the study area

The experiment was conducted in the Amhara region North Shewa Efratanagidiem woreda at Yimlloirrigation site. The site is located 290 km north of Addis Ababa, and 154 km from Debrebirhan town. The geographic location of the experimental site is 39^0 54’ 27’’ E and 10°17’

28’’N with an altitude of 1514 m.a.s.l. The area has two major seasons; rainy and dry season. The rainy season lasts from the beginning of June to the end of September with mean annual rainfall of 822 mm, while the dry season lasts mainly from October to the end of May. The hottest months, February, April and May with a mean monthly maximum temperature of 27.7°C, while the coldest months are November and December with a mean minimum temperature of 11.5°C. The average relative humidity during the dried months is 64%.

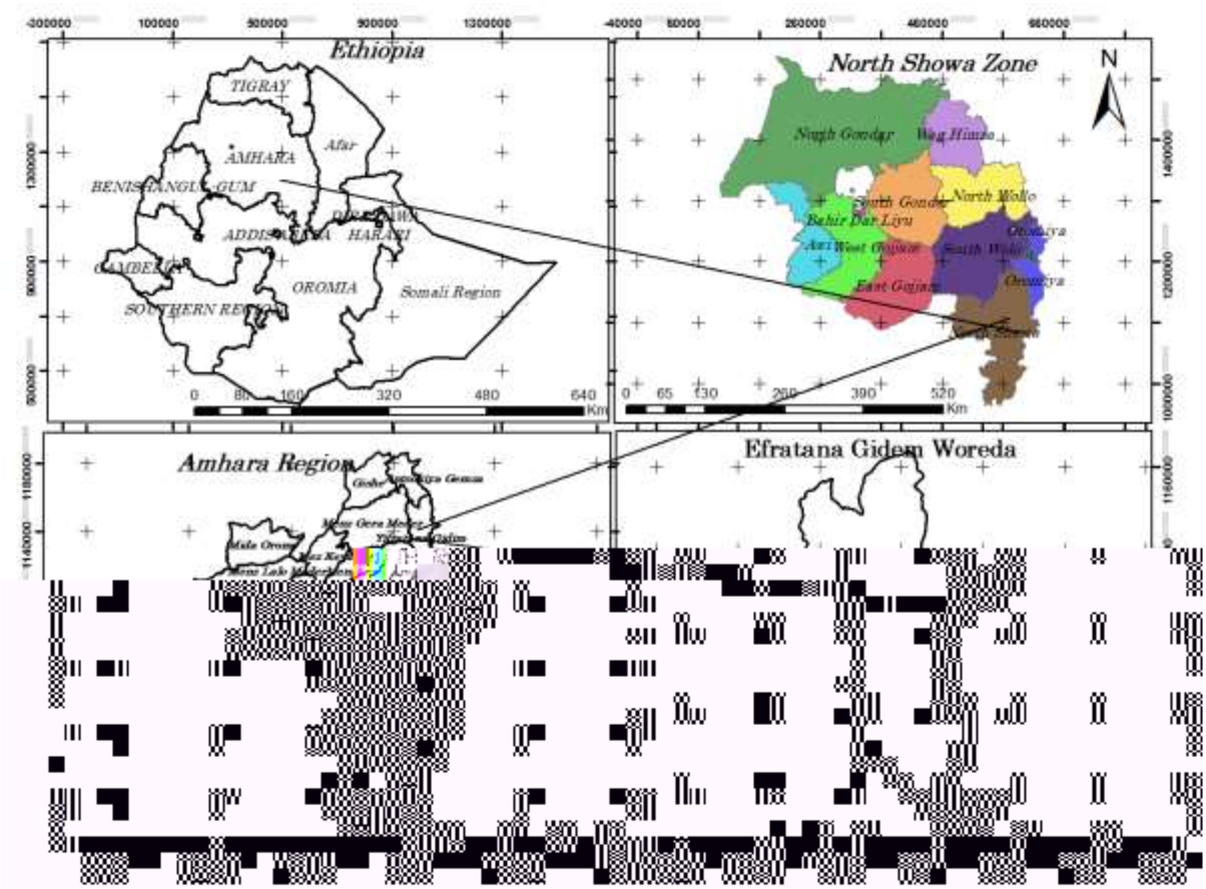

Figure 6. location map of the study area

Soil sampling and analysis

The composite soil samples were taken at depth of 20 cm using a soil sampling auger from the experimental site randomly and ensuring that each treatment was represented within each unit. The samples were taken just before planting to determine the physic-chemical properties. The soil properties of the site (Texture, Bulk density, pH, EC, permanent filleting point, field capacity of the soils) have been determined using the standard soil lab procedures.

Table 1. Physicochemical property of soil at the study area

Site	pH	EC (ds/mm)	Soil texture Clay (%)	Silt (%)	Sand (%)	Textural class	Bulk density g/cm3	PW %	FC %	OC %	OM %	Saturation %
Yimllo	7.8	0.23	38	34	28	Clay loam	1.37	23.4	37.2	1.76	3.04	48.3

The Kc values of potato were fixed at 0.5, 0.77, 1.10, 1.15 and 0.75, for initial, development-1, development-2, middle, and late-stage respectively according to FAO irrigation and drainage paper No. 56 (Allen et al., 1998). The allowable water depletion of potato was assumed to be 0.35 of total available water (P = 0.35) during the whole growing cycle as suggested in FAO 56 (Allen et al., 1998).

ETo was multiplied by an empirical potato Kc (Allen et al., 1998) to calculate ETc values for the experiment. ETc was calculated for each crop development stage and then set to treatment data arrangements.

The experimental area was well prepared in November, just plowed two times with local Marsha. Naturally loose soil, which offers tuber expansion, reach in organic matter, having good drainage aeration are suitable. All experimental plots were irrigated with a uniform amount of water a few days before planting to make the soil soft, well-aerated, well-drained, and workable. The experiment was conducted in a randomized complete block design with 15 treatments and 3 replications, block as a replication. The total plot size was 8.4m^2 for data collection and yield assessment. Treatments corresponds to different irrigation depths applied based on the full CROPWAT generated depth (100% of ETC) with generated fixed interval (12 day). Therefore, the treatment arranges by cascade the generated depth and interval up and down with 25% and 3 days respectively. So the treatment, 50%, 75%, 100%, 125%, 150% of ETC with 12-day interval; before 3 day of CROPWAT generated depth 50%,75%,100%, 125%, 150% of ETC with 9-day interval and after 3 day of CROPWAT generated depth 50%, 75%,100%, 125%, 150% of ETC with 15-day interval. The required fertilizer rates were applied as per the agronomic recommendation 168 Kg/ha urea and 182 Kg/ha NPS.

Data collection

The data collected were the number of stand count, plant height, and tuber yield and number of tubers, then computed water use efficiency from the collected data. After physiological maturity, the sample was taken from the plot area 5.4m^2. Great care was taken to avoid injury and bruising during harvesting, leaving tubers in soil to make the skin too thick for having good data and convert to hectare base.

The basic expression of agricultural water productivity is a measure of output of a given system to the water it consumes, for the whole system or parts of it, defined in time and space. So, the weighed samples of tubers from each plot were converted into kilogram per hectare and divide by their respective total amount of irrigation water supplied throughout the cropping season to determine the water use efficiency (Cook et al., 2006).

$$WUE = \frac{Y}{NIR}$$

Where, WUE is water use efficiency in kg /m^3, Y is crop tuber yield in kg/ ha and NIR is total net irrigation requirement m^3.

Statistical analysis

All yield, yield components and water use efficiency data were subjected to analysis of variance using PROC GLM ANOVA of SAS (statistical analysis software) version 9.0 (SAS Institute, 2004). The significant differences among treatment means for each treatment were compared using Dunken's multiple range test at $p<0.05$ significant difference and at $p<0.01$ highly significant difference.

Results and discussion

The crop consumptive use of potato was determined by using CROPWAT version 8 model with an input of climatic parameters like; minimum and maximum temperature, Relative humidity, wind speed, sunshine hours, solar radiation, crop coefficient, length of growing period and soil parameters.

Climatic parameters

Climate is one of the most important factors determining the crop water requirements needed for unrestricted optimum growth and increased crop yields. The principal climatic parameters such as precipitation, solar radiation, temperature, wind and humidity influence the crop water requirement (CWR). Evaporation and transpiration occur at a potential rate when the supply of water is unlimited and the evapotranspiration of the crop (ETc) becomes higher. Solar radiation supplies the energy for the ETc processes. With increasing day length or solar radiation,

by applying 14.67 mm with a 15 days interval. Marketable and total yield of potato tuber as well as water use efficiency (WUE) showed highly significant difference at (P>0.05).

Table 2. Effect of irrigation regime on potato yield and yield parameters and water use efficiency at Efratanagidiem

Treatment	PH (cm)	TD (mm)	TY (ton/ha)	MY (ton/ha)	WUE (kg/mm/ha)
14.67 mm with 12 day	71	55	22.259^{c}	19.351c	97^{b}
22.00 mm with 12 day	71	53	26.725^{bc}	24.067^{bc}	77^{bc}
29.34 mm with 12 day	71	53	27.698^{abc}	24.988^{abc}	59^{cde}
36.67 mm with 12 day	78	55	29.155^{ab}	26.377^{ab}	49de
44.00 mm with 12 day	77	55	31.146^{ab}	28.372^{ab}	44de
14.67 mm with 9 day	76	53	27.859^{abc}	25.538^{ab}	126^{a}
22.00 mm with 9 day	75	55	29.180^{ab}	26.175^{ab}	89^{b}
29.34 mm with 9 day	76	54	27.910^{abc}	25.977^{ab}	66^{cd}
36.67 mm with 9 day	70	54	30.291^{ab}	27.808^{ab}	57^{cde}
44.00 mm with 9 day	77	57	33.653^{a}	30.993^{a}	52de
14.67 mm with 15 day	75	51	21.529^{c}	19.069^{c}	93^{b}
22.00 mm with 15 day	76	52	27.570^{abc}	24.790^{bc}	78^{bc}
29.34 mm with 15 day	69	53	26.771^{bc}	24.586^{bc}	58^{cde}
36.67 mm with 15 day	76	54	29.806^{ab}	27.559^{ab}	51de
44.00 mm with 15 day	72	53	26.429^{bc}	23.868^{bc}	37^{e}
CV (%)	14.9	9.4	17.7	17.9	24.2
LSD (0.05)	Ns	Ns	5435.4	5201.7	2.7

NB. Ns = mean non- ically highly

yield, WUE = water use efficiency.

In this experiment, potato tuber yield ranged from 21.5 t/ha to 33.65 t/ha and the water use efficiency ranged from 37 kg/mm / ha to 126 kg/ mm / ha . As reported by (Kassu *et al*, 2017), potato tuber yield in the experiment varied from 16.78 to 33.6 t ha^{-1}, while water use efficiency (WUE) varied from 68.46 to 198.73 kg/ mm/ha . The tuber yield obtained in this experiment agrees with the tuber yield obtained in other studies. For instance, the application of 20 mm irrigation depth with every 6 days brought 33.6 t/ha potato tuber yield (Kassu *et al*, 2017).

The application of 53 mm of irrigation depth with an irrigation interval of 9 days (150% of model depth) resulted in the highest potato tuber yield of 33.65 t/ha. This treatment has had 6 t/ha more tuber yield advantages above the tuber yield obtained with the application of 100% ETC of 27.7t/ha. The best yield obtained 33.65 t/ha and 52 kg/mm/ha water use efficiency with the application 572 mm irrigation depth throughout the growing season. This finding is similar to Tolga *et al*, (2006) who foundin Turkey that a maximum of 45 t/ha with the application of 597mm irrigation depth throughout the growing season. Potato production in developed countries is estimated as 40 t/ha; whereas in developing countries ranged from 5-25 t/ha (FAO, 2002).

The best combination for the Yimllow site for better production with limited water resources is the application of 22.00 mm (75% of model generated depth) with 9 day gives 29.18 t/ha total yield and 89 kg/mm/ha. However, the lowest potato tuber yield was obtained with the application of 32 mm irrigation depth (75% of model generated depth) with every 15 days irrigation interval, which had a 12 ton/ha tuber yield penalty compared with the CROPWAT treatment yield. The application of 25mm depth (50% of model generated depth) with 12 days intervals also resulted in the lowest tuber yield (22.26t/ha).

Water use efficiency

The WUE obtained in this experiment corresponds to the WUE obtained with other studies. For instance, the WUE gained with the application of 15 mm with every 7 days was 12 kg/m^3/ha as reported by Kassu et al, 2017. Potato productivity increases, as the applied water amount increases in the low lands and increases with reduction in water application in high lands area.

The application of 18 mm depth (50% of model) of irrigation water with every 9 days gave the highest WUE (126 kg / mm/ ha), which had an advantage of about 77 kg/mm/ ha) water use efficiency above the CROPWAT treatments. But it resulted in a 1.3 ton/ha yield penalty when compared with the CROPWAT treatment yield. The lowest water use efficiency (37 kg/ mm/ha) is obtained with the application of 97mm irrigation water depth with 15 days irrigation interval. Therefore, the lower the amount of water applied to the field, the higher the water use efficiency (yuan,2003). As the water amount applied increases, water productivity and tuber yield increases and then decreases at excess water application.

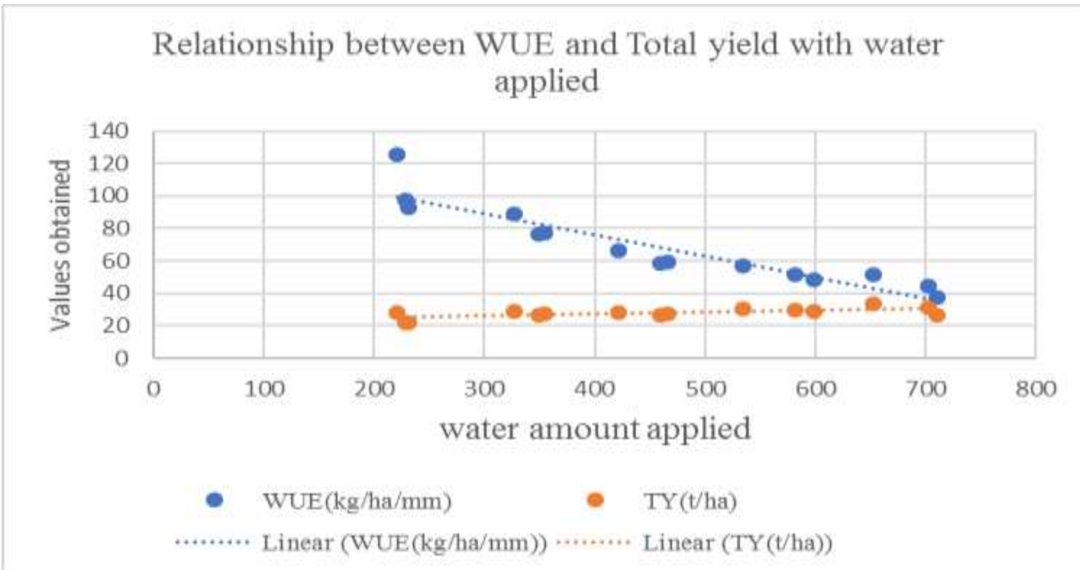

Figure 3. Relationship of water use efficiency and yield to the amount of water applied.

So where does the optimal yield attained if the yield increases with increased water application? to obtain optimum yield of potato tuber at Ataye Yimllow and other similar agro-ecological zone and soil type, it is better to apply 75% of the CROPWAT depth of water with 9 days irrigation interval. That is as irrigation water amounts increase, potato tuber yields also increase to some extent and tend to decrease when the irrigation water amounts increase. As Reported by Yuan (2003) the total tuber yields of potatoes increased with an increasing amount of irrigation water.

The correlation between yield and yield components is presented in Table3; plant height was non-significantly correlated to all parameters. Tuber diameter was positively and strongly correlated with total and marketable yield but negatively and non-significantly correlated with WUE. The result also indicated that WUE was negatively correlated with all other parameters.

Table 3. The correlation between yield and yield components

	PH	TD	TY	MY	WUE
PH	1.00				
TD	0.35^{ns}	1.00			
TY	0.41^{ns}	0.65^{*}	1.00		
MY	0.41^{ns}	0.62^{*}	1.00**	1.00	
WUE	-0.02^{ns}	-0.24^{ns}	-0.49^{ns}	-0.49^{ns}	1.00

*NB Ns=non-significant, *- -*
diameter, TY= tuber yield, WUE=water use efficiency.

Conclusion and Recommendations

In the present study, the CROPWAT model was used to determined water requirement and scheduling using the soil data, crop growth? period, crop coefficients and climatic parameters as input data for potatoes at Yimllow irrigation site. CROPWAT model gave different potato tuber yields and water use efficiencies among the treatments. Application of 75% of CROPWAT depth (22.00 mm) with an interval of 9 days was the best combination for the Yimllow site with limited water resource that provided better tuber yield production (29.18 t/ha total yield)and WUE (89 kg/mm/ha). Therefore, The application of 22 mm depth of water with 9 days irrigation interval results in 29.18 t/ha for Yimllow irrigation site and other similar agro-ecological condition and soil types. This is because it improves good irrigation water management with optimum potato tuber yields. Furthermore, it is easy to demonstrate and adopt the improved agricultural water management practices, which save water and increase crop productivity. This result is particularly important as it allows farmers to increase their income through better tuber yield, lower production costs and the water saved used more profitably to irrigate supplemental lands, thus achieving a more efficient and rational use of land and water resources.

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