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Effect of irrigation regimes on yield and water use efficiencies of potato

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Abstract

Poor irrigation water management is one of the major factors limiting crop production in Ethiopia. This study was, therefore, conducted at three different locations in the southeastern Ethiopia for 2 consecutive years to investigate the effects of different irrigation depths and intervals with furrow irrigation system on tuber yield, biomass yield and water use efficiency of potato. The treatments consisted of four irrigation regimes. Three of them were determined using FAO-Cropwat 4 Windows 4.3 computer model based on maximum irrigation efficiency and minimum yield loss. The fourth treatment was farmers' practices for each location. The irrigation treatments were laid out in randomized complete block design with 3 replications. Results showed that irrigation regimes determined using FAO-Cropwat 4 Windows 4.3 computer model gave superior tuber and biomass yields and water use efficiencies of potato compared to farmers' practices at all locations. Higher values of crop and water productivity were obtained when scheduled at application of 20 mm irrigation water every 6 days, 15 mm irrigation water every 7 days and 15 mm irrigation water every 9 days for Sheled, Golja and Lemu areas, respectively. It could be conclude that farmers were over irrigating their farms without equivalent returns. The water saved through optimized irrigation can be used more profitably to irrigate supplemental lands, thus achieving a more efficient and rational use of land and water resources.

Keywords: Irrigation scheduling; Evapotranspiration; Crop water requirement; Irrigation water requirement; Water use efficiency; yield.

Introduction

When population was few and drought was not as frequent as it is now, rain-fed agriculture could and did feed the population of Ethiopia. But now, rain-fed cultivation alone in the highlands will no longer support the population, even in good years (Mulugeta, 2002). The effectiveness of rainfall, even in high rainfall areas, is vitiated by its erratic occurrence and uneven distribution. Making use of the available water resources in the form of irrigation is, therefore, crucial to supplement rain-fed cultivation and to produce in non-rainy seasons, too. There is also scarcity of water during dry seasons. For country like Ethiopia, which is continuously affected by drought, famine and poverty, irrigation plays a very significant role to relive from recurrent food shortages since irrigation is the most common means of ensuring sustainable agriculture and coping with periods of in adequate rainfall (Dessaleghn, 1999).

Water is the key input in crop production (FAO, 1971). The crops should get adequate water at various stages of the growth of plants to give satisfactory yield. Full benefit of crop production technologies such as high yielding varieties, fertilizer use, multiple cropping and plant protection measures can be derived only when adequate supply of water is derived. On the other hand, optimum benefit from irrigation is obtained only when other crop production inputs are provided and technologies applied (Dilip, 2000). Hence, irrigation is an alternative means of supplying these important factors to plants.

Irrigation will directly contribute to increase food security in the country, bring about higher income for farmers through increased agricultural production, higher employment opportunities, improved foreign exchange earnings, improved livelihood for the citizens and contribute much to poverty reduction efforts launched by the government (FAO, 1979). Irrigation also plays a very significant role for reducing the growing pressure on the land by bringing unused land under cultivation. It is also possible to increase production by producing double in a year and hence, growing more food for internal market, improve food security and nutritional status of the population (FAO, 1971).

Since irrigation schemes are created at a huge cost, it is necessary to derive maximum benefit from the created potential. To avoid yield reduction and adverse effects on the soil properties irrigation scheduling, i.e., application in times of crop need with just enough amount of water need to be followed (Rockström and Barron, 2000). The interval between two irrigations should be as wide as possible to save irrigation water without affecting adversely the growth and yield (Dilip, 2000).

Almost all of the irrigation schemes of Arsi zone, the southeastern part of Ethiopia, are small scale, traditional and characterized by poor on-farm water management practices. Consequently, their performances are poor, too (Haileslassie et al., 2016; Demeku et al., 2011). Farmers seem to have awareness about the benefits of irrigation and proven ability to organize themselves to manage small scale irrigation systems. However, the irrigation system lacks scientific management. Farmers either irrigate over the crop water requirement, which causes water logging, rise of water table, salinity, etc or under irrigate their farms, which results in scarcity of water for plant physiological activities. Appropriate times and sufficient amounts are unknown. This in turn resulted in yield reduction and adverse changes on soil chemical properties (Haileslassie et al., 2016; Demeku et al., 2011; Van Halsema et al., 2011).

The crops grown in the area under irrigation are often horticultural crops especially roots and vegetables. They are very important crops in the region because they are rich sources of minerals and vitamins, increase the working capacity of farmers and their family, increase their income, create job opportunity, decrease poverty, etc. (AVRDC, 1990). Among them, one of the most important crops cultivated under irrigation is potato (*Solanum tuberosum*). Regardless of its importance in improving food security and cash income of smallholder potato growers (Tufa et al., 2015), the yield of potato per unit area is very low. For example, the national average productivity of irrigated potato in Ethiopia was only 3.7 t ha^{-1} (CSA, 2015), while the world average was 16.8 t ha^{-1} (FAOSTAT, 2008). This could be due to inadequate management of irrigation water by the farmers in addition to other factors of irrigated potato production system

(Bezabih and Mengistu, 2011). Therefore, this research activity was conducted to determine the appropriate frequency and amount of irrigation water for improving the productivity of potato crop.

Materials and Methods

Description of the study sites

Field experiments were conducted on farmers' fields at Ziway Dugda, Tiyo and Lemu-Bilbilo districts of Arsi zone in the southeastern part of Ethiopia in 2007 and 2008 (Figure 1). The specific experimental sites were Sheled, Golja and Lemu in Ziway Dugda, Tiyo and Lemu-Bilbilo districts, respectively. Sheled, Golja and Lemu belong to lowland, midland and highland parts of the country, respectively (MoA, 2000). Summary of descriptions of the study sites has been shown in Table 1 below.

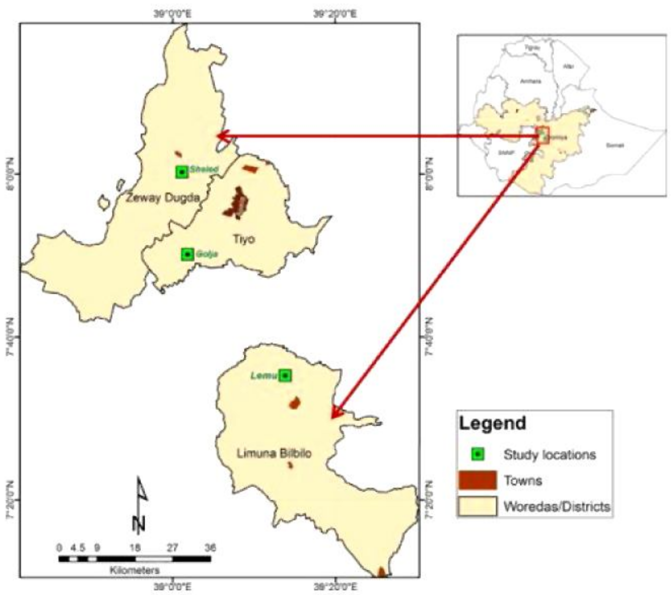

Figure 1. Study sites.

Table 1. Summary of descriptions of the study sites.

Parameters	Locations		
	Sheled	Golja	Lemu
Minimum temperature (°C)	12.3	10.3	6.8
Maximum temperature (°C)	26.3	22.9	19.1
Rainfall (mm)	689.0	698.8	1203.0
Altitude (m a.s.l.)	1686	2277	2633
Latitude	$8^0$00'13.6"	$7^0$50'7.7"	$7^0$35"16.5"
Longitude	$39^0$01'7.5"	$39^0$01'48.1"	$39^0$13'49.5"
Category	Lowland*	Midland*	Highland*

(* based on MoA, 2000)

Soil type, sampling and analysis

The dominant soil types of Golja and Lemu is eutric Vertisol while Sheled is mollic Andosol (IUSS Working Group WRB, 2006). Soil samples were collected and analyzed in the soil laboratory of Kulumsa Agricultural Research Center. Accordingly, the soil texture of all of the study sites is clay loam. The average bulk densities of Sheled, Golja and Lemu were 1.15, 1.19 and 1.13 gm cm^{-3}, respectively. The soil water contents at field capacity and permanent wilting point were 31 and 16%, respectively with average total available water 15% in volume percentage.

Crop information

Since there were no site specific estimated crop coefficients (K_c) in the country, values of the potato K_c were accessed from FAO irrigation and drainage paper No. 56 (Allen et al., 1998). K_c values were fixed at 0.5, 1.15 and 0.75, respectively for the initial, middle and late growth stages. Maximum root depth was fixed at 0.6 m. 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).

Evapotranspiration, crop water requirement and irrigation scheduling

There were no well-established weather stations in all of the three study sites. For that reason, CLIMWAT was used to generate the required climatic data. CLIMWAT is a climatic database to be used in combination with the computer program CROPWAT and provides long-term monthly mean values of seven climatic parameters, namely daily maximum and minimum temperatures, relative humidity, wind speed, sunshine hours, solar radiation, monthly (effective) rainfall and reference evapotranspiration calculated with the Penman-Monteith method (Giovanni and Jürgen, 2006). Latitude, longitude and altitude were directly measured at the sites using Geographic Positioning System and used to access meteorological parameters from CLIMWAT.

Minimum and maximum temperatures, relative humidity, wind speed, sunshine hours and solar radiation of each individual experimental site were used to calculate reference evapotranspiration (ET_o). The ET_o of individual locations were calculated on daily and summarized monthly bases by employing FAO Penman-Monteith method (Allen et al., 1998) using a decision support tool called Cropwat 4 Windows version 4.3 computer model developed by FAO (Martin, 1996) based on FAO irrigation and drainage paper No. 56 (Allen et al., 1998). The FAO CROPWAT program along with CLIMWAT incorporates procedures for and allows the calculation of ET_o, crop water requirements and irrigation scheduling for various crops under various climate, crop and soil conditions (Martin, 1996; Giovanni and Jürgen, 2006). ET_o was multiplied by an empirical potato K_c (Allen et al., 1998) to calculate an estimate of crop evapotranspiration (ET_c) values for each sites. ET_c was calculated for every day and crop development stages and then cumulated to treatment data.

Experimental set-up and procedure

Four different irrigation treatments were tested. Three of them were determined using Cropwat 4 Windows version 4.3 computer model developed by FAO (Martin, 1996). Those three irrigation depths and frequencies were determined depending on alternatives for minimum yield losses and maximum irrigation efficiencies for each site.

The fourth treatment was farmers' practices of each site. The experiment was laid out in randomized complete block design with three replications. Summary of treatments used during the experiment has been presented in Table 2 below.

Table 2. Summary of treatment descriptions of the study sites.

Treatments	Locations		
	Sheled	Golja	Lemu
T_1	Traditional (every 5 days)	Traditional (every 7 days)	Traditional (every 15 days)
T_2	13 mm every 4 days	11 mm every 5 days	15 mm every 9 days
T_3	16 mm every 5 days	15 mm every 7 days	21 mm every 12 days
T_4	20 mm every 6 days	27 mm every 9 days	28 mm every 15 days

All experimental plots at each site were planted during the first week of January with an improved potato variety, namely *Gudene*. Potato tubers were drilled by hand in plot sizes of 5.25 m by 4.5 m with a distance of 0.75 m and 0.30 m between rows and plants with in a row, respectively. Hence, there were a total of 7 rows with in a plot and 15 potato tubers with in a single row. The inter-spacing between plots and replications were kept at 0.75 m and 1.5 m, respectively in order to minimize edge effect of irrigation.

All experimental plots were fertilized with recommended rate of nitrogen and phosphorous, 105 - 92 kg N – P_2O_5 ha^{-1}. Phosphorus fertilizer was applied to all plots as basal dose at planting in the form of di-ammonium phosphate (DAP) while the recommended rate of nitrogen fertilizer was uniformly applied in splits, half at planting and the remaining half prior to hilling in the form of urea. Hoeing and weeding were carried out three times per season by hand. Fungicide, namely Ridomil Gold® and insecticide, namely Selecron®500EC were used against downy mildew and insect pest incidences, respectively.

Irrigation water was applied to each plot using furrow irrigation systems diverted from a nearby river. Measured depths of irrigation water were delivered to each plot according to the treatment arrangements and irrigation schedule through a water meter, namely 2-inch partial flume, which was installed few meters before the start of experimental plots. All experimental plots were irrigated with uniform amount of water few days before planting to make the soil workable. Irrigation was started just after planting based on the treatments arrangement and the last irrigation events took place at physiological maturity.

The crop was harvested at full maturity after 90, 100 and 110 days of planting at Sheled, Golja and Lemu, respectively when 90 % plants showed leaf senescence and the plant tips started drying up.

Data collection

The data collected or determined were number of tillers $plant^{-1}$, number of tuber $plant^{-1}$, plant height, tuber yield, biomass yield and water use efficiency. Haulm was mowed, recorded for biomass determination and removed a week before harvesting. At the end of physiological maturity, a net plot area of 16.875 m^2 (the central five rows of each plot, 3.75 m by 4.5 m) was harvested manually and weighed to determine total tuber yield. All the supplied irrigation water was recorded and summed up to find out the total amount of irrigation water applied per cropping season and each treatment. The weighed samples of tubers from each plot of the four treatments were converted into kilogram per hectare and divided by their respective total amount of irrigation water supplied throughout the cropping season to determine the water use efficiency. The following relationship was employed to calculate water use efficiency (Zhang et al., 1998; Oweis and Zhang, 1998; Bos, 1980, 1985).

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

where, WUE is water use efficiency in kg ha^{-1} mm^{-1}, Y is crop tuber yield in kg ha^{-1} and ET_c is total actual crop evapotranspiration in mm.

Statistical analysis

Analysis of variance was carried out for each of the measured or computed parameters following the method described by Gomez and Gomez (1984). All yield, yield components and water use efficiency data were subjected to analysis of variance using PROC ANOVA of SAS version 9.0 (SAS Institute, 2004) statistical software. The significance of differences among treatment means was compared using least significant difference (LSD test).

Results and Discussion

Climate

The climatic data of the three locations are presented in Tables 3, 4 and 5 below. The mean maximum temperatures at Sheled, Golja and Lemu were 26.3 °C, 22.9 °C and 19.1 °C, respectively. The corresponding values for mean minimum temperatures were 12.3 °C, 10.3 °C and 6.8 °C, respectively. January to March was a period with the highest records of mean maximum temperatures at Lemu. The corresponding period at Golja and Sheled was from March to May. October to December was a period with the lowest records of mean minimum temperatures at Lemu. The corresponding period at Golja and Sheled was from November to January. Generally, comparison among sites indicated that maximum and minimum temperatures were the highest at Sheled (lowland), the lowest at Lemu (highland) and intermediate at Golja (midland). This indicated that Sheled is hotter than other two sites; hence, more loss of water through evapotranspiration is expected at Sheled than other two sites. Weather condition at Lemu was cooler with intermediate value for Golja.

The mean annual rainfalls at Sheled, Golja and Lemu were 689 mm, 699 mm and 1203 mm, respectively. As expected, the amount and distribution of rainfall got decreased as one went from highland (Lemu) to lowland (Sheled). The rainfall trend at Lemu followed a predictable trend; the lowest rainfall was recorded in December; it gradually increased and reached peak in July; then, it got decreased and reached the lowest in December again. However, the rainfall did not follow distinct features at Golja and Sheled with the worst trend corresponding to Sheled.

The mean annual humidity at Sheled, Golja and Lemu were 65.8%, 64.7% and 73.8%, respectively. Humidity was the highest at Lemu. Significant differences of humidity were not observed between Golja and Sheled; they had almost similar values. The period of highest records of humidity was from July to September at all locations.

The mean annual wind speed at Sheled and Golja were the same, 87.8 km hr^{-1}. The value at Lemu, 85.4 km hr^{-1}, was a little bit lower than other two locations. The highest values of wind speed were recorded in June at all locations. The trend of wind speed at Lemu was more or less similar throughout the year; however, there were great variabilities at Golja and Sheled.

The values for sunshine were 7.8, 6.7 and 6.1 hours at Sheled, Golja and Lemu, respectively while the corresponding values for solar radiation were 20.41, 18.74 and 18.04 $MJm^{-2}day^{-1}$. This revealed that the highest mean annual sunshine hours and solar radiation were recorded at Sheled, but the lowest for majority of the months at Lemu. Therefore, more losses of soil water in the form of evapotranspiration are expected from Sheled. The lowest sunshine hours and solar radiation was recorded between July to September at all locations.

Table 3. Climatic conditions of Lemu in Lemu-Bilbilo district in the southeastern Ethiopia.

Month	Maximum temperature (°C)	Minimum temperature (°C)	Humidity (%)	Wind speed (km day^{-1})	Sun shine hours (hr)	Solar radiation (MJ m^{-2} day^{-1})	Total rainfall (mm)
January	20.5	6.3	61	86	8.9	21.0	50
February	21.0	7.2	64	86	7.6	20.2	59
March	21.2	8.2	64	86	7.1	20.4	76
April	20.2	8.3	64	86	5.6	18.1	93
May	19.8	7.6	72	78	6.3	18.6	115
June	18.4	6.9	79	95	5.1	16.4	130
July	16.1	7.1	89	86	3.1	13.6	234
August	16.2	6.7	91	86	3.3	14.3	215
September	17.5	6.6	89	86	4.5	16.3	120
October	18.2	6.0	79	78	5.9	17.9	53
November	19.2	5.5	69	86	7.7	19.5	44
December	20.3	5.1	64	86	8.7	20.2	14
Average	19.05	6.79	73.75	85.42	6.15	18.04	
			Total				1203

Table 4. Climatic conditions of Golja in Tiyo district in the southeastern Ethiopia.

Month	Maximum temperature (°C)	Minimum temperature (°C)	Humidity (%)	Wind speed (km day^{-1})	Sun shine hours (hr)	Solar radiation (MJ m^{-2} day^{-1})	Total rainfall (mm)
January	22.8	8.2	59	112	7.4	18.7	14
February	23.7	9.2	54	86	7.8	20.4	34
March	24.6	10.9	56	86	6.3	19.1	73
April	24.8	12.0	55	69	6.1	18.9	72
May	24.4	12.1	58	78	6.9	19.6	76
June	23.2	11.2	68	130	7.2	19.6	77
July	21.2	11.2	80	95	4.5	15.7	104
August	21.0	11.0	84	86	5.3	17.4	112
September	21.4	10.7	84	60	4.1	15.6	86
October	23.0	10.6	69	69	7.0	19.4	35
November	22.6	9.0	54	104	8.6	20.6	7
December	22.6	7.5	55	78	8.6	19.9	10
Average	22.9	10.3	64.7	87.8	6.7	18.7	
Total							699

Table 5. Climatic conditions of Sheled in Ziway Dugda district in the southeastern Ethiopia.

Month	Maximum temperature (°C)	Minimum temperature (°C)	Humidity (%)	Wind speed (km day^{-1})	Sun shine hours (hr)	Solar radiation (MJ m^{-2} day^{-1})	Total rainfall (mm)
January	26.2	10.3	60	112	9.7	22.0	12
February	26.6	12.1	54	86	9.3	22.7	47
March	27.4	12.9	56	86	8.4	22.3	44
April	28.5	13.2	57	69	7.7	21.4	85
May	28.6	12.8	60	78	7.6	20.6	41
June	27.0	13.4	69	130	7.6	20.2	72
July	24.6	14.3	81	95	5.1	16.6	132
August	24.2	14.1	84	86	5.8	18.1	118
September	24.4	13.1	84	60	5.3	17.5	89
October	26.2	12.4	71	69	8.4	21.5	32
November	25.5	10.3	56	104	9.3	21.6	11
December	26.2	8.8	57	78	9.0	20.4	6
Average	26.3	12.3	65.8	87.8	7.8	20.4	
Total							689

Reference evapotranspiration (ET_o)

The computed ET_o for each site has been summarized in Figure 2 below. The computed results for ET_o varied from 2.29 mm day^{-1} in July to 3.65 mm day^{-1} in March at Lemu, 2.88 mm day^{-1} in September to 3.83 mm day^{-1} in June at Golja and 3.26 mm day^{-1} in July and September to 4.39 mm day^{-1} in March at Sheled. Generally, the lowest ET_o values were recorded with in a period between July to September, which is the wet season, at all locations. The lowest values attributed to the highest rainfall and humidity and the corresponding reduced values for temperature and radiation. While the highest ET_o was recorded in dry season with peak values in March at Lemu and Sheled, and in June at Golja. It attributed to the highest values of temperature and radiation and reduced values for rainfall and humidity. These results are in accordance with Wubengda et al. (2014) and Adeniran et al. (2010), which showed that ET_o was lowest during the peak of the rainy season and highest during the peak of the dry season for the respective study areas.

Comparison of the three locations revealed that the highest and lowest ET_o values were recorded at Sheled and Lemu areas, respectively (Figure 2). That was due to the highest temperature and radiation values in Sheled than Lemu areas (Tables 3, 4 and 5). The value for Golja was intermediate. Those differences attributed to agroecologies, where the study sites are located.

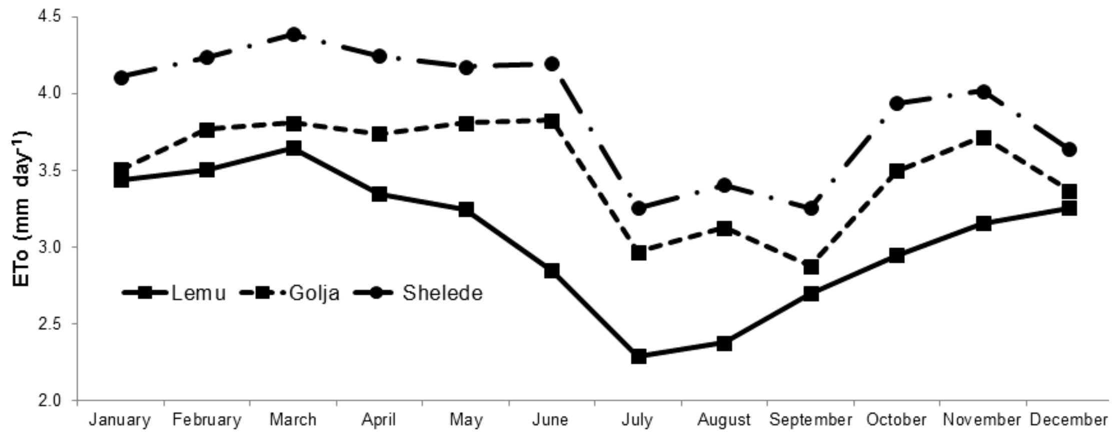

Figure 2. Comparison of reference evapotranspiration at Lemu, Gloja and Sheled in the southeastern Ethiopia.

Correlation analysis (Table 6) indicated that maximum temperature, radiation, sunshine hours and humidity were the most influential climatic parameters that significantly determined the ET_o values at all locations with the strongest effect corresponding to maximum temperature. The correlation coefficients for maximum temperature were 0.96, 0.85 and 0.84 for Lemu, Golja and Sheled, respectively. The correlation coefficients for radiation were 0.94, 0.81 and 0.84 for Lemu, Golja and Sheled, respectively. The corresponding values for humidity were all less than zero, -0.93, -0.77 and -0.76, indicating its negative impact on ET_o. The influences of minimum temperature and wind speed were not significant. This result is in conformity with Wubengda et al. (2014) in which they reported that maximum temperature, relative humidity and sunshine hours are the most important climatic parameters that determine ET_o in the southeastern part of Ethiopia, where this study was conducted. They also reported that minimum temperature has the lowest correlation coefficient with ET_o.

Table 6. Correlation coefficients of regression between daily values of ET_o and each climatic parameter in the southeastern Ethiopia.

Location	Maximum Temperature	Minimum Temperature	Humidity	Wind speed	Sun shine hours	Radiation
Lemu	0.959636	0.164506	-0.92986	-0.18785	0.848456	0.936795
Golja	0.847965	0.081277	-0.7743	0.32062	0.636678	0.806382
Sheled	0.844756	-0.19828	-0.76226	0.271705	0.69382	0.837607

Comparison of total monthly precipitation and evapotranspiration at all locations are presented in Figure 3, 4 and 5 below. Analysis of rainfall indicated that it was concentrated from May to September at Lemu and July to August at Golja and Sheled. Except for the period of May to September at Lemu and July to August at Golja and Sheled, evapotranspiration far exceeded total rainfall for majority of the months in all the seasons and locations. Acute deficiencies for majority of the months indicated that irrigation should be planned for potato cultivation since rainfall is insufficient to meet the crop water needs in all of the study sites and will become increasingly more so in the future for ensuring food security.

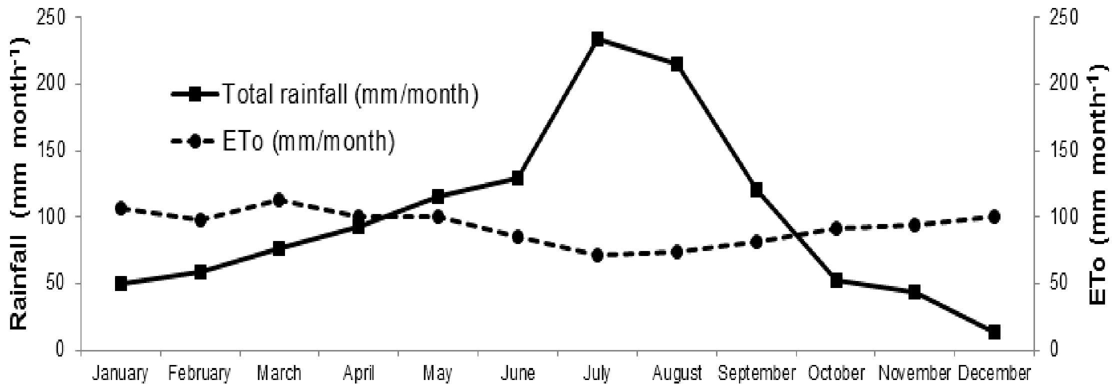

Figure 3. Comparison of reference evapotranspiration and total rainfall at Lemu in the southeastern Ethiopia.

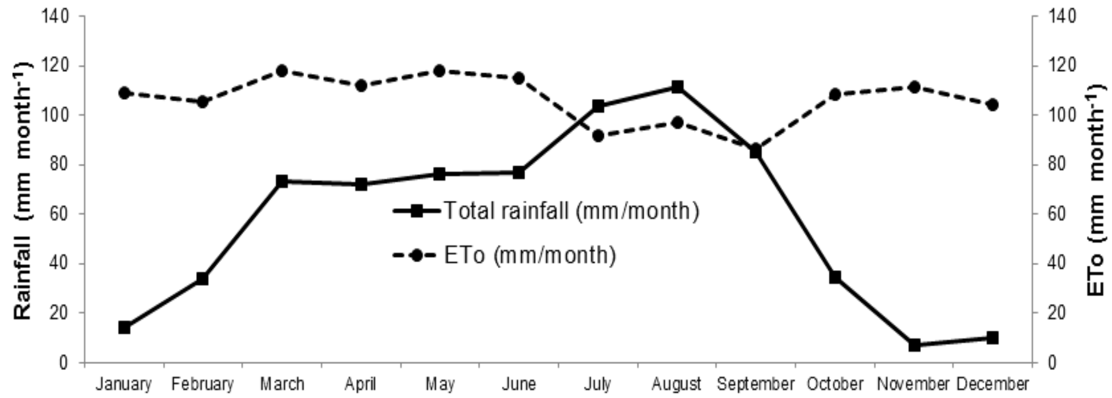

Figure 4. Comparison of reference evapotranspiration and total rainfall at Golja in the southeastern Ethiopia.

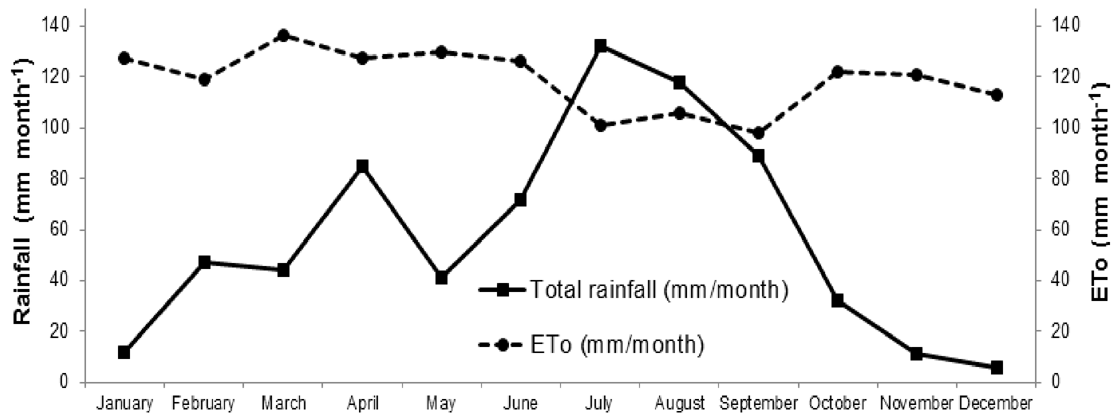

Figure 5. Comparison of reference evapotranspiration and total rainfall at Sheled in the southeastern Ethiopia.

Determination of crop water and irrigation requirements

Potato crop evapotranspiration (ET_c) over the whole season amounted to 414, 441 and 501 at Lemu, Golja and Sheled, respectively (Table 7). The highest values of ET_c

for Sheled area were associated with the highest temperature compared to Lemu and Golja areas. The highest temperature induced the loss of soil water in the form of evapotranspiration and the contribution to refill soil water from rainfall was relatively less. However, values of ET_c for Lemu area were relatively low because of the relatively low temperature compared to Sheled and Golja areas. In addition, the soil moisture was better maintained from the relatively highest amount of rainfall and humidity.

The calculated irrigation water requirements were 176, 305 and 379 mm season^{-1} for Lemu, Golja and Sheled, respectively (Table 7). However, due to unexpected rain and impact of averaged weather parameters, the actual irrigation water requirements were 188, 195 and 233 mm season^{-1} at Lemu, Golja and Sheled, respectively.

Table 7. Net irrigation requirements.

Location	Crop water requirement (mm season^{-1})	Total rain (mm season^{-1})	Effective rain (mm season^{-1})	Net irrigation requirement (mm season^{-1})
Lemu	414.29	265.12	238.07	176.22
Golja	440.52	149.65	135.64	304.88
Shelled	500.87	133.34	121.42	379.45

Note: effective rainfall was calculated using USDA S.C. method.

Summary of the irrigations conducted at each location has been summarized in Table 8 below. Potato was irrigated 12 to 18, 8 to 16 and 7 to 12, times as per treatment at Sheled, Golja and Lemu, respectively in order to maintain root zone soil water content above allowable depletion threshold and returning soil water content back to field capacity. The corresponding total irrigation input ranged from 224 to 364, 165 to 330 and 180 to 245 mm at Sheled, Golja and Lemu, respectively. The result of the irrigation requirement indicated that the highest amount of irrigation water was applied in the farmers' practices treatments at all locations. However, all other three treatments, which were determined based on Cropwat 4 Windows version 4.3 computer model consumed relatively lower irrigation water without soil moisture deficits.

The highest and lowest irrigation requirements were recorded at Sheled and Lemu, respectively. This was because of the agroecological differences; Lemu was located in the highlands, where there is cool climate while Sheled was located in the lowland, where the climate was hot. Golja was located at intermediate agroecological condition. These results are in conformity with Brouwer and Heibloem (1986). They reported that a certain crop grown in a sunny and hot climate needs per day more water than the same crop grown in a cloudy and cooler climate.

Table 8. Irrigation depths, number of irrigation applications and seasonal irrigation water consumption values of potato.

Treatments	Total No of irrigation	Total amount of water (mm)
	Lemu	
Traditional (35 mm every 15 days)	7	245
15 mm Every 9 days	12	180
21 mm Every 12 days	9	189
28 mm Every 15 days	7	196
	Golja	
Traditional (30 mm every 7 days)	11	330
11 mm Every 5 days	16	176
15 mm Every 7 days	11	165
27 mm Every 9 days	9	243
	Sheled	
Traditional (26 mm every 5 days)	14	364
13 mm Every 4 days	18	234
16 mm Every 5 days	14	224
20 mm Every 6 days	12	240

Tuber yield

The result of analysis of variance indicated that irrigation regimes significantly influenced the tuber yield of potato at all locations as shown in Table 9 below. Generally, tuber yield significantly increased with increments in the amount of irrigation water in the low land (Sheled) and increased with reduction in amount of irrigation water in the high land (Lemu). Previous studies also reported the strong impact of irrigation on potato production and confirms that under tropical conditions irrigation is required for potato cultivation (Cantore et al., 2014; Demelash, 2013; Ierna and Mauromicale, 2012; Ierna et al., 2011).

At Sheled, application of 20 mm irrigation water every 6 days brought the highest tuber yield (33.6 t ha^{-1}) of potato. However, statistically similar tuber yield of potato were also obtained from the applications of 13 mm irrigation water every 4 days and farmer's practice (35 mm irrigation water every 5 days). The lowest tuber yield was recorded from the application of 16 mm irrigation water every 5 days.

At Golja, application of 27 mm irrigation water every 9 days gave statistically superior tuber yield of potato compared to the farmers' practice. However, there was no statistically significant tuber yield differences among the three irrigation regimes determined based on Cropwat 4 Windows version 4.3 computer model. Application of 11 mm irrigation water every 5 days, 15 mm irrigation water every 7 days and 27 mm irrigation water every 9 days gave tuber yields of 30.2, 32.8 and 33.2 t ha^{-1}, respectively. Application of 27 mm irrigation water every 9 days gave tuber yield advantage of 3.44 t ha^{-1} compared to the farmer's practice.

Application of 15 mm irrigation water every 9 days, gave statistically the highest tuber yield of potato (21.6 t ha^{-1}) at Lemu. This irrigation regime, which was the lowest level of irrigation water, was superior over all other higher application treatments.

Generally, at Sheled, which belongs to the lowland area, there was high loss of soil water in the form of evapotranspiration. In order to maintain the lost soil water, there should be an increased application of irrigation water. The highest crop water needs are found in areas which are hot, dry, windy and sunny (Brouwer and Heibloem, 1986). It was because of this reason that increasing irrigation water amounts, which satisfied the soil water deficit, resulted in relatively higher tuber yields. Yuan (2003) reported that total tuber yields of potato increased with increasing amount of irrigation water. However, at Lemu, which belongs to the highland area, increasing irrigation water amounts resulted in relatively reduced yields. This might be attributed to the accumulation of excess moisture in the root zone as a consequence of relatively low evapotranspiration. FAO (2008) reported that frequent irrigation with relatively cold water may decrease the soil temperature below the optimum value of 15 to 18 °C for tuber formation. Also, soil aeration problems can sometimes occur in wet, heavy soils. Compared to Sheled and Golja, the tuber yield of Lemu was so low. The variety might not be the best one for Vertisol of Lemu.

Biomass yield

The result of analysis of variance further indicated that irrigation regimes significantly influenced the biomass yield of potato at all locations (Table 9). At Sheled, application of 20 mm irrigation water every 6 days brought the highest biomass (5.0 t ha^{-1}) yields of potato. However, application of 13 mm irrigation water every 4 days also resulted in statistically similar biomass yield (4.95 t ha^{-1}) of potato. These two irrigation regimes gave statistically superior biomass yield of potato over the farmers' practice. The lowest biomass yield was recorded from the farmer's practice (26 mm every 5 days). At Golja, application of 27 mm irrigation water every 9 days brought statistically superior biomass yield of potato (2.6 t ha^{-1}). It gave a biomass yield advantage of 0.8 t ha^{-1} compared to farmers' practice. The biomass yield of potato at Lemu was not significantly affected by irrigation regime.

Similar to the tuber yield, increasing irrigation water amounts resulted in relatively higher biomass yields at Sheled, which belongs to the lowland area. This attributed to the highest loss of soil water and its consequent high demand for irrigation water to replenish to field capacity to satisfy the crop demand.

Water use efficiency

Analysis of variance also indicated that water use efficiencies of potato were significantly influenced by irrigation regimes at all locations (Table 9). Similar results were also reported by many researchers (Cantore, 2014; Badr, 2012; Yuan, 2003). The result generally showed higher values in the three irrigation treatments determined using FAO-Cropwat 4 Windows version 4.3 computer model and lower in the farmers' practices. The lower the amount of irrigation water received, the higher the water use efficiency (Yuan, 2003).

The water use efficiencies of the entire three treatments determined using Cropwat 4 Windows version 4.3 computer model were superior over the farmers' practices at Sheled indicating that farmers were applying more irrigation water without equivalent yield returns. However, there were no statistically significant water use efficiency differences among the three irrigation regimes. Application of 13 mm irrigation water every 4 days, 16 mm irrigation water every 5 days and 20 mm irrigation water every 6 days resulted in water use efficiencies of 135.3, 131.4 and 140.0 kg ha^{-1} mm^{-1}, respectively. Compared to farmers' practice, they gave water use efficiency advantages of 45.5, 41.6 and 50.2 kg ha^{-1} mm^{-1}, respectively.

Superior water use efficiency (198.7 kg ha^{-1} mm^{-1}) was obtained from the application of 15 mm irrigation water every 7 days at Golja. The lowest water use efficiency was recorded from the farmer's practice. Application of 15 mm irrigation water every 7 days gave water use efficiency advantage of 108.4 kg ha^{-1} mm^{-1} indicating that farmers' practices were wasting irrigation water, which could cultivate extra agricultural lands and increase crop production.

Application of 15 mm irrigation water every 9 days gave statistically the highest water use efficiency (120.2 kg ha^{-1} mm^{-1}) at Lemu. This irrigation regime was superior over all other three treatments. Inferior result was recorded from the farmers' practice. Compared to farmers' practices, application of 15 mm irrigation water every 9 days resulted in a water use efficiency advantage of 51.7 kg ha^{-1} mm^{-1}.

Generally, productivity of water significantly increased with increments in amount of irrigation water in the low land (Sheled) and increased with reduction in amount of irrigation water in the high land (Lemu). At Lemu, which belongs to the highland area, increasing irrigation water amounts resulted in relatively reduced water use efficiency. This might be attributed to accumulation of excess moisture in the root zone and consequently resulted in reduced yield of potato. This in turn resulted in reduced water use efficiency. Compared to Sheled and Golja, the water use efficiency of Lemu were so low. This was due to the reduced tuber yield of potato.

Table 9. Table of means for the effect of irrigation regimes on yield and water use efficiency of potato in 2008 and 2009.

Effect	Yields (t ha^{-1}) and water use efficiency (kg $ha^{-1}mm^{-1}$) parameters								
	Sheled			Golja			Lemu		
	Tuber yield (t ha^{-1})	Biomass yield (t ha^{-1})	Water use efficiency (kg $ha^{-1}mm^{-1}$)	Tuber yield (t ha^{-1})	Biomass yield (t ha^{-1})	Water use efficiency (kg $ha^{-1}mm^{-1}$)	Tuber yield (t ha^{-1})	Biomass yield (t ha^{-1})	Water use efficiency (kg $ha^{-1}mm^{-1}$)
Year									
2008	28.99^{b}	3.38^{b}	112.88^{b}	38.37^{a}	1.57^{b}	181.05^{a}	18.17^{a}	2.08^{b}	91.44^{a}
2009	34.71^{a}	5.67^{a}	135.41^{a}	24.67^{b}	2.31^{a}	117.77^{b}	18.63^{a}	5.17^{a}	94.31^{a}
LSD	2.01	0.46	7.48	2.35	0.24	11.54	1.03	1.05	5.40
Treatment									
T_1	32.70^{a}	3.89^{b}	89.84^{b}	29.80^{b}	1.71^{bc}	90.30^{d}	16.78^{b}	3.79^{a}	68.46^{c}
T_2	31.67^{ab}	4.95^{a}	135.33^{a}	30.23^{ab}	1.50^{c}	171.79^{b}	21.63^{a}	3.21^{a}	120.16^{a}
T_3	29.43^{b}	4.21^{b}	131.40^{a}	32.79^{ab}	1.99^{b}	198.73^{a}	17.82^{b}	3.92^{a}	94.27^{b}
T_4	33.60^{a}	5.04^{a}	139.99^{a}	33.24^{a}	2.55^{a}	136.81^{c}	17.36^{b}	3.64^{a}	88.58^{b}
Mean	31.85	4.52	124.14	31.52	1.94	149.41	18.40	3.64	92.87
CV	7.20	11.54	6.88	8.52	14.26	8.82	6.40	18.65	6.64
LSD	2.84	0.65	10.57	3.32	0.34	16.32	1.46	0.84	7.63

(Values with the same letters are not statistically significant)

Conclusions

The results of this study showed that all irrigation treatments determined based on Cropwat 4 Windows version 4.3 computer model gave superior yields and water use efficiencies of potato compared to farmers' practices at all locations indicating that good irrigation water management strongly required for improved crop cultivation. The study also confirmed that CLIMWAT can be considered as good database to generate climatic parameters for the determination of irrigation regimes in areas, where there are no well-established weather stations. Having considered their contributions for increased crop and water productivity of potato, application of 20 mm irrigation water every 6 days, 15 mm irrigation water every 7 days and 15 mm irrigation water every 9 days have been recommended for Sheled, Golja and Lemu areas, respectively and other similar agroecologies. These fixed irrigation intervals with pre-determined amount of water depth could be very important for the areas with poor cultural irrigation water management and no soil water measuring devises. It eases demonstration and adoption of the improved agricultural water management practices, which save water and increase crop productivity. This result is particularly important as it may allow farmers to increase their income through better tuber yield, lower production costs and also because the water saved may be used more profitably to irrigate supplemental lands, thus achieving a more efficient and rational use of land and water resources.

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