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Determination of Optimal Irrigation Scheduling for Potato (Solanum tuberosum L.) at Holeta, Centeral High Land of Ethiopia

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Abstract
The knowledge of crop water requirement is an important practical consideration to improve water use efficiency in irrigated agriculture. Water use efficiency can be improved by proper irrigation scheduling, which is essentially governed by crop evapotranspiration (ETc).Therefore, this activity is aimed to evaluate the responses of crops to irrigation regime (when and how much) and to identify WP under optimal irrigation regime. Field experiment was conducted during 2013 and 2014 to determine the optimal irrigation regime of Potato (Local name: Belete) at Holeta Agricultural Research center under five irrigation treatments (Irrigation at -40% ASMDL, -20% ASMDL, ASMDL, +20% ASMDL and +40% ASMDL). For irrigation treatment at allowable soil moisture depletion (ASMDL), irrigation was scheduled when 30% of the total water available was depleted. Plant heights and tuber yield were measured and WP was calculated. Plant height and tuber yield did not vary significantly with irrigation treatments. But WP of -40% ASMDL resulted highly significant difference ($P<0.01$) in both consecutive years. Reducing the soil moisture depletion level by 40% from the recommended fraction (0.3) has significantly increased the water productivity. However, a significant yield reduction was not observed under this treatment. So it's possible to conclude that applying 40% less from the ASMDL can be used for areas where water is a limiting factor. For areas where water is not a problem, using the FAo recommended ASMDL which is treatment 3 is recommended.
Keywords: Plant height, tuber yield, allowable soil moisture depletion level (ASMDL), irrigation regime, Water Productivity (WP).

INTRODUCTION

Irrigation has a multi-faceted role in contributing towards food security, self-sufficiency, food production and exports. It encompasses a wide range of interventions that enhance productivity and result into profitability for the rural farming population and the nation as a whole. For the substantial areas managed by smallholder farmers through traditional irrigation systems or water harvesting, it assists with both food and cash crops production enabling farmers and surrounding communities to benefit both directly and indirectly from the crops produced. In large-scale commercial farms, it enables crop production for local and export markets with significant impacts on the country's economy (Chiza, 2005).

Irrigation contributes to the national economy in several ways. At the micro level, irrigation leads to an increase in yield per hectare and subsequent increases in income, consumption and food security (Bhattarai and Pandy, 1997; Vaidyanathan et al., 1994; Ahmed and Sampath, 1992; Lipton et al., 2003; Hussain and Hanjra, 2004). Irrigation enables smallholders to diversify cropping patterns, and to switch from low-value subsistence production to high-value market-oriented production. Irrigation can benefit the poor specifically through higher production, higher yields, lower risks of crop failure, and higher and all year round farm and non-farm employment (Hussain and Hanjra, 2004).

Ethiopia has an estimated irrigation potential of 3.5 million hectares (Awulachew et al., 2007b). During 2005/2006 the total estimated area of irrigated agriculture in the country was 625,819 ha, which, in total, constitutes about 18% of the potential (MoWR, 2006). It is planned to expand irrigation development in the country by an additional 528,686 ha by the year 2010 (Atnafu, 2007; MoWR, 2006), which will constitute about 33% of the potential. Potato yield is reduced by both over- and under-irrigation. A mere 10 percent deviation from optimum water application for the growing season may begin to decrease yield. Yield reductions due to over irrigation can be attributed to poor soil aeration, increased disease problems, and leaching of nitrogen from the shallow crop-root zone.

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. In 2001 E.C., 0.94 million tons of potato tubers were produced nationally from 164 thousand ha of land (CSA, 2003). The Amhara National Regional State contributed 36.1% of the annual national potato production. However, the regional average potato tuber yield (4.8 t/ha) is less than the national average yield (5.7 t/ha) (CSA, 2003). Factors such as late blight (*Phytophtora infestans*) and bacterial wilt (*Pseudomonas solanacearum*) infections, poor crop management and shortage of adaptable and high yielding varieties contributed to the low productivity of potato in the region (Tesfaye and Yigzaw, 2008).

In Ethiopia potato is produced in the rainy season under rainfed condition and dry season using irrigation. In 2002, the irrigated potato production system contributed 58.7% of the annual potato tuber produced and 76.8% of the total area of land planted with potato in the country (CSA, 2006). Likewise, in the Amhara National Regional State, irrigated potato production system contributed 84.2% of the area and 65.5% of the annual potato production. Although irrigated potato production system contributed the lion's share both in the country and the region, its productivity (3.7 t/ha) is lower than the rainfed (10.5 t/ha) system (CSA, 2003).

Crops that are kept within acceptable stress limits during their growth cycle have the potential to produce optimum yields of high quality. The aim of irrigation scheduling is to keep soil moisture within a desired range, usually between field capacity (full point) and a predetermined refill point for optimal growth. In order for an irrigation schedule to be effective, it has to tell us when to water and how much to apply. Irrigation scheduling is one of the most important tools for developing best management practices for irrigated areas.

Yield and quality of crops suffer due to insufficient water supply and improper scheduling of irrigation. Available irrigation water has to be utilized in a manner that matches the water need of the crop. The knowledge of crop water requirement is an important practical consideration to improve water use efficiency in irrigated agriculture. Water use efficiency can be improved by proper irrigation scheduling, which is essentially governed by crop evapotranspiration (ETc).Therefore, this activity is aimed to evaluate the responses of crops to irrigation regime (when and how much) and to identify WP under optimal irrigation regime.

MATERIALS AND METHODS

Experimental Site

The field experiment was conducted for two consecutive years from 2013 to 2014 at Holetta Agricultural Research Center ($09^0 03'$N and $38^0 30'$E, 2400 m above sea level with mean annual rainfall of 1044 mm. The mean maximum and minimum temperatures were 22.0^0C and 6.1^0C, respectively with a mean relative humidity of 60.6%). The main rainy season is from June to September when it receives 70% of the annual rainfall. The experimental site has a nitisol soil with a pH of 5.24 and an average organic matter content of 1.8%. The soil contained 0.17% nitrogen, 4.55 ppm phosphorus and 1.12 potassium Meq/100 g soil (HARC, 2001).

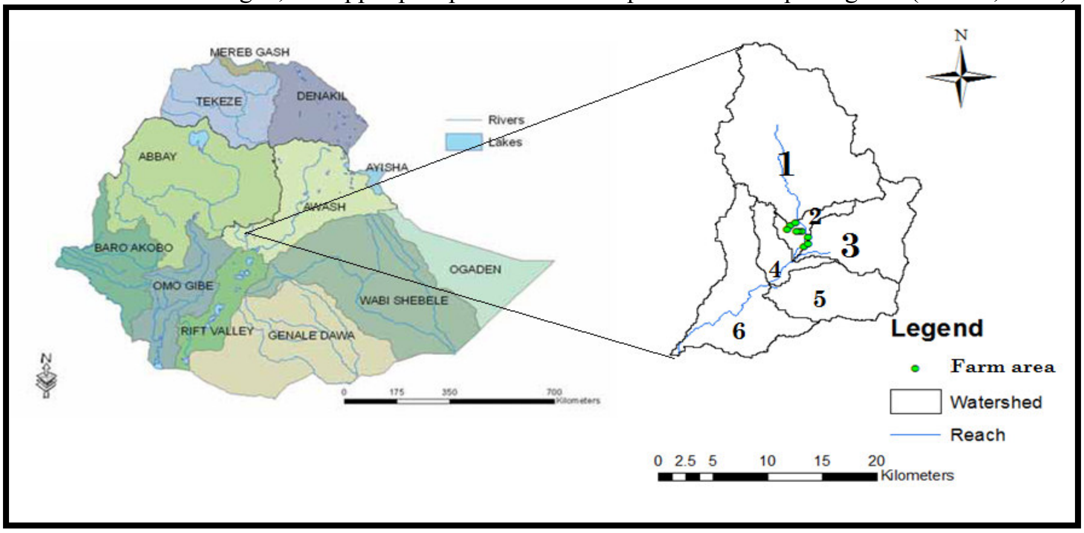

Figure1.Experimentalsite

Table 1. Long-term monthly climatic data of the experimental area

Months	T_{max} (^OC)	T_{min} (^OC)	RH (kpa)	U (m/s)	N (%)	RF (mm)
January	3.7	23.4	50	99	85	18.5
February	5.3	24.1	50	109	83	35
March	7	24.5	51	118	73	58.9
April	8.5	23.4	56	117	67	76.5
May	8.1	24.5	55	114	70	64.5
June	7.8	22.4	68	82	53	115.9
July	9.2	20.3	79	74	30	245.8
August	9.1	19.5	80	68	30	257.3
September	7.6	20.5	72	79	46	126.3
October	4.7	21.8	56	101	74	22.8
November	2.3	22.6	50	105	90	9.7
December	2.2	23.1	49	98	89	5.6

Source: Holeta metrological station

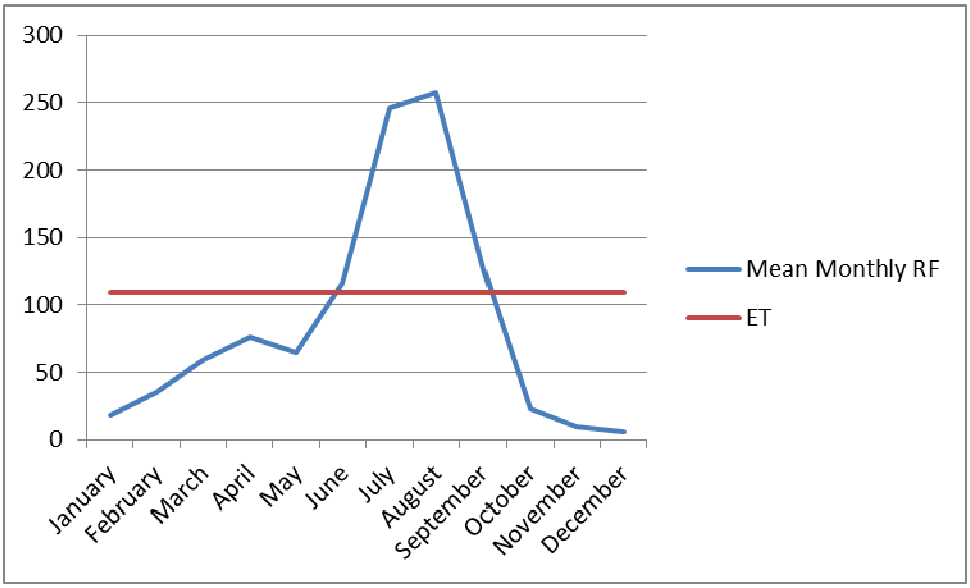

Figure 2.Comparison of mean monthly rain fall (RF) and potential evapotranspiration (EP)

Table 2. Physical characteristics of soil at the experimental site

Soil depth	Soil texture	Bulk density (g/cm3	Field capacity (%)	Wilting point (%)	Available water (mm)
30 cm	Clay loam	1.15	31.52	22.19	32.19
60 cm	Clay loam	1.15	32.56	22.28	50.23

Table 3. Crop input data of potato

Parameter	Growth stage				Total growing period
	Initial	Development	Mid	Late	
Length of growing season (days)	25	30	35	30	120
Crop coefficient (Kc)	0.5	0.83	1.15	0.75	
Rooting Depths (m)	0.30	0.45	0.60	0.60	

Source: FAO Cropwat model (Smith et al., 2002)

Treatments and experimental design
Randomized complete block design with three replications was used. The experiment included 5 treatments randomized in plots as follows: 1) -40% of available soil moisture depletion level (ASMDL), 2) -20% of available soil moisture depletion level (ASMDL), 3) available soil moisture depletion level (ASMDL), 4) +20% of available soil moisture depletion level (ASMDL) and 5) +40% of available soil moisture depletion level (ASMDL).

Experimental procedure and management practice
Potato *(S. tuberosum L.),* Belete variety were planted on 17th and 24th of January, 2013 and 2014, respectively. Planting was performed by hand. Plot size was 4.5 m wide and 5 m long. The distances between rows and plants were 0.75 m and 0.3 m and the distance between plots and between replications were 1 m and 1.5 m respectively. Potato plots were fertilized with 46kg/h P as DAP and 23kg/ha N as Urea during sowing and, additional 23kg/ha N was applied as Urea Plants were initially well-watered to have suitable germination and favourable plant stand. Furrow irrigation method was used, and the amount of water applied was measured using 2 inch Parshal flume. Irrigation scheduling was done based on soil water depletion replenishments using the CROPWAT program. Crop water requirement was calculated using CROPWAT program based on the FAO Penman-Monteith method. Soil water level was monitored by using the gravimetric soil moisture content determination method. Soil sample was taken from well irrigated plots just before irrigation to check the moisture content at management allowable depilation level and two day after irrigation to check the moisture content to field capacity level. The regular tillage and agricultural operations of growing potato of the location were followed. All other agronomic practices were kept normal and uniform for all the treatments including pre-irrigation and one irrigation after germination.

Data collection
Representative three row potato plant samples were harvested after plant height recorded and collected per plot. Data on potato yield and yield parameter like plant height, tuber yield was collected.

Calculation of Water Productivity (WP)
Water productivity was estimated as a ratio of aboveground dry matter at maturity or grain yield to the total Etc through the growing season and it was calculated using the following equation (Zwart and Bastiaanssen, 2004).

$$CWP = (Y/ET)$$

Where, CWP is crop water productivity (kg/m^3), Y crop yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Data Analysis
Data collected were statistically analyzed using statistical analysis system (SAS) software version 9.0 using the general linear programming procedure (GLM). Mean separation using least significant difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

RESULTS AND DISCUSSION
Effect of Soil Moisture Depletion Levels on Potato Height
In order to evaluate the effect of soil moisture depletion levels on plant height, the plant height from ground level to apex stem were measured and the results are presented in Table 1.The analysis of variance showed that the effect of Allowable soil moisture depletion level on plant height was not differ significantly. Though findings have been reported by Aklilu (2009) who concluded that a 50% Etc resulted in 43.5 cm height of pepper whereas, a 75 and 100% ETc resulted in 56.8 and 60.7cm height, respectively.

Table 4.Effect of soil moisture depletion levels on potato height

Treatments	Height (cm)
-40% ASMDL	75.00
-20% ASMDL	74.17
ASMDL	76.83
+20% ASMDL	78.33
+40% ASMDL	73.33
CV (%)	8.65
LSD (0.05)	NS

Effect of Soil Moisture Depletion levels on tuber yield of potato
The effect of soil moisture depletion level on potato tuber yield is presented in Table 2.The over year analysis result has indicated that, the tuber yield is not significantly affected by different soil moisture depletion levels.

Table 5.Response of tuber yield under different soil moistuire depletion levels

Treatments	Yield (t/ha)
-40% ASMDL	36.21
-20% ASMDL	29.91
ASMDL	35.22
+20% ASMDL	34.69
+40% ASMDL	38.24
CV (%)	10.89
LSD (0.05)	NS

Water Productivity of Potato Tuber Yield

Water productivity of potato tuber yield as a function of the amount of applied water is presented in Table 3. The highest water productivity (14.62 kg/m^{3}) of yield was obtained under -40% ASMDL whereas the lowest water productivity (0.24 kg/m^3) of potato yield was obtained under +40 ASMDL. According to Zwart and Bastiaanssen (2004), globally measured average WP values per unit water depletion are 1.09, 1.09, 0.65 and 1.80 kg/m^3 for wheat, rice, cotton, and maize respectively.

Table 6. Water productivity of tuber yield of potato

Treatment	WP of tuber yield (kg/m^3)
-40% ASMDL	14.62^a
-20% ASMDL	9.08^b
ASMDL	8.52^{bc}
+20% ASMDL	6.99^a
+40% ASMDL	6.61^c
CV (%)	10.35
LSD (0.05)	2.30

*Means followed by different superscripts are statistically different

The trend of WP in this experiment is in agreement with the findings of Yuan *et al.* (2004) who reported that the trends WP for the production of total fresh berry yields. The authors concluded that the lower the amount of irrigation water received, the higher the water productivity obtained for the drier plant biomass and berry yields. Mao *et al*. (2003) reported that highest WP of cucumber yield was obtained in treatment groups with minimal irrigation levels. Similarly, Sezen *et al*. (2005) reported that higher WP was obtained with lowest irrigation level in field grown beans. However, lower irrigation level resulted in lower total yield. Water productivity probably will become more important as access to water become more limited (Shdeed, 2001).

CONCULUSIONS AND RECOMMENDATIONS

The results of the study revealed that, irrigating in a shorter frequency with limited amount applied enhance water productivity of potato without significantly reducing the yield from the higher yielding treatments which is treatment 5 (+40 ASMDL). This study showed that managing the soil moisture content at different depletion level has no influence on tuber yield of potato, Whereas, Water productivity is highly influenced (treatment 1: -40% ASMDL). Reducing the soil moisture depletion level by 40% from the recommended fraction (0.3) has significantly increased the water productivity. However, a significant yield reduction was not observed under this treatment. So it's possible to conclude that applying 40% less from the ASMDL can be used for areas where water is a limiting factor. For areas where water is not a problem, using the FAo recommended ASMDL which is treatment 3 is recommended. Moreover, it is possible to suggest that, employing +40 ASMDL will be advantageous in reducing labour cost since this treatment used a longer scheduling. Hence further investigation and verification work is recommended under different climatic conditions.

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