academicJournals

Vol. 8(11), pp. 1144-1154, 11 April, 2013
DOI: 10.5897/AJAR2013.6961
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Deficit irrigation scheduling for potato production in North Gondar, Ethiopia

Nigus Demelash

Gondar Agricultural Research Center, P. O. Box 1337, Ethiopia.

Accepted 4 April, 2013

Scarcity of water is the most severe constraint for development of agriculture in arid and semi-arid areas. Under this condition, irrigation management has to be improved while still achieving high yield. This study was conducted in North Gondar zone in 2010/2011 to investigate deficit irrigation scheduling on potato yield and yield components. Nine treatment combination: Irrigation frequency based on Cropwat model output, two modified irrigation frequency and two deficit irrigations of 25 and 50% were laid out with three replications in randomized complete block design (RCBD) in factorial combinations. It was found that irrigation scheduling significantly affected yield and some yield components. The highest marketable tuber yields was obtained from 0% deficit irrigation and frequency of F1-2 days (T9) which was 26.33 t ha^{-1}, whereas 25% deficit irrigation with F1-2 days frequency (T8) gave 25.68 t ha^{-1}. The lowest marketable yield was 3.4 t ha^{-1} from T4. The highest water use efficiency (WUE) were obtained from T7 and T8 which were 6.61 and 5.59 kg mm^{-1}, respectively. Therefore, applying 75% of full irrigation depth throughout the whole growing season with frequency based on Cropwat model scheduling -2 days resulted better potato yield and saved significant depth of water which improved WUE.

Key words: Potato, deficit irrigation scheduling, water use efficiency, water saving.

INTRODUCTION

Irrigation is an age-old art-perhaps as old as civilization. Nevertheless, the increasing need for crop production due to the growing population in the world is necessitating a rapid expansion of irrigated agriculture throughout the world. As population increases and development calls for, the allocations of ground and surface water for the domestic, agriculture and industrial sectors increased; as a result the pressure on water resources intensifies. The increasing stress on freshwater resources brought about by ever rising demand of water is of serious concern (FAO, 2008). Despite the increase in water use by sectors other than agriculture, irrigation continues to be the main water user on a global scale. Irrigated agriculture consumes more than 70% of the water drawn from the rivers of the world and for the developing world; the proportion can reach 80% (FAO, 2002). In addition, the demand on the limited finite water supplies is increasing from time to time. Different economic sectors other than agriculture such as, hydroelectric production, industries, fishery, recreation or tourism, river, or lake navigation etc., also depend on water. Further, the trend for maintaining the natural river flows aimed at maintaining the natural environment has been increasing implying that the water that could be

*Corresponding author. E-mail: d.nigus19@gmail.com

be abstracted for irrigation has to be regulated. Improving the efficiency of water use will contribute to saving water for irrigation development, thus, improving the productivity of irrigation, and to the expansion of other water dependant economic sectors.

The situation is no more different in Ethiopia. It has been clearly and loudly stated that if Ethiopia is to feed its ever increasing population, lessen risk of catastrophes caused by drought, and increase population density in the arid and sparsely populated areas, continuous and extensive effort need to be made towards developing irrigated agriculture and intensifying agricultural production.

For a country like Ethiopia that follows Agricultural Development Lead Industrialization (ADLI), there is no readily identifiable yield increasing technology other than improved seed-irrigation, fertilizer approach. Irrigation will, therefore, play an increasingly important role now and in the future both to increase the yield from already cultivated land and to permit the cultivation of what is today called marginal or unusable land due to moisture deficiency (FAO, 2002). In addition, production intensification without irrigation in the face of vagaries of weather cannot be imagined.

Moreover, under the traditional rain dependent agricultural system, improving crop management under rainfed condition could not be expected to provide a reliable output satisfying the ever increasing demands for food. Therefore, use of irrigated agriculture together with other productivity enhancing technologies such as deficit irrigation is the way out to ensure productivity which can meet the growing demand for agricultural produces.

The Federal and Regional Governments in Ethiopia have given due emphasis to irrigated agriculture to ensure food self-sufficiency. For instance, the Amhara Regional State has many irrigation development projects undergoing within the region. The Koga, Rib and Megech projects are among those in the region. In most irrigable lands, horticultural crops play an important role in contributing to the household food security. The horticultural crops such as garlic, onion, carrot being cash crop with nutritional value generate income for the poor households. Higher profits can be achieved by increasing productivity and production throughout the year when efficient irrigation system is used.

With increasing municipal and industrial demands for water, its allocation for agriculture is decreasing steadily. The major agricultural use of water is for irrigation, which, thus, is affected by decreased supply. Therefore, innovations are needed to increase the efficiency of use of the water that is available. There are several possible approaches. Irrigation technologies and irrigation scheduling may be adapted for more-effective and rational uses of limited supplies of water. It is necessary to develop new irrigation scheduling approaches, not necessarily based on full crop water requirement, but once designed to ensure the optimal use of allocated water with deficit irrigation scheduling. Deficit (or regulated deficit) irrigation is one way of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied: the crop is exposed to a certain level of water stress either during a particular period or throughout the whole growing season. The expectation is that any yield reduction will be insignificant compared with the benefits gained through diverting the saved water to irrigate additional land. The grower must have prior knowledge of crop yield responses to deficit irrigation (Shock et al., 1998).

Many researchers have evaluated the feasibility of deficit irrigation and whether significant savings in irrigation water are possible without significant yield penalties (Shock et al., 1998; Zhang et al., 2006; Shahnazari et al., 2007; Serhat and Abdurrahim, 2009). Similar works on potato (Trebejo and Midmore, 1990; Minhas and Bansal, 1991) and on many other crops have demonstrated the possibility of achieving optimum crop yields under deficit irrigation practices by allowing a certain level of yield loss from a given crop with higher returns gained from the diversion of water for irrigation of other crops. This new concept of irrigation scheduling has different names, such as regulated deficit irrigation, pre-planned deficit evapotranspiration, and deficit irrigation (English et al., 1990).

In North Gondar zone, Megech irrigation area, irrigation is typically applied on a routine basis without scheduling and inadequate management of irrigation water has been an important limiting factor to potato production. The farmers generally lack knowledge on aspects of soil-water-plant relationship and they apply water to the crop regardless of the plant needs. They seem to relate irrigation occurrence to days after planting with fixed intervals and water amounts rather than to crop stage progress. Therefore, irrigation scheduling based on deficit irrigation requires careful evaluation to ensure enhanced efficient use of increasingly scarce irrigation water in this area. The knowledge of proper irrigation scheduling, when to irrigate and how much water to apply, is essential to optimize crop production per unit water and for sustaining irrigated agriculture on permanent footing (Anac et al., 1999). In many deve-loping countries like Ethiopia, irrigation interval turns are mutually agreed and fixed among growers according to a pre-fixed schedule, this situation is no more different in North Gondar zone. However, this method does not give due consideration to crop water requirement, soil and water relations, yield responses, scarcity of water and climatic conditions. It is therefore, with this rationale that this study was conducted with objectives to determine optimum deficit irrigation depth and frequency relations, and to estimate WUE of potato for the study area.

MATERIALS AND METHODS

General description of the study area

The study area is located in the northwest part of Amhara National Regional State; North Gondar zone (12.50°N latitude and 37.24°E

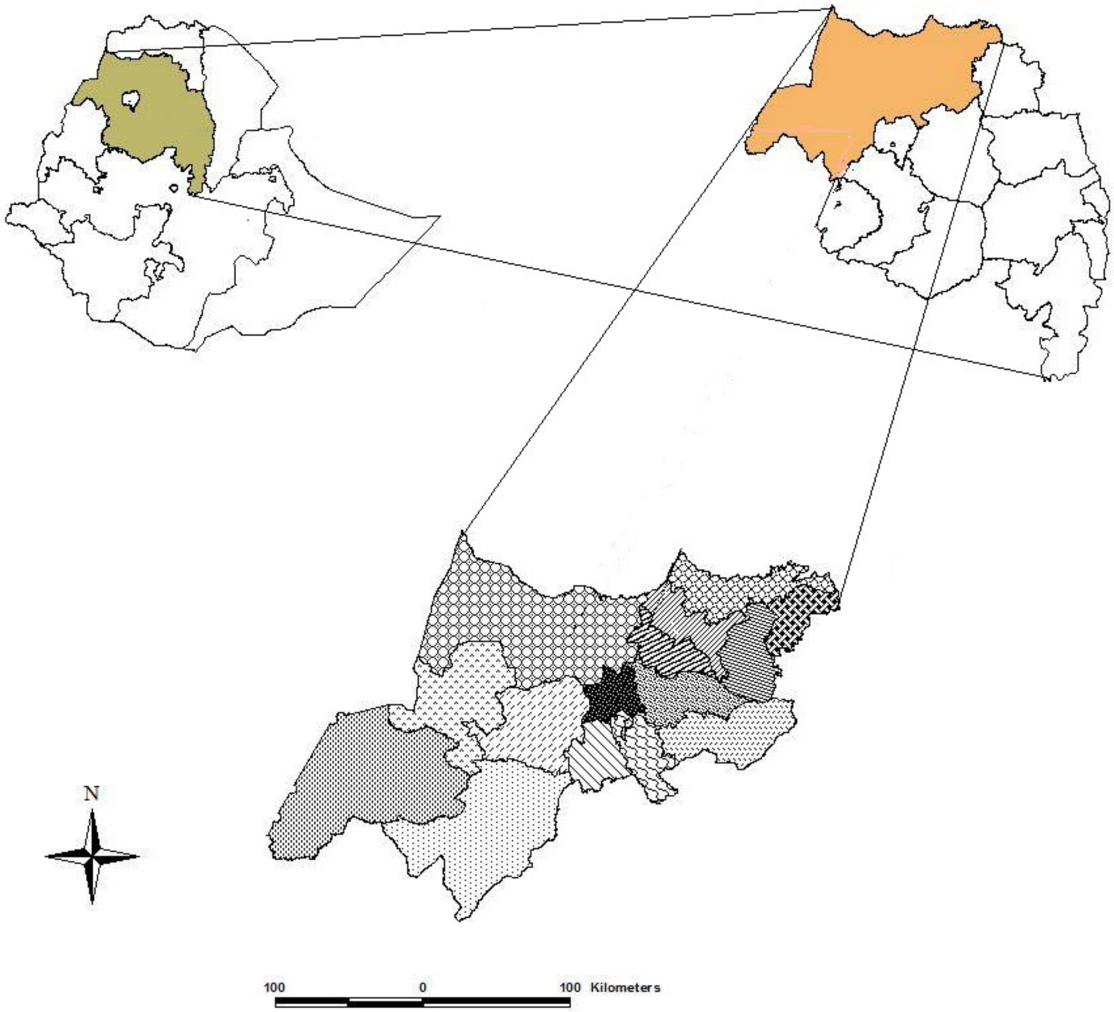

Figure 1. Location map of the study area.

longitude). The altitude of the experimental site is at about 2380 m above mean sea level (Figure 1). Rainfall is seasonal, varying in depth, space and time. The mean annual rainfall (1979 to 2009) in the area is about 1101 mm (Table 1) and it is erratic and uneven in distribution. The mean maximum temperature of the area is about 30.6°C, while the mean minimum temperature is about 12°C. The mean annual rainfall (1979 to 2009) in the area is about 1101 mm (Table 1) and it is erratic and uneven in distribution (NMSA, 2009).

Experimental design and treatments

The study was conducted from 07/12/2010 to 05/04/2011. The experiment involved a factorial combination of two deficit and one control irrigation depth and three irrigation frequencies laid out in randomized complete block design (RCBD) with three replications. The treatments combinations were:

T1 = F1L1 - (Irrigation frequency based on Cropwat model output and application of 50% deficit irrigation)
T2 = F1L2 - (Irrigation frequency based on Cropwat model output and application of 25% deficit irrigation)
T3 = F1L3 - (Irrigation frequency based on Cropwat model output and application of 0% deficit irrigation)
T4 = F2L1 - (Irrigation frequency based on Cropwat model output + 2 days and application of 50% deficit irrigation)
T5 = F2L2 - (Irrigation frequency based on Cropwat model output scheduling + 2 days and application of 25% deficit irrigation)
T6 = F2L3 - (Irrigation frequency based on Cropwat model output + 2 days and application of 0% deficit irrigation)
T7 = F3L1 - (Irrigation frequency based on Cropwat model -2 days and application of 50% deficit irrigation)
T8 = F3L2 - (Irrigation frequency based on Cropwat model -2 days and application of 25% deficit irrigation)
T9 = F3L3 - (Irrigation frequency based on Cropwat model -2 days and application of 0% deficit irrigation)

Well-sprouted potato tubers were planted on prepared ridges in rows with 70 cm spacing between rows and 30 cm between plants. Each plot consisted of four ridges and five furrows. Each furrow bed had 40 cm width at the bottom. The furrow had a parabolic shape with an average depth of 8 cm and width of 20 cm at the top. Fertilizer was applied on the prepared ridges in a band form and incorporated into the soil. The rate of fertilizer applied was 111 kg N ha^{-1} and 90 kg P_2O_5 ha^{-1}. Half of the rate of nitrogen (N) fertilizer and full rate of phosphorus (P) fertilizer were applied at sowing. The second half of the N fertilizer as urea was applied at 45 days after planting.

Table 1. Climate data and reference evapotranspiration at Gondar (1979 to 2009).

Month	Rainfall (mm)	Minimum temperature (°C)	Maximum temperature (°C)	Relative humidity (%)	Wind speed (m s^{-1})	Sunshine hour (h)	ETo (mm day^{-1})
January	5.0	19.4	27.6	36.2	1.4	9.5	4.64
February	4.5	19.9	30.6	33.5	1.4	9.0	5.17
March	18.2	21.7	29.7	34.7	1.6	8.1	5.61
April	35.9	17.7	29.6	37.9	1.5	7.7	5.48
May	87.3	15.7	28.3	48.6	1.7	7.0	4.84
June	151.2	14.1	25.3	67.1	1.7	4.5	3.72
July	297.3	13.3	22.7	79.2	1.1	4.4	3.14
August	278.5	13.2	22.8	79.4	1.1	5.0	3.30
September	119.1	12.8	24.9	70.1	1.2	7.0	3.90
October	73.3	12.7	26.2	55.4	1.1	7.6	3.93
November	22.4	12.2	27.0	46.9	1.1	8.8	3.83
December	8.7	18.6	27.2	42.1	1.0	9.0	4.12
Total	1101.4						
Average	91.78	15.9	26.8	52.5	1.3	7.9	4.31

Table 2. 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	
Depletion level (p)	0.25	0.2	0.15	0.50	
Yield response factor (Ky)	0.45	0.80	0.80	0.30	

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

Determination of crop and irrigation water requirement of potato

Crop water requirement of potato was determined using the Cropwat model based on the climatic data of the area, the crop to be grown (potato). Input data for the model were obtained from the National Meteorological Services Agency, Soil laboratory results and FAO publications. Thirty (30) years (1979 to 2009) meteorological data was used to estimate crop water requirement and the data was obtained from Bahir dar National Meteorological Station. Calculations of water and irrigation requirements utilize inputs of climate, crop and soil data, as well as method of irrigation and rainfall data. Reference evapotranspiration was calculated from temperature, humidity, sunshine and wind speed data, according to the FAO Penman-Monteith method (Allen et al., 1998).

As per the output of the model, the optimum seasonal irrigation requirement was found to be 517.46 mm. As per the Cropwat program, the anticipated effective rainfall during the growing season was about 23.17 mm. However, there was no rainfall during the experiment period. Analysis of monthly reference evapotranspiration (ETo) calculated from meteorological data of 30 years data (1979 to 2009) meteorological station shows that the minimum reference ETo occurred in July (3.14 mm day^{-1}) and the maximum in March (5.61 mm day^{-1}) (Table 2).

The soil data include information on total available soil water content and maximum infiltration rate. These were determined by gravimetric method and double ring infiltrometer, respectively. The initial soil water content at the start of the season was also needed and was determined to be 156 mm m^{-1} of soil depth. Through the soil moisture content and evapotranspiration rates, the soil water balance was calculated on weekly bases by the Cropwat model.

Soil analysis

In the laboratory, soil samples were analyzed for bulk density, soil moisture, field capacity, permanent wilting point, soil texture, and soil pH at the Adet Agricultural Research Centre.

Soil texture of the field was determined in the laboratory using Hydrometer method. Soil bulk density was determined from undisturbed soil sample taken using a metal cylinder (core sampler) of known volume (100 cm^3) that was driven into the soil of desired depth and calculated as the ratio of oven dry weight of soil to a known cylinder core sampler volume. Since bulk density varies considerably spatially, the measurements were taken at three different soil depths of the soil profile and three samples across the experimental site. The gravimetric method was used to determine the soil moisture content and calculated as a dry weighed fraction (Michael, 2008).

The water content at field capacity was determined in the laboratory by using a pressure (porous) plate apparatus by applying

Table 3. Irrigation depth and number of irrigation under each treatment.

Treatment	Number of irrigation (days)	Net irrigation (mm)
T1	17	238.0
T2	17	356.5
T3	17	475.0 (optimum)
T4	14	183.4
T5	14	274.5
T6	14	365.8
T7	25	346.6
T8	25	507.3
T9	25	664.3

-1/3 bar to a saturated soil sample. When water is no longer leaving the soil sample, the soil moisture was taken as field capacity. Permanent wilting point was also determined by using pressure membrane apparatus by applying -15 bar to a saturated soil sample. When water is no longer leaving the soil sample, the soil moisture was taken as permanent wilting point. Soil pH was determined from saturation pest extract using pH meter.

Plant and yield parameters measured

Data were recorded on plot basis and extrapolated in hectare basis. All parameters were determined and calculated from the middle two rows. Plant height, number of stems, days to physiological maturity, average number of tubers per plant, marketable tuber, unmarketable tuber yield and total tuber yield were recorded. Irrigation IWUE was computed as the ratio of the yield (kg ha^{-1}) to the depth of irrigation applied (m^3) (Michael, 2008).

Depth of irrigation under the different treatments

All treatments were set according to the initially planned framework and received the required irrigation depth and frequency (Table 4). Table 3 shows the net depths of water applied to each treatment and the number of irrigation in the experiment period. It is to be stressed that there was no rainfall during the experiment period.

Data analysis

The data collected from the field study were subjected for analysis of variance (ANOVA) using SAS software. Whenever treatment effects were significant, mean comparison were made using least significant difference (LSD).

RESULTS AND DISCUSSION

Characterization of the experimental soil

The result of the textural analysis of the soil from the experiment site (Table 5) showed that the composition of clay, silt and sand percentage were 33.76, 38.62 and 27.62, respectively. Thus, as per the USDA soil textural classification, the soil was classified as clay loam soil.

The bulk density of soil of the area showed variation with depth (Table 6). It varied between 1.19 and 1.33 g cm^{-3} and generally the surface soil had slightly lower bulk density than the subsurface soil. The soil had an average bulk density of 1.24 g cm^{-3}. The soil pH of the experimental field also varied with depth. The pH of the experimental site ranged from 5.57 to 6.35 in the 0 to 60 cm depth. The average pH of the soil was 6.07 which showed that the soil of the site was suitable for potato crop production with regard to soil pH.

The water content at field capacity and permanent wilting point of the soil were determined to be 32.21 and 19.52%, respectively. The moisture content at field capacity varied with depth between 35.63 and 29.10% on mass basis. The top 0 to 20 cm had a larger average water content of field capacity value of 35.63%, while the subsurface 40 to 60 cm had a lower value of field capacity that was 29.10%. The moisture content at permanent wilting point also showed variation with depth with values of 21.56% at the top (0 to 20 cm) and at the subsurface (40 to 60 cm) the value of permanent wilting point was 17.89%.

Total available water (TAW) which is the depth of water that a crop can extract from its root zone is directly related to variation in field capacity and permanent wilting point. The total average available soil moisture was 156.67 mm m^{-1} of soil depth and the maximum infiltration rate of the soil was 40 mm h^{-1}. As a result, high value of TAW is found in top soil; whereas lower values are found in the subsurface soil (Table 6).

Agronomic response of potato

Plant height

Plant height was significantly ($P < 0.05$) influenced by variation in the depth and frequency of water application. Irrigation depth × irrigation frequency interaction was found to be significant with respect to plant height (Table 7). T9 which received the maximum depth irrigation with frequency of F1-2 days of irrigation water and T8 which received the 75% of full irrigation depth with frequency of F1-2 days of irrigation water had the highest plant height. Whereas the most stressed crops that is, T4 had the

Table 4. Irrigation scheduling of potato throughout the growing season.

Treatment 1		Treatment 2		Treatment 3		Treatment 4		Treatment 5		Treatment 6		Treatmen t 7		Treatment 8		Treatment 9	
F1	L 1	F 1	L2	F 1	L3	F2	L 1	F 2	L 2	F 2	L 3	F3	L1	F3	L 2	F3	L 3
7	7.2	7	10.7	7	14.3	9	7.2	9	10.7	9	14.3	5	7.2	5	10.7	5	14.3
8	8.8	8	13.1	8	17.5	10	8.8	10	13.1	10	17.5	5	7.2	5	10.7	5	14.3
8	9.5	8	14.2	8	18.9	10	9.5	10	14.2	10	18.9	6	8.8	6	13.1	6	17.5
7	11.7	7	17.5	7	23.3	9	11.7	9	17.5	9	23.3	6	8.8	6	13.1	6	17.5
6	12.1	6	18.2	6	24.2	8	12.1	8	18.2	8	24.2	6	9.5	6	14.2	6	17.5
6	12.8	6	19.1	6	25.5	8	12.8	8	19.1	8	25.5	7	11.7	7	17.5	7	23.3
5	15.1	5	22.6	5	30.1	7	15.1	7	22.6	7	30.1	7	11.7	7	17.5	7	23.3
5	14.2	5	21.3	5	28.4	7	14.2	7	21.3	7	28.4	5	12.1	5	18.2	5	24.2
5	14.7	5	22.1	5	29.4	7	14.7	7	22.1	7	29.4	5	12.1	5	18.2	5	24.2
5	15.0	5	22.5	5	30.0	7	15.0	7	22.5	7	30.0	4	12.8	4	19.1	4	25.5
5	15.3	5	22.9	5	30.5	7	15.3	7	22.9	7	30.5	4	15.1	4	19.1	4	25.5
5	15.5	5	23.2	5	30.9	7	15.5	7	23.2	7	30.9	4	16.1	4	22.6	4	25.5
5	14.7	5	22.0	5	29.3	7	14.7	7	22.0	7	29.3	3	14.2	3	21.3	3	28.4
5	16.8	5	25.1	5	33.5	7	16.8	7	25.1	7	33.5	3	14.7	3	22.1	3	28.4
7	15.9	7	23.9	7	31.8	-	-	-	-	-	-	3	14.7	3	22.5	3	28.4
8	17.5	8	26.3	8	35.0	-	-	-	-	-	-	3	15.0	3	22.9	3	28.4
10	21.2	10	31.8	10	42.4	-	-	-	-	-	-	3	15.3	3	23.2	3	28.4
-	-	-	-	-	-	-	-	-	-	-	-	3	16.5	3	22	3	28.4
-	-	-	-	-	-	-	-	-	-	-	-	3	14.7	3	22	3	28.4
-	-	-	-	-	-	-	-	-	-	-	-	4	16.8	4	25.1	4	33.5
-	-	-	-	-	-	-	-	-	-	-	-	4	18.6	4	23.9	4	33.5
-	-	-	-	-	-	-	-	-	-	-	-	4	15.9	4	23.9	4	33.5
-	-	-	-	-	-	-	-	-	-	-	-	5	17.5	5	26.3	5	35.0
-	-	-	-	-	-	-	-	-	-	-	-	5	18.5	5	26.3	5	35.0
-	-	-	-	-	-	-	-	-	-	-	-	8	21.2	8	31.8	8	42.4

L, Irrigation depth in mm; F, irrigation frequency in days.

Table 5. Particle size distribution.

Soil depth (cm)	Particle size distribution (%)		
	Clay	Silt	Sand
0 - 20	36.07	35.09	28.84
20 - 40	33.23	38.62	28.15
40 - 60	32.12	42.16	25.72
Average	33.76	38.62	27.62

Table 6. Results of laboratory analysis for samples from the experimental site.

Soil depth (cm)	Bulk density (g cm^{-3})	pH	FC (%)	PWP (%)	TAW (mm m^{-1})
0 - 20	1.19	5.57	35.63	21.56	167.43
20 - 40	1.20	6.29	31.89	19.10	153.48
40 - 60	1.33	6.35	29.10	17.89	149.09
Total average	1.24	6.07	32.21	19.52	156.67

shortest plant height (Table 7). Stressing the crop by 25% deficit throughout the growing season with frequency of F1-2 days had a comparable plant height to 0% deficit with the same frequency. As shown in Table 7, plant

Table 7. The influence of full and deficit irrigation on plant height (cm) of potato.

Irrigation frequency (F)	Irrigation levels (L)			Mean (F)
	L1	L2	L3	
F1	41.0^{ef}	43.0^{de}	47.3^{b}	43.8^{b}
F2	40.3^{f}	42.3^{def}	44.0^{dc}	42.2^{c}
F3	46.3^{bc}	57.0^{a}	58.6^{a}	55.3^{a}
Mean (L)	42.5^{c}	47.4^{b}	51.3^{a}	
LSD (0.05) for mean F			1.26	
SE±			1.04	
LSD (0.05) for mean L			1.26	
SE±			1.04	
LSD (0.05) for F × L		2.33		
SE±		1.1		

Means followed by the same letter within a column or row are not statistically significantly different at 5% level of significance.

Table 8. The influence of full and deficit irrigation on stem number, days to maturity, average tuber number per hill and unmarketable tuber yield of potato.

Treatment	Number of stems per hill	Days to maturity	Average tuber number per hill	Unmarketable yield (t ha^{-1})
T1	4.01	107	4.8^{f}	3.74^{e}
T2	2.89	109	5.6^{cde}	4.56^{de}
T3	4.41	110	6.5^{cd}	5.87^{b}
T4	3.57	107	4.0^{f}	3.25^{f}
T5	3.89	107	5.4^{ef}	2.86^{g}
T6	4.07	109	5.8^{cde}	4.46^{c}
T7	3.7	111	6.7^{c}	4.17^{cd}
T8	4.3	110	8.2^{b}	2.68^{g}
T9	4.5	116	10.5^{a}	8.12^{a}
LSD (0.05)	NS	NS	1.59	0.42
CV (%)	8.3	1.9	9.5	5.7
SE±	0.50	3.3	0.56	0.2

Means followed by the same letter within a column or row are not statistically significantly different at 5% level of significance.

height increased consistently from 40.33 cm for an irrigation depth of 50% of full irrigation depth and F1+2 frequency of application of water requirement to 62.6 cm to that of full irrigation and F1-2 days irrigation frequency of application.

The main effect of irrigation depth and frequency on plant height was also showed significant ($p < 0.05$) difference (Table 7). Thus, it is possible to conclude from the present observation that irrigation frequency is helpful in amplifying the effect of irrigation depth on plant height.

Stem number

Both irrigation depth and frequency showed non-significant difference in stem number (Table 8). Despite the fact that stem number is one of the most important yield components in potato, the results of the present study showed that the influences of irrigation depth and frequency on stem number were statistically non-significant. This could be due to the fact that stem number is determined very early in the ontogeny of the plant. It could also be due to the case that this trait was not influenced much by irrigation depth and frequency unless the depth of irrigation is too low.

Days to physiological maturity

Data on days to physiological maturity of potato was influenced by variation in the moisture level of the soil. However, there was no statistically significant difference in different levels of irrigation water on days to maturity between treatments T1 to T8 (Table 8). However, Treatment 9 with the maximum depth and frequency of irrigation application experienced a prolonged time to

Table 9. The influence of full and deficit irrigation on marketable yield (t ha^{-1}) of potato.

Irrigation frequency (F)	Irrigation levels (L)			Mean (F)
	L1	L2	L3	
F1	7.96^{e}	15.12^{d}	20.81^{b}	14.63^{b}
F2	3.40^{f}	3.98^{f}	8.16^{e}	5.18^{c}
F3	18.74^{c}	25.68^{a}	26.33^{a}	22.58^{a}
Mean (L)	9.03^{c}	14.93^{b}	18.43^{a}	
LSD (0.05) for mean F			0.61	
SE±			0.50	
LSD (0.05) for mean L			0.61	
SE±			0.50	
LSD (0.05) for F × L		1.13		
SE±		0.54		

Means followed by the same letter within a column or row are not statistically significantly different at 5% level of significance.

maturity. Similar result was also observed by Marouelli and Silva (2007).

Average tuber number per hill

The average tuber number results obtained are presented in Table 8. There was statistically significant ($P < 0.05$) difference in average number of tuber among the treatment. The highest numbers of tubers were recorded from treatment T9. However, there was a considerable size variation in this treatment. Extra large and too small tuber sizes were observed. The lowest average number of tubers was observed for T4 indicating that there was considerable variation in the number of tubers among the treatments.

There were significant ($P < 0.05$) responses to application irrigation depth and frequency in actual tuber numbers (Table 8). The highest average number of tuber (10.46) was found in treatment T9. The lowest number (4.47) was found in the treatment T4. Application of optimum irrigation at T8 gave relatively better tuber size with relatively higher tuber number as compared with the treatments. T3 and T7 also showed better performance in tuber size and number.

Marketable tuber yield

The difference observed in marketable tuber yield between treatments was statistically significant ($p < 0.05$). However, there was no statistically significant difference in marketable tuber yield between T9 and T8 which gave 26.33 and 25.68 t ha^{-1}, respectively. The lowest marketable yield was observed in T4, which was 3.4 t ha^{-1} (Table 9).

Decreasing irrigation depth from 100% application to 75% application with frequency of F1-2 days throughout the growing season decreased marketable tuber yield from 26.33 to 25.68 t ha^{-1} (Table 9). The difference in marketable yield was only 0.65 t ha^{-1}, which was statistically non significant. However, increasing irrigation depth from 50% application with irrigation frequency of F1+2 days to 100% application with F1-2 days application frequency and 75% application with F1-2 days application frequency increased marketable tuber yield from 3.40 to 26.33 t ha^{-1} and 25.68 t ha^{-1}, respectively (Table 9).

The yield increment due to irrigation depth and irrigation frequency was statistically significant ($p < 0.05$) between T4 and T9, and between T4 and T8. This result is similar to other study (Serhat and Abdurrahim, 2009). Potato needs frequent-irrigation for a good growth and yield. Yield is considerably affected by storage quality; disease resistance, the time, depth and frequency of irrigation. Water excess in the soil decreases the oxygen diffusion rate in the root zone (Wan and Kang, 2006) affecting crop yield increment.

As shown from Table 9, the interaction effect of irrigation depth (L) with irrigation application frequency (F) on marketable tuber yield was found to be significant ($p < 0.05$). The main effect of irrigation depth and frequency on marketable tuber yield was also statistically significant ($p < 0.05$). Improper irrigation depth and frequency can substantially reduce yields by increasing the proportion of rough, misshapen tubers and smaller sized tubers.

Widely fluctuating soil water contents and/or too frequent application of irrigation with maximum irrigation depth creates the greatest opportunity for developing these tubers defects results in increasing unmarketable tubers. Growth cracks are also associated with wide fluctuations in soil water availability and corresponding changes in tuber turgidity and volume of internal tissues (King and Stark, 1997).

Table 10. The influence full and deficit irrigation on total tuber yield (t/ha) of potato.

Irrigation frequency (F)	Irrigation levels (L)			Mean (F)
	L1	L2	L3	
F1	11.70[f]	19.68[e]	26.67[c]	19.35[b]
F2	6.64[g]	6.84[g]	12.62[f]	8.70[c]
F3	22.91[d]	28.36[b]	34.45[a]	27.57[a]
Mean (L)	12.75[c]	18.29[b]	24.58[a]	
LSD (0.05) for mean F			0.72	
SE±			0.59	
LSD (0.05) for mean L			0.72	
SE±			0.59	
LSD (0.05) for F × L		1.33		
SE±		0.63		

Means followed by the same letter within a column or row are not statistically significantly different at 5% level of significance.

Unmarketable tuber yield

As shown in Table 8, significant ($p < 0.05$) difference in unmarketable tuber yield was observed among the treatments. Similarly, there was statistically significant ($p < 0.05$) difference in unmarketable tuber yield between T9 and T8 which was 8.12 and 2.67 t ha^{-1}, respectively. This result seemed to suggest that unmarketable tuber yield can be controlled more effectively by irrigation depth and frequency management. The unmarketable tuber yield was significantly reduced from 8.12 to 2.67 t ha^{-1}. Decreasing irrigation depth from 100% application to 75% application with the same irrigation frequency of F1-2 days throughout the growing season reduced unmarketable tuber yield from 8.12 to 2.67 t ha^{-1}, which was 5.45 t ha^{-1}. The result showed in Table 8 that, improper irrigation depth and frequency substantially reduce yields by increasing the proportion of rough, misshapen tubers. Widely fluctuating soil water contents create the greatest opportunity for developing these tubers defects (Serhat and Abdurrahim, 2009; King and Stark, 1997).

Total tuber yield

Total potato tuber yield remarkably increased with the application of water. Application of optimum irrigation scheduling significantly increased total tuber yield (Table 10). Applying the right depth of irrigation and frequency of application increased the total tuber yield of potato production. This result is comparable to those obtained in other studies (Faberio et al., 2001; Ferreıra and Carr, 2002). The highest total tuber yield (34.45 t ha^{-1}) was recorded in the treatment T9. The lowest total tuber yield (11.70 t ha^{-1}) on the other hand was recorded in the treatment T4.Total potato tuber production in the experiment was proportional to the availability of water but as stress intensity increased total tuber yield decreased (Table 10). Total tuber yield was affected severely when stress was imposed throughout the growing season with low irrigation frequency.

As depicted in Table 10, the yield response of potato to variations in soil moisture was statistically highly significant ($P < 0.05$). This result is also in agreement with the finding of Ferreira and Carr (2002). Treatments 9 and 8 with maximum and optimum depth of irrigation water and frequency of application resulted in highest total yield. Whereas the stressed plant with minimum irrigation depth and frequency resulted in lowest yield.

As shown in Table 10, the L and F interaction effect was highly significant in increasing total tuber yield. The result was evident that as the level of irrigation water depth and time of application increases towards the optimum value, tuber yield also increased. Similarly, increasing the level of frequency highly significantly increased total tuber yield from 13.8 to 24.9 t ha^{-1}.

Above ground biomass

The ANOVA showed that irrigation scheduling significantly affected the above ground biomass ($p < 0.05$). As shown in Table 11, the irrigation depth and frequency interaction effect was significant ($p < 0.05$) in increasing above ground biomass from 14.54 to 46.19 t ha^{-1} as the depth of irrigation increased from 50% deficit irrigation to 0% deficit irrigation. The positive response of above ground biomass with increasing frequency of irrigation and the level of irrigation depth could be attributed to vegetative growth. The results also revealed that interaction of irrigation depth and irrigation frequency was statistically significant ($p < 0.05$) on above ground biomass (Table 11). The highest biomass was obtained when 0% deficit irrigation in combination with F1-2 days irrigation frequency (T9). However, the difference between these treatments was not statistically significant. It is also interesting to note that the least above ground

Table 11. The influence of full and deficit irrigation on biomass yield of potato

Irrigation frequency (F)	Irrigation levels (L)			Mean (F)
	L1	L2	L3	
F1	14.54[e]	24.56[d]	32.17[b]	23.76[b]
F2	8.75[g]	9.45[f]	15.63[e]	11.28[c]
F3	29.68[c]	34.10[b]	46.19[a]	36.66[a]
Mean (L)	17.66[c]	22.70[b]	31.33[a]	
LSD (0.05) for mean F			1.27	
SE±			1.04	
LSD (0.05) for mean L			1.27	
SE±			1.04	
LSD (0.05) for F × L		2.32		
SE±		1.1		

Means followed by the same letter within a column or row are not statistically significantly different at 5% level of significance.

Table 12. WUE of potato.

Treatment	Total tuber yield (kg ha^{-1})	Net irrigation (mm)	WUE (kg mm^{-1})	Water Saved[1] (mm)	Water saved[2] (mm)
T1	1170	238.0	4.92	426.8	237.5
T2	1968	356.5	5.52	308.1	118.7
T3	2667	475.0	5.61	189.3	0
T4	664	183.4	3.62	481.0	291.6
T5	684	274.5	2.49	389.8	200.5
T6	1262	365.8	3.45	298.5	109.2
T7	2291	346.7	6.61	317.7	128.4
T8	2836	507.3	5.59	157.0	-32.3
T9	3445	664.3	5.19	0	-189.3

Water Saved[1] = Saved water in relative to the maximum water depth (T9), Water saved[2] = Saved water in relative to the Cropwat estimate (T3).

biomass was recorded with the lowest irrigation amount and frequency.

Water use efficiencies

The result of this study showed that WUE was variable depending on the treatments applications (Table 12). The highest WUE was obtained from T7 and T8 which was 6.61 and 5.59 kg mm^{-1}, respectively. However, T8 (25.68 t ha^{-1}) gave highest marketable yield than T7, and 18.74 t ha^{-1}, respectively. The lowest value was obtained from T5 and T4. These results are similar to that reported by Onder et al. (2005).

Applying irrigation water 75% of full irrigation depth throughout the whole growing season with frequency of F1-2 days improved WUE. The proper application of deficit irrigation practices can generate significant savings in irrigation water allocation without significant yield reduction. The difference in marketable yield between T8 and T9 was only 0.65 t ha^{-1}, which was statistically insignificant in terms of yield change. However, significant depth of water was saved (Table 12).

The results in Table 12 showed that significant depth of water was saved without significant yield reduction. 157.0 mm water was saved in T8 relative to T9. Hence, diverting the saved water to increase the area irrigated may compensate for decreases in crop yields.Experimental results from field trials confirmed that with deficit irrigation strategies it is possible to increase WUE and save water for irrigation at T6 and T7. This could be especially important for areas facing with drought and limited water resources for agricultural production.Compared with full irrigation, the deficit irrigation treatments saved significant depth of water to irrigation, leading to increase of WUE. Similar data were obtained by other authors (Liu et al., 2005; Shahnazari et al., 2007). Water productivity increases under deficit irrigation, relative to its value under full irrigation, as shown experimentally for many crops (Fan et al., 2005; Zwart and Bastiaanssen, 2004).

Conclusions

One of the irrigation management practices which could result in water saving is deficit irrigation. This experiment was conducted to study the effects of different irrigation levels and irrigation frequencies on yield and water productivity of potato (*Solanum tuberosum* L.) in North Gondar zone, Ethiopia. This study results confirmed that with deficit irrigation strategies it is possible to increase yield, water productivity and save significant depth of water for irrigation. The highest marketable yield was obtained from T9 which was 26.33 t ha^{-1} and T8 gave 25.68 t ha^{-1}. The lowest marketable yield was in T4 (3.4 t ha^{-1}). Since, the yield difference was between T8 and T9 was insignificant, 25% deficit irrigation with frequency based on Cropwat model scheduling -2 days irrigation interval was suitable to recommend. High WUE values were obtained from in T7 (6.61 kg mm^{-1}) and T8 (5.59 kg mm^{-1}). However, T8 gave higher marketable yield than T7 which were 25.68 and 18.74 t ha^{-1}, respectively. The lowest value was obtained from T5 and T4. Therefore, T8 (25% deficit irrigation and F1-2 days interval of irrigation application) was better in performance than T7 and the water productivity of potato in the study area was estimated as 4.54 to 5.06 kg m^{-3}.

Irrigation systems best suited to this task were capable of light, uniform, and frequent water applications which was 75% full irrigation and F1-2 days interval of irrigation application. Timing and depth of water application was determined as 75% of full irrigation in combination with F1-2 days irrigation frequency which was applied to minimize soil water fluctuations throughout the growing season. Potato needs frequent-irrigation for a good growth and yield and for high water productivity. It can, therefore, recommended that applying irrigation water 75% of full irrigation depth throughout the whole growing season of potato with frequency based on Cropwat model scheduling -2 days resulted better yield, saved significant depth of water and improved WUE which can be taken as optimum irrigation depth and frequency.

ACKNOWLEDGEMENTS

The author greatly appreciates the Amhara Region Agricultural Research Institute (ARARI), Gondar Agricultural Research Center (GARC) for granting the financial support for the research. All staff members of the GARC who offered unforgettable support are appreciated.

REFERENCES

Allen R, Pereira L, Raes D, Smith M (1998). Crop evapotranspiration: guidelines for computing crop water requirements. FAO Irrigation and Drainage. Rome, Italy: FAO. p. 56.

Anac MS, Ali UI, Tuzel IH, Anac D, Okur B, Hakerlerler H (1999). Optimum irrigation scheduling for cotton under deficit irrigation conditions. In: Kirda, C., Moutonnet, P., Hera, C. and Nielsen, D.R. (eds). Crop yield response to deficit irrigation, Dordrecht, The Netherlands, Kluwer Academic Publishers.

English MJ, Musick JT, Murty VV (1990). Deficit irrigation. In: Hoffman GJ, Towell TA, Solomon KH. (eds). Management of farm irrigation systems, St. Joseph, Michigan, United States of America, ASAE.

Faberio C, Olalla FMS, Juan JA (2001). Yield size of deficit irrigated potatoes. Agric. Water Manage. 48:255-266.

Fan T, Stewart BA, Payne WA, Wang Y, Song S, Luo J, Robinson CA (2005). Supplemental irrigation and water: yield relationships for plasticulture crops in the loess plateau of China. Agron. J. 97:177–188.

FAO (Food and Agriculture Organization) (2002). Crops and Drops. Land and Water Development Division. Rome, Italy.

FAO (Food and Agriculture Organization) (2008). Crops and Drops. Land and Water Development Division. Rome, Italy.

Ferreıra TC, Carr MKV (2002). Response of potatoes (*Solanum tuberasum L.)* to irrigation and nitrogen in a hot, dry climate: I. water use. Field Crops Res. 78:51-64.

King BA, Stark JC (1997). Potato irrigation management for on-farm potato research. Potato research and extension proposals for cooperative action. University of Idaho, College of Agriculture. pp. 88-95.

Liu F, Jensen CR, Shahnazari A, Andersen MN, Jacobsen SE (2005). ABA regulated stomatal control and photosynthetic water use efficiency of potato (*Solanum tuberosum* L.) during progressive soil drying. Plant Sci. 168:831–836.

Marouelli W, Silva W (2007). Water tension thresholds for processing tomatoes under drip irrigation in Central Brazil. Irrigation Sci. 25:411–418.

Michael AM (2008). Irrigation Theory and Practice. Indian Agriculture Research Institute. New Delhi. India. pp. 427-429.

Minhas JS, Bansal KC (1991). Tuber yield in relation to water stress at stages of growth in potato (*Solanum tuberosum* L.). J. Indian Potato Assoc. 18:1-8.

NMSA (National Meteorological Service Agency) (2009). Climate and Agro-climate resource of Ethiopia. National Meteorological Service Agency of Ethiopia, Bahir dar.

Onder S, Caliskan ME Onder, Caliskan S (2005). Different irrigation methods and water stress effects on potato yield and yield components. Agric. Water Manage. 73:73–86.

Serhat A, Abdurrahim K (2009). Water-Yield Relationships in Deficit Irrigated Potato. J. Agric. Fac. Uludag University, Bursa.

Shahnazari A, Liu F, Andersen MN, Jacobsen SE, Jensen CR (2007). Effects of partial root-zone drying on yield, tuber size and water-use efficiency in potato under field conditions. Field Crop Res. 100:117-124.

Shock CC, Feibert EG, Saunders LD (1998). Potato yield and quality response to deficit irrigation. Horticultural Sci. 33:655-659.B

Smith M, Kivumbi D and Heng L K (2002). Use of the FAO CROPWAT model in deficit irrigation studies. In: Deficit irrigation practice. Water report . Rome, Italy. p. 22

Trebejo I, Midmore DJ (1990). Effects of water stress on potato growth, yield and water use in a hot and cool tropical climate. J. Agric. Sci. 114:321-334.

Wan S, Kang Y (2006). Effect of drip irrigation frecuency on radish (*Raphanus sativus* L.) growth and water use. Irrigation. Sci. 24:161-174.

Zhang B, Li FM, Huang G, Cheng ZY, Zhang Y (2006). Yield performance of spring wheat improved by regulated deficit irrigation in an arid area. Agric. Water Manage. 79:28–42.

Zwart SJ, Bastiaanssen WGM (2004). Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agric. Water Manage. 69:115–13