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Original Paper

Effects of Irrigation Scheduling on Yield of Potato and Water Productivity Southern, Ethiopia

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***Abstract*— Irrigation water is one of the major limiting factors that affect crop production in Ethiopia. Irrigation scheduling is an important technique for quantifying water required by plants at a particular interval to improve irrigation efficiency. The objective of this study was to evaluate the irrigation scheduling effects on potato yield and water productivity. The study was designed in four experimental treatments as: 5, 7, 9 days intervals, and Farmer practice arranged in randomized complete block design with three replications. The two years combined yield results showed that a maximum yield of 21.99ton/ha was obtained from 9 days irrigation interval treatment and a minimum yield of 15.80ton/ha was obtained from Farmer's practice. Maximum and minimum water productivity of 3.34 kg/m3 and 2.4 kg/m3 were obtained from 9-day irrigation intervals and farmers' practice, respectively. From these results, it can be observed that to attain the maximum potato yield and water productivity in the study area, it is better to use 9-days irrigation interval with a determined irrigation water amount.**

Keywords*— *Farmers practice, irrigation scheduling, water productivity, Potato.

I. Introduction

Potato production ranks fourth in the world after rice, wheat, and maize, with 321 million tons produced on 19.6 hectares of land [1]. Potato is one of the most preferred crops in Ethiopia for food consumption. In Ethiopia, most of the potato production is under a rainfed agriculture system. However, a significant portion of the national yield also comes from irrigation production. According to [2–4], potato is one of the most water-efficient crops and the production of calories per unit of water is high compared with other crops. Since the potato crop has a shallow-root system, it is highly water-stress sensitive [5–8]. Therefore, effective water management is most important to attaining the maximum yield and water productivity.

The world's largest water resource consumer is the agricultural sector, linked with important food crop production using irrigation [9][26]. Effective agricultural water management is an important issue to attain the objectives of improving agricultural yield and water productivity. Irrigation scheduling is one of the beneficial techniques used for quantifying water required at a particular interval in plants and thereby improving irrigation efficiency. According to [10,11], poor irrigation water management, poor uniformity, and poor distribution of water can be cited as the most frequent problems of surface irrigation, resulting in waterlogging, salinization, and low water use efficiency. Water application in times of crop need with just enough water to be followed [12]. The knowledge of when to irrigate and how much water to apply is essential to optimize crop production per unit area. In this regard, numerous researchers confirm the importance of irrigation scheduling on different crops. According to [13], irrigation scheduling significantly affects the yield and water use of onions. [14] argue that management allowed deficit (MAD) based irrigation scheduling significantly affects the tuber and dry matter yield of potato. [11] claim that different irrigation regimes provide statistically different tuber and biomass yields of potato.

This study aimed to identify the most suitable irrigation schedule (the irrigation interval and amount of water) for potato in Southern Ethiopia to improve yield and water productivity. Knowledge of the relationship between soil, water and plants is important for effective irrigation scheduling. In the study area potato is the most familiar crop with the irrigation system. So far, there have been no studies conducted concerning the irrigation scheduling of potato in the study area. Farmers follow traditional methods of irrigation, which result in low yield production and low efficiency irrigation use [15,16]. Their irrigation interval turns are mutually agreed upon and fixed among growers according to a pre-determined schedule. However, this method does not give due consideration to crop water requirements, soil and water relations, yield responses, scarcity of water, and climatic conditions.

II. Materials and Methods

A. Description of the Study Area

The experiment was conducted at Misrak Azernet Berbere woreda, Silte Zone, in southern Ethiopia. The study area was geographically located at $07^{0}02'1°$N latitude and $38^{0}20'51°$E longitude with an altitude of 2483 m.a.s.l. The area has usually bimodal rainfall climatic conditions (Belg and mihr in local languages) with the first phase usually starting in March and the second phase of the rainfall begins in June yearly. The mean daily temperature is 17.5°C with a maximum of around 26°C in during dry seasons.

B. Experimental Treatments and Design

The experiment constituted four irrigation intervals, viz., 5, 7, and 9-days intervals, and farmer practice as a check. The amount of irrigation water for each interval was calculated based on climatic and crop data. The experimental treatments were arranged in a randomized complete block design (RCBD) with three replications. The experiment was conducted for two succussive dry season of the years 2019 and 2020.

C. Soil Data

The composite soil sample was collected from the experimental field to determine physical and chemical properties such as texture, bulk density, the water content at FC and PWP, and pH. The bulk density was calculated using:

$$\mathrm{BD} = \frac{\text{Weight of dry soil(gm)}}{\text{Volume of the same soil(cm}^3)}$$

Where: BD is bulk density (gm.cm3)

The water content of the soil at field capacity and the permanent wilting point was determined in the laboratory by using pressure membrane apparatus. It was adjusted to 0.33bar to determine field capacity and 15bar to determine the permanent wilting point. Total available water (TAW) in the root zone was computed as the difference in moisture content between FC and PWP [17]. It is computed as follows:

$$\mathrm{TAW} = \frac{(\mathrm{FC} - \mathrm{PWP}) * \mathrm{Dr}}{100} * \mathrm{BD}$$

Where: TAW is total available water (mm/Dr), FC is water content at field capacity (%), PWP is water content at permanent wilting point (%), Dr is effective depth of root zone (mm) and BD is bulk density of the soil (g/cm^3).

D. Climatic Data

There were no established meteorological nearby stations in the experimental area. Therefore, New locClim1.10 database software program was used to generate weather data. The New locClim database program provides average climatic data for locations with no gauged data are available [18]. Maximum and minimum temperature (˚C), humidity (%), wind speed (km/day) and sunshine (hours), and rainfall (mm) of the experimental site was obtained from New locClim1.10 software.

E. Determination of Crop Water Requirement (CWR)

For the determination of crop water requirement, the effect of climate on crop water requirement, which is the reference crop evapotranspiration (ETo), and the effect of crop characteristics (Kc) are important [19]. Crop water requirements over the growing season were calculated from reference evapotranspiration (ET_o) and crop coefficient (Kc). Crop evapotranspiration is computed as:

$$\mathrm{ETc} = \mathrm{kc} * \mathrm{ETo}$$

Where: ETc is crop evapotranspiration (mm/day), kc is crop coefficient (fraction), ETo is reference evapotranspiration (mm/day)

The FAO irrigation and drainage paper No. 56 was used to determine the crop coefficient of potato [17], since there were no location-based crop coefficients determination for potato in Ethiopia. The New locClim estimated climatic data was used to compute the reference evapotranspiration (ET_o) of each month using CROPWAT8.0 model. The net irrigation requirement was calculated using the CROPWAT computer program based on [17] recommendation:

$$\mathrm{IRn} = \mathrm{ETc} - \mathrm{Pe}$$

where, IRn is net irrigation requirement (mm), ETc in mm, and Pe = effective rainfall (mm)

The effective rainfall (pe) is estimated using the method given by [17].

Pe = (P (125 – 0.2*P))/125 for P <= 250 mm

Pe = 125 +0.1*P for P > 250 mm

where, P is total rainfall (mm) and Pe is effective rainfall (mm) However, since there was no rainfall during the experimental period, Pe is equal to zero and the net irrigation requirement was taken as equal to the crop water requirement. Gross irrigation requirement was calculated by:

$$IR_g = \frac{IR_n}{Ea}$$

Where IR_g is gross irrigation requirement (mm), IR_n is net irrigation requirement (mm), Ea is application efficiency (Fraction)

The initial irrigation interval was calculated using net irrigation and crop water requirement:

$$I = \frac{IR_n}{ETc}$$

where, I, is irrigation interval in days

The depth of irrigation water applied in each irrigation event was measured by partial flume. The time required to deliver the desired depth of water into each plot was calculated as:

$$T = \frac{A * dg}{6Q}$$

Where: T is time (minute), dg is gross irrigation depth (cm), A is an area of the plot (m^2), and Q is the flow rate (l/s).

The depth of water that can be applied in the next irrigation without adversely affecting the crop yield could be computed as follows:

RAW = TAW*p

where, RAW is the readily available water (mm) and p is the depletion fraction which is assumed as 40%.

F. Agronomic Practice

The experimental field was arranged based on the slope of the field, which is suitable for furrow irrigation. Plowing, weeding, and leveling of the field were done for all plots equally in order to reduce bias. Each plot had a 16 m^2 (4 m x 4 m) area. The space between plots and blocks was 1 m and 1.5 m, respectively. A sprouted potato bulb was used as seed for planting and a regular irrigation schedule was followed based on the pre-scheduled irrigation interval and amount of water for each treatment. The space between potato plants and rows was kept at 40 cm and 1 m, respectively. The recommended NPS (200 kg/ha) fertilizer was applied during planting and urea (100 kg/ha) was applied in a split of which 1/2 was applied during planting and the other half was applied after 6 weeks after planting. The amount of irrigation applied in each irrigation event was measured using a 3-inch partial flume. The irrigation water was applied in a furrow irrigation system with an application efficiency of 60%.

G. Data Collection

The crop data, such as the number of tubers per plant, marketable yield, and non-marketable yield weight, were recorded from each plot. Sample plants were selected from each plot to count the number of tubers, and the average tuber number for each treatment was recorded. At the end of the season, yield data was taken from each plot and the average treatment yield was recorded. According to Lemma and [20], the harvested yield needs to be grouped into quality for the market according to its size and degree of damage. The collected data was subjected to statistical analysis.

H. Crop Water Productivity (CWP)

Physical water productivity can be expressed as the quotient of agricultural products to the amount of water used ("more crop per drop"), whereas economic water productivity *is* expressed as the value gained per unit of water consumed [21]. More importantly in water scare regions, maximizing the water use efficiency has become popular strategy to combat drought impacts [22]. In this study, the crop water productivity was calculated by dividing the harvested yield in kg by the seasonal volume of water used. The CWP was computed as*:*

$$CWP(Kg/m3) = \frac{Yield(kg)}{ETc(m3)}$$

The SAS 9.0 statistical software package was used to analyze the data, which was done in accordance with the standard RCBD procedures. When the treatment effects were found to be significant, mean differences were identified using LSD to compare the statistical difference among treatment means.

III. Results and Discussion

A. Soil Physical Properties

Based on the soil textural classification of the USDA, the experimental field soil was clay loam soil. The soil bulk density, FC, and PWP were 1.03g/cm^3, 35.74%, and 17.81%, respectively. This bulk density value was lower than the critical threshold level (1.4gm/m^3**)** for any texture soil class [23]. In general, these values are suitable for crop root growth.

B. Irrigation Water MAnagement

Gross irrigation was computed by considering an application efficiency of 60%. The depth of irrigation water applied to each plot was the gross depth of irrigation. The calculated net irrigation water requirements were 31.6mm, 83.7mm, 179.4mm, and 102.1 mm per season for the initial, development, mid-season, and late-season stages, respectively.

C. Effects of Irrigation Scheduling on Potato yield

The two-year combined yield and number of tubers per plant results are presented in Table 3. The maximum total and marketable tuber yield of potato was obtained at a 9-day irrigation interval and it was statistically superior to all other irrigation intervals. However, there was no statistically significant tuber yield difference between irrigation intervals of 5 and 7 days. This result is in line with the result obtained by [11]. The minimum total and marketable tuber yield of potato were obtained from farmers' practices. The least unmarketable tuber yield was recorded from a 9-day irrigation interval, and it was smaller than all other treatments. Furthermore, the number of potato tubers per plant was also highest at the 9-day irrigation interval, but there was no statistically significant difference with the 5- and 7-day irrigation intervals. The smallest number of potato tubers per plant was recorded from farmers' practice and shows no significant difference between the 5- and 7-day irrigation intervals.

Both the highest yield and number of tubers per plant are obtained from the 9-day interval treatment. Crop yield and water productivity are strongly co-related to soil and crop property. The irrigation interval is extremely affected by the soil textural class [24]. As it is shown in Table 1, the soil textural class of the experimental area is clay loam, which has high water storage capacity. In clay-textural soil, frequent irrigation intervals have the probability of creating water logging and soil nutrient leaching, which may result in yield and water productivity reduction. As it is shown in Table 3, the farmers' practice treatment resulted in a minimum total yield and also a minimum number of tubers per plant. In the study area, farmers apply water regardless of soil property information because they think that yield maximization is related to high water application.

TABLE I. Soil Analyzed Results

Parameters	Soil result
Sand (%)	35.23
Clay (%)	36.23
Silt (%)	28.54
Textural class	Clay loam
Bulk density (gm/cm3)	1.03
Field capacity (%)	35.74%
Permanent wilting point (%)	17.8 %,
Soil Infiltration rate (mm/hr)	11.4

D. Effects of Irrigation Scheduling on crop physical water productivity

The maximum crop physical water productivity is obtained from a 9-day irrigation interval, which is 3.3 kg/m3, and the minimum water productivity is attained from farmers' practice treatment, which is 2.4 kg/m3. We can observe that between the maximum and minimum water productivity there is a 0.9kg/m3 difference. The crop physical water productivity of the treatments in this experiment is presented in Table 4. The yield of farmer's practice treatment is the lowest, so its water productivity is the lowest too. This result indicates application of the right amount of water at the right time increases not only yield but also improves water productivity.

Effective irrigation scheduling improves the water productivity of crops [25]. Effective irrigation scheduling improves water productivity in two ways. The first one is due to optimum water application; the crop can get conducive root zone aeration and can reduce the crop diseases that come from water logging conditions. The susceptibility of crops to water logging depends on crop and soil type. More generally, waterlogged conditions can affect crop yields and water productivity. The second one is that effective irrigation scheduling can reduce the application of unusable water, that is, water that cannot be used by the crop. Much of the applied water is not used by crops. A portion of the water deep percolated out of the root zone, and some of it may have runoff from the field. Effective irrigation scheduling reduces this water loss and can increase water productivity.

TABLE II. IRRIGATION WATER REQUIREMENTS OF POTATO

Date	Stages (days)	ETC mm/day	IRn mm/period	IRg mm/period
Dec 1 to 19	Initial (19)	1.7	31.6	52.7
Dec 20 to Mar 10	Deve (31)	2.7	83.7	139.5
	Mid (40)	4.5	179.4	299.0
Mar 11 to Apr 10	Late (27)	3.8	102.1	170.1
Total	117	12.6	396.8	661.3

TABLE III. MEAN YIELD & YIELD COMPONENT VALUE OF POTATO DURING 2019 AND 2020

Treatments	NTPP	NMY(t/ha)	MY (t/ha)	TY (t/ha)
5 day interval with 100% CWR	13^{ab}	0.51a	19.18^{b}	19.69^{b}
9 day interval with 100% CWR	14^{a}	0.22^{c}	21.78^{a}	21.99^{a}
7 day interval with 100% CWR	12^{ab}	0.71^{a}	17.64^{b}	18.35^{b}
Farmers practice	10^{b}	0.83^{a}	14.97^{c}	15.80^{c}
CV	13	9.53	13.12	7.15
LSD (5%)	3.45	0.17	1.83	1.66

NFPP-Number of tuber per Plant, NMY-non-marketable yield, MY- Marketable yield, TY - Total Yield, t-tone, and ha-hectare

TABLE IV. EFFECTS OF IRRIGATION SCHEDULING ON WATER PRODUCTIVITY

Treatments	m^3/ha	Yield(kg/ha)	WP (kg/m^3)
5-day interval with 100% CWR	6613	19690	3.0
9-day interval with 100% CWR	6613	21990	3.3
7-day interval with 100% CWR	6613	18350	2.8
Farmers practice	6577	15800	2.4

NB: m3/ha- the volume of water applied per hectare

IV. CONCLUSION

This study illustrates that differences in irrigation interval significantly affect the yield and water productivity of potato. Information on when and how much to irrigate is an important part of irrigation production to attain the required yield and water productivity. Crop yield is the result of the environmental and genetic make-up of the crop. Application of optimum water at the right time provides the required yield and water productivity in combination with other optimum environmental factors. From this experiment, we can conclude that frequent irrigation regardless of the soil property reduces the potato yield significantly (for example, farmers' practice treatment in this experiment). For soils that have high water holding capacity, for example, clay soils, the irrigation interval needs great consideration. Before irrigation, the soil water holding capacity, irrigation interval at specific crop growth stages, and amount of water that needs to be applied have to be known. For this specific experimental area, the 9-day irrigation interval gives the highest yield and water productivity. The 9-day irrigation interval also reduces the cost of production, such as labour and fuel, compared with other treatments since the working days are reduced. This result is particularly important as it may allow farmers to increase their income through better yields and minimize labor costs. Therefore, an irrigation interval of 9-days is the most recommended in this specific study area and other similar agro-ecologies.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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