

Determination of Optimal Irrigation Scheduling for Maize (*Zea Mays*) at Teppi, Southwest of Ethiopia

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Abstract

Appropriate irrigation practice is relevant for increased crop productivity and conservation of water resources. No or little concern has been given to the necessity and extension of existing irrigation technologies while the impacts of climate change are visible throughout Ethiopia. A field study was carried out for determining optimal irrigation scheduling for maize production at Teppi, South west Ethiopia for three successive years. The objectives of the study were to evaluate the effect of different irrigation regime (different soil moisture depletion levels) on yield and water use efficiency of hybrid maize (BH-140). The treatments were set based on the recommended soil moisture depletion levels for maize (MAD=0.55). Then five levels of soil moisture depletion were selected for evaluation of optimum irrigation scheduling namely SMD1 (60%), SMD2 (80%), SMD3 (100%), SMD4 (120%), and SMD5 (140% of the recommended value, 0.55). The result indicated that SMD4 has significantly ($P<0.05$) increased the grain yield and water use efficiency of maize crop on a clay loam textured soil. In addition the total crop water requirement was 535.60 mm. However, the reduced soil moisture depletion level below the recommended values (SMD1 and SMD2) has resulted lower both grain yield and crop water use efficiency. This study also revealed that the appropriate irrigation interval at each crop growth stage should be identified for ease of work to the users.

Keywords: Irrigation scheduling; Water use efficiency; Maize; Teppi

Introduction

Irrigation practice is one of the measures for increasing crop production for Ethiopia whose major economic development is dependent on agricultural production. The country has experienced with severe drought occurrences for the last four decades even though ample amount of water resource from precipitation, surface and sub-surface exist in its periphery.

Ethiopia is one of the largest maize producing countries in Africa. Maize, in Ethiopia, is the main food securing crop that accounted 16.7% in terms of calorie intake, surveyed nationally at 2004/05 [1].

However, the cultivation of maize is mostly dependent on rainfall. Awulachew has explained that the country should double its cereal production to meet the rapidly growing population food demand by 2025 [2]. For this reason, the country is fortunate to cultivate more lands through irrigation especially in its Southwest part where deep fertile soil resources exist.

In the study area, little concern has been given to the necessity and extension of irrigation technologies due to the presence of sufficient rainfall. However, recently, the occurrence of erratic rainfall or impact of climate change drastically reduced crop production. Consequently, traditional irrigation practices are being used for cultivating vegetables in different areas. However, both crop and irrigation water requirement including irrigation scheduling are not known. For better production of medium matured maize crop, Doorenbos has recommended 500 to 800 mm depth of water depending on the climate [3]. In addition, Allen has expressed the soil moisture depletion level for maize should be 0.55 [4]. However, the recommendations are needed to be verified on the operational environment since the crop water requirement is dependent on the type of crop (variety) and climatic condition. For effective use of available water resource, it is relevant to determine the actual crop water need and the right time of water application (irrigation scheduling). Hence, this study was conducted to determine the optimum irrigation scheduling based on the soil moisture depletion levels for hybrid maize (BH-140) at Teppi (Figure 1 & 2). The identified information is important for increased crop production and productivity, improved irrigation water management, and conservation of the environment.

Materials and Methods

General description of the study area

The experiment was conducted at Teppi National Spice Research Center, on station. It is found in Southwest of Ethiopia which is 611 km far from Addis Ababa. It is located at 7.180 N latitude and 35.420 longitudes E with an altitude of 1200 masl. The mean maximum and minimum monthly temperature is 29.850°C to 18.010°C. The area is categorized as hot to warm humid/sub-humid low lands with an annual rainfall of 1563.24 mm. The soil has deep clay loam texture, and 7.3 mm/h intake rate. The source of irrigation water is Shay River which is suitable for irrigation purpose.

Experimental design

The experiment was done for three consecutive years (2013-2015). It was arranged in randomize complete block design with three replications. The treatment was rated for five levels of soil moisture depletion (SMD). The recommended allowable soil moisture depletion for maize is 55% of the total available soil moisture that was used as 100% of SMD. The rates were 60%, 80%, 100%, 120%, and 140% of SMD. The total number of plots was fifteen where the size of each plot was 4 m². Hybrid maize variety (BH-140) was sown at the seed rate of the area (25 kg/ha) and all the recommended practices for the area were applied during the growing season (Figure 3).

Climatic and soil data collection

Climatic data and Reference evapotranspiration: Long-term (20

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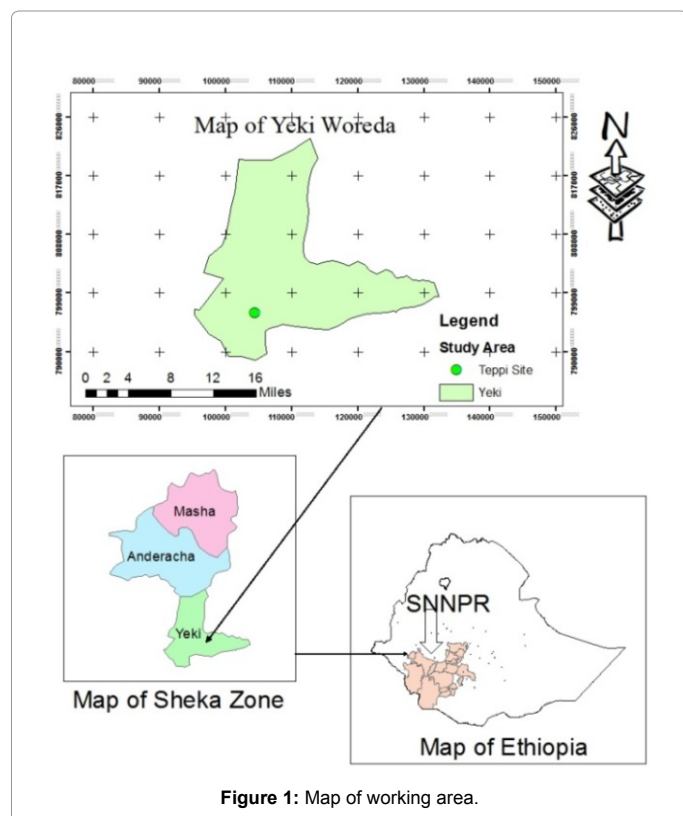


Figure 1: Map of working area.

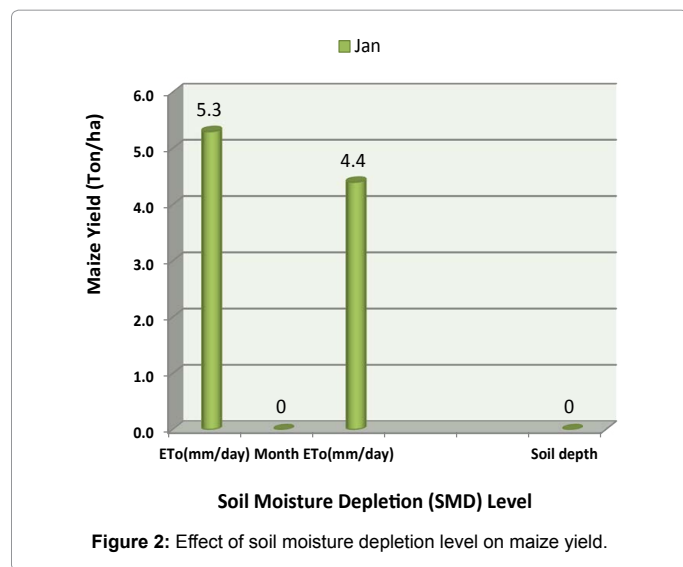


Figure 2: Effect of soil moisture depletion level on maize yield.

years) monthly climatic data of Teppi area was collected from National Meteorological Agency of Ethiopia. The parameters included are rainfall, maximum and minimum temperature, relative humidity, wind speed, and sunshine hours. The monthly reference evapotranspiration of Teppi area was estimated by using FAO CROPWAT 8 program by using long term climatic data (Table 1).

Crop water requirement

For research purpose, the crop water requirement is determined by summing the net depth of water required (dnet) at each irrigation event throughout the crop growing season. The amount of water applied to

the crop root zone was applied based on the soil moisture depletion level at each growth stage (Table 2). The net irrigation requirement was calculated using the water balance formula.

$$\text{NIR} = d_{\text{net}} - \text{Pe} - \text{GW} - \Delta\text{SW} \quad (1)$$

Where,

NIR=Net irrigation requirement, mm

dnet=Net depth of water required, mm

Pe=Effective precipitation, mm

GW=Ground water recharge, mm

ΔSW=Change in soil water content, mm

Water table of the experiment site is deep enough and vertical towards the crop root zone was assumed as negligible. Hence, the ground water recharge is negligible.

The net depth of water required (dnet) was determined by the equation provided by [5].

$$d_{\text{net}} = \text{TAW} \times \text{Zr} \times \text{P} \quad (2)$$

Where,

dnet=Net depth of water required (mm)

P=Allowable soil moisture depletion by the crop (0.55).

TAW=Total available soil moisture (mm/m).

$$\text{TAW} = 10 \times (\theta_{\text{FC}} - \theta_{\text{PWP}}) \times \text{Zr} \quad (3)$$

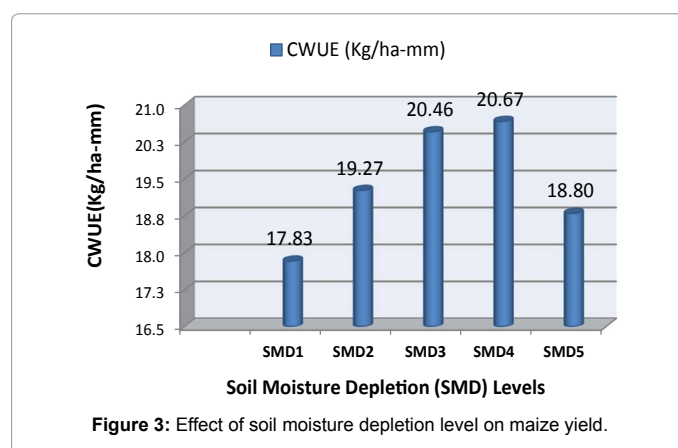


Figure 3: Effect of soil moisture depletion level on maize yield.

Month	Jan	Feb	Mar	April	May	June	Average
ETo (mm/day)	5.3	5.9	5.9	5.3	4.9	4.7	
Month	July	Aug	Sep	Oct	Nov	Dec	5.1
ETo (mm/day)	4.4	4.6	5.1	5.2	5.3	5	

Table 1: Monthly reference evapotranspiration of Teppi, Southwest of Ethiopia.

Soil depth	Bulk density	Field capacity	Wilting point	Available water/ depth
	g/cm ³	%	%	mm
0-30cm	1.27	37.1	26.8	130.17
30-60cm	1.27	37.8	25.5	156.21
60-90cm	1.27	38	25.6	157.48
Average	1.27	37.6	26	147.96

Table 2: Soil physical characteristics of study area.

Where,

TAW=Total available soil moisture, mm/m

θ_{FC} =Volume moisture content held at field capacity, %

θ_{PWP} =Volume moisture content held at wilting point, %

Zr=Effective crop root depth, m

Effective rainfall was computed using the National Resource Conservation [6] method and it is described in the following equations.

$$Pe = \frac{[P \times (125 - 0.2 \times 3 \times P)]}{125}; \text{ for } P < 250/3 \quad (4)$$

$$Pe = \frac{125}{3} + 0.1P; \text{ for } P > 250/3 \quad (5)$$

Where,

Pe=Effective precipitation determined in mm/decade.

P=Total precipitation occurred in the crop growing season in the area, in mm/decade.

Gross irrigation requirement (GIR)

GIR is determined using the following formula developed by [5].

$$GIR = \frac{NIR}{(1 - LR) \times Ea} \times 100 \quad (6)$$

Where,

GIR=Gross irrigation requirement (mm)

NIR=Net irrigation requirement (mm)

LR=Leaching requirement (fraction)

Ea=Application efficiency (%)

Irrigation scheduling

Irrigation frequency: The number of days between two subsequent irrigations, irrigation frequency, was determined by using equation (7).

$$IF = \frac{Y}{ETc} \quad (7)$$

Where,

IF=Irrigation frequency (days)

d_{net} =Net depth of water required (mm)

ETc=Crop evapotranspiration (mm/day)

The crop evapotranspiration used in irrigation frequency determination was estimated by multiplying crop coefficient with reference crop evapotranspiration [7].

Yield and water use efficiency

The fresh maize grain yield and water use efficiency was selected as dependent variable. CWUE is the quantity of crop yield (Kg/ha) produced per unit depth (mm) of water used [8].

$$CWUE = \frac{Y}{ETc} \quad (8)$$

Where,

CWUE=Crop water use efficiency, kg/ha-mm

Y=Yield of crop, kg/ha

ETc=Crop water requirement, mm

Data collection and analysis

From three consecutive years, data on grain yield and water use efficiency of maize were recorded. The results of yield and water use efficiency were subjected to Analysis of Variance test using the general linear model (GLM) in SAS 9.2 program. The least significant difference (LSD) test at 5% of probability was employed to distinguish among the treatment means.

Results and Discussion

Crop water requirement

The maize, BH-140 variety, was planted on February 26, 2013-2015. As shown detail in Table 3, ten irrigation events with 390.66 mm total irrigation water supplied in the entire crop growing period. The amount of rainfall occurred during cultivation time was very small and the presence of irrigation water could show its importance.

Maize grain yield

The results of pooled mean from the three consecutive years showed that the use of different soil moisture depletion levels were significantly effective ($P < 0.05$) in maize production. As described in Table 4, the mean maize grain yield was gained as 10.4 ton/ha. The maximum yield was obtained when the soil moisture depletion level was reached 120% (SMD4) of the recommended level (55%). However, the yield has declined by 12.7% when the soil moisture depletion level was reduced from the recommended by 40%. The least grain yield was obtained from SMD1 which was practiced with frequent irrigation application or increased number of irrigation event that has the most payments for labors.

Maize water use efficiency

The effect of different management allowable depletion levels were significant ($P < 0.05$) on maize water use efficiency. As described in Table 4, the efficiency of an individual crop to convert irrigation water to maize grain was high in treatment SMD4 which has given 24.3 kg/ha-mm. The minimum crop WUE was 21.01 kg/ha-mm that has showed the least effectiveness of using water for making maize grain. The response of crop water use efficiency had increasing tend when the soil moisture depletion rose from SMD1 to SMD4 but SMD5 was seen with longest irrigation interval and crop stress that has led to reduced water use efficiency.

Conclusion

This study showed that managing the soil moisture content at

Irrigation Event	CWR	Pe	NIR	GIR
	mm	mm	mm	mm
1	7.12	0	7.12	10.17
2	8.9	0	8.9	12.71
3	14.24	3.05	11.19	15.98
4	32.04	6.2	25.84	36.91
5	64.04	5.2	58.84	84.06
6	101.99	4.8	97.19	138.84
7	103.22	0	103.22	147.45
8	103.3	15	88.3	126.14
9	100.77	30.6	70.17	100.24
Total	535.6	64.95	470.65	672.36

Note: CWR=Crop water requirement; Pe=Effective rainfall; NIR=Net irrigation requirement; GIR=Gross irrigation requirement

Table 3: Crop water requirement and irrigation scheduling for (120% MAD).

Treatment	GY	CWUE
	Ton/ha	Kg/ha-mm
SMD1 (60%)	9.567 ^b	17.833 ^b
SMD2 (80%)	10.32 ^{ab}	19.267 ^{ab}
SMD3 (100%)	10.97 ^{ab}	20.456 ^{ab}
SMD4 (120%)	11.078 ^a	20.667 ^a
SMD5 (140%)	10.07 ^{ab}	18.800 ^{ab}
Mean	10.4	19.4046
LSD (5%)	1.44	2.7118
CV (%)	14.38	14.47

Note: GY=Grain yield of Maize; CWUE=Crop water use efficiency

Table 4: Response of maize (BH140) for different irrigation regimes.

different depletion level has influenced the production and water use efficiency of hybrid maize. The total crop water requirement is 535.60 mm. Reducing the soil moisture depletion level by 40% from the recommended fraction (0.55) has significantly reduced both the grain yield and crop water use efficiency. In addition under clay loam soil texture, the use of frequent irrigation is not advisable due to water logging problem. In other hand, by increasing the soil moisture depletion level with 20% over the recommendation or depleting 66% of the total available soil moisture, the grain yield and crop water use efficiency could be improved. Since the area has humid climatic condition and heavy textured soil, longer irrigation interval is advised against water logging. This study also revealed that the appropriate irrigation interval at each crop growth stage should be identified in the area for ease of work to the users.

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