Determination of Optimum Irrigation Scheduling and Water Use Efficiency for Maize Production in North-West Ethiopia

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Abstract
In irrigated agriculture, efficient water management is an important element. Such practices can help bust sustainable production and maintain farm profitability in which there is limited water resource. This study aimed to generate information on optimal irrigation scheduling for Maize on Vertisol in Metekel Zone, North-West of Ethiopia for proper use of irrigation water and consequently improvements in irrigated agriculture. The study was conducted by Pawe Agricultural Research Center for two years. Where long term metrological data (23 years) and CropWat software were used to determine optimum irrigation scheduling for Maize. The experiment was laid out in Random Complete Block Design (RCBD) with three replications. Five treatments of irrigation were employed and the amount of water which was applied in each irrigation interval was measured with partial flume. Grain yield, water use efficiency and other yield component parameters of maize subjected to different allowable soil moisture depletion levels had a statistical significant in 2011 but no significance different in 2012 However, maximum grain yield of 3777 kg/ha and 2951 kg/ha was obtained from 140 % Available Soil Moisture Depletion Level (ASMDL) followed by 2753 kg/ha and 2598 kg/ha at 80% ASMDL of two years. Besides; the highest water use efficiency of 1.970 kg/m^3(2011) and 2.103 kg/m^3(2012)was obtained at 80% and FAO recommended ASMDL respectively. Therefore, the obtained results are valuable in improving water productivity but economic analysis should be included for further recommendation.
Keywords: CropWat, ASMDL, Optimum scheduling, and Weather parameters.

1. Introduction

Ethiopia is known to be endowed with a huge surface and ground water resources that has given a prestige of being called the water tower of East Africa. Quite a significant number of lakes, dams and reservoirs are also found in various parts of Ethiopia. The national master plan study indicated that Ethiopia has 12 river basins, which provide an estimated annual surface run off of ~125 billion m^3 and groundwater potential vary from 2.6 to 13.5 billion m^3. The total potential irrigable land in Ethiopia is 5.3. Mha (Awlachew, 2010 and 2011) including 1.6 Mha through rain rater harvesting. Based upon the various river basin master plans and land and water resources survey, the aggregate irrigation potentials of Ethiopia have been estimated to be 2.6 Mha net (FAO, 2014), and the gross irrigation potential would be about 3.7 million hectares. The total irrigated area till 1998 was only 197,250 ha, this figure had increased to 2.34 million hectare in 2014/15. Expansion of the area under cultivation is a finite option, especially in view of the marginal and vulnerable characteristics of large parts of the country's land and increasing population. Increasing yields in both rain-fed and irrigated agriculture and cropping intensity in irrigated areas through various methods and technologies are therefore the most viable options for achieving food security (IWMI, 2005). Agriculture sector is facing increasing challenges in the face of changing climate, rapid population growth, increasing salinity accumulation, land degradation, decreasing availability of land and competition for scarce water resources. One of the most important considerations in increasing and stabilizing agricultural production is through irrigation and drainage development, reclamation of degraded lands and wise use of water resources (Gebremedhin and Asfaw, 2015; Hagos et.al, 2009). The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in any country (Diriba *et.al,* 2013). Although Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of agricultural water management.

Irrigation implies the application of suitable water to crops in sufficient amount at the suitable time. Salient features of any improved method of irrigation is the controlled application of the required amount of water at desired time, which leads to minimization of range of variation of the moisture content in the root zone , thus reducing stress on the plants. Irrigation scheduling is the process of determining when to irrigate and how much irrigation water to apply (Ali, 2010). The depth of irrigation water which can be given during one irrigation application is however limited. The maximum depth which can be given has to be determined and may be influenced by the soil type and the root zone depth. Thus, just after planting or sowing, the crop needs smaller and more frequent water applications than when it is fully developed. Hence, there is limited information on the water use efficiency, frequency and amount of water in production of irrigated maize. The objectives of this study is to evaluate the responses of crops to frequency and amount of irrigation and water use efficiency of irrigated maize production on Vertisols of Metekle Zone of Benishagul Regional state, North-West of Ethiopia

2. Materials and methods

2.1 Study area description

The study was conducted in Metekel zone of Benishangul and Gumuz Regional State, North-West of Ethiopia. It is the largest zone of the region covering an area of 3,387,817 hectares consisting of seven 7 districts: Wombera, Bullen, Manbuk, Dibate, Mandura, Guba and Pawe special Woreda. The topography of the zone presents undulating hills slightly sloping down to low land Plateaus having varying altitudes from 600- 2800 m.a.s.l. and the annual rainfall of the area is 900-1580mm. About 80% of the area is characterized by sub-humid and humid tropical climate with annual minimum and maximum temperature of 20^{o}C and 35^{o}C respectively (Metekel Zone, Department of Agriculture). The dominant vegetation cover of the region is characterized by different types of woodland which include broad-leaved deciduous woodland, acacia woodland, riparian woodland along the major rivers, Boswellia woodland and bamboo thicket (UNDP/ECA, 1998). According to Ministry of Agriculture (MoA) and Agricultural Transformation Agency (ATA), 2013; the surrounding of Metekel Zone has a wide climatic range within hot to warm moist lowlands (M1) and hot to warm sub humid lowlands (SH1) agro-ecological zones.

2.2 Experimental design

The experiment was conducted for 2 consecutive years (2011 and 2012). It was arranged in RCBD with 3 replications. The treatment was rated for 5 levels of soil moisture depletion (ASMDL). The recommended allowable soil moisture depletion for maize is 55% (Allen et al., 1998) of the total available soil moisture that was used as 100% of ASMDL. The rates were 60%, 80%, 100%, 120%, and 140% of ASMDL. The total number of plots was 15 where the size of each plot size of 5.1m X 3.75m and all the recommended agronomic practices were applied during the whole growing period.

Table 4. Treatment combinations

Description	**Treatments**
SMD1	60% ASMDL
SMD2	80% ASMDL
SMD3	100% ASMDL*
SMD4	120% ASMDL
SMD5	140% ASMDL

* FAO recommended allowable soil moisture depletion for Maize (Allen et al., 1998).

2.3 Input parameters and data descriptions

2.3.1 Climatic and soil data of study area.

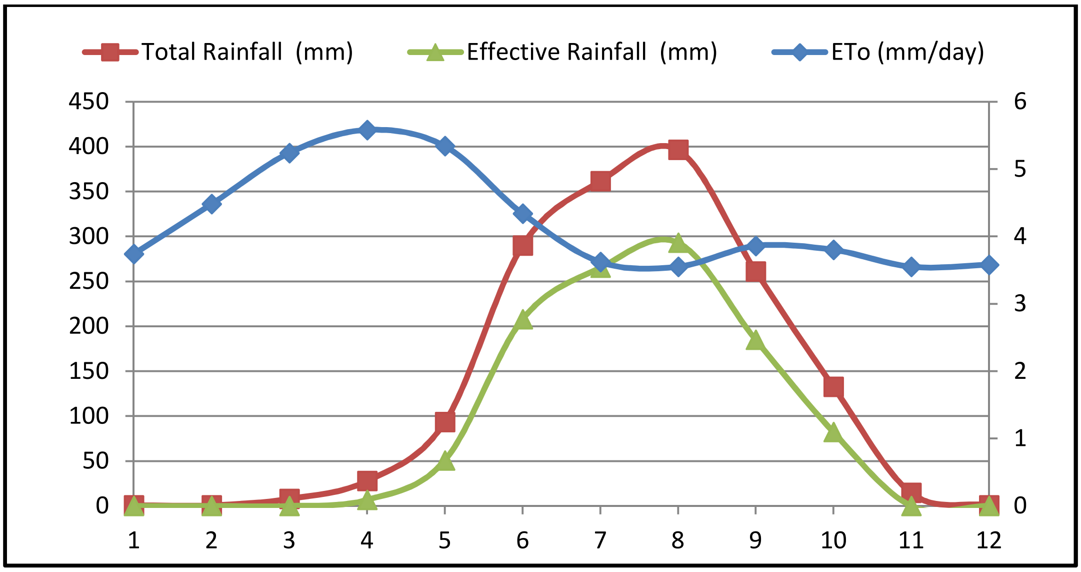
More than 23 years climatic data of study area (Pawe) and its surrounding were collected from Pawe Agricultural Research Center and National Meteorological Agency (NMA) of Ethiopia. The used parameters used were rainfall, maximum and minimum temperature, relative humidity, wind speed, and sunshine hours. Then monthly reference Evapo-transpiration (ETo) of the study area was estimated by CROPWAT8 software model (Table-2).

Table 5. Estimated ETo from climatic data records of 23years (1987-2011)

Longitude-36.05E Latitude-11.15N Altitude-1120 m.a.s.l									
Month	Max. temp.	Min. temp.	Relative humidity	Wind speed	Sun shine	Solar radiation	Total rainfall	Effective rainfall	**ETo**
	(0C)	(0C)	(%)	km/day)	hours	(MJ/M2/d)	(mm)	(mm)	**(mm/day)**
January	34.19	11.81	38.25	39.85	9.67	21.12	0.71	0	**3.78**
February	36.18	14.49	40.29	53.58	9.28	22.05	0.64	0	**4.58**
March	37.64	17.93	44.69	65.49	8.71	22.54	7.85	0	**5.24**
April	37.43	19.35	48.10	75.89	8.85	23.22	27.79	6.7	**5.60**
May	34.91	19.39	58.30	78.53	8.02	21.56	93.23	50.6	**5.27**
June	30.06	18.09	66.62	78.70	6.45	18.85	289.79	207.8	**4.31**
July	27.76	17.81	71.68	58.69	4.56	16.20	361.37	265.1	**3.57**
August	27.74	17.57	71.12	51.06	4.80	16.86	396.25	293	**3.55**
September	29.05	17.30	67.16	46.71	6.12	18.59	261.06	184.9	**3.81**
October	30.46	16.84	62.51	29.68	7.27	19.50	132.57	82.1	**3.87**
November	32.36	14.12	46.89	27.69	9.29	20.83	14.37	0	**3.85**
December	33.70	12.15	40.23	41.35	9.77	20.61	0.72	0	**3.84**
Average	**32.62**	**16.40**	**54.65**	**53.93**	**7.73**	**20.16**	**1586.36**	**1090.20**	4.27

From long term trend of main rainfall of the study area, the maximum was recorded in August flowed by July, June and September respectively. These are called wet season in the area because it receives ample amount of rainfall hence no irrigation is recommended not even supplemental but minimum or no effective rainfall in February followed by December, January and March respectively and these are a dry season which needs full irrigation in the area. However; maximum and minimum reference Evapo-transpiration (ETo) was recorded as 5.60 and 3.55 mm/day in April and August respectively (Fig.-1).

Figure 2. Mean Monthly rain fall, effective rainfall and ETo values of study area



The soil type of the study area is characterized by heavy clay soil with initial available soil moisture depletion level 111-129 (mm/meter depth) and total available soil moisture level was 222-259 (mm/meter depth) varying with soil depth. Hence; the soil is heavy clay, a mean infiltration rate was recorded 70 mm/day and the bulk density was varying from 1.12-1.31gm/cm3 across the depth of 1.2 meter (Table 3).

Table 6. The soil characteristics and description of different area around Pawe

Soil description	Heavy Clay to clay loam
Total available soil moisture	222.30-259.15 (mm/meter depth)
Percentage of Initial soil moisture depletion	50%
Initial available soil moisture depletion	111.15-129.575(mm/meter depth)
Maximum infiltration rate	50-90 (mm/day)
Maximum rooting depth	Up to 1.5meter
Bulk density	1.12-1.31gm/cm^3

2.3.2 Crop water requirement and irrigation scheduling

According to Savva and Frenken, 2002, crop water requirement usually refers to the Evapo-transpiration from excellently managed, large, well-watered fields. This fields achieve full production under the given climatic conditions and varies substantially during the growing period mainly due to variation in crop canopy and climatic conditions ((Djaman et.al, 2013). For this study, daily crop water requirement was determined by equation-1. Irrigation water requirement (IR) had been calculated by long-term rainfall data from each study sites. Long-term monthly rainfall data was obtained from the study sites and probability analysis was used to establish the dependable rainfall occurrence at 20, 50 and 80% probability levels representing wet, normal and dry seasons, respectively. The obtained values were used during the computation of CWR. Generally, IR can be estimated from the expression:

CWR = ETo x Kc ………………………….. (1)

IR = CWR – Effective rainfall ….………. (2)

Where; CWR= crop water requirement (mm/day) and **Kc** is in fraction which is an empirical ratio of actual crop water use to reference Evapo-transpiration. The Kc- values were obtained obtained from reference texts, in FAO Irrigation and Drainage Paper No. 33 and 56. In this study the CWR was computed using Penman-Monteith method (Allen et al., 1998) from a computer based CropWat models and IR= irrigation requirement (mm).

Effective rainfall which was part of the rainfall that entered into the soil and became available for crop production in mm. Different formulae were available to compute effective rainfall but for this study dependable method equation (3) and (4) was use because it had been developed based on the analysis of different arid and sub-humid climates (USDA, 1997).

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

$$Pe = 125 / 3 + 0.1P; \quad \text{for} \quad P > 250 \ldots\ldots (4)$$

Where; Pe = Effective precipitation determined in mm and **P =** Total precipitation occurred in the crop growing season in the area, in mm.

The preliminary soil physical data for the study area was determined by using equation (5). Since the figures were on weight basis, it was converted to volume bases. But Permissible depletion levels for maize crop were determined at different growth stages using equation (6).

$$TAW = (FC - PWP) \times BD \times Rd \times 10 \ldots\ldots (5)$$

$$ASMDL = TAW \times p \ldots\ldots (6)$$

Where: TAW = Total available soil moisture, mm/m; **FC** = Field capacity of the soil in wt. bases (%); **PWP** = Permanent wilting point of the soil in wt. bases (%); **BD** = Bulk density (g/cm^3) and **Rd** = Root depth (m), **ASMDL =** Available soil moisture depletion level or net irrigation requirement (mm) and **P** = Allowable soil moisture depletion by the crop (0.55).

Crop Evapo-transpiration (ETc) of maize was determined using FAO CROPWAT computer model. Besides, effective rainfall was calculated with this model. Using mean Maize Evapo-transpiration at different growth stages.Net irrigation requirement, irrigation water application interval were calculated and gross amount of water to be applied to the field was determined using 60 % irrigation efficiency separately (Yi, et.al, 2010).

$$\text{Interval (Days)} = \frac{\text{Net IR}}{\text{ETc}} \ldots\ldots (7)$$

$$GI = \frac{\text{Net IR}}{Ea} \ldots\ldots (8)$$

Where; Net IR = Net Irrigation Requirement or ASMDL (mm), **ETc =** Crop Evapo-transpiration (mm/day), **GI =** gross amount of water (mm) and **Ea =** irrigation application efficiency (%).

2.4 Data collection and analysis.

The selected verity of **maize (BH-540)** was planted in January for the consecutive two years in Pawe woreda of Village-24. During the implementation period all agronomic parameters and data of irrigation water was collected following the data sheet including date of 50% emergency, days of 95% maturity, stand count at harvesting, biomass yield (BMY), grain yield (GY) and 100 seed weight. The main yield parameters BMY, GY data and water use efficiency (WUE) were analyzed by appropriate statistical package. The water use efficiency was also calculated using equation (9) and analyzed using SAS software.

$$WUE = \frac{Y}{I} \ldots\ldots (9)$$

Where: WUE=Water use efficiency (kg/m^3) is the amount of maize grain yield per meter cubic of irrigation water applied, **Y** = Yield of maize (kg/ha) **& I** = Total irrigation water applied (m^3/ha).

3. Results and discussion

3.1 Crop water requirement and irrigation scheduling

Computer models, CROPWAT 8 and VTFIT, were used for the computation of the reference crop Evapo-transpiration (ETo) and crop water requirement (CWR) of maize in the study area. The reference crop evapotranspiration (ETo) and crop water requirement (CWR) of Maize for the selected area has been prepared. ETo was computed on monthly basis and CWR was computed for the growing period of the corresponding crops. Since there was no determined crop coefficient (Kc) so far for this area, the FAO recommended Kc values for the maize growth stages are used to calculate CWR. The local planting date of the crops had been used for the computation. The Etc and Irrigation requirement of maize in the study area is shown in Table 4.

Table 7. CWR and Irrigation scheduling of maize in main season of irrigation

Growing Stage	Days	Kc	Etc	Irri. req	Net irr.	Gross irr	Flow (l/s/ha)	Total RF	Effective RF	Rain Loss	Actual irrg. Req.	Irr. interval (days)
Initial	20	0.6	18	18	18.7	22.2	0.38					
Development	35	0.75	121.3	121.3	102.9	127.8	0.75					
Mid	40	1.2	185.2	185	224.9	318.6	1.86					
Late	30	0.85	177.6	162.4	132	182.5	0.91					
Total	125		**502.1**	**486.8**	**478.5**	**651.1**	**3.9**	**56.8**	**54**	**2.8**	**445.7**	**14**
Planting date (dd/mm)			1-Jan	Harvesting date (dd/mm)			5-May					

3.2 Biomass (BM) and grain yield (GY).

Based on the ETc and FAO, the available moisture depletion level had been calculated and field experiment was done for two years to evaluate the effect of deferent moisture depletion level on maize yield and water use efficiency. The biomass yield and grain yield data in 2011 showed significant differences ($P \leq 0.05$) among irrigation treatments. Reducing or increasing the amount of water application interval was significantly affect yield of maize at Pawe Vertisoil of village-24. The highest grain yield increment observed when the application of water was 140% ASMDL and it is 3777kg/ha which is 52% greater that the least yield obtained at treatment 1 (60% ASMDL). The highest biomass yield was also obtained at 140% ASMDL; that was 16,923 kg/ha which is 50 % greater than the least biomass yield obtained at treatment 2 (80% ASMDL). Besides; in 2012, it was observed that there was no significant different at ($P \leq 0.05$) among or interval of biomass and grain yield of maize. The highest grain yield increment was observed on treatment 5 (140% ASMDL) that was 2951kg/ha which is 40 % greater than the least yield obtained at treatment 3 (100% ASMDL). The greatest biomass yield was also obtained at treatment 5 (140% ASMDL), that is 13,072 kg/ha which was about 26% greater than the least biomass yield obtained at treatment 4 (120% ASMDL). Both years analyses showed that the maximum biomass and obtained grain yield was obtained at optimal irrigation regime of 140% ASMDL. Therefore, 140% of ASMDL was identified as best performing for Vertisoil irrigated fields in the study area (Table-5).

3.3 Water use efficiency

The effects of testing different levels of allowable moisture depletion level using maize crop were highly significant at ($P \leq 0.05$). In 2011, the maximum efficiency of the crop to convert irrigation water to grain was high in treatment 2 (80% ASMDL) which had 1.970 kg/m^3 and 2.103 kg/m^3 (100% ASMDL) in 2012. However; the minimum water use efficiency was 1.027 kg/m^3 and 1.220 kg/m^3 in 2011 and 2012, respectively. The response of crop water use efficiency had an increasing tendency when the soil moisture depletion increased from 60 to 100% of ASMDL, but at 140% ASMDL which received longest irrigation interval and crop stress and relatively led to reduced water use efficiency (Table-5).

Table 8. Average biomass yield and grain yields of maize

Treatments	2011			2012		
	BM (kg/ha)	GY (kg/ha)	WUE (kg/m^3)	BM (kg/ha)	GY (kg/ha)	WUE (kg/m^3)
1=60%ASMDL	11795	1822	1.417	11619	2220	1.500
2=80%ASMDL	8433	2753	1.970	9877	2598	1.653
3=100%ASMDL	11168	1916	1.027	11910	1797	2.103
4=120%ASMDL	11339	2690	1.297	9586	1850	1.733
5=140%ASMDL	16923	3777	1.273	13072	2951	1.220
CV (%)	**28.12**	**31.68**	**10.41**	**36.35**	**33.1**	**12.04**
LSD@0.05	**4269.9**	**721.13**	**0.274**	**NS**	**NS**	**0.372**

4. Conclusion and recommendations

This study showed that decreasing the amount of allowable soil moisture depletion level than the FAO recommended had significantly reduced both the grain yield and crop water use efficiency. According to Djaman et.al, 2013 the maximum production of a medium maturity grain crop required between 500 -800mm of water depending on the climate. The obtained result lied within FAO recommendation range. However, Reducing the ASMDL by 40% from the recommended has significantly affected the grain yield of maize and also water use efficiency. Therefore, optimum irrigation of 140%ASMDL is recommended to enhance the biomass and grain yield of maize in the study area.

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