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Irrigation water planning for crops in the central highlands of Ethiopia, aided by FAO CROP WAT MODEL

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Information on crop water requirement of crops is vital for irrigation water planning. In the central parts of Ethiopia, agriculture has solely been dependent on rain-fed until recent time that irrigation for vegetable production is becoming one activity for crop production. However, irrigation practice in terms of the amount of water to be used and frequency of application has lacked proper knowledge. The purpose of this study is therefore to deliver the preliminary information on seasonal water requirement of different crops based on the widely used FAO crop wat model. The lowest values of reference evapotranspiration were observed for Akaki, followed by Debere Zeit, Alemtena and Modjo. Accordingly, the results showed Onion requires frequent application of irrigation followed by tomato while wheat needs longer interval that in all the sites. The seasonal net irrigation application for Onion (60%field efficiency) is 2890, 2920, 3870, 3840 m^3 for Debre Zeit, Akaki, Modjo, and Alem-Tena with their respective orders. Tomato requires net application of irrigation amount, 4650, 4030, and 5560, 4720 m^3/ha for the sites, Debre Zeit, Akaki, Modjo and Alemtena respectively. Similarly, at Debre Zeit, Chickpea needs 3000 cubic meter per hectare while wheat requires 3670 m^3 of irrigation water.

Key words: Crop water requirement, field efficiency, irrigation frequency, FAO CROP WAT 8.1

INTRODUCTION

Water for agriculture is becoming increasingly scarce in the light of growing water demands from different sectors (IWMI 2010). Water supply matters in the world that will soon have to grow food for billions more people as world population is projected to peak at 9.3 billion in 2050, an increase of 28%. Analysis showed that the total crop water requirement of all major crops increased with the rising temperature thereby increasing the simulated irrigation water demand (Kijne, 2010; Surendran et al., 2014). In the future, food and livelihood security may be challenged due to global environmental changes, particularly global climatic changes that evidence has

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gradually shown to be appearing (Aggarwal and Singh, 2010). Developments in irrigation are often instrumental in achieving high rates of agricultural goals but proper water management must be given due weightage in order to effectively manage water resources. Better management of existing irrigated areas is required for growing the extra food to fulfill the demand of increasing population (Hari Prasad et al., 1996).

Irrigation water management is a crucial component of any irrigation project. Wise use of water resources is becoming the important element in agriculture as the demand for the resource is dramatically increasing because of population pressure and hence feeding the world is a priority issue. Knowledge of crop water requirements is therefore quite helpful for planning a sound irrigation scheduling where water can be used efficiently and effectively.

Over last two decades, considerable progresses have been made to understand key factors controlling crop water requirement and consequently led to development of new techniques of evapotranspiration (ET) estimation (Patel et al. 2005) but operational applications of ET estimates yet heavily rely on the FAO-56 model because of minimum requirement of phonological and standard meteorological inputs (Evett et al., 1995; Kite and Droogers, 2000; Allen, 2000; Eitzinger et al., 2002). In FAO-56 approach, actual ET is calculated by combining reference evapotranspiration (ETo) and Kc. The Food and Agriculture of the United Nations has been extensively working on models that are capable of estimating crop water requirement and exercising irrigation scheduling of crops for any irrigation project for the last thirty years. The models have been widely used in the in the research, academia and developments sectors.

Understanding crop water needs is essential for irrigation scheduling and water efficient use in an arid region (Parry et al., 2005). Further, with increasing scarcity and growing competition for water, judicious use of water in agricultural sector will be necessary (Ali, 1991). Predicting water needs for irrigation is necessary for the development of an adequate water supply and the proper size of equipment. In our study area consistent information on irrigation water use is still lacking. The objective of this study was to estimate irrigation water requirement of rice (*Oryza sativa*) using the Cowpat model. Cowpat is a FAO model for irrigation management designed by Smith (1991) which integrates data on climate, crop and soil to assess reference evapotranspiration (ETo), crop evapotranspiration (ETc) and irrigation water requirements.

The CROPWAT model developed by the FAO Land and Water Development Division includes a simple water balance model that allows the simulation of crop water stress conditions and estimations of yield reductions based on well-established methodologies for determination of crop evapotranspiration (FAO, 1998) and yield responses to water (Doorenbos and Kassam, 1979). CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain-fed conditions or deficit irrigation (Doorenbos and Kassam, 1979).

In Ethiopia, the major portion of irrigation water management is cultural where farmers are irrigating as long as the water is available, without considering whether it is above or below the optimum of the crop water requirement. For large dams, the information of crop water requirement of the proposed crops is usually used for design purposes and it is not exercised on the real duty of irrigation operation, however. Moreover, in areas where, farmers are cultivating on small scale, the same information is critically limiting and more water is believed to be wasted. The aim of this research is therefore to estimate the crop water requirement of some crops in the central highlands of Ethiopia where information can be available for small irrigators so that it can be applicable for sound irrigation water management.

MATERIALS AND METHODS

The study was undertaken in the Central part of Ethiopia, and the sites were, Debre Zeit, Akaki, Mojdo, and Alemtena. The soils for Akaki and Debre Zeit black vertisols, where Modjo and Alemtena have light texture soils. The map of the study sites is as shown in Figure 1.

The crops included in this study were: Onions, Tomato, and Wheat. The reference evapotranspiration values (ET0) for each of the sites were calculated from the long term meteorological variables (Monthly Minimum and Maximum temperature, wind speed, sunshine hours and relative humidity) using the crop wat vewrsion 8.1, based on the Pen man-Moeinth formula. From the long term ETo data, the best estimate was obtained by the fitting the values in to different probabilistic functions of using the Easy Fit computer model. The soils physical properties of the sites (Texture, Bulk density, basic infiltration rate, Water holding capacity of the soils) has been determined using the standard soil lab procedures. The Kc values have been adopted from the FAO 33 and 56 of the irrigation and drainage papers. FAO crop wat computer model has finally been employed to obtain the crop water requirements of the crop and exercising irrigation scheduling for each of the sites.

RESULTS AND DISCUSSION

The reference evapotranspiration (ETo) values of the different sites have been presented in Table 1. As can be seen from the table, the lowest values of reference evapotranspiration were recorded for Akaki, followed by

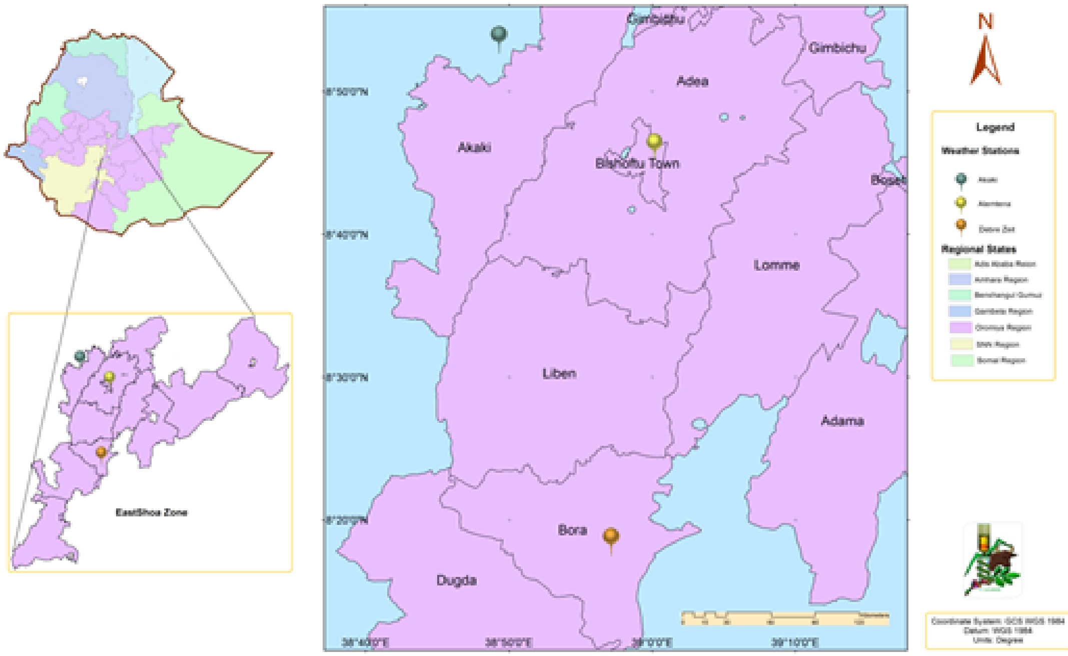

Figure 1. Location map of the study sites.

Table 1. Reference evapotranspiration (mm/day) values of the different sites.

Months	Akakai	Sites		
		Alem-Tema	Modjo	Debre Zeit
January	4.87	4.70	4.99	4.73
February	4.71	5.14	5.41	5.40
March	4.87	5.56	5.93	5.37
April	5.24	5.48	5.87	5.60
May	4.68	5.60	5.86	5.76
June	4.79	5.33	5.57	5.76
July	4.01	4.53	4.86	3.80
August	4.07	4.59	4.83	3.75
September	4.58	4.81	5.21	4.13
October	4.84	4.96	5.28	5.10
November	4.09	4.82	5.02	4.64
December	4.76	4.54	4.82	4.49

Debere Zeit, Alemtena and Modjo. The highest monthly ET0 for Akaki was observed in April (5.24 mm/day), while the lowest was detected in July (4.01 mm/day which corresponds to the mid of the main growing season in the area. Similarly, at Alemtena, the highest was in May (5.6 mm/day and the lowest value, 4.53 mm/days was for July. The highest value, 5.93 mm/day was observed in March while the lowest in December around Modjo. August had the lowest (3.75 mm/day) reference evapotranspiration value around Debre Zeit but the highest, 5.76 mm/day was seen both in May and June for this particular site.

The probable irrigation season for Debre Zeit and Akaki may start as early as November where the evapotranspiration rates are relatively low until the crops will have full maturity and hence planting during those periods will have two advantages; using the soil moisture reserve that could have been stored from that recedes in late September or early October. Secondly, planting crops at times of low evapotranspiration is implicated that the demand of the crops for water is also low. Therefore, irrigation water saving is more practical for early planning

Table 2. Crop Water and Irrigation Requirement of Different Crops at Debre Zeit (m^3/ha).

Crop	Planting Date	Growing period	Seasonal Etc/m^3/ha)	Irrigation requirement (m^3/ha)
Onion	15-Jan	95	4364	3900
Tomato	15-Jan	145	7127	6211
Chickpea	15-Jan	110	5780	5044
Wheat	15-Jan	130	4899	4317

Table 3. Crop water and irrigation requirement of different crops Akaki (m^3/ha).

Crop	Planting date	Growing period	Seasonal Etc/m^3/ha)	Irrigation requirement (m^3/ha)
Onion	15-Jan	95	4017	3472
Tomato	15-Jan	145	6354	5296
Chickpea	15-Jan	110	4500	3781
Wheat	15-Jan	130	5225	4295

Table 4. Crop water and irrigation requirement of different crops Modjo (m^3/ha).

Crop	Planting Date	Growing period	Seasonal Etc/m^3/ha)	Irrigation requirement (m^3/ha)
Onion	15-Jan	95	4624	4226
Tomato	15-Jan	145	7421	6649
Chickpea	15-Jan	110	5181	4669
Wheat	15-Jan	130	6083	5445

in November. Similarly for areas in Modo and Alemtena, October panting could favor water conservation as rainfall recedes early in these areas as compared to Debre Zeit and Akaki. However, the soils in Alemtena is relatively light textured that, unlike that of the other sites (Vertisols), soil water stored from main rain season could not be significant. Thus proper planning in irrigation operation in the later areas is more crucial.

For planting in mid-January at Debre Zeit, onion needs a seasonal net irrigation water requirement of 4364 m^3, while tomato, Chickpea, and Wheat require, 7127, 5780 and 4899 m^3 reactively (Table 2). At times when irrigation water is critical, crops like wheat and onion can be a choice for this particular area. Alternatively water application limiting to more water sensitive stages can also be an advantage. For instance, wheat is more sensitive to water stress during anthesis and heading. Thus, by irrigating water below the demand during to the rest of the crop growth stages can help farmers to save irrigation water.

At Akaki, the crop water requirement for onion, Tomatoes, Chickpea, and Wheat is in the order of 4017, 6354, 4500, and 5225 m^3/ha (Table 3). The demand of the crops for water in this area is irrelatively lower than at Debre Zeit. This is duet to Akaki is more in the highland than Debre Zeit where temperature could also be lower and correspondingly the crop water demand is reduced in relative terms. Interestingly, chickpea and onion are observed to demand less water. This is congruent with the current practice of crop production in the central highlands of Ethiopia where chickpea is grown on residual moisture after the main rainy season.

Similarly, the crop water requirements of the crops at Modjo, Onion, Tomato, Chickpea and Wheat are 4624, 7421, 5181 and 6083 m^3/ha, respectively (Table 4). The result obtained for this particular area also showed that onion and chickpea are the least water demanding as compared to tomato and wheat. Again, at times when water may be limiting, the choice for these two crops may be advised. However, as this study has not consider the economic return of irrigation practice for crops, caution should be taken in selecting crops, unless, water is so critical that crop production under irrigation may be under severe stress.

The crop water demand of the crops at Alemtena is presented in Table 5. Accordingly, growing tomato under irrigation is observed to require the highest (7004 m^3/ha) followed by wheat (5721 m^3/ha), chickpea (4870 m^3/ha) and onion (4347 m^3/ha).

From the analysis, onion is observed to require frequent irrigation application at al study sites. At Debre Zeit, onion the average irrigation frequency is about 12 days while tomato required to be irrigated every 18 day while chickpea and wheat 20 and 28 days respectively

Table 5. Crop water and irrigation requirement of different crops Alem-Tena (m^3/ha).

Crop	Planting Date	Growing period	Seasonal Etc/m^3/ha)	Effective rainfall	Irrigation requirement (m^3/ha)
Onion	15-Jan	95	4347	32.8	4016
Tomato	15-Jan	145	7004	97.8	5977
Chickpea	15-Jan	110	4870	40.1	4465
Wheat	15-Jan	130	5721	54.1	5161

Table 6. Irrigation schedule of different crops at Debre Zeit.

Crops		Seasonal net irrigation (m^3/ha)	No.
Onion	Interval	13,13,13,11,11,11,11,11	2890
	Depth (mm)	28,28,28, 41,41,41,41,41	
Tomato	Interval (days)	23,23,23,15,15,15,15,15	4650
	Depth (mm)	50,50,50,63,63,63,63,63,	
Chickpea	Interval (days)	24,24,16,16,16	3000
	Depth (mm)	54,54,64,64,64	
Wheat	Interval (days)	54,22,22,15	3670
	Depth (mm)	87,94,94, 92	

Table 7. Irrigation schedule of different crops at Akakai.

Crops		Seasonal net irrigation (m^3/ha)	No.
Onion	Interval	13,13,13,13,11,11,11,11,	2920
	Depth (mm)	32,32,32,32,41,41,41,41,	
Tomato	Interval (days)	19,25,25,17,17,17,24	4030
	Depth (mm)	39,56,56,63,63,63,63	
Chickpea	Interval (days)	26,21,21,21	2360
	Depth (mm)	47,63,63,63	
Wheat	Interval (days)	55,26,26	
	Depth (mm)	89,91,91	2710

after the first irrigation with full field capacity (Table 6). Similarly the average depth of water required is 35, 56, 58, 92 mm for onion, tomato, chickpea and wheat in their respective orders.

At Akaki, onion the average irrigation frequency is about 12 days similar with what observed at Debre Zeit while tomato required to be irrigated every 21 days, chickpea and wheat 22, and 35 days respectively after the first irrigation with full field capacity (Table 7). The implication is that frequency of irrigation in the highland is relatively higher that could be attributed to the lower evaporative demand due to low temperature. Accordingly, the average depth of water required for onion ranged from 32 mm in the first irrigation (during germination and developmental crop growth stages) and should reach up to 41 mm during the critical growth stages, may be fruit setting. For wheat, the average irrigation depth is around 90 mm that can be served in three irrigation cycles, unlike that the rest of the crop that have significant variation in irrigation frequency in their crop growth stages. For instance, tomato requires 25 days of irrigation interval in its mid stage while in the subsequent stages the frequency of irrigation can be reduced to up to 17 days and again in ripening stage, the

Table 8. Irrigation schedule of different crops at Alemtena.

Crops		Seasonal net irrigation(m^3/ha)	No.
Onion	Interval	10,10,10,10,7,7,7,7,7,7,7,7,7,7	3840
	Depth(mm)	21,21,21,21,30,30,30,30,30,30,30,30,30,30	
Tomato	Interval(days)	16,16,16,13,13,9,9,10,10,10,10	4720
	Depth(mm)	34,34,34,45,45,44,48,48,48,48	
Chickpea	Interval(days)	18,13,11,11,11,11,11	3180
	Depth(mm)	40,48,46	
Wheat	Interval(days)	42,20,14,14,14,17	4050
	Depth(mm)	56,69,71,71,71,67	

interval goes higher to 24 days.

At Alemtena, the irrigation interval for all crops is relatively more frequent than Debre Zeit and Akaki. Due to the fact that the evaporative demand is relatively higher and also the soils in this area is light textured and storage of water in the soil depth can be smaller. According to the results, the irrigation interval for onion ranges from 10 (in the first growth stages) and 7 days during the later growth stags (Table 8). The irrigation depth during irrigation application should not be below 21 mm in the earlier stages and 30 mm in the advanced stages for onion. Tomato requires less frequent irrigation during the earlier stages (16 days) and more frequent irrigation application is required at later stages and the depth of irrigation should be kept at 48 mm. Chickpea and wheat are also requiring less frequent irrigation during the earlier stages, 13- 8 days for chickpea, and 20 -40 days for wheat after the firs irrigation with field capacity.

Similarly, At Modjo, the irrigation interval for all crops is relatively more frequent than Debre Zeit and Akaki. Due to the fact that the evaporative demand is relatively higher. The interval for irrigation application for onion ranges from 7-11 while it requires less frequent in the latter stages. The irrigation depth for each irrigation cycle progressively develops from 18 mm at the earlier sage to 33 mm in the middle of the crop growth stages and ultimately drops to 30 mm further in the advanced stages. Likewise, the interval for irrigation application is more frequent in the middle of the crop growth stages for tomato (10 days) and relatively less frequent in the latter stages. The depth of irrigation should be kept 35 mm in the earlier days and goes up to as high as 47 mm in the latter stages. Chickpea and wheat require more frequent irrigation during the mid and latter crop growth stages, 11 days for chickpea and 15 for wheat. The depth of irrigation develops 35 to 48 mm for chickpea while wheat need to irrigated to the minimum 69 mm for most of the crop growth stages, with exception for its initial stage that requires 54 mm.

In general, the water consummation level of the sites for growing those crops is in the order of Akaki, Debre Zeit, Alemtena, and Modjo respectively, Akakai consumes the lowest. To summarize, in all the sites, Onion requires frequent application of irrigation followed by tomato while wheat needs longer interval. The seasonal net irrigation application for Onion is as shown in Tables 8 and 9.

Conclusions

Understanding crop water needs is believed assist decision making in irrigation water management. The objective of this study was to estimate crop water need and seasonal crop water demand of crops in the central highlands of Ethiopia. FAO CROP WAT model was employed for the purpose and the results showed that the seasonal net irrigation application for Onion (60% field efficiency) is 2890, 2920, 3870, 3840 m^3 for Debre Zeit, Akaki, Modjo, and Alem-Tena with their respective orders. Tomato requires net application of irrigation amount, 4650, 4030, 5560, 4720 m^3/ha for the sites, Debre Zeit, Akaki,Modjo and Alemtena respectively. Similarly, at Debre Zeit, Chickpea needs 3000 m^3/ha while wheat requires 3670 m^3 of irrigation water. The information generated can be helpful for small scale irrigators in the study sites where the same is critically limiting. Farmers are culturally irrigating their fields only based on the availability of water regardless of the crop water need, too much and too low is equally affect the yield of irrigated crops. Thus, up until, the analysis of this result can be verified in the field, farmers can be advised to apply the information generated from this study and the follow up of this work is now undertaken to make the information complete.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

Table 9. Irrigation schedule of different crops at Modjo.

Crops		Seasonal net irrigation (m^3/ha)	No.
Onion	Interval	8,11,11,11,7,7,7,7,7,7,7,7,7	3870
	Depth(mm)	18,33,33,33,30,30,30,30,30,30,30,30,30	
Tomato	Interval(days)	14,14,14,10,10,10,10,10,10,10,12,12,13	5560
	Depth(mm)	35,35,35,46,46,46,46,46,46,46,47,47	
Chickpea	Interval(days)	17,17,11,11,11,11,11,11,	358
	Depth(mm)	35,35,48,48,48,48,48,48	
Wheat	Interval(days)	39,19,15,15,15,15	3990
	Depth(mm)	54,69,69,69,69,69	

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