Original Research Article

ASSESSMENT OF CROP-WATER ESSENTIALITY OF ALFALFA USING FAO-CROPWAT MODEL-8.0

Abstract

To control the overexploitation of accessible water resources, it has become essential to define proper strategies for planning, development, and management of water resources. Proper modification in traditional irrigation practices helps improve water use efficiency. CROPWAT is an FAO suggested model for proper management of irrigation. CROPWAT model integrates with soil, crop, and climate information for estimation of reference evapotranspiration (ET_0), crop evapotranspiration (ETc), crop water requirement (CWR) and irrigation water requirements (IWR). It also develops and manages the irrigation scheduling. The CWR for Junagadh Region is estimated as 544.2 mm and irrigation requirement as 542.5 mm for alfalfa crop. CROPWAT 8.0 model can efficiently and effectively calculate the evapotranspiration and net requirements of irrigation water. The CROPWAT 8.0 Model can play an important role in the irrigation management practices as well as irrigation scheduling of crops over manual irrigation practicing using different water supply systems.

Keywords: CROPWAT, Irrigation Schedule, Alfalfa, Crop evapotranspiration and CWR

INTRODUCTION

The water requirement for any crop is a major factor which decides the yield and its productivity. Crop water requirement depends on climatic conditions, crop area and type, soil type, growing seasons and crop production frequencies (George *et al*., 2000). The crop needs to be watered sufficiently at critical stages so that a good reap can be yielded. But, the conventional methods of irrigation such as surface water irrigation have resulted in water shortages accompanied by the water scarcity naturally occurring as a repercussion of climatic variability. Reduction in agricultural productivity and water use efficiency are mainly due to conventional method of irrigation (flooding) and poor adoption of scientific water management practices (Dhayal *et al.,* 2023). Irrigation water supplies are declining and paucity of water has been observed all over the world. In India, it can be said that agriculture is the largest end user of water where much effort must be kept for its efficient use in agriculture (Surendran *et al.,* 2013). India has recently touched the population mark of 1.4 billion becoming the most populous nation on the globe. This signals the increasing water requirements of such a big populace and thus we need to employ smart water consumptive strategies to overcome water shortages. Increased population demands more food and thus to meet the food requirements of this ever-increasing population with resources getting limited, is a huge challenge. The main problem is that we are not making judicious use of water. At field level, water use efficiency under conventional method of irrigation is as low as 50 to 60 per cent (Dhayal *et al.*, 2023). For proper management of water, two things are necessary to be kept in mind: irrigation scheduling and efficient utilization of irrigation water. Improving the water use efficiency in irrigated farming can also help to realize the full benefits of other production inputs, like fertilizers, high quality seeds, tillage, energy and machinery (Sharma *et al*., 2015). Since water is an invaluable and limited resource and the studies on scheduling of irrigation, water use efficiency, consumptive use of water and moisture distribution pattern in the soil are of pivotal importance for attaining maximum crop yields.

Alfalfa is an ancient crop which originated in South-Central Asia and got spread prodigiously to the Mediterranean Basin, and eventually to South and North America. It can be produced under rainfed or irrigated conditions and is harvested or cut several times a year depending on climatic conditions and management. Harvest management has been proven to significantly impact yields (Orloff and Putnam, 2007; Teixeira *et al*., 2008). Alfalfa is essential in the animal husbandry food chain being used as hay, silage, or pellets; and is as such worldwide traded as a commodity (FAOSTAT, 2022). It has higher transpiration ratio (Michael, 2007). Keeping in view such a huge amount of water required, the irrigation efficiency plays an important role. To avoid yield reduction and adverse effects on the soil properties, irrigation scheduling *i.e.* application in times of crop need with just enough amount of water needs to be followed (Rockstorm and Barron, 2007). Irrigation not only helps in increasing the green fodder and dry fodder yields, but also improves the quality of fodder (Kumar, 1979). These evidences throw light on the importance of water scheduling and its consumptive use in a crop like lucerne.

Realizing the importance of irrigation scheduling, various computer models have been developed which improve the irrigation water use efficiency. These models are the emerging trend in the field of water use efficiency. CROPWAT software is one such model developed as a decision support system for estimation of irrigation scheduling and crop water requirement. It is one of the models being extensively used in the field of water management throughout the world which is designed by Smith (1991) of the Food Agricultural Organization (FAO). Crop water requirements of major crops in North coastal districts of Andhra Pradesh has been sorted with the long-term climatic data by using CROPWAT 8.0 model (FAO, 2009). It facilitates the estimation of the crop evapotranspiration, crop water requirements and irrigation schedule with different cropping patterns for irrigation planning (Gowda *et al*., 2013). The two major functions that this model is capable of performing are as follows:

1. To compute crop water requirements and reference evapotranspiration.
2. To develop irrigation schedules under various management conditions and scheme water supply.

This paper focuses on the use of CROPWAT model 8.0 version in the estimation of water requirement of Lucerne in order to make efficient irrigation water use and increasing the water use efficiency.

MATERIAL AND METHODS

2.1 Study Location

The present investigation was carried out at ‘Farming System Research Station, Department of Agronomy, College of Agriculture, Junagadh Agricultural University, Junagadh, Gujarat (India) during winter cycle (*Rabi* season) 2021-22. The farm is geographically situated at an altitude of 60 m above sea level on 21.5^0 N latitude and 70.5^0 E longitude. The rainy season commences in the second fortnight of June and ends in September with average rainfall of 1088.55 mm.

2.2 Crop water requirement

The crop water requirement is the amount of water equal to what is lost from a cropped field by ET and is expressed by the rate of ET in mm/day. Estimation of CWR is derived from crop evapotranspiration (ETc) which can be calculated by the following equation.

$$ET_c = K_c * ET_0$$

Where, Kc is the crop coefficient.

It is the ratio of the crop ETc to the ET0, and it represents an integration of the effects of four essential qualities that differentiate the crop from reference grass, and it covers albedo (reflectance) of the crop–soil surface, crop height, canopy resistance, and evaporation from the soil. Due to the ET differences during the growth stages, the Kc for the crop will vary over the developing period which can be divided into four distinct stages: initial, crop development, mid-season, and late season. The reference evapotranspiration ET_0 is calculated by FAO Penman-

Monteith method, using decision support software –CROPWAT 8.0 developed by FAO, based on FAO Irrigation and Drainage Paper 56 (FAO, 2002). The FAO CROPWAT program (FAO, 2009) incorporates procedures for reference crop evapotranspiration and crop water requirements and allows the simulation of crop water use under various climate, crop and soil conditions (www.fao.org).

2.3 Meteorological data

Meteorological data of ten years was collected from meteorological station located near the experimental sites. Meteorological parameters used for calculation of ET_0 are latitude, longitude and altitude of the station, maximum and minimum temperature (^oC), maximum and minimum relative humidity (%), wind speed (m/s) and sunshine hours which were collected and the average values have been fed to the model. Rainfall data collected from the same station is also fed to the software which would generate the effective rainfall data (Table 1).

2.4 Crop data

Groundnut is the major crop in this region during rainy cycle and groundnut – wheat being the most popular cropping system. CROPWAT software needs certain information like crop coefficient, Kc values (initial, mid and late growth stages), depth of root, crop duration time, critical depletion and yield response factor which have been taken from FAO Irrigation and drainage paper 56. The yield response factor (K_y) is the ratio of relative yield reduction to relative evapo-transpiration deficit that integrates the weather, crop and soil conditions which make crop yield less than its potential yield in the face of deficit evapo-transpiration. Sowing and harvesting date were taken according to the guide from agricultural operations over this area. Sowing dates were taken at 15 days interval starting from December 15th.

2.5 Soil data

Soil type in this area is medium black clay. The software needs some general information about the soil *viz.* total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion and initial available soil moisture.

2.6. Irrigation Schedule

Irrigation scheduling determines the correct measure of water to irrigate and the correct time for irrigation. The CROPWAT model calculates the ET_0, crop water requirement and irrigation requirements to develop the irrigation schedules under different administration conditions and water supply plans.

RESULTS AND DISCUSION

Climatic data

The climatic data and the potential evapotranspiration during the investigation time are presented in Table 1. The ETo was 3.11 to 6.54 mm while wind speed was 0.8 to 2.4 m/s during the crop cycle. The sunshine hours were 1.6 to 9.6 meaning the sky was overcast most times of the day. The maximum and minimum temperature were 40.76 and 11.43^{0}C which was optimum for alfalfa crop growing in semi-arid region. The average of effective precipitation during 2021-22 and 2022-23 of the area was 651.7 mm throughout the year (Table 1.). The effective precipitation was high in July to September. This effective rainfall was negligible from November to May.

During the alfalfa crop growth, there were no rainfall that was why irrigation was needed. The patterns of irrigation water requirement and field water supply deviated from the observed trends in response to temperature changes. This is likely to be the case in this study because during no rainfall crop required more irrigation water.

Table 1: Climate characteristics, rainfalls, and ET_0 of experiment area (average of 2021-22 and 2022-23 period) obtained using CROPWAT software

Month	Temperature		Humidity %	Wind speed (m/s)	BSS	Rainfall (mm)	ET (mm/ day)	Rad (MJ/m^2/ day)	ETo
	Min.	Max.							
Jan	11.43	27.75	54.31	1.3	6.7	0.1	4.3	16.6	3.11
Feb	14.18	32.01	49.71	1.1	8.9	0	5.4	19.2	3.84
March	20.17	38.00	38.64	1.4	9.6	0	8.3	22.4	5.57
April	23.23	40.76	46.03	1.5	9.3	4.8	8.8	23.5	6.42
May	25.82	38.76	56.92	2.4	7.6	26.55	8.8	21.4	6.65
June	26.33	36.70	67.66	2.4	4.2	92.65	6.8	16.2	5.21
July	24.77	31.51	82.78	2.3	1.6	461.25	3.0	12.3	3.34
August	24.02	31.71	80.10	1.9	2.4	213.45	3.2	13.2	3.43
September	23.80	31.38	81.48	1.3	4.0	480.15	3.0	14.7	3.39
October	21.60	34.40	59.07	0.9	8.6	64.4	4.4	19.4	4.26
November	16.71	33.61	49.88	0.8	7.9	0	4.3	16.4	3.47
December	15.11	29.87	52.80	1.1	6.8	0	4.3	14.1	3.13

Crop water requirements for alfalfa under semi-arid region during the short rains are shown in Table 2. The Kc at initiation stage was 0.50 while ETc was 1.62 and 12.86 mm per day and per decade, respectively. Effective rainfall at this stage was zero mm per decade. The leaf area was minimal, and actual evapotranspiration was predominantly in form of soil evaporation. The low Kc value observed at this stage was because the crop was just establishing itself with low canopy and there was very little ground cover hence minimal water requirement. This is because the higher the evaporative demand from the atmosphere, the faster the soil dries and the smaller the Kc value (Van Ranst and Verdoodt, 2005). At vegetative stage, the Kc values increased to 0.56, 0.70, 0.82 and 0.95 in decade 3 (Dec.), 1, 2, and 3 (Jan.) respectively. The ETc also increased to 1.57 to 6.13 mm/day during crop cycle period.

The rapid development of the crop at vegetative stage requires a lot of water that is why irrigation at this time is a must for crop. Water depletion at this stage was very rapid and increased as the crop developed (Figure 2) and was more than the Readily Available Moisture (RAM). The Kc and ETc reached maximum value of 1.11 and 67.4 mm per decade at vegetative stage, respectively (Table 2).

Table 2: Daily and Decadal Crop Water Requirement of alfalfa at the experimental site (average of 2021-22 and 2022-23)

ETo station		**Junagadh**				**Crop**	**Alfalfa**
Rain station		**Junagadh**				**Planting date**	**27/11**
Month	**Decade**	**Stage**	**Kc (coefficient)**	**ETc (mm/day)**	**ETc (mm/decade)**	**Eff. Rain (mm/decade)**	**Irr. Req. (mm/decade)**
Nov.	3	Init.	0.50	1.68	6.7	0.0	6.7
Dec.	1	Init.	0.50	1.62	16.2	0.0	16.2
Dec.	2	Init.	0.50	1.57	15.7	0.0	15.7
Dec.	3	Devp.	0.56	1.76	19.4	0.0	19.4
Jan.	1	Devp.	0.70	2.17	21.7	0.0	21.7
Jan.	2	Devp.	0.82	2.55	25.5	0.0	25.5
Jan.	3	Devp.	0.95	3.20	35.2	0.0	35.2
Feb.	1	Mid.	1.08	3.81	38.1	0.0	38.1
Feb.	2	Mid.	1.11	4.14	41.4	0.0	41.4
Feb.	3	Mid.	1.11	4.82	38.5	0.0	38.5
Mar.	1	Mid.	1.11	5.53	55.3	0.0	55.3
Mar.	2	Mid.	1.11	6.17	61.7	0.0	61.7
Mar.	3	Late	1.05	6.13	67.4	0.1	67.3
Apr.	1	Late	0.94	5.78	57.8	0.6	57.2
Apr.	2	Late	0.85	5.44	49.0	0.8	48.1
Total					**549.6**	**1.6**	**547.9**

Table 3: Irrigation schedules for Alfalfa crop during the study period as per the CROPWAT model

Date	Day	Stage	Rain (mm)	Ks fraction	ETa (%)	Depletion (%)	Net irrigation (mm)	Deficit (mm)	Loss (mm)	Gross irrigation	Flow (l/s/ha)
29 Nov.	3	Initial	0.0	1.00	100	32	17.3	0.0	0.0	24.8	0.96
10 Dec.	14	Initial	0.0	1.00	100	32	20.0	0.0	0.0	28.6	0.30
24 Dec.	28	Dev.	0.0	1.00	100	34	25.4	0.0	0.0	36.2	0.30
18 Jan.	53	Dev.	0.0	1.00	100	63	59.1	0.0	0.0	84.5	0.39
13 Feb.	79	Mid.	0.0	1.00	100	85	94.4	0.0	0.0	134.9	0.60
5 Mar.	99	Mid.	0.0	1.00	100	86	95.1	0.0	0.0	135.9	0.79
21 Mar.	115	End	0.0	1.00	100	86	95.5	0.0	0.0	136.4	0.99
7 Apr.	132	End	0.3	1.00	100	91	101.1	0.0	0.0	144.4	0.98
19 Apr.	End	End	0.0	1.00	0	54					

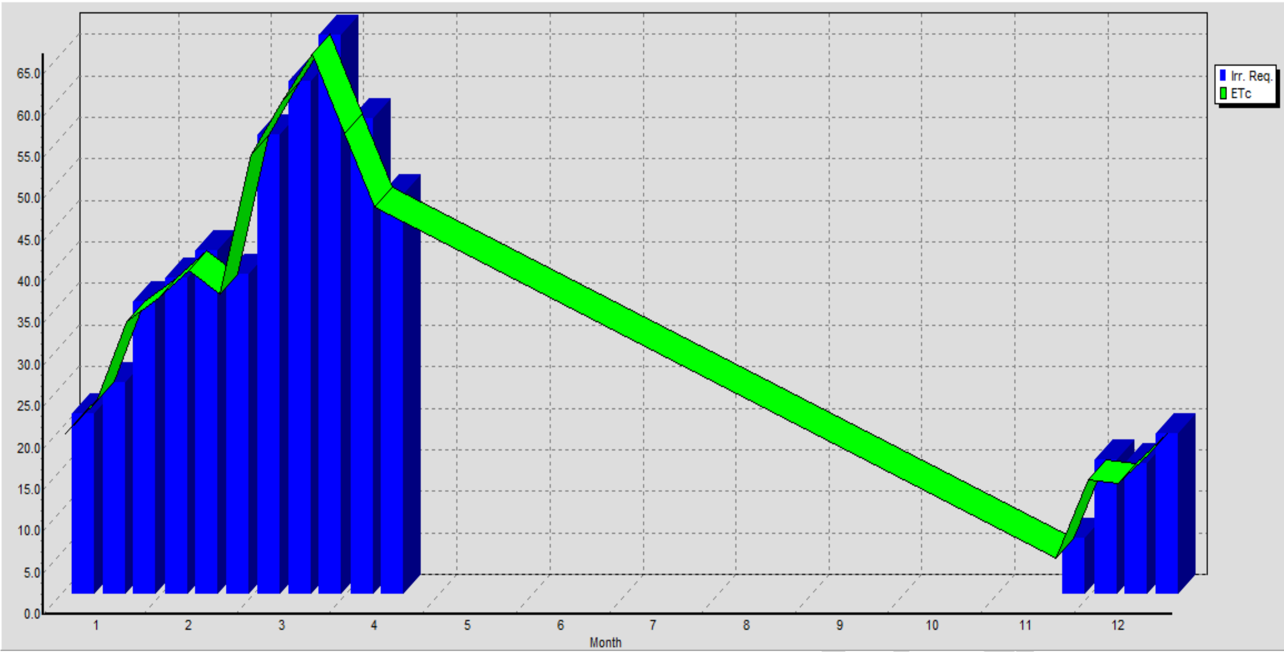

Fig. 1: Crop water requirement of the alfalfa crop during crop cycle period (2021-22 and 2022-23)

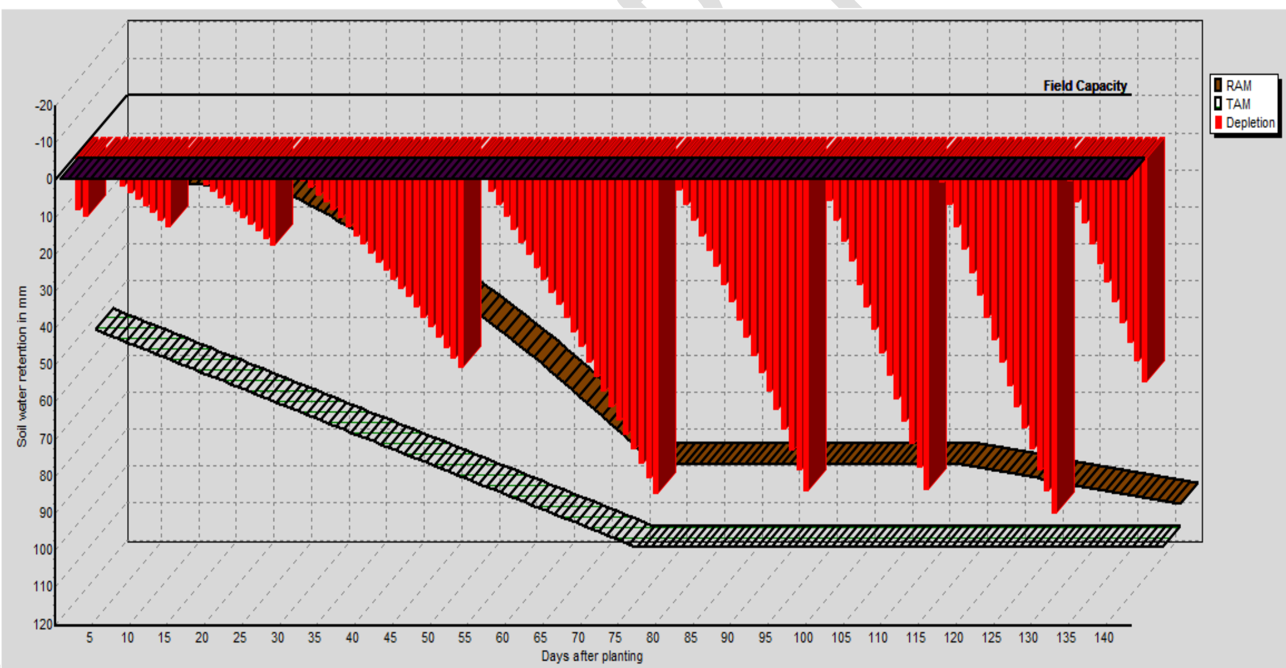

Fig. 2: Irrigation scheduling graph for alfalfa crop during crop cycle

Table 4: Total gross irrigation, total net irrigation and efficiency of rain

Totals			
Total gross irrigation	725.6 mm	Total rainfall	1.6 mm
Total net irrigation	507.9 mm	Effective rainfall	1.6 mm
Total irrigation losses	0.0 mm	Total rain loss	0.0 mm
Actual water use by crop	544.2 mm	Moist deficit at harvest	60.0 mm
Potential water use by crop	544.2 mm	Actual irrigation requirement	542.5 mm
Efficiency irrigation schedule	100 %	Efficiency rain	100 %
Deficiency irrigation schedule	0.0 %		

The overall, ETc value required for optimal production with enough water is given using CROPWAT crop irrigation schedule in Table 2 as 549.6 mm in the study area. The total actual water use by crop during the crop growth period is 544.2 mm (Table 3). The total net irrigation was 507.9 mm and gross irrigation was 725.6 mm. The irrigation efficiency was 100 % and there were no irrigation losses. It has been compared with irrigation scheduling, when we apply irrigation through IW/CPE ratio more or less water as per the demand of crop stage. But on the basis of CROPWAT, we can manage the irrigation water and proper amount of water as per the demand of alfalfa crop. The data of CROPWAT model is showing that there is no yield reduction due to 100 % critical depletion (Table 5). The seasonal yield response factor was 0.80%.

Table 5: Yield reduction at 100% of critical depletion

Yield reductions					
Stage label	**A**	**B**	**C**	**D**	**Season**
Reduction in ETc	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Yield response factor	0.45	0.60	1.20	1.10	0.80
Yield reduction	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %
Cumulative yield reduction	0.0 %	0.0 %	0.0 %	0.0 %	0.0 %

Figure 1 shows the predicted irrigation water requirements from initiation stage to maturity stage in the study area. Irrigation requirement was low at initiation and increased to a maximum at development and vegetative stages (Figure 1). The most sensitive growth periods of alfalfa to water deficit is when actual evapotranspiration is less than maximum crop evapotranspiration (ETa < ETm) and are highest at vegetative > development > initiation period in that order; particularly during and just after transplanting (Doorenbos and Kassam, 1979).

The total available moisture was 97 mm at maximum compared to RAM that was about 77 mm (Figure 2). The moisture depletion level was high in March month compared to other development stages reflecting a higher water use by the crop at this stage. This depletion was beyond the RAM during vegetative development stage. The rapid growth combined with the relatively poor ground cover even with enough irrigation water could have led to high atmospheric water demand which gave rise to ETa of less than 100% and higher water irrigation requirements compared to other stages. However, this reduction is negligible and can be ignored when recommending this option.

Irrigation scheduling for optimal alfalfa growth

Results show that alfalfa crop required higher net irrigation water from February to April as compared to December and January (Table 3). Supplementary irrigation at this growth stage would result in an increase in alfalfa fodder yield. After the processing of CWR calculations and soil data input on the basis of the information previously collected (Table 1). The overall reduction in yield was negligible at 0% meaning optimal yields would be attained at this irrigation schedule. These are critical stages at which adequate water must be given so as to achieve optimal yields (Nurrudrin and Madramootoo, 2001; Obreza *et al.*, 2010; Patanè and Cosentino, 2010).

Conclusion

An attempt was put forward to compute the crop water requirements of alfalfa in Saurashtra region of Gujarat using CROPWAT 8.0 model developed by FAO. Proper and optimal scheduling of irrigation using CROPWAT 8.0 enabled the efficient water use. The Penman-Monteith method was used for evapotranspiration calculation in the model. Up to 91% of critical soil moisture depletion was considered for irrigation. The model predicted the daily, decadal as well as monthly crop water requirement at different growing stages of alfalfa crop. The crop water requirement and irrigation requirement for alfalfa are respectively 544.2 mm and 542.5 mm. From the results, it is evident that efficient water management becomes crucial and critical in normal or deficit rainfall years. In view of the above findings, it was recommended to use the CROPWAT 8.0 model to predict the crop water requirements for different crops with high degree of accuracy and can suggest the crop pattern and crop rotation to farmers**.**

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