A-5941
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RESEARCH ARTICLE   Indian Journal of Agricultural Research, Volume Issue : ()

Estimation of Irrigation Requirement and Schedule in Southern Odisha for Major *Rabi* Cereal Crops using FAO CROPWAT 8.0 Model

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10.18805/IJARe.A-5941

ABSTRACT

Background: The increasing population and need for higher quantity of food grain production necessitates efficient use of limited water in the country, as agriculture sector alone uses 78% of water resources of India. During *rabi* season, mostly the crops are grown with irrigation in southern Odisha. There is no enough information on water and irrigation requirement of maize, sorghum and pearl millet crops grown in the region, which necessitated this study.

Methods: The model-based study involving FAO CROPWAT 8.0 was used for the estimation of gross and net irrigation requirement and scheduling of maize, sorghum and pearl millet grown in southern Odisha.

Result: The water requirement estimated with FAO CROPWAT 8.0 model during *rabi* for maize, sorghum and pearl milletgrown in Southern Odisha was 252.3, 197.9 and 172 mm and irrigation requirement was 231.2, 178.8 and 156.3 mm respectively.

Key words: CROPWAT 8.0, Irrigation requirement, Maize, Sorghum, Pearl millet.

INTRODUCTION

Agricultural sector is facing two major challenges: the ever-increasing population growth that places continuous increase in the demand (Hedayat, 2005) and the need to improve utilization methods of the limited water resources (Falkenmark and Rockstrom, 2004). India faces high water stress and the country is amongst those with the most fragile and uncertain water resources in the world. Further, the agriculture uses 78 per cent share of water use in in the country (Mancosu *et al.*, 2015). One of the main responses to these emerging challenges is to focus on improving water productivity in agriculture, as even small improvements will have large implications for local and national water budgets and allocation policies (Global Water Partnership 2000).

During *rabi* (Rain free period), the crops like maize, bajra and sorghum are cultivated under irrigated conditions in India. There is an increase in cultivated area during *rabi*season which has a significant impact on food grain production in the country through increased cropping Intensity (Waha *et al.,* 2020).Selection of right crop and scheduling irrigation enhances the water productivity. For proper use of limited water, there is a need to know the water requirement of crops for selection of them according to water availability and its proper scheduling. Such information is not available for southern Odisha.In absence of estimations of water requirement of crops through experimentation, the model-based approach serves as decision support system for optimal scheduling of irrigation thus paving a way towards increased water productivity.The FAO CROPWAT 8.0 is a model based approach developed by the Department of Land and Water Resources, FAO for the calculation of crop water demand based on soil, climate and crop data. This is one of the precise and globally accepted models that serves as a decision support system by estimating the crop evapo-transpiration and effective rainfall thus computing the net irrigation requirement of the crop. Further, this software also suggests the dates for scheduling irrigation targeting maximum water productivity (Surendran *et al.,* 2015).

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How to cite this article: Sagar, L., Sairam, M. and Reddy, M.D. (2022). Estimation of Irrigation Requirement and Schedule in Southern Odisha for Major *Rabi* Cereal Crops using FAO CROPWAT 8.0 Model. Indian Journal of Agricultural Research. DOI: 10.18805/IJARe.A-5941.

Submitted: 16-11-2021 **Accepted:** 30-05-2022 **Online:** 13-07-2022

Majority of rural people in southern Odisha earn their livelihood fromagriculture. This region is conducive for cultivation in all the three seasons if moisture is not limited. The cereal production in *rabi*season of south Odisha region is predominated by maize, sorghum and pearl millet.

Keeping this in view, the crop water requirement and irrigation schedule for *rabi* maize, sorghum and pearl millet cultivated in red sandy loam soils of Southern Odisha was estimated using FAO CROPWAT 8.0 and presented in this paper.

MATERIALS AND METHODS

Study area

The study area selected for the estimation of irrigation water requirement was Southern Odisha located between longitude

72°97′ to 85°05′E and latitude 18°34′ to 20°66′ N. The meteorological data of Koraput was used which is located between longitude 81°24.2′ E to 84.2° E and latitude 17°4′ N to 20°7′ N. This area is mainly dominated by red and lateritic soils.

Methodology

The CROPWAT 8.0 model developed by the Department of Land and Water Resources of FAOis a computer program for the calculation of crop water demand based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns (Roja*et al.* 2020a). CROPWAT 8.0 can also be used to evaluate farmers irrigation practices and to estimate crop performance under both rainfed and irrigated condition. The basic functions of this model include estimation of reference evapo-transpiration, crop evapo-transpiration and irrigation water requirement.

Data used for estimation of ETo

Monthly climatic data *viz,* minimum temperature, maximum temperature, relative humidity, wind velocity, duration of bright sunshine hours of Koraput located in studyarea was used (Table 1) for the estimation of reference evapo-transpiration (ETo) using Penman-Monteith formula by FAO CROPWAT 8.0.

Rainfall data

Monthly rainfall data of Koraputwas used for calculation of effective rainfall (Table 1). USDA soil conservation method is used in this software .

USDA Soil Conservation Service formula:

Case 1: Peff = Pmon * (125 - 0.2 * Pmon) / 125
(If Pmon<= 250 mm)

Case 2: Peff = 125 + 0.1 * Pmon (If Pmon > 250 mm)

Peff = Effective Precipitation

Pmon = Monthly Precipitation

Crop data

In Southern Odisha, during *rabi* season, the cultivation of crops usually begins after the harvest of *kharif* rice. In general, *rabi* maize, sorghum and pearl millet are sown around 15th of November and theses crops - maize, sorghum and pearl millet take 120, 110 and 100 days respectively to complete their life cycle. Duration and sowing date mentioned in the software helps to determine the phenophase of the crops. At each phenophase Kc value, rooting depth (m), critical depletion value and crop yield response factor were decided based on the duration of the crops (Doorenbos and Kassam, 1979) and presented in the Table 6. The yield response factor (Ky) is the ratio of relative yield reduction to relative evapo-transpiration deficit that integrates the weather, crop and soil conditions that make crop yield less than its potential yield in the face of deficit evapo-transpiration also estimated in the model. The crop data used in this experiment were presented in Table 2.

Soil data

The soils in Koraputare mainly of two types 1) Alfisols, 2) Ultisols (DLIC, 2016). In the present study, red sandy loam soils were considered based on their predominance in this region. The total available soil moisture, maximum infiltration rate, maximum rooting depth, initial soil moisture depletion of this soil type were in the tune of 100 mm/meter, 30 mm/day, 900 cm, 50 per cent, respectively and the initial soil moisture was 50 mm/meter which is 50% of available soil moisture.

Table 1: Monthly meteorological data and estimated reference evapo-transpiration (ETo) using FAO Cropwat.

Month	Min temp °C	Max temp °C	Humidity %	Windkm /day	Sun hours	Rad MJ /m²/day	ETo mm/day	Rainfall mm	Effective rainfall mm
January	12.6	26.6	56	5	7.6	16.6	2.37	4.0	4.0
February	14.6	30.3	48	6	8.4	19.4	2.95	7.0	6.9
March	18.8	33.6	41	7	7.4	19.7	3.38	7.0	6.9
April	22.1	36.3	41	7	12.0	27.8	5.00	15.0	14.6
May	24.2	36.6	45	8	12.0	28.0	5.45	31.0	29.5
June	23.3	31.2	69	10	9.6	24.1	4.98	190.0	132.2
July	21.9	27.3	83	12	6.2	19.0	3.89	263.0	151.3
August	21.2	27.3	85	10	6.7	19.7	3.90	265.0	151.5
September	20.6	28.1	83	7	7.9	20.7	4.02	179.0	127.7
October	18.2	27.9	76	6	8.4	19.8	3.58	125.0	100.0
November	15.5	26.7	70	6	7.3	16.5	2.75	13.0	12.7
December	12.7	25.5	64	6	7.4	15.8	2.34	6.0	5.9
Total	-	-	-	-	-	-	-	1105	743.4
Average	18.8	29.8	63	8	8.4	20.6	3.72	-	-

Table 2: Details of the major *rabi* cereals crop required as per the CROPWAT model.

Crop name	Planting date	Harvesting date	Critical depletion (cm)	Rooting depth (m)	Crop growth periods (days)				
					Initial	Development	Mid	Late	Total
Maize	15th Nov	14th March	0.55	1.00	20	30	40	30	120
Sorghum	15th Nov	4th March	1.00	1.40	20	25	35	30	110
Pearlmillet	15th Nov	22nd Feb	1.00	1.20	15	25	35	25	100

Table 3: Daily and decadal crop water requirement of *rabi* cereals in the study area.

Crop	Crop water requirement														
Maize	Month	Nov	Nov	Dec	Dec	Dec	Jan	Jan	Jan	Feb	Feb	Feb	Mar	Mar	
	Decade	2	3	1	2	3	1	2	3	1	2	3	1	2	
	Stage	Init	Init	Deve	Deve	Deve	Mid	Mid	Mid	Mid	Late	Late	Late	Late	
	Kccoeff	0.3	0.3	0.36	0.62	0.92	1.14	1.14	1.15	1.15	1.05	0.81	0.58	0.39	
	ETc mm/day	0.82	0.78	0.89	1.46	2.16	2.68	2.71	2.94	3.16	3.10	2.52	1.83	1.28	
	ETc mm/dec	4.9	7.8	8.9	14.6	23.7	26.8	27.1	32.3	31.6	31.0	20.1	18.3	5.1	52.3
	Eff rain mm/dec	0.3	1	2.6	1.8	1.6	1.4	1.1	1.5	2.0	2.4	2.4	2.1	0.8	21.0
	Irr. req. mm/dec	4.7	6.9	6.3	12.8	22.1	25.4	26	30.8	29.5	28.5	17.8	16.2	4.1	231.2
Sorghum	Month	Nov	Nov	Dec	Dec	Dec	Jan	Jan	Jan	Feb	Feb	Feb	Mar		
	Decade	2	3	1	2	3	1	2	3	1	2	3	1		
	Stage	Init	Init	Deve	Deve	Mid	Mid	Mid	Mid	Late	Late	Late	Late		
	Kccoeff	0.3	0.3	0.35	0.6	0.86	0.95	0.95	0.95	0.89	0.75	0.62	0.53	-	
	ETc mm/day	0.82	0.78	0.88	1.4	2.02	2.23	2.24	2.43	2.46	2.21	1.91	1.68	-	
	ETc mm/dec	4.9	7.8	8.8	14	22.3	22.3	22.4	26.7	24.6	22.1	15.3	6.7	-	197.9
	Eff rain mm/dec	0.3	1	2.6	1.8	1.6	1.4	1.1	1.5	2	2.4	2.4	0.8	-	18.9
	Irr. req. mm/dec	4.7	6.9	6.2	12.2	20.6	20.9	21.3	25.2	22.6	19.7	12.9	5.7	-	178.8
Pearl millet	Month	Nov	Nov	Dec	Dec	Dec	Jan	Jan	Jan	Feb	Feb	Feb	-		
	Decade	2	3	1	2	3	1	2	3	1	2	3	-		
	Stage	Init	Deve	Deve	Deve	Mid	Mid	Mid	Late	Late	Late	Late	-		
	Kccoeff	0.3	0.3	0.47	0.73	0.93	0.95	0.95	0.93	0.73	0.47	0.31	-		
	ETc mm/day	0.82	0.79	1.16	1.7	2.19	2.23	2.24	2.38	2	1.38	0.97	-		
	ETc mm/dec	4.9	7.9	11.6	17	24	22.3	22.4	26.2	20	13.8	1.9	-	-	172
	Eff rain mm/dec	0.3	1	2.6	1.8	1.6	1.4	1.1	1.5	2	2.4	0.6	-	-	16.3
	Irr. req. mm/dec	4.7	6.9	9	15.2	22.4	20.9	21.3	24.7	17.9	11.4	1.9	-	-	156.3

Inti-Initial stage, Deve- development stage, Mid- middle stage, Late -late stage of crop; Irr. req- irrigation requirement.

Crop water requirement

The crop water requirement for the given crop duration was computed using the input *viz.* climate, crop and soil data of the region. The crop evapo-transpiration (ETc) was calculated by the equation:

$$ETc = Kc \times ETo$$

Where,

Kc is the crop coefficient, ETc is crop evapo-transpiration and ETo is reference evapo-transpiration. Difference between crop evapo-transpiration and the effective rainfall determines the total irrigation requirement of the crop.

Irrigation scheduling

Irrigation scheduling determines when to irrigate and how much amount of water to be given to the crop at each irrigation. In this study, irrigation was scheduled at 50 per cent critical soil moisture depletion and irrigation was applied till the soil is refilled to field capacity at 70 per cent efficiency.

RESULTS AND DISCUSSION

Estimated reference evapo-transpiration

The reference evapo-transpiration was maximum in the month of May (5.45 mm/day) and least was estimated in the month of December (2.34 mm/day) (Table 1). This might due to high average temperature, wind velocity, sunshine hours in the month of May resulting in increased atmospheric demand for moisture and vice versa in the month of January (Luo *et al.,* 2021; Todorovic *et al.,* 2013).

Crop water requirement

The value of daily or decadal crop water requirements for *rabi* maize, sorghum and pearlmillet for Southern Odisha was presented in the Table 3. The highest crop water

Table 5: Estimated amount of irrigation (mm) required by maize, sorghum and pearl millet.

Particulars	Maize	Sorghum	Pearl millet
Gross Irrigation	399.9 mm	288.8 mm	260.2 mm
Net Irrigation	280.0 mm	202.2 mm	182.2 mm
Actual water Use by crop	251.0 mm	196.2 mm	171.1 mm
Effective rainfall	19.8 mm	17.7 mm	13.9 mm
Moist deficit at harvest	1.3 mm	46.3 mm	1.4 mm
Actual irrigation requirement	231.2 mm	178.5 mm	157.2 mm

Table 4: FAO CROPWAT based irrigation schedules of *rabi* cereals in the study area.

Crop	Date	Day	Stage	Rain mm	Ka fraction	Eta %	Depletion %	Net Irrigation mm	Deficit mm	Loss mm	Gross Irrigation mm
Maize	15Nov	1	Init	0.0	1.00	100	53	16.5	0.0	0.0	23.6
	23Nov	9	Init	0.3	1.00	100	28	11.9	0.0	0.0	17.0
	5Dec	21	Dev	0.0	1.00	100	28	16.9	0.0	0.0	24.1
	18Dec	34	Dev	0.0	1.00	100	29	22.3	0.0	0.0	31.8
	28Dec	44	Dev	0.0	1.00	100	28	25.7	0.0	0.0	36.7
	8Jan	55	Mid	0.0	1.00	100	30	30.1	0.0	0.0	43.0
	19Jan	66	Mid	0.0	1.00	100	29	28.7	0.0	0.0	40.9
	29Jan	76	Mid	0.0	1.00	100	28	27.6	0.0	0.0	39.4
	8Feb	86	Mid	0.0	1.00	100	29	29.1	0.0	0.0	41.5
	19Feb	97	End	0.0	1.00	100	32	31.7	0.0	0.0	45.3
	12Mar	118	End	0.0	1.00	100	40	39.6	0.0	0.0	56.5
	14 Mar	End	End	0.0	1.00	100	1				
Sorghum	15Nov	1	Init	0.0	1.00	100	53	17.1	0.0	0.0	24.4
	23Nov	9	Init	0.3	1.00	100	31	16.2	0.0	0.0	23.1
	6Dec	22	Dev	0.0	1.00	100	30	25.4	0.0	0.0	36.2
	20Dec	36	Dev	0.0	1.00	100	27	32.3	0.0	0.0	46.2
	3Jan	50	Mid	0.7	1.00	100	26	36.1	0.0	0.0	51.6
	20Jan	67	Mid	0.0	1.00	100	26	36.2	0.0	0.0	51.8
	6Feb	84	End	0.0	1.00	100	28	38.9	0.0	0.0	55.6
	4Mar	End	End	0.0	1.00	100	33				
Pearl millet	15Nov	1	Init	0.0	1.00	100	53	17.0	0.0	0.0	24.3
	21Nov	7	Init	0.3	1.00	100	26	11.8	0.0	0.0	16.9
	30Nov	16	Dev	0.0	1.00	100	26	16.9	0.0	0.0	24.1
	12Dec	28	Dev	0.0	1.00	100	28	26.2	0.0	0.0	37.4
	26Dec	42	Mid	0.7	1.00	100	31	36.8	0.0	0.0	52.5
	12Jan	59	Mid	0.0	1.00	100	30	36.3	0.0	0.0	51.8
	29Jan	76	End	0.0	1.00	100	31	37.3	0.0	0.0	53.2
	22Feb	End	End	1.00	100	29					

Table 6: Rooting depth, yield response factor and critical depletion of three prominent *rabi* cereals in southern Odisha.

Crop	Rooting depth (m)	Yield response factor				Critical depletion (fraction)		
		Initial	Development	Mid season	Late season	Initial	Mid season	Late season
Maize	1.00	0.40	0.40	1.30	0.50	0.55	0.55	0.80
Sorghum	1.40	0.20	0.40	0.55	0.20	0.60	0.50	0.80
Pearlmillet	1.20	0.40	0.60	1.25	0.80	0.50	0.60	0.70

requirement in maize occurs in the midseason phase, during third decade of January (32.3 mm). While the lowest water demand value was observed during initial phase. This might be due to less metabolic activities in the plants during initial days of crop growth while the plants need the most water during cob formation phase (Roja *et al.*2020b; Roja *et al.* 2020c). The crop water requirement estimated by CROPWAT 8.0 for the *rabi* maize in Southern Odisha was 252.3mm. Similarly, for sorghum and pearl millet, the total crop water requirement estimated to be 197.9 and 172 mm, respectively. The irrigation requirement for *rabi* maize, soghum and pearl millet was computed after estimating the actual rainfall contribution in satisfying the part of water requirement. The computed irrigation requirements for *rabi* maize, sorghum and pearlmillet were 231.2, 178.8 and 156.3 mm, respectively.

Irrigation scheduling

In Southern Odisha, under red sandy loam soils the irrigation scheduled at 50 per cent of critical depletion with a quantity of water sufficient to refill the soil to 100% field capacity, the maize, sorghum and pearl millet require 11, 7 and 7 irrigations respectively during their and growing periods. The net irrigation requirement of maize, sorghum and pearlmillet were 280, 202.2 and 182.2 mm respectively and gross irrigation requirement was 399.9, 288.8 and 260.2 mm, respectively. Similar findings were reported by Ramulu *et al.* (2010) in maize; Kumar *et al.* (2021) in pearlmillet; Rahma *et al.* (2018) in sorghum. The detailed irrigation scheduling is reported in Table 4 and Table 5.

CONCLUSION

Due to inclusion of wide range of inputs for running of FAO CROPWAT 8.0 *viz.* meteorological, soil and crop data from the study area made it a most ideal decision-making tool in irrigation planning. In the present study, it can be concluded that *rabi*maize requires maximum water requirement followed by sorghum and pearl millet. Maize requires eleven irrigations followed by seven irrigations by both sorghum and pearl millet respectively.Accepting this model-basedapproach in scheduling irrigation is expected to have wide scope in reducing the wastage of irrigation water and to improve water productivity of a crop in a given region.

Conflict of interest: None.

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