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Water Requirements and Irrigation Scheduling of Direct Seeded Rice-Wheat using CROPWAT Model

Amandeep Vashisht[1] • Sanjay T. Satpute[2*]

[1]Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, CO-80521, USA
[2]Department of Soil and Water Engineering, P.A.U., Ludhiana 141004, Punjab

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ABSTRACT

To conserve water, some form of irrigation scheduling should be used by the farming community. The simulation study was conducted with the objectives of determining irrigation water requirement and irrigation scheduling of directed seeded rice (DSR) and wheat irrigated by sprinkler irrigation system. The irrigation efficiency of 80% was considered for the study. From the study, for DSR, at 20% critical depletion, the total seasonal water requirement and irrigation requirement was found as 639.4 mm and 207.8 mm, respectively. The crop water requirement was same for 20%, 30% and 40% critical depletion because it was calculated on the basis of meteorological data. Due to change in critical soil moisture depletion from 20% to 30%, the effective rain efficiency found to increase from 42.9 % to 49.6%. Again due to change in critical soil moisture depletion from 30% to 40%, the effective rain efficiency found to increase from 49.6% to 52.2%. Due to change in effective rain efficiency, the actual irrigation requirement varied from 321.4 mm at 20% critical depletion to 252.7 mm at 40% critical depletion. Results revealed that the irrigation should be done at 40% critical depletion to achieve 0% yield reduction. In case of wheat, the total seasonal water requirement and irrigation requirement was found as 411 mm and 334 mm, respectively. The actual water use by the crop was 407.7 mm at 92.4 % rainfall efficiency considering 50% critical depletion. The actual irrigation requirement was found to be 252.7 mm. Irrigation should be done at the critical depletion to achieve 0% yield reduction of wheat and maximum rainfall efficiency. Results also revealed that the irrigation flow requirement for wheat found maximum in the month of March, i.e. 0.52 l/s/ha whereas the irrigation flow requirement for DSR found maximum in the month of August, i.e. 0.24 l/s/ha.

1. Introduction

Water demand has been growing rapidly due to population growth and increasing living standards, and as a result, water shortage has become serious problem which have made it necessary to improve integrated technology and multidisciplinary water resources management capabilities. Proper water management practices are the need of the day to enhance food production while save water as much possible or in other words to increase water use efficiency of field crops.

Besides the increasing demand of water for other purposes (industry and domestic use), degradation of water quality will also limit the water availability for agriculture sector in the coming future (FAO, 56). So the only tool to overcome this phenomenon is enhancing the water use efficiency, it is also called water productivity. Irrigation uses 80% of the available fresh water resources of the area, of which less than 30% is effectively utilized by the crop, and the rest is consumed by deep percolation and poor management practices.

*Corresponding author: sanjay4471@gmail.com

This infructuously consumed water not only leads to a great waste, but also causes water logging and salinization that adversely affects the productivity of most irrigated land of the area. On the other hand, the local farmers have no appropriate plan for irrigation-they just traditionally wait for rain and only irrigate their crops when an extreme drought has occurred. They actually do not know how much crop yield can be improved through irrigation, when and how much water is needed to irrigate their crops. So, in order to improve water use efficiency, it is essential to understand how much water is required by the crops in different periods, that is to say a practical and simplified irrigation schedule is needed for irrigated area.

Punjab state of the Indian subcontinent has been playing a leading role in the agricultural transformation of India and is considered as the most fertile plains for the livelihood of millions of people of India (Dhillon et al. 2010). Therefore, sustainable production of rice and wheat in Punjab is crucial for the food security of country. One approach to reduce water and labor demand is to grow dry-seeded rice with alternate wetting and drying instead of flooded puddled-transplanted rice (PTR). Direct seeded rice-wheat system is now considered to be an emerging production system in Punjab and other parts of India and Asia (Chauhan, 2012; Chauhan et al. 2012). Therefore, there is need to schedule irrigation for these crops considering the pressurised irrigation system as an alternative over the surface irrigation methods.

Irrigation scheduling has been in practice primarily for regulating an optimum water supply for better productivity, with soil water content always being maintained within the confines of readily available water (RAW) capacity. Irrigation scheduling is the application of water to crops in proper amount and at the proper time, resulting in maximum crop yields and minimum leaching of water and nutrients below crop root zone and subsequently to the groundwater. Irrigation scheduling can be accomplished using a water-balance accounting method, by monitoring soil moisture deficit or by monitoring plant-water potential (stress). Computer model simulation is an emerging trend in the field of water management. Water managers, irrigation agronomists, engineers and researchers are taking a keen interest in model simulation for the easier solution to problems faced by them. With availability of a few software such as CROPWAT and WEAP software, estimation of irrigation scheduling for an individual crop is no longer a weary and time intensive exercise for irrigation engineers. In this way, irrigation scheduling can be brought into use over the existing practical applications.

CROPWAT is one of the models that are being extensively used in the field of water management throughout the world which is designed by Smith (1991) of the Food Agricultural Organization (FAO). CROPWAT facilitates the estimation of the crop evapotranspiration, crop water requirements and irrigation schedule with different cropping patterns for irrigation planning (Kuo et al. 2006; Gowda et al. 2013; George et al. 2000; Gouranga and Verma, 2005; Martyniak et al. 2006; Dechmi et al. 2003; Zhiming et al. 2007). Considering rationale presented, the objectives considered for this study were to determine the crop water requirement of direct seeded rice (DSR)-wheat system and to design an indicative irrigation schedules for DSR-wheat system using CROPWAT under different levels of water availability, with an objective to reduce the quantity of water and labour through optimum irrigation, thereby making maximum use of soil moisture storage.

2. Materials and Methods

Appropriate irrigation schedules for main crops in Punjab i.e. rice and wheat, need to be developed to achieve better water use efficiency and management of depleting fresh water resource. In the present study, sprinkler irrigated direct seeded rice (DSR) and wheat was considered for irrigation scheduling with 80% irrigation efficiency.

Irrigation Scheduling:

Irrigation scheduling has been in practice primarily for regulating an optimum water supply for better productivity, with soil water content always being maintained within the confines of readily available water (RAW) capacity. Irrigation scheduling can be brought into the realms of use, or at most the refinement of existing practical applications can be thought of. CROPWAT handles irrigation scheduling for each crop individually.

Application of CROPWAT 8.0

Computerized program can easily access databases for climate and crop characteristics to allow for speedy determination of irrigation water requirements. In the event, real data is unavailable, an indicative schedule can be worked out based on averaged climatic conditions experienced in the study area for a significant length of time.

The Food and Agricultural Organization (FAO) CROPWAT model for irrigation scheduling offers the possibility to:

- Design an indicative irrigation schedules and its impact over yield
- Evaluate field irrigation program in terms of efficiency of water use and yield reduction
- Simulate field irrigation program under water deficiency conditions, rain-fed conditions, supplementary irrigation, etc.

Input required in this software includes three types of data:

To work out irrigation scheduling, the CROPWAT 8.0 demands meteorological data, crop data and soil data to be input in the program (Table 1). This is facilitated by a number of windows that pop up one after another to let user feed a particular set of data. CROPWAT computes ETo by applying Penman-Monteith method recommended by FAO and is claimed to offer consistent result as compared to other methods used for identical purpose.

. **Meteorological data:**

i) Climate data:

The meteorological data were collected for four years (2009-2012) from School of Climate Change and Agricultural Meteorology, PAU, Ludhiana. These data include daily maximum and minimum temperature, daily relative humidity, daily wind speed and daily sunshine hoursThe daily average of all these data were calculated and used in the model.

Table 1. Inputs required for CROPWAT

Parameter or variable	Unit
Location data	
Country	
Station	
Latitude	°
Longitude	°
Altitude	m
Daily meteorological data	
Maximum temperature	°C
Minimum temperature	°C
Relative air humidity	%
Wind speed	m/s
Bright sunshine	h
Precipitation	mm
Soil data	
Total available soil water	mm/m depth
Maximum rain infiltration rate	mm/d
Maximum rooting depth	m
Initial soil water depletion	%
Crop data	
Planting date	day/month
Harvesting date	day/month

These parameters are essential to calculate ETo. CROPWAT calculate radiation and ETo depending on climate data.

ii) Rain data:

The daily rainfall data were collected from the School of Climate Change and Agricultural Meteorology, PAU, Ludhiana for four years (2009-2012) and the average of four years data was used in CROPWAT software to obtain effective rainfall which was calculated in the software using USDA soil conservation service method.

Crop data:

The software needs some information about DSR and wheat crops i.e. crop name, planting date, harvesting date, crop coefficient (Kc), rooting depth, length of plant growth stages, critical depletion and yield response factor. Sowing date for DSR was considered as June 11 and harvest date was considered as October 18 whereas, for wheat crop, planting date was specified as November 10 and harvest date was considered as April 13. The values for crop data for DSR and wheat are mentioned in Table 2 and 3.

Soil data:

Presence of sand, silt, and clay in various proportions determines the type of soil, and its moisture holding capacity. The soil type considered in present study is classified in the software as medium soil which is predominant in Ludhiana district of Punjab. The software needs some general soil data like total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion and initial available soil moisture which is presented in Table 4.

Table 2 Crop data: Direct Seeded Rice (DSR)

Crop parameter	Initial	Development	Mid-season	Late	Total
Kc	0.62	-	1.16	0.67	
Length, days	20	35	45	30	130
Rooting depth, m	0.10		0.60	0.60	
Critical depletion factor	0.20		0.20	0.20	
Yield response factor	1.00	1.09	1.32	0.50	1.10
Crop height, m			1.00		

(Source: Choudhury et al. 2013 and FAO 66, 2012)

For DSR, two more values of critical depletion factor were considered i.e. 30% and 40%.

Table 3. Crop data: Wheat

Crop parameter	Initial	Development	Mid-season	Late	Total
Kc	0.44	-	1.15	0.40	
Length, days	30	45	50	30	155
Rooting depth, m	0.15		1.20	1.20	
Critical depletion factor	0.50		0.50	0.50	
Yield response factor	0.20	0.60	0.50	0.40	1.0
Crop height, m			1.00		

Table 4. Soil data: Medium Soil

Parameter	Value
Total available soil moisture (FC-PWP)	120 mm/m
Maximum infiltration rate	90 mm/day
Maximum rooting depth	180 cm
Initial soil Moisture depletion (as % TAM)	0 %

Irrigation scheduling options:

Irrigation scheduling options in CROPWAT allows a range of options, depending upon the objective of the user and the design restrictions that the irrigation system imposes. The scheduling options refer to two different categories:

i) Timing options related to WHEN irrigation is to be applied. Based on constraints imposed by water availability at the source, user can select most appropriate choice among them and evaluate its impact on the yield and other losses.
ii) Application options refer to HOW MUCH water is to be given per irrigation turn. Additionally, user can also modify irrigation efficiency according to the method of irrigation practiced in the region.

Simulations

The key steps in the simulations were:

1. Run the model for Rice and wheat crop with the daily average climatic data and single scheduling criteria: irrigated crop

Analyze the model results and select the most suitable irrigation schedule options.

3. Results and Discussions:

The CROPWAT 8.0 was used to prepare the irrigation schedule of DSR and wheat crop. The model was run for medium soils under same level of water availability.

The model predicted the daily, decadal as well as monthly crop water requirement at different growing stages of rice and wheat crops.

Direct seeded rice (DSR):

For this crop, the irrigation timing option and irrigation application was selected from the dropdown options of irrigation scheduling menu. The no yield reduction and maximum rainfall efficiency was considered for selecting irrigation timing.

When Critical depletion = 20%

Crop Water Requirement:

All the required climate data, rainfall data, crop data and soil data for DSR was placed in appropriate window to predict the crop water requirement. The results include the daily ETc in that particular decade days, decadal ETc, decadal effective rainfall and decadal irrigation requirement at different growing stages of DSR (Table 5). The results of crop water requirement revealed that the total seasonal water requirement for DSR was found 639.4 mm and the total rain received during the cropping period was 736.6 mm, out of which 438.9 mm was effective rainfall as predicted by the model. The results also revealed that the net seasonal irrigation requirement was 207.8 mm for rice crop. From the results, it was found that the value of daily ETc decreased from as high as 6.50 mm/day to as low as 2.80 mm/day as the temperature decreased from June to October.

Table 5. Daily and decadal ETc and irrigation requirement

Month	Decade	Stage	Crop Coefficient, Kc	ETc, mm/day	ETc, mm/dec	Eff. rain, mm/dec	Irr. Req., mm/dec
June	2	Init	0.62	6.10	61.0	31.6	29.5
June	3	Init	0.62	5.89	58.9	47.7	11.2
July	1	Devel	0.70	4.75	47.5	43.7	3.9
July	2	Devel	0.86	4.99	49.9	50.4	0
July	3	Devel	1.02	4.83	53.1	53.4	0
Aug	1	Mid	1.15	6.50	65.0	21.5	43.5
Aug	2	Mid	1.16	5.05	50.5	56.8	0
Aug	3	Mid	1.16	5.21	57.3	37.8	19.5
Sep	1	Mid	1.16	4.60	46.0	33.7	12.3
Sep	2	Late	1.15	4.77	47.7	47.9	0
Sep	3	Late	1.03	4.57	45.7	8.2	37.5
Oct	1	Late	0.87	3.43	34.3	6.4	28
Oct	2	Late	0.72	2.80	22.4	0	22.4
Total					**639.4**	**438.9**	**207.8**

Irrigation scheduling:

For the application of irrigation, the critical soil moisture depletion was considered at 20%. The irrigation timing option and irrigation application was selected from the dropdown options of irrigation scheduling options. From the results, it was found that the yield reduction will not occur at any growing stage of DSR with maximum rainfall efficiency as predicted with irrigation at 20 % critical depletion and by refilling the soil to the field capacity (Table 6). The detailed results of total gross irrigation, total net irrigation, actual water use by crop and potential water use by crop is given in the Table 7. The rain efficiency of 42.9 % was found and by this efficiency, effective rainfall was found to be 315.7 mm. The total net irrigation varied from the irrigation requirement due to change in effective rainfall efficiency. When the depletion of total available moisture (TAM) reaches its critical value i.e. upto readily available moisture (RAM), irrigation event should be taking place to bring back the soil water content to its field capacity. The Fig. 1 showed the irrigation schedule pattern for DSR at 20% critical depletion.

Table 6. Yield reduction at 20% 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	1.00	1.09	1.32	0.50	1.10
Yield reduction	0.0	0.0	0.0	0.0	
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0 %

Table 7. Total gross irrigation, total net irrigation and efficiency of rain at 20% critical depletion

Totals			
Total gross irrigation	384.2 mm	Total rainfall	736.6 mm
Total net irrigation	307.4 mm	Effective rainfall	315.7 mm
Total irrigation losses	0.0 mm	Total rain loss	420.9 mm
Actual water use by crop	637.1 mm	Moist deficit at harvest	14.0 mm
Potential water use by crop	637.1 mm	Actual irrigation requirement	321.4 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	42.9 %
Deficiency irrigation schedule	0.0 %		

When critical depletion = 30%

Crop Water Requirement:

The crop water requirement was calculated on the basis of meteorological data so the crop water requirement was not affected due to the change in critical depletion factor. The values of the crop water requirement (CWR) and irrigation requirement (IR) remained same.

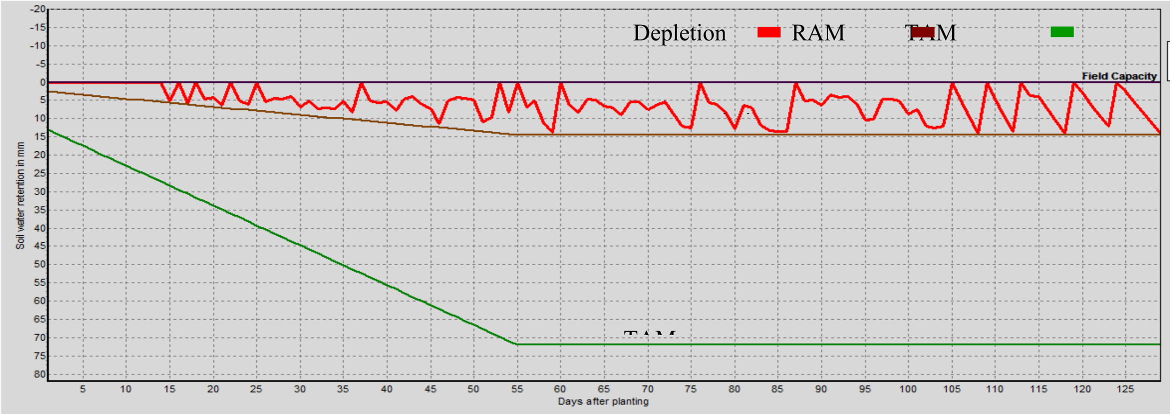

Fig. 1. Irrigation scheduling graph for DSR at 20% critical depletion

Irrigation scheduling:

From the results, the no yield reduction at all the growing stages was predicted with maximum rainfall efficiency and with the condition that the irrigation should be done at 30% critical depletion and refill the soil to the field capacity. The detailed results of total gross irrigation, total net irrigation, actual water use by crop and potential water use by crop is also given in the Table 8. Due to change in critical soil moisture depletion from 20% to 30%, the effective rain efficiency found to increase from 42.9 % to 49.6%. The total net irrigation varied from the irrigation requirement due to change in effective rainfall efficiency which was found to be 365.7 mm. The Fig. 2 showed the irrigation schedule pattern for DSR at 30% critical depletion.

When critical depletion = 40%

Crop Water Requirement:

The crop water requirement in this model was calculated on the basis of meteorological data so the crop water requirement was not affected due to the change in critical depletion factor. The values of the CWR and IR remained same

Table 8. Total gross irrigation, total net irrigation and efficiency of rain at 30% critical depletion

Totals			
Total gross irrigation	339.2 mm	Total rainfall	736.6 mm
Total net irrigation	271.4 mm	Effective rainfall	365.7 mm
Total irrigation losses	0.0 mm	Total rain loss	370.9 mm
Actual water use by crop	637.1 mm	Moist deficit at harvest	0.0 mm
Potential water use by crop	637.1 mm	Actual irrigation requirement	271.4 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	49.6 %
Deficiency irrigation schedule	0.0 %		

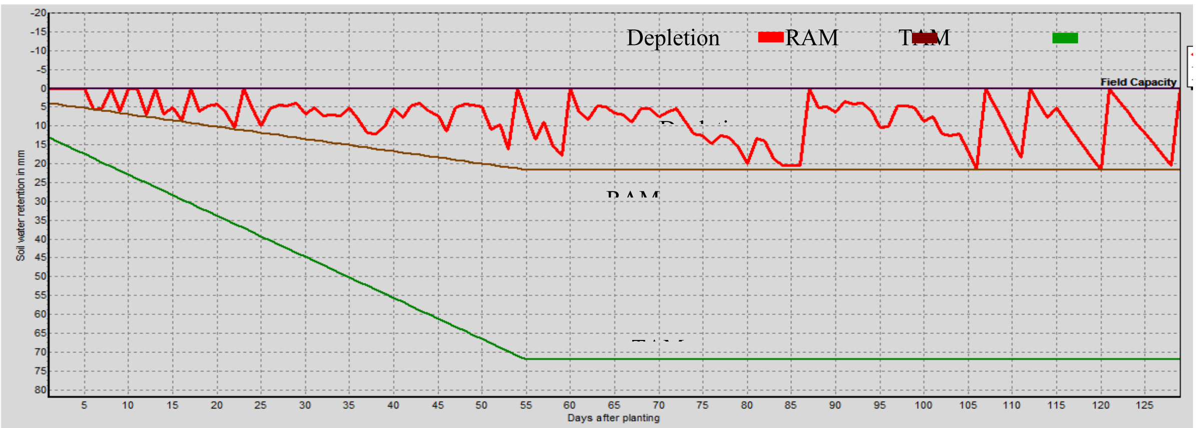

Fig. 2. Irrigation scheduling graph for DSR at 30% critical depletion

Irrigation scheduling:

In this case, the critical soil moisture depletion was considered as 40%. Model predicted 0% yield reduction at all the growing stages with maximum rainfall efficiency and with the condition that the soil should be refilled to the field capacity. The detailed results of total gross irrigation, total net irrigation, actual water use by crop and potential water use by crop is given in the Table 9. Due to change in critical soil moisture depletion from 30% to 40%, the effective rain efficiency found to increase from 49.6% to 52.2% i.e. from 365.7 mm to 384.4 mm. The total net irrigation varied from the irrigation requirement due to change in effective rainfall efficiency. The Fig. 3 showed the irrigation schedule pattern for DSR at 40% critical depletion.

Wheat Crop

Crop Water Requirement:

All the required climate data, rainfall data, crop data and soil data for wheat crop was placed at appropriate window to predict the crop water requirement. The results include the daily ETc, decadal ETc, decadal effective rainfall and decadal irrigation requirement at different growing stages of wheat (Table 10). The results of crop water requirement revealed that the total seasonal water requirement for wheat crop was found as 411 mm. The total rain received during the cropping period was 79.2 mm out of which 75.1 mm was effective rainfall as predicted by the model..

The effective rainfall was contributed towards the crop water requirement From the results, the value of daily ETc increased from as low as 1.3 mm/day (less crop growth and cooler climate) to as high as 4.78 mm/day (more crop growth and warm climate). The net seasonal irrigation requirement was found to be 334 mm. The results revealed that in all the decades of each month of the growing period of crop, the irrigation requirement was less than the ETc except for 2^{nd} and 3^{rd} decade of the November, 3^{rd} decade of January and February, respectively, because of rainfall during this period.

Irrigation scheduling:

Irrigation scheduling was done at 50 % critical soil moisture depletion. The irrigation timing option and irrigation application was selected from the dropdown options of crop schedule options. The criteria considered for the selection of irrigation timing option includes the no yield reduction and maximum rainfall efficiency (Table 11). The irrigation efficiency of 80% was considered with irrigation application by sprinkler irrigation system. After the analysis, no yield reduction at all the growing stages with maximum rainfall efficiency was predicted with 14 days irrigation interval and refilled the soil to the field capacity. The results revealed that the total gross irrigation was 418.1 mm and total net irrigation was 334.5 mm (Table 12). The actual water use by the crop was 407.7 mm whereas the efficiency of the rain was 92.4 %. The Fig. 4 showed the irrigation schedule pattern for wheat crop. Irrigation should be applied when depletion line in the graph showed the peak.

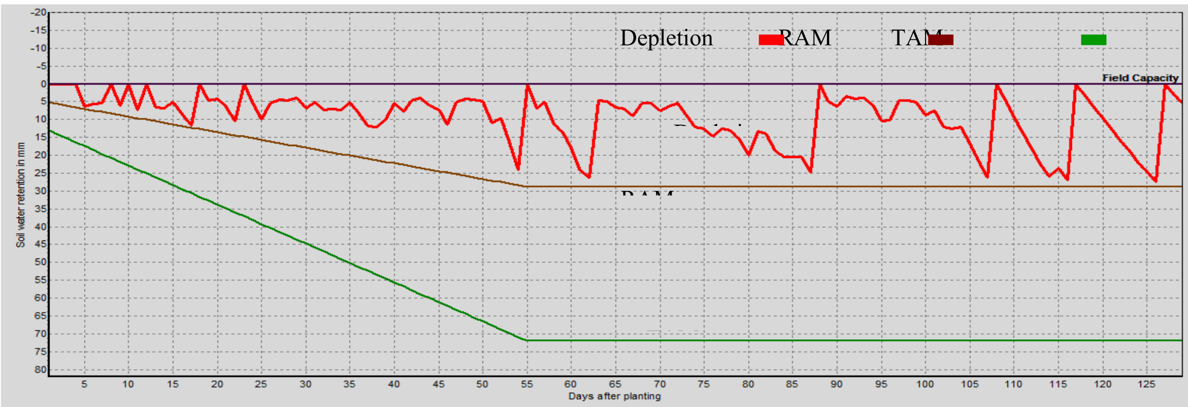

Fig. 3. Irrigation scheduling graph for DSR at 40% critical depletion

Table 9. Total gross irrigation, total net irrigation and efficiency of Rain at 40% critical depletion

Totals			
Total gross irrigation	309.0 mm	Total rainfall	736.6 mm
Total net irrigation	247.2 mm	Effective rainfall	384.4 mm
Total irrigation losses	0.0 mm	Total rain loss	352.2 mm
Actual water use by crop	637.1 mm	Moist deficit at harvest	5.5 mm
Potential water use by crop	637.1 mm	Actual irrigation requirement	252.7 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	52.2 %
Deficiency irrigation schedule	0.0 %		

Table 10. Daily and decadal ETc and irrigation requirement

Month	Decade	Stage	Crop Coefficient, Kc	ETc, mm/day	ETc, mm/dec	Eff rain, mm/dec	Irr. Req., mm/dec
Nov	1	Init	0.44	1.30	1.30	0	1.3
Nov	2	Init	0.44	1.23	12.3	1.1	11.2
Nov	3	Init	0.44	0.99	9.90	0	9.9
Dec	1	Devel	0.44	1.08	10.8	5	5.8
Dec	2	Devel	0.55	1.30	13.0	2.2	10.8
Dec	3	Devel	0.72	1.40	15.4	4.4	11
Jan	1	Devel	0.89	1.13	11.3	8.2	3.2
Jan	2	Devel	1.06	1.73	17.3	14	3.3
Jan	3	Mid	1.18	2.57	28.2	0	28.2
Feb	1	Mid	1.18	2.81	28.1	12.5	15.5
Feb	2	Mid	1.18	3.04	30.4	10.1	20.3
Feb	3	Mid	1.18	3.65	29.2	0.1	29.1
March	1	Mid	1.18	4.59	45.9	1.9	44
March	2	Late	1.13	5.30	53.0	2.1	50.9
March	3	Late	0.87	4.78	52.6	3.1	49.5
April	1	Late	0.60	4.23	42.3	7.2	35
April	2	Late	0.43	3.39	10.2	3.3	4.7
Total					**411.1**	**75.1**	**333.9**

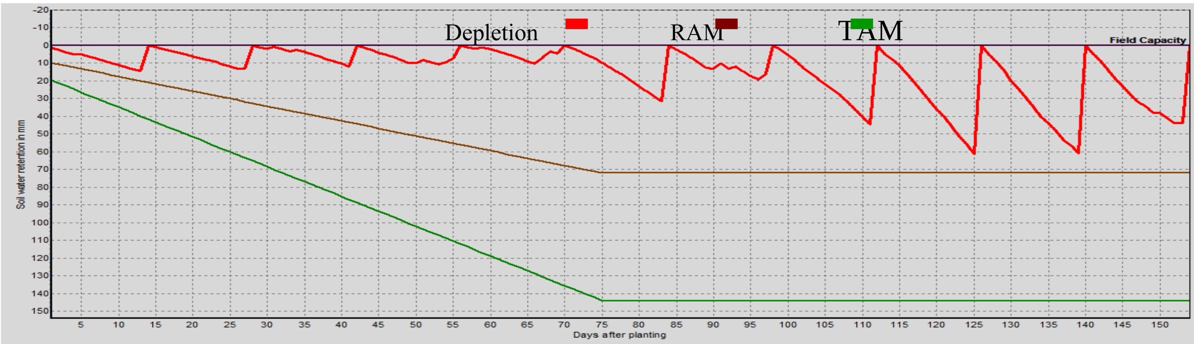

Fig.4. Irrigation scheduling graph for wheat

Table 11. Yield reduction at 50 % 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	0.20	0.60	0.50	0.40	1.00
Yield reduction	0.0	0.0	0.0	0.0	
Cumulative yield reduction	0.0	0.0	0.0	0.0	0.0 %

Table 12 . Total gross irrigation, total net irrigation and efficiency of rain

Totals			
Total gross irrigation	418.1 mm	Total rainfall	79.2 mm
Total net irrigation	334.5 mm	Effective rainfall	73.2 mm
Total irrigation losses	0.0 mm	Total rain loss	6.0 mm
Actual water use by crop	407.7 mm	Moist deficit at harvest	0.0 mm
Potential water use by crop	407.7 mm	Actual irrigation requirement	334.5 mm
Efficiency irrigation schedule	100.0 %	Efficiency rain	92.4 %
Deficiency irrigation schedule	0.0 %		

Table 13. Precipitation deficit and irrigation requirement for actual area

Month	Precipitation deficit, mm		Net scheme Irrigation requirement			Irrigated area (% of total area)	Irr. req. for actual area, l/s/ha
	Rice	Wheat	mm/day	mm/month	l/s/ha		
Jan	0	32.8	1.1	32.8	0.12	100	0.12
Feb	0	61.9	2.2	61.9	0.26	100	0.26
March	0	139.5	4.5	139.5	0.52	100	0.52
April	0	39	1.3	39	0.15	100	0.15
May	0	0	0	0	0	0	0
June	40.7	0	1.4	40.7	0.16	100	0.16
July	3.9	0	0.1	3.9	0.01	100	0.01
Aug	63.1	0	2	63.1	0.24	100	0.24
Sep	49.8	0	1.7	49.8	0.19	100	0.19
Oct	50.3	0	1.6	50.3	0.19	100	0.19
Nov	0	22.4	0.7	22.4	0.09	100	0.09
Dec	0	27.1	0.9	27.1	0.1	100	0.1

Cropping Pattern and Schemes:

The rice- wheat cropping pattern considered three subsets. The first was rice-wheat pattern with critical depletion of 20 percent for rice and 50 percent for wheat, the second was rice-wheat pattern with critical depletion of 30 percent for rice and 50 percent for wheat and the third was rice-wheat cropping pattern with critical depletion of 40 percent for rice and 50 percent for wheat. For both the crops, it was considered that the all the area is under cultivation i.e. 100 % area in respective seasons. The results revealed that the irrigation requirement for month of May found to be nil because no crop was sown in this month (Table 13). Also, it was very small for the month of July because in July precipitation deficit was very less i.e. 3.9 mm. Results also revealed that the irrigation flow requirement for wheat found maximum in the month of March, i.e. 0.52 l/s/ha whereas the irrigation flow requirement for DSR found maximum in the month of August, i.e. 0.24 l/s/ha.

Conclusions:

Following conclusions have been drawn:

1. The results of crop water requirement of DSR revealed that the total seasonal water requirement for DSR was 639.4 mm as predicted by the model and gross irrigation requirement considering 80 % irrigation application efficiency was estimated to be 384.2 mm, 339.2 mm and 309.0 mm at critical depletions of 20%, 30% and 40%, respectively, with rainfall efficiency of 42.9%, 49.6% and 52.2%.
2. From the results, irrigation for direct seeded rice should be applied at 40% critical depletion to achieve 0% yield reduction and maximum rainfall efficiency.
3. The results of crop water requirement of wheat crop revealed that the total seasonal water requirement for wheat crop was 411 mm as predicted by the model and the total gross irrigation requirement considering 80% irrigation application efficiency was found to be 418.1 mm at critical depletion of 50% considering 92.4% rainfall efficiency.
4. From the results, irrigation for wheat should be applied at 50% critical depletion to achieve 0% yield reduction and maximum rainfall efficiency.
5. The irrigation flow requirement for wheat found maximum in the month of March, i.e. 0.52 l/s/ha whereas the irrigation flow requirement for DSR found maximum in the month of August, i.e. 0.24 l/s/ha.

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