Journal of Medicinal Plants Studies
www.PlantsJournal.com

ISSN (E): 2320-3862
ISSN (P): 2394-0530
NAAS Rating 2017: 3.53
JMPS 2017; 5(3): 338-342

Received: 20-03-2017
Accepted: 22-04-2017

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Water requirement of wheat crop for optimum production using CROPWAT model

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Abstract
A field experiments was conducted during *rabi* seasons of 2014-2015 and 2015-2016 at the Agro met Farm, N.D. University of Agriculture and Technology, Kumarganj, Faizabad (U.P.) The treatment comprised of four levels of irrigation schedule *Viz.*, I_1 (critical stages), I_2 (0.6 IW: CPE ratio), I_3 (0.8 IW: CPE ratio), and I_4 (1:0 IW: CPE ratio). The findings of present investigation indicated that the growth and yield attributes of wheat were significantly influence due to different irrigation schedule. The results, further revealed that growth attributes such as plant height (cm) and Leaf area index (LAI) were found significantly higher under I_1 (critical stages) treatment. The highest grain yield (52.3 and 52.2 q/ha) and straw yield (65.8 and 66.9 q/ha) recorded under I_1 (critical stages) treatment. The lowest grain yield (51.2 and 51.9 q/ha) and straw yield (64.4 and 65.3 q/ha) was recorded under I_2 (0.6 IW: CPE ratio).Water requirement of wheat crop simulated by CROPWAT model was 237.8 and 266.9 mm for the whole crop season during 2014-15 and 2015-16 respectively. In initial stage minimum water requirement was simulated by model. The highest crop water requirement (130.7& 136.7 mm / decade) recorded in the late stage of growth which was 45.0 and 48.7% of total water requirement of wheat crop during the years 2014-15 and 2015-16. The phase wise reduction in Etc, yield and cumulative yield reduction was less in I_1 (critical stages) as compared to other treatments.

Keywords: cropwat model, yield reduction, leaf area index, grain yield, straw yield, water requirement.

Introduction
CROPWAT is a computer program for irrigation planning and management, developed by the Land and Water Development Division of FAO (FAO, 1992) [3]. Its basic functions include the calculation of reference evapotranspiration, crop water requirements, and crop scheme irrigation. Through a daily water balance, the user can simulate various water supply conditions and estimate yield reductions and irrigation and rainfall efficiencies. Typical applications of the water balance include the development of irrigation schedules for various crops and various irrigation methods, the evaluation of irrigation practices, as well as rainfed production and drought effects. There are two new versions of the CROPWAT: one is CROPWAT v 7.0 that contains a completely version in Pascal, developed with the assistance of the Agricultural College of Velp, Netherlands. It overcomes many of the shortcomings of the original 5.7 version. CROPWAT 7.0 is a DOS-application, but it runs without any problem in all MS-WINDOWS environments. Another one is CROPWAT for Windows that is written in Visual Basic and operates in the Windows environment. It has been developed with the assistance of the International Irrigation & Development Institute (IIDS) of the University of Southampton, UK. Both versions use the same FAO (1992) [3] Penman-Montieth method for calculating the reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations. Some of the interpolation methods used in CROPWAT for Windows are slightly different (up to 2%) to those used in CROPWAT 7.0.

Materials and Methods
Model input data
The CROPWAT model version 8.0 was calibrated for wheat crop for different irrigation regimes. Daily weather data (minimum temperature, maximum temperature, relative humidity, sunshine hours) have been given as input for computation of ETO. Similarly rainfall was also given as input for calculation of effective rainfall. The crop characteristic such as planting date, phase wise Kc values, stage duration, rooting depth were given. In soil file soil characteristics Total available soil moisture (mm/meter), rain infiltration rate (mm/day),

rooting depth (cm) and initial soil moisture depletion (%) were also given as input. There after the model was simulated for various irrigation options for scheduling of irrigation.

Experimental site

The experimental site is located at the main campus of university on the left side of Faizabad - Raibareilly road at a distance of 43 km away from Faizabad district headquarter.

Climate in brief

The local of experimental site lies between a latitude of $24^0$47' and $26^0$56' N and longitude of $82^0$12' and $83^0$98' E and an altitude of 113 m mean sea level, in the gangetic alluvium of eastern Uttar Pradesh. The Faizabad district falls in semi-arid zone, receiving a mean annual rainfall of about 1063 mm, out of which about 89 percent of the total rainfall is received during south-west monsoon (from June to September) with few showers (4%) in winter season. On the basis of average rainfall intensity during monsoon season it was that rainfall mostly occurred between July to September while mid-September onwards.

Experimental details

The PBW 343 cultivars of wheat was sown at 15th Nov. during the year 2014-15 and 2015-16 with recommended package of practices Farm, N.D. University of Agriculture and Technology, Kumarganj, Faizabad (U.P.).

Scheduling of irrigation

A fixed quantity of 60 mm of water was applied to the concerned experimental plots according to the irrigation schedules of the respective treatment. Irrespective of the treatments, uniform irrigation was given immediately after sowing to all the treatments for better establishment of the crop. The cumulative pan evaporation values were calculated from daily pan evaporation measured with the help of USWB class 'A' open pan evaporimeter installed at meteorological observatory, which was in the proximity of the experimental plot. A fixed depth of 60 mm irrigation water was applied to each treatment at irrigation based on IW: CPE ratio of 0.6, 0.8 and 1.0, respectively.

Plant height (cm)

Five plants were selected randomly in each plot and tagged for measuring height at different intervals. Height was measured at 30, 45, 60, 75, 90, 105 and 120 DAS with the help of meter scale from ground surface to the tip of the topmost leaf before heading and up to the base of the ear head after heading.

Leaf area index (LAI)

The leaf area was measured at 30, 45, 60, 75, 90, 105 and 120 DAS of the crop. The plants of 25 cm row length were taken and green leaves were separated to record their surface area by automatic leaf area meter. All the leaves were grouped into three viz., small, medium and large. Five leaves from each group were taken and their surface areas were measured. Areas of five leaves were multiplied with respective leaf numbers of a group and sum of all the three gave the total leaf area. For obtaining index, leaf area was divided by the ground area.

$$\text{LAI} = \frac{\text{Leaf area}}{\text{Ground area}}$$

Grain yield (qha^{-1})

After weighing the total biomass of each plots. The produce of each net plot was threshed separately and cleaned grain were air dried to maintain 12 per cent moisture. The grain yield was recorded in kg per plot and finally converted into quintal per hectare.

Straw yield (q ha^{-1})

The yield of straw was calculated by subtracting the grain yield from the total biological yield of the crop.

Result and discussion

Plant height

Plant height of wheat showed statistically significant variation due to moisture regime at 30,45,60,75,90,105 and at 120 DAS under the present trail (Table.1).The taller plant (18.3&18.2,32.6&32.5, 43.4&44.1,66.4&67.5, 88.5&90.0, 91.3&92.9, 95.3&96.9cm) was recorded from I_1(critical stages) at 30, 45, 60, 75, 90, 105 and 120 DAS both year 2014-15 and 2015-16 respectively and at par with I_4while the shorter plant (17.3&17.2, 28.5&28.4, 38.0&38.6, 56.6&57.6, 75.5&76.6, 79.8&81.2, 83.4&84.8) was recorded from I_2 (0.6 IW:CPE ratio). (Sharma *et al.* 1990) [35]

Leaf area index (LAI)

Moisture regime in terms of leaf area index of wheat was presented in Table 2. at 30, 45, 60, 75, 90, 105 and 120 DAS (Moisture regime, date of sowing and variety had no significant influence on the leaf area index of wheat at 30 DAS. In general the leaf area index increased with the advancement of the crop growth and reached to its maximum at 75 DAS and thereafter it decreased because of senescence of leaves. The I_1 moisture regime noticed significantly higher LAI (2.4 and 2.4) at 45 DAS, (4.0 and 4.1) at 60 DAS,(4.0 and 4.1) at 75 DAS, (4.1 and 4.2) at 90 DAS,(3.4 and 3.5) at 105 DAS, (2.0 and 2.1) at 120 DAS during the year 2014-15 and 2015-16, respectively over other moisture regime (Ahmad 2002) [1].

Grain Yield

The data pertaining to grain yield was recorded and presented in Table 3. The statistical comparison of the results of grain yield revealed that differences in yield due to differences in the different irrigation treatments were found statistically significant. I_1 (critical stages) treatment yielded the highest (52.3 q/ha and 53.2 q/ha in the year 2014-15 and 2015-16 respectively) as compared to I_2, I_3 and I_4 treatment. However, I_1 and I_4 were found to be at par with each other in respect of their respective yields. The lowest grain yield with I_2 (45.8 and 46.5 q/ha) during the year 2014-15 and 2015-16, respectively. (Maliwal *et al*. (2000) [4].

Straw yield (t/ha)

Data pertaining to straw yield indicated that the moisture regimes had significant effect on the straw yield of wheat (Table 3.). Highest straw yield (65.8&66.9q/ha) was recorded in I_1 (critical satges) treatment and lowest (57.5&58.5q/ha) under I_2 treatment. Treatment I_1 and I_4 treatment were found to be at par with each other. (Brahma *et al.* 2006) [2].

Water requirement of wheat crop

The water requirement of wheat crop simulated by CROPWAT model has been given in table 4.and 5.Water requirement of wheat crop simulated by CROPWAT model was 237.8 and 266.9 mm for the whole crop season during 2014-15 and 2015-16 respectively. The wheat crop season was divided into four stages *i.e* Initial stage, development

stage, mid stage and late stage. The effective rainfall during whole crop season was 55.7and 34.7mm during both years 2014-15 and 2015-16. In the initial stage of wheat crop growth, it needed minimum quantity of water (15.6& 17.8 mm / decade) in the November month and ETc was 15.6& 17.8 mm/decade during both years. The crop water requirement increased by increasing the growth stage of wheat crop. The highest crop water requirement (130.7& 136.7 mm / decade) recorded in the late stage of growth which was 45.0 and 48.7% of total water requirement of wheat crop during the years 2014-15 and 2015-16 respectively (Mahesh 2013).

Phase wise yield reductions of wheat crop using CROPWAT model

The phase wise reduction in Etc, yield and cumulative yield reduction under I_1 to I_4 irrigation treatment was simulated by CROPWAT model and results are presented in Table 6. Results showed that 4.2 & 4.5, 22.6 & 23.2, 5.8 & 6.2 and 4.8 & 5.2 mm seasonal ET reduction was noted under I_1, I_2, I_3, and I_4 treatments during both years 2014-15 and 2015-16 respectively. Maximum ETc reduction was noted under I_2 (0.6 IW/CPE) treatment and lowest under I_1 (critical stages) treatment. Similarly 4.2 & 4.5, 22.6 & 23.2, 5.8 & 6.2 and 4.8 & 5.2 %cumulative yield reduction was simulated by model for I_1, I_2, I_3 and I_4 treatment of both year respectively. Lowest yield reduction (4.2% & 4.5%) was observed under I_1 (critical stages) treatment and highest reduction (22.6 % & 23.2%) under I2 treatment during both year 2014-15 and 2015-16 respectively. Under I_2treatment 28 & 30, 10.9 &12.5, 32.6 & 33.6 and 6.4 & 7.3 mm reduction in ETc (mm) at initial, development, mid and late stage of wheat affected yield as compared to other treatment of both year 2014-15 and 2015-16 respectively. Reduction in ETc during initial stage of crop was not affecting negatively on final yield. The reduction in ETc during mid and late stage negatively affecting final yield of wheat of both year 2014-15 and 2015-16 respectively (Mukesh 2012)

Table 1: Effect of Irrigation level on plant height of wheat.

Treatments	Plant Height (cm)													
	30 DAS		45 DAS		60 DAS		75 DAS		90 DAS		105 DAS		120 DAS	
	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016
Moisture Regime														
I_1 (Critical stages)	18.3	18.2	32.6	32.5	43.4	44.1	66.4	67.5	88.5	90.0	91.3	92.9	95.3	96.9
I_2 (0.6 IW: CPE)	17.3	17.2	28.5	28.4	38.0	38.6	56.6	57.6	75.5	76.7	79.8	81.2	83.4	84.8
I_3 (0.8 IW: CPE)	17.2	17.1	29.8	29.7	39.7	40.4	59.3	60.2	79.0	80.3	83.6	85.0	87.3	88.7
I_4 (1.0 IW: CPE)	17.5	17.9	31.3	32.1	41.7	42.3	62.2	63.1	83.0	86.1	87.8	91.2	91.7	95.2
SEm±	0.40	0.39	0.48	0.72	0.64	0.66	1.31	0.96	1.74	1.71	1.35	1.84	1.41	2.12
CD at 5%	NS	NS	1.66	2.48	2.21	2.27	4.52	3.32	6.03	5.93	4.66	6.36	4.86	7.35

Table 2: Effect of Irrigation level on leaf area index of wheat

Treatments	Leaf area index (LAI)													
	30 DAS		45 DAS		60 DAS		75 DAS		90 DAS		105 DAS		120 DAS	
	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016
Irrigation level														
I_1 (Critical stages)	1.8	1.8	2.4	2.4	4.0	4.1	4.0	4.1	4.1	4.2	3.4	3.5	2.0	2.1
I_2 (0.6 IW: CPE)	1.7	1.7	2.1	2.1	3.5	3.6	3.4	3.5	3.5	3.6	2.9	3.0	1.7	1.7
I_3 (0.8 IW: CPE)	1.7	1.7	2.2	2.2	3.7	3.8	3.6	3.6	3.7	3.7	3.0	3.1	1.8	1.8
I_4 (1.0 IW: CPE)	1.7	1.7	2.3	2.4	3.9	3.9	3.7	3.9	3.9	3.9	3.2	3.3	1.9	2.0
SEm±	0.04	0.04	0.03	0.05	0.06	0.06	0.08	0.08	0.08	0.06	0.07	0.07	0.04	0.04
CD at 5%	NS	NS	0.12	0.17	0.21	0.20	0.27	0.27	0.28	0.20	0.23	0.23	0.14	0.14

Table 3: Effect of Irrigation level on grain and straw yield of wheat of wheat

Treatments	Grain yield (q/ha)		Straw yield (q /ha)	
	2014-2015	2015-2016	2014-2015	2015-2016
Irrigation level				
I_1 (Critical stage)	52.3	53.2	65.8	66.9
I_2 (0.6 IW : CPE)	45.8	46.5	57.5	58.5
I_3 (0.8 IW : CPE)	47.9	48.7	60.2	61.2
I_4 (1.0 IW : CPE)	51.2	51.9	64.4	65.3

Table 4: Water requirement of wheat crop using CROPWAT model during 2014-15

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.5	0.9	5.4	0	5.4
Nov	3	Init	0.5	1.02	10.2	0	10.2
Dec	1	Deve	0.57	0.99	9.9	4.2	5.7
Dec	2	Deve	1	1.57	17.2	6.3	10.9
Dec	3	Mid	1.49	2.24	22.4	6.7	15.7
Jan	1	Mid	1.65	2.14	21.4	11	10.4
Jan	2	Mid	1.65	1.89	18.9	12.5	6.4
Jan	3	Mid	1.65	1.86	20.4	9.3	11.1
Feb	1	Mid	1.65	3.39	33.9	2.6	31.3
Feb	2	Late	1.55	3.82	38.2	0	38.2
Feb	3	Late	1.31	3.85	30.8	0.7	30.1
Mar	1	Late	1.07	3.5	35	2.4	32.6
Mar	2	Late	0.81	2.98	29.8	0	29.8
					293.5	55.7	237.8

Table 5: Water requirement of wheat crop using CROPWAT model during 2015-16

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	2	Init	0.5	1.1	6.6	0	6.6
Nov	3	Init	0.5	1.12	11.2	0	11.2
Dec	1	Deve	0.59	0.95	9.5	4.7	4.8
Dec	2	Deve	1.2	1.45	14.5	2.4	12.1
Dec	3	Mid	1.59	2.13	23.43	0	23.43
Jan	1	Mid	1.68	2.16	21.6	10.5	11.1
Jan	2	Mid	1.68	2.09	20.9	8.5	12.4
Jan	3	Mid	1.68	1.95	21.45	5.9	15.55
Feb	1	Mid	1.68	3.41	34.1	1	33.1
Feb	2	Late	1.6	3.95	39.5	0	39.5
Feb	3	Late	1.34	4.01	32.8	0	32.8
Mar	1	Late	1.09	3.61	36.1	1.5	34.6
Mar	2	Late	0.82	2.98	29.8	0	29.8
					301.4	34.5	266.9

Table 6: Phase wise yield reductions of wheat crop using CROPWAT model during 2014-15 and 2015-16.

Treatments	Particulars	Wheat stage									
		Initial		Development		Mid		Late		Season	
		2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016	2014-2015	2015-2016
Moisture Regime											
I1 (critical stages)	Yield response factor	0.2	0.2	0.7	0.7	0.8	0.8	0.6	0.6	1	1
	Reduction in Etc (mm)	28	30	0	0	0	0	0	0	4.2	4.5
	Yield reduction (%)	6.5	6.8	0	0	0	0	0	0	0	0
	Cumulative yield reduction (%)	6.5	6.8	6.7	6.9	6.7	6.9	6.7	6.9	4.2	4.5
I2 (0.6 IW: CPE)	Reduction in Etc (mm)	28	30	10.9	12.5	32.6	33.6	6.4	7.3	22.6	23.2
	Yield reduction (%)	6.5	6.8	3.7	4.3	5.3	5.8	3.2	3.9	0	0
	Cumulative yield reduction (%)	6.5	6.8	11.6	12.4	25.9	26.7	14.8	15.2	22.6	23.2
I3 (0.8 IW: CPE)	Reduction in Etc (mm)	28	30	1.6	1.9	0	0	0	0	5.8	6.2
	Yield reduction (%)	6.5	6.8	0.9	1.2	0	0	0	0	0	0
	Cumulative yield reduction (%)	6.5	6.8	6.8	7.1	6.6	6.8	6.3	6.5	5.8	6.2
I4 (1.0 IW: CPE)	Reduction in Etc (mm)	28	30	0.6	0.9	0	0	0	0	4.8	5.2
	Yield reduction (%)	6.5	6.8	0.5	0.8	0	0	0	0	0	0
	Cumulative yield reduction (%)	6.5	6.8	6.8	7.2	6.8	7.2	6.8	7.2	4.8	5.2

Conclusion

Results from this study that the plant height, leaf area index, grain yield and straw yield was found significantly highest under I_1 (critical stages) treatment as compared to rest treatments. Water requirement of wheat crop simulated by CROPWAT model was 237.8 and 266.9 mm during the year 2014-15 and 2015-16. The highest crop water requirement (130.7& 136.7 mm / decade) recorded in the late stage of growth which was 45.0 and 48.7% of total water requirement of wheat crop during the years 2014-15 and 2015-16. The phase wise reduction in Etc, yield and cumulative yield reduction was less in I_1 (critical stages) as compared to other treatments.

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