WATER MANAGEMENT FOR WHEAT THROUGH SOIL MOISTURE SIMULATION USING SPAW MODEL

K.K. Singh, L.S. Rathore, Nisha Mendiratta and S.A. Saseendran

NATIONAL CENTRE FOR MEDIUM RANGE WEATHER FORECASTING, DST,
MAUSAM BHAVAN, LODI ROAD, NEW DELHI 110003, INDIA
Tel: 11-4619815 Fax: 11-4690108
E-mail: ncmrwf@tifac.ernet.in

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ABSTRACT

To identify best viable irrigation schedule,i.e. when to irrigate under limited water supply, Soil-Plant-Atmosphere-Water (SPAW) model has been tried to study the impact of water stress on wheat yield under sandy loam at Delhi. The model run has been made for an array of treatments (total 64) combining different sets of irrigation schedule varying from nil to six irrigations at different phenological stages viz: Crown Root Initiation (C), Tillering (T), Jointing (J), Flowering (F), Milking (M) and Dough (D). In all treatments, soil is considered to be at field capacity level at the time of sowing. Water use efficiency (WUE) was considered as a basis to formulate intensity of irrigation.

The estimated maximum yield by model depicting the most productive irrigation schedule for 1, 2, 3, 4, 5 and 6 number of irrigations are 1.5, 19.8, 31.2, 37.3, 40.7 and 43.3 q/ha respectively. The results of the experiment suggests that it is advisable to irrigate at T; T-J; T-J-F; T-J-F-M; T-J-F-M-D; C-T-J-F-M-D respectively for 1, 2, 3, 4, 5 and 6 number of irrigations to harvest the maximum yield. Results indicate that moisture stress at tillering affect the crop yield most severely, hence it is not advisable to skip irrigation at this stage. Jointing, Flowering and Milking succeed in the order of preference. The prime schedule with four irrigations (T-J-F-M) produced 37.3 q/ha of yield. The enhancement in the yield level through one additional irrigation is only by 9% over four irrigation treatment. Further, application of irrigation at all six stages lead to elevate the yield level by 7% over five irrigation treatment. As the increment in the yield of wheat through 5th and 6th irrigation is marginal, it may be more profitable for those farmers who have got ample land holding with limited water resource to grow wheat with four irrigations and raise crops having low water requirements (like Brasicca, Blackgram etc.) with the water saved from curtailing two irrigation on wheat.

INTRODUCTION

Wheat farming in India has been almost revolutionised with the introduction of the high yielding dwarf wheat varieties in 1963-64. The dwarf varieties are highly responsive to irrigation and fertiliser applications. Irrigated agriculture has traditionally been considered as a method of bringing stability to crop production through reduced yield variability. In dry regions where water availabilty is limited, irrigators want and need to efficiently utilize irrigation water applied. One aspect of improved irrigation water management strategy centres on the use of irrigation scheduling. The most practical criterion commonly adopted by the farmers for scheduling of irrigations to wheat is the one based on the physiological growth stages critical in demand for water. Gautam *et al.* (1968) working on the sandy loam soils of Delhi observed that four irrigations applied at proper stages of crop growth yielded as much as an intensive irrigation practice with six irrigations. Chauhan *et al.* (1970) also working on the sandy loam soils of Delhi investigated that yield of wheat did not increase in proportion to the increase in number of irrigations and at each frequency the irrigations applied at some growth stages were more beneficial to the wheat than those applied at the other stages. Most of the workers have observed that in case of dwarf varieties of wheat, irrigation at C stage (22 days after sowing-DAS) resulted in the maximum production per unit of water applied and therefore this stage was considered as the most critical stage for irrigation (Dastane and Patel 1968; Yadav 1972; Michael and Pandey 1975). Critical periods for soil water stress for wheat are possibly during booting and heading and two weeks before pollination (FAO 1986).

The information on critical stages is useful in areas with limited water resources where maximum WUE is aimed at. But due to ,firstly, vast variability of genotypes, soil and atmosphere, it is not possible to conduct agronomic experiments for every situation and make valid recommendations, and secondly, monitoring soil moisture profile dynamics on a real time basis is not always possible, *crop simulation models* have been used increasingly in the economic analysis of irrigation management, practically irrigation scheduling. These models explicitly represent the dynamic aspect of crop water use and response governed by soil and genotype. Also, environmental influences are an explicit part of simulation model. This feature allows for the application of the model to a wide range of genotype, soil and environmental condition. Optimization of irrigation management stratagies and systems using crop simulation models has been actively pursued by many individuals (Bernardo *et al*. 1988; Rao *et al*. 1988; Epperson *et al*. 1993). The major objective of this study is to use SPAW model to compare various irrigation management stratagies to identify the best viable irrigation schedule for wheat crop under limited water supply in dry land.

MATERIAL AND METHODS

Model: The SPAW model developed by Saxton *et al*. (1974) was chosen for use in this study because the technique is relatively simple, with reasonably sound physical base and incorporates sufficient degree of detail with minimal requirements of daily inputs consisting of routinely measured meteorological data. This model has been found to adequately describe, integrate and relate the plant-soil-atmosphere processes as demonstrated by several applications (Sudar *et al*. 1981; Saxton and Bluhm 1982; Rathore *et al*. 1994; Singh *et al*. 1995).

The model computes a daily soil water profile budget by considering weather input, crop growth status and soil profile water holding characteristics. Daily estimates of three components of actual evapotranspiration (ET), interception evaporation, soil water evaporation and plant transpiration, are obtained by a complex set of relationship representing the current status of soil, plant and weather variables. The water budget is completed by considering runoff, infiltration, soil water redistribution and percolation at the lower soil boundary.

A cumulative water stress index (WSI) for the growing season was computed as shown below

$$WSI = (1-Tai/Tpi) * YSi \quad ...(1)$$

where n is number of days of growing season, Tai and Tpi are daily actual and potential transpiration measurements and YSi is yield susceptibility factor. The end of season water-stress index was related to yield using the following linear relationship reported by Sudar *et al*. (1981):

$$Ya = Ym - Bi * WSI \quad ...(2)$$

where Ya and Ym are actual and maximum yields,Bi is the regression coefficient.

Model calibration: Rathore *et al*. (1994) has calibrated and tested this model for irrigated wheat at Delhi using prescribed information on wheat growth characteristics and soil alongwith daily weather data for 11 wheat crop seasons (1979-80 to 1989-90) recorded at IARI, New Delhi observatory. The model is able to simulate the observed fluctuations in moisture content of different layers of soil profile reasonably well and brings out the general pattern of observed variations in actual evapotranspiration.

In order to calibrate the stress-index subroutine, yield susceptibility values for wheat at different growth stages as developed from data reported in literature (Gajri and Prihar 1985; FAO 1986) are given in Table 1.

Table 1
Yield suceptibility to water stress Vs. crop age

DAS	0	10	25	30	40	50	60	75	80
YS	.0	.20	.35	.25	.25	.30	.40	.45	.40

DAS	90	100	120	130	150
YS	.30	.20	.10	.05	.00

A daily water stress value was multiplied by the yield susceptibility value for that date and these quantities were summed over the growing season (equation 1) to provide an accumulated WSI. Thus the accumulated WSI values at the end of the crop season were computed for 11 consecutive crop seasons and correlated with actual observed crop yields (Source: India Meteorological Department station at WTC, IARI). The results showed reasonable agreement between yield reduction and the computed WSI (r= -0.92) and corresponding regression equation was found to be

YIELD = 50.9 - 5.69 * WSI ...(3)

Experiment conducted: In the present study an experiment was conducted for wheat crop under sandy loam soil of Delhi which falls in the North-Western Plains Zone of India (ICAR 1980). Here the irrigated wheat is planted in November and beginning of December and harvested by the second fortnight of April. The crop season 1984-85 was chosen because there were practically no rains except in second week of April 1985. Weekly weather conditions from November, 1984 through April, 1985 are given in Table 2.

Table 2

Weekly Weather data for wheat crop-season (Nov.-Apr.) 1984-85recorded at Delhi

Month/ Week	Rain-fall (mm)	Tmax (deg.C)	Tmin (deg.C)	Evapo-ration (mm/day)
Nov 5-11	0.0	29.5	10.8	3.7
12-18	0.0	29.1	9.9	3.2
19-25	0.0	28.1	10.1	2.7
26-2 Dec	0.0	25.3	7.4	0.7
Dec 3-9	0.0	25.5	6.9	1.7
10-16	0.0	25.0	7.8	2.7
17-23	0.0	22.4	4.4	3.1
24-31	0.6	21.2	6.2	2.0
Jan 1-7	0.0	16.9	7.4	1.5
8-14	0.0	19.6	5.3	1.8
15-21	0.0	20.4	7.1	2.5
22-28	0.0	21.9	6.7	2.4
29-4 Feb	0.0	22.8	5.4	2.9
Feb 5-11	0.0	24.1	5.9	3.3
12-18	0.0	24.8	5.0	3.8
19-25	0.0	27.7	8.6	4.9
26-4 Mar	0.0	29.9	11.2	5.2
Mar 5-11	0.0	31.5	12.2	5.3
12-18	0.0	32.1	12.5	6.4
19-25	0.0	31.6	14.7	6.1
26-1 Apr	0.0	35.7	17.5	6.7
Apr 2-8	0.8	34.7	18.9	6.4
9-15	5.0	35.3	18.1	5.9
16-22	0.0	39.4	20.0	7.9
23-29	0.0	40.3	20.6	9.8

Sowing was done on November 27, 1984 in rows 22.5 cm apart. Fertilizers were applied as per recommended package. The crop was harvested on April 12, 1985. This data det pertains to the research farms of IARI, New Delhi. In order to assess the effect of varying schedule and frequency of irrigation on yield, the model run was made for an array of treatments (total 64) combining different sets of irrigation schedule varying from nil to six irrigations at different phenological stages viz. C (22 DAS), T (45 DAS), J (65 DAS), F (85 DAS), M (105 DAS) and D (120 DAS). In all treatments soil is considered to be at field capacity level at the time of sowing. For each simulation, an end of growing season WSI was computed which was used to predict the yield using the equation (3).

RESULTS AND DISCUSSIONS

The relationship as given by equation (3) assume a potential yield of 50.9 Q/ha. The 8.9 units of WSI or more are assumed to produce no yield i.e. crop undergoes severe stress during the vegetative and reproductive phase and finally dies. Results from the experiment for varying schedule at different frequency of irrigation are discussed frequencywise:

No irrigation - crop suffers from severe stress and does not survive. Nonetheless, it is worth to analyse the status of the soil moisture in the root zone vis-a-vis WSI during different phenostages. Soil water in root zone was 60% and 45% of maximum available soil moisture (ASM) at C and T stages. Crop water requirement was met fully up to C because optimum depletion limit of ASM for wheat has been observed to be about 40 to 50% in the surface 60 cm depth on the sandy loam of Delhi (IARI 1977). A nominal stress was developed during pre-tillering phase leading to give WSI 0.15 at T stage. It is tillering and onward, plant starts facing water stress as reflected in daily stress value. On average plant water requirement satisfaction are 75%, 45%, 30% and 20% during the periods T-J, J-F, F-M and M-D respectively. The relative impact on yield of water stress at different stages are reflected in accumulated WSI i.e. 0.04 units at C, 0.15 units at T, 2.14 units at J, 6.83 units at F, 10.58 units at M and 12.25 units at D stages.

One irrigation - crop yield is not economically viable, nonetheless, results indicate that irrigation at T or J is preferred to that at CRI stage. The logic is that irrigation at T or J stages would make the crop enter into reproductive phase and thus lead to give some yield. It is too late to irrigate at F, M or D stage as crop will die by then.

Two irrigations - crop does not survive if either first irrigation is held up to F or M or first applied at C followed by a long gap (80 DAS). First irrigation at C followed by second at F makes drastic reduction in the yield. Therefore, in case of two irrigation the first irrigation at C is not important because soil moisture at this stage is above the threshold limit. To obtain higher yield, it is therefore recommended to provide first irrigation just after T or J followed by second in succession.

Three irrigations - results indicate that one can not afford to apply first irrigation at F stage or beyond. Poor yield is harvested if the first irrigation is provided at C and subsequently long gap is there till F. Crop performed even worse if second one is awaited till M causing still longer dry spell. Higher production is achieved if the first irrigation is applied at T and providing remaining two in succession i.e. J-F or J-M.

Four irrigations - avoiding irrigation at T and J leads to comparably poorest yield. Maximum yield is obtained when four irrigations are applied in succession from T stage. Skipping of irrigation is recommended in the beginning (C) and towards the end (D) of the crop period.

Five irrigations - results indicate that deleting one irrigation at either C or D has the least effect on the crop production, hence skipping irrigation should be preferred in the order of D through T.

The best combinations of phenological stages at different frequecy of irrigation schedules alongwith their maximum yield, hence called the prime schedule of irrigation, are given in table 3. It is clear from the table 3 that there is a significant increase in the yield if farmers move from one to two irrigations. Yield increases further with increase in number of irrigations from two through six, but the response to irrigation, i.e. WUE, decreased gradually up to four irrigation and sharply thereafter.

Table 3
Prime schedule of irrigation giving maximum yield for diffrent number of applications

Frequency of irrigation	Prime schedule of irrigation	Yield Q/ha
Nil	-	0.0
One	T	1.5
Two	T-J	19.8
Three	T-J-F	31.2
Four	T-J-F-M	37.3
Five	T-J-F-M-D	40.7
Six	C-T-J-F-M-D	43.3

It is not affordable to skip irrigation at Tillering which emerged to be the most CRITICAL STAGE. Jointing, Flowering and Milking succeed in order of preference. The prime schedule with four irrigations (T-J-F-M) produced 37.3 q/ha of yield. The enhancement in the yield level through one additional irrigation is only by 9% over four irrigation treatment. Further, application of irrigation at all six stages lead to elevate the yield level by 7% over five irrigation treatment. Under the circumstances if available water is not enough to meet the suggested prime schedule, the farmers can even plan for 3 number of irrigations loosing yield only by 16%.

CONCLUSIONS

Tillering is the most critical stage followed by Jointing and Milking. Hence adequate moisture level in the root zone at these phases is mandatory for obtaining good yield. As the crop enter senescence, the impact of moisture stress on yield is toned down. Also, depletion in soil moisture level at Crown Root Initiation does not seem to be critical due to low evapotranspiration rate. Hence, one may prefer to choose skipping irrigation at this stage over T, J, F and M stages under limited water supply. As the increment in the yield of wheat through 5th and 6th irrigation is marginal, it may be more profitable for those farmers who have got ample land holding with limited water resource to grow wheat with four irrigations and raise crops having low water requirements (like Brasicca, Blackgram etc.) with the water saved from curtailing two irrigation on wheat.

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BIOGRAPHY

1. K.K. Singh - M.Sc., Ph.D. (Agromet.), crop weather modelling (CWM), agromet advisory services (AAS).
2. L.S. Rathore - M.Sc., Ph.D.(Agric.), CWM, AAS, water management of crops.
3. Nisha Mendiratta -M.Sc(Agric.Physics) CWM, AAS.
4. S.A. Saseendran - M.Sc.(Meteorology), agrometeorology of plantation crops, CWM, AAS.

Nature of Work at NCMRWF

The authors are working at Application Division of National Center for Medium Range Weather Forecasting. The main mandate of Application Division is to organise AAS in the country in collaboration with India Meteorological Department, Indian Council of Agricultural Research and different State Agricultural Universities (SAUs). The authors are directly involved in preparation of Medium Range Weather Forecasts for different agroclimatic zones of the country employing NWP model outputs; dissemination of forecasts to SAUs; coordination of farm-weather service involving preparation/ dissemination of Agromet Advisory Bulletins by SAUs and feedback analysis. They are also involved in carrying out research work related to crop weather relationship and technique development for agrometeorological forecasting.