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Research Paper

Critical stages of wheat (*Triticum aestivum*) for irrigation under different water availability conditions in Vertisols of Central India

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ABSTRACT

The field experiment was conducted during winter (*rabi*) seasons of 2015–16 and 2016–17 at ICAR-Indian Agricultural Research Institute, Regional Station, Indore, Madhya Pradesh, to identify most critical stages of wheat (*Triticum aestivum* L.) under varying availability of irrigation water for higher and economic wheat production in Vertisols of Central India. Total 15 treatments consisting of the control and different critical stages for irrigation, viz. crown-root initiation (CRI), late tillering, late jointing, late flowering and late milking, and their combinations were selected for irrigation. Results indicated that 4 irrigations applied at CRI + tillering + late jointing + late flowering stages resulted in the maximum plant height (93.3 cm), spike length (10.47 cm), spikelets/spike (17.4), 1,000-grain weight (45.4 g), grain yield (5.32 t/ha), soil plant analysis development (SPAD) value (54.4), normalized difference vegetation index (NDVI) value (0.76), energy output (184,704 MJ/ha), net returns (₹66,385/ha) and benefit : cost ratio (2.59). Above values including biological yield (13.86 t/ha) and sodium dodecyl sulfate (SDS) value (40.4 ml) were almost similar with 5 irrigations applied at all critical stages, but substantially higher over rest of the treatments. In case of lower levels of irrigations, 3 irrigations applied at CRI + late tillering + flowering; 2 irrigations applied at tillering + flowering and 1 irrigation at late tillering stage recorded higher, energy efficient and economical wheat productivity than with their similar level of irrigation at the other stages. Water-use efficiency, canopy temperature, energy-use efficiency and energy productivity were decreased with the increase in the levels of irrigation. Hence, for getting higher, energy-efficient and economic wheat grain production, 4 irrigations can be applied at CRI + tillering + late jointing + flowering stages. In case of availability of only 3 irrigations, crop should be irrigated at CRI + tillering + flowering stages, 2 irrigations at tillering + flowering and single irrigation at tillering stage in Vertisols of Central India.

Key words: Economics, Energetics, Grain and biological yields, Irrigation scheduling, Wheat

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops of the world and in India, it stands second next to rice in area and production. It is widely grown crop and sown almost in all climatic conditions including temperate zone and tropical and sub-tropical areas at higher elevation. Water is the most important input of wheat production and essential at every developmental phase, starting from seed germination to plant maturation for harvesting the maximum potential yield. Kumar *et al*. (2014) reported a positive correlation between grain yield and irrigation frequencies. Availability of adequate amount of moisture at critical stages of plant growth not only optimizes the metabolic process in plant cell but also increases the effectiveness of the inherent as well as applied mineral nutrients to the crop. Though adequate normal irrigations are essential for bumper crop production, but when there is scarcity of water, it becomes imperative to differentiate the critical growth stages of the crop where irrigation could be missed, without significant reduction in the grain yields. It is observed that, proper scheduling of irrigation to supply adequate quantum of water during the moisture sensitive period of flowering and grain-formation stages, yet allowing moderate stress at vegetative and maturity stages produce the optimum yield with maximum water-use efficiency and water economy (Reddy and Reddy, 1993). Irrigation missing at some critical growth stage sometime drastically reduces grain yield by reducing the test weight of the grain. Hence, efficient water management is one of the most important agronomic management practices, which leads to improve crop productivity.

In Central Zone of India, monsoon rains determine the recharge of groundwater and harvesting of water in ponds for subsequent use for irrigating the wheat crop during the winter (*rabi*) season and has a significant bearing on its

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productivity. Most of the soils of this zone are fine clay-dominated soils (Vertisols) and water harvested in the ponds of these soils does not last long enough to provide irrigation for the entire growth period of wheat crop because of high losses by seepage through cracks and evaporation. Though there are some areas in the zone having assured irrigation through tube-wells, majority of wheat-producing area belongs to above category, i.e. under limited as well as shorter period water-availability conditions. Thus, irrigation water is one of the major constraints to higher productivity of wheat in the Central India. The erratic distribution of rainfall in the region further aggravates the problem. Hence, there is a need for developing strategies for efficient utilization of limited available water to maximize wheat yield with maximum water-use efficiency. Irrigation scheduling is the application of water to crops in proper amount and at the proper time, resulting in the maximum crop yields and minimum leaching of water and nutrients below crop root zone and subsequently to the groundwater (Vashisht *et al.,* 2015). Irrigation scheduling on the basis of critical physiological stages of wheat is an age-old practice but information on identification of most critical stage of wheat for irrigation as per availability of water is still lacking. Hence, this investigation was carried out to identify the critical stages of wheat as per availability of water for irrigation for getting higher and economical wheat productivity in Vertisols of Central India.

MATERIALS AND METHODS

The field experiment was conducted during the winter (*rabi*) season of 2015–16 and 2016–17 at ICAR-Indian Agricultural Research Institute, Regional Station, Indore (22°37’N latitude and 75°50’E, 557 m above mean sea level), Madhya Pradesh and has semi-arid tropical climate with mean annual rainfall of 758 mm. The soil was a deep Vertisols (Typic Haplustert) with clayey texture (52% clay) and bulk density of 1.34 Mg/m^3, having *p*H 8.2, electrical conductivity 0.32 dS/m (1 : 2 soil : water ratio), medium in organic carbon (0.51%), available N (252.5 kg/ha) and available P (12.2 kg/ha), and high in available K (467.5 kg/ha). Total 15 treatments, consisting of control (no irrigation) (T_1), 1 irrigation at crown-root initiation (CRI, T_2), 1 irrigation at late tillering (T_3), 2 irrigations at CRI + late jointing (T_4), 2 irrigations at CRI + late flowering (T_5), 2 irrigations at late tillering + late flowering (T_6), 2 irrigations at late tillering + late milking (T_7), 3 irrigations at CRI + late tillering + late flowering (T_8), 3 irrigations at CRI + late jointing + late milking (T_9), 3 irrigations at late tillering + late flowering + late milking (T_{10}), 4 irrigations at CRI + late tillering + late jointing + late flowering (T_{11}), 4 irrigations at CRI + late tillering + late jointing + late milking (T_{12}), 4 irrigations at CRI + late tillering + late flowering + late milking (T_{13}), 4 irrigations at CRI + late jointing + late flowering + late milking (T_{14}) and 5 irrigations at CRI + late tillering + late jointing + late flowering + late milking (T_{15}), were tested in randomized block design with 3 replications. Mean values of maximum temperatures were almost same in both the years, i.e. 31.6 (ranged from 26.5 to 39.7°C) and 31.2°C (varied from 25.9 to 40.0°C) but mean minimum temperature values differed substantially during crop-growth period in both the years, viz. in 2015–16 (16.3°C with a range of 10.7 to 22.9°C) and 2016–17 (13.1°C with a range of 8.4 to 22.1°C). The values of mean relative humidity 71.1 (ranged 65.3 to 76.0%) and 77.2% (69.4 to 84.0%), and open pan evaporation 3.9 mm/day (ranged from 2.1 to 7.9 mm/day) and 4.4 mm/day (ranged from 2.3 to 9.2 mm/day) were observed during the first and second years respectively. There was no occurrence of rainfall in both the years during crop-growth period. The wheat cultivar ‘HI 1544’ was used in the trial. The crop was sown on 14 November 2015 and 11 November 2016 and harvested on 6 April 2016 and 5 April 2017 during the first and second years, respectively. Recommended treatment-wise NPK (kg/ha) fertilizer doses, viz. T_1 to T_3 (60-30-15), T_4 to T_8 (80-40-20) and T_9 to T_{15} (120-60-30) were applied. In T_1, all 3 fertilizers were applied basal and in rest of the treatments, P and K applied basal and N in 2 splits–50% at sowing + 50 at first irrigation. The soil samples were analysed for organic carbon available N, P and K contents and determined by modified Kjeldahls, procedure by using Kjeltec Auto Analyser, calorimetric by vanado-molybdate yellow colour method and flame photometer method (Jackson, 1973) respectively. Moisture contents (%) were measured by moisture meter probe (NPM-160-B). A chlorophyll meter was used to measure SPAD (soil-plant analyses development) readings in leaves of wheat at flag-leaf stage. Instrument Green Seeker was used for normalized difference vegetation index (NDVI) analysis data recording. Growth data, i.e. plant height and number of tillers/m^2, were observed from 2 places of each plot and averaged. Five random tillers were uprooted from each plot and used for recording data on yield attributes. All the data were statistically analyzed using analysis of variance (ANOVA) as applicable to randomized block design (Gomez and Gomez, 1984). The significance of the treatment effects was determined using F-test. Energy inputs and outputs were calculated using the energy equivalents as suggested by Panesar and Bhatnagar (1987) and Devasenapathy *et al.* (2009). Economics was worked out on the basis of mean data over 2 years, and prevalent market prices for different outputs and inputs were used.

RESULTS AND DISCUSSION

Growth and yield attributes

Data of growth and yield attributes indicated that, irrigation schedules had significant effect on growth and yield attributes, viz. plant height, tillers/m^2, spike length, spikelets/spike, grains/spike, 1,000-grain weight and hectoliter weight (Table 1). The growth and yield attributes increased significantly with each successive increase in the number of irrigation up to the 4 irrigations applied at different physiological critical stages of irrigation, and thereafter there was no significant improvement in growth and yield attributes of wheat. Treatment T_{11}, where 4 irrigations were applied at CRI + tillering + late jointing + flowering recorded maximum values of most of the growth and yield attributes, viz. plant height, spike length, spikelets/spike, grains/spike and 1,000-grain weight, which were statistical at par with 5 irrigations but significantly higher over lower levels of irrigations. Similarly, treatments T_8, T_6 and T_4 recorded higher values of growth and yield attributes compared with their same levels of irrigation. The reason for increased plant height might be owing to optimum soil-moisture supply that promoted the cell-division and cell expansion and thereby stem elongation, which virtually increased the plant height. However, the increase in number of tillers might be owing to enhanced vegetative growth, because of beneficial role of water in maintaining cell turgidity and cell division, and also meristmatic cell elongation in the auxiliary buds that in turn trigged the various activities and increased supply of photosynthates and thereby increase in number of tillers (Nayak *et al*., 2015). While higher values of yield attributes under T_{11} and T_{15} treatments might be owing to adequate availability of water as per requirement of crop and better conductive rhizosphere environment for higher uptake of nutrients which in turn boost the growth, leading to the development of higher yield attributes through supply of more photosynthates towards the sink. Moisture stress during the growth and reproductive phase under different treatments might have hampered the supply of photosynthates towards the sink, resulting in poor growth and yield attributes. Kumari *et al*. (2013) also noticed that, skipping irrigation in different critical stages of irrigation of wheat has significant effect on growth and yield attributes.

Grain and biological yields, and harvest index

Irrigation schedules had significant effect on grain and biological yields (Table 1). The maximum grain yield of wheat was obtained under T_{11}, where irrigations were applied at CRI + tillering + late jointing + flowering and which being at par with T_{15} and T_{12}, was significantly higher over rest of the treatments. Among treatments with 3 irrigations (T_8 to T_{10}), T_8 where irrigations were applied at CRI + tillering + flowering recorded significantly higher grain yields to the tune of 12.7 and 20.7% higher over T_9 and T_{10} respectively. However, 2 irrigations (T_4 to T_7), T_6 where irrigations were applied at tillering + flowering resulted in the highest grain yield (4.32 t/ha), which was statistically at par with T_4 and T_5 but significantly higher over T_7. Single irrigation applied at tillering stage showed its superiority to irrigation applied at CRI stage and recorded higher grain yield, but difference was non-significant. The lowest yield was obtained with the control (no irrigation-T_1). Lower grain yield at T_1 might be due to moisture stress which increased the soil strength and decreased the root

Table 1. Effect of irrigation schedules on growth, yield attributes and yield of wheat (pooled data of 2 years)

Treatment	Plant height (cm)	Tillers/ m^2	Spike length (cm)	Spikelet/ spike	Grains/ Spike	1,000-grain weight (g)	Hectoliter weight (g)	Grain yield (t/ha)	Biological yield (t/ha)	Harvest index
T_1, Control (no irrigation)	68.3	213.7	7.53	13.3	33.2	40.6	82.7	2.34	5.90	39.7
T_2, CRI	80.3	276.2	8.88	15.5	39.5	42.0	83.0	3.38	8.52	39.7
T_3, LT	80.2	292.7	8.85	15.5	39.3	42.1	81.8	3.45	8.89	38.8
T_4, CRI + LJ	82.5	288.3	8.75	16.5	39.5	41.8	82.4	4.15	10.49	39.6
T_5, CRI + LF	79.5	325.4	8.98	16.3	40.2	44.8	83.6	4.05	10.13	40.0
T_6, LT + LF	86.0	317.2	9.05	15.8	39.8	45.1	83.5	4.32	10.91	39.6
T_7, LT + M	79.8	268.9	8.52	15.2	39.5	41.6	82.2	3.24	8.78	36.9
T_8, CRI + LT + LF	86.3	331.3	9.58	16.7	44.8	43.6	83.0	4.61	11.46	40.2
T_9, CRI + LJ + LM	88.3	336.4	9.02	15.9	42.6	41.4	81.7	4.09	10.64	38.4
T_{10}, LT + LF + LM	79.9	320.0	8.83	15.4	41.3	44.4	83.2	3.82	9.97	38.3
T_{11}, CRI + LT + LJ + LF	93.3	386.2	10.47	17.4	49.4	45.4	82.0	5.32	13.84	38.4
T_{12}, CRI +LT + LJ + LM	91.7	383.7	10.2	16.8	46.4	41.0	82.0	5.03	13.29	37.8
T_{13}, CRI + LT + LF + LM	84.8	370.0	9.78	16.7	44.6	44.3	83.1	4.78	12.38	38.6
T_{14}, CRI + LJ + LF + LM	90.9	359.2	9.34	16.5	43.9	46.1	84.1	4.94	12.73	38.8
T_{15}, CRI + LT + LJ + LF + LM	93.0	397.9	10.07	17.3	48.5	44.9	82.5	5.30	13.86	38.2
SEm±	1.13	9.27	0.15	0.26	1.11	0.34	0.26	0.11	0.31	-
CD (P=0.05)	3.20	26.2	0.48	0.75	3.16	0.96	0.75	0..32	0.88	-

CRI, Crown root initiation; LT, late tillering; LJ, late jointing; LF, late flowering; LM, late milking growth and also its proliferation, thereby decreasing the absorption of nutrients leading to poor crop yield. Irrigation just after dry sowing for come-up germination is a prevalent method of sowing of the region and comparatively high moisture-retention capacity of Vertisols (Bandhyopadhyay *et al.*, 2010), soil could give good yield of wheat even in the control plot. Higher grain yield of wheat crop with 4 irrigations applied at CRI + tillering + late jointing + flowering is the result of combined effect of various yield-contributing components. These results are in line with Meena *et al*. (2015) and Kumar *et al.* (2017). Result of grain yield clearly indicated that, optimum soil moisture up to the stage of late flowering played a vital role in enhancing wheat yield and the fifth irrigation at milking stage has not exerted much beneficial effect on wheat in Vertisols of Central India. The values of harvest index indicated that, the different irrigation treatments did not exert any special trend and variation under different irrigation levels.

Moisture content and water-use efficiency

Moisture content (%) observed (15 cm depth) just before irrigation at all critical stages showed that, it was significantly influenced by irrigation scheduling except the CRI stage due to a uniform irrigation applied just after dry sowing as a come-up irrigation to facilitate the germination (Table 2). In the control (no irrigation) treatment, moisture content was gradually decreased at each critical stage of wheat from 31.5% at CRI to 11.3% at harvesting. However, continuously higher moisture contents were maintained up to harvesting (35.1%) under T_{15}, where irrigations were applied at all the 5 critical stages. In other treatments, where irrigation was scheduled at milking stage showed higher moisture contents at harvesting. Stoppage of irrigation under different treatments under 1, 2 or 3 irrigations gradually decreased the moisture content at next critical stages of wheat due to continuous evapo-transpiration (ET) losses of water by soil and standing crop.

Water-use efficiency (WUE) showed that, each increase in irrigation level substantially decreased the values of WUE with minimum value of 17.7 kg/ha-mm recorded under T_{15}, where 5 irrigations were applied at different critical stages. It might be due to proportionately

Table 2. Moisture content (%), water-use efficiency and physiological parameters of wheat as influenced by irrigation schedules (pooled data of 2 years)

Treatment	Moisture content (%) at different stages (just before irrigation)						Water-use efficiency (kg/ha-mm)	Physiological and quality parameters (at flag-leaf stage)			
	CRI	Late tillering	Late jointing	Late flowering	Late milking	At harvesting		SPAD	NDVI	Canopy temperature (°C)	SDS values (ml)
T_1, Control (no irrigation)	31.5	24.9	23.2	20.9	14.0	11.3	-	46.4	0.54	24.2	36.0
T_2, CRI	30.7	30.3	28.1	26.0	18.4	15.8	56.3	48.6	0.65	22.6	37.3
T_3, LT	31.4	25.7	30.2	28.7	19.8	18.5	57.5	49.3	0.67	22.0	37.7
T_4, CRI + LJ	31.2	29.2	28.0	30.6	22.1	20.2	34.6	50.7	0.68	23.0	37.3
T_5, CRI + LF	32.7	30.0	28.9	24.3	24.1	20.5	33.7	50.0	0.64	23.3	37.7
T_6, LT + LF	31.9	24.9	32.4	28.7	25.0	20.7	36.0	51.8	0.70	21.5	38.3
T_7, LT + M	32.7	24.4	31.7	27.6	20.1	31.7	27.0	50.1	0.66	22.6	37.7
T_8, CRI + LT + LF	31.8	30.3	31.0	28.8	27.1	25.3	25.6	52.0	0.74	21.4	38.3
T_9, CRI + LJ + LM	32.5	28.9	28.7	30.5	22.7	32.7	22.7	52.7	0.70	21.9	38.0
T_{10}, LT + LF + LM	32.5	25.3	30.6	25.5	24.7	33.8	21.2	51.4	0.66	22.3	37.0
T_{11}, CRI + LT + LJ + LF	31.9	30.3	32.2	33.0	28.3	25.3	22.2	54.4	0.76	20.7	39.7
T_{12}, CRI +LT + LJ + LM	32.2	30.0	32.6	33.0	24.8	32.9	20.9	52.9	0.74	21.4	38.7
T_{13}, CRI + LT + LF + LM	31.6	30.0	31.4	29.2	25.8	33.0	19.9	51.7	0.73	21.8	38.0
T_{14}, CRI + LJ + LF + LM	32.3	29.5	28.1	30.6	25.2	33.7	20.6	52.6	0.71	21.4	38.7
T_{15}, CRI + LT + LJ + LF + LM	32.6	30.9	31.7	32.7	25.6	35.1	17.7	53.4	0.76	20.6	40.0
SEm±	0.65	0.90	0.78	0.84	1.34	1.13	-	0.68	0.006	0.29	0.54
CD (P=0.05)	NS	2.62	2.25	2.42	3.88	3.28	-	1.96	0.017	0.84	1.56

CRI, Crown root initiation; LT, late tillering; LJ, late jointing; LF, late flowering; LM, late milking; SPAD, soil plant analysis development; NDVI, normalized difference vegetation index; SDS, sodium dodecyl sulfate lower increase in wheat yields compared with quantity of water applied to the crop. Treatment with same levels of irrigation recorded similar trend as obtained for grain yield owing to higher grain yields under similar quantity of water used.

Physiological parameters

Different irrigation levels showed significant influence on SPAD values (Table 2). Loh *et al.* (2002) reported a significant correlation between SPAD values and chlorophyll content of Benjamin fig leaves. The minimum SPAD value (46.4) was observed under control (T_1) and it gradually increased with each increase in irrigation frequency and maximum SPAD reading of 54.4 observed with T_{11}, which being at par with T_6, T_8, T_9, T_{12} to T_{15} was significantly higher over rest of the treatments.

Normalized difference vegetation index (NDVI), which is generally used to determine the greenness of vegetation and observe the distinct colours (wavelength) of visible and near-infrared sunlight. When sunlight strikes objects, certain wavelength of this spectrum are absorbed and other wavelengths are reflected. The pigment in plant, i.e. chlorophyll, strongly absorbs visible light for use in photosynthesis, while cell structure of the leaves on the other hand strongly reflects near-infrared light. In present study, NDVI values observed at flag-leaf stage also showed significant variation due to different irrigation schedules with minimum value (0.54) recorded under T_1 (no irrigation), which might be owing to comparatively less greenness under water stress than the other treatments. The NDVI values were gradually increased with the increase in frequency of irrigation under different treatments. The maximum NDVI value (0.76) recorded under T_{11} (CRI + tillering + late jointing + flowering) was identical to that of T_{15} but significantly higher than rest of the treatments. It might be owing to adequate availability of water as per requirement of crop without missing any critical stage of wheat for irrigation, resulted similar greenness and observed similar NDVI values.

Canopy temperature (CT) of standing crop was also observed, which was significantly influenced due to different irrigation schedules and the maximum canopy temperature was recorded (24.2°C) under the control, which was gradually decreased with each increase in irrigation levels under different irrigation treatments. The minimum CT observed under T_{15} (20.6°C) was statistically at par with treatments T_{11}, T_{12} and T_{14}, but significantly lower than the other treatments. It may be due to maintaining of lower temperature of crop canopy under higher availability of soil-moisture content under increased frequency of irrigation.

Quality parameters

The swelling capacity of the gluten proteins of wheat affects the rate of sedimentation of a meal suspension in the sodium dodecyl sulfate (SDS) medium and better-quality gluten gives rise to slower sedimentation and higher SDS-values (Table 2). Different irrigation schedules had significant influence on the SDS values of grain. Increased frequency of irrigation recorded higher sedimentation. Treatment T_1 resulted in the lowest sedimentation value (36.0) and the highest SDS value (40.0) recorded with T_{15} was statistically at par with T_{11}, T_{12} and T_{14} treatments but significantly higher than rest of the treatments. It shows that adequate availability of water to wheat crop ensures the better quality of produce and any missing of critical stage of wheat for irrigation had its negative impact on quality of produce with respect to sedimentation value.

Energetics

Computation of energetics as detailed in Table 3 on mean data basis revealed that, the input energy values were increased with each successive increase in irrigation levels and minimum input energy value (7,212.8 MJ/ha) was recorded under the control (T_1) and the maximum (24,337.3 MJ/ha) with treatment T_{15}. The difference in input energy values is mainly because of energy used in differential levels of irrigation, fertilizers, manual labourers utilization etc. for different agricultural activities. While difference in output energy is the result of crop yields and energy values multiplication. The maximum energy output (184,704 MJ/ha) recorded under treatment T_{11} was almost similar to T_{15} but substantially higher than the other treatments owing to higher grain and biological yields. The maximum energy efficiency (10.9) and energy productivity (324.4 g/MJ) were recorded under the control (T_1) owing to minimum uses of agricultural inputs, and these values were decreased with each increase in levels of irrigation due to proportionately lower increase in wheat productivity compared to input energy consumed. However, at similar levels of irrigation, output energy, energy efficiency and energy productivity followed the similar trend of wheat as grain productivity. The maximum energy output efficiency (1,275.2 MJ/day) recorded under treatment T_{15} owing to higher biological yield of wheat was almost similar to T_{11} (1,273.8 MJ/day) but substantially higher than rest of the treatments.

Economics

Economical parameters worked out on the basis of prevalent market prices of inputs and outputs showed that, the maximum net returns (₹ 66,385/ha) and benefit : cost ratio (2.59) were recorded under treatment T_{11} and these values were followed by T_{15} and T_6 respectively (Table 3).

Table 3. Effect of irrigation schedules on energetics and economics in wheat (based on mean data of two years)

Treatment	Energetics				Economics			
	Energy input (×10³ MJ/ha)	Energy output (×10³ MJ/ha)	Energy efficiency	Energy productivity (g/MJ)	Energy output efficiency (MJ/day)	Cost of cultivation (×10³ ₹/ha)	Gross returns (×10³ ₹/ha)	Net returns (×10³ ₹/ha)	Benefit: cost ratio
T_1, Control (no irrigation)	7.2	78.9	10.9	324.4	544.1	26.8	46.9	20.1	1.75
T_2, CRI	13.1	113.9	8.69	257.8	785.8	28.8	67.8	39.0	2.35
T_3, LT	13.1	118.7	9.05	263.1	818.7	28.8	69.8	41.0	2.42
T_4, CRI + LJ	16.3	140.2	8.62	255.2	967.3	33.5	83.3	49.9	2.49
T_5, CRI + LF	16.3	135.5	8.33	249.1	934.6	33.5	81.0	47.5	2.42
T_6, LT + LF	16.3	145.9	8.97	265.7	1,006.1	33.5	86.7	53.3	2.59
T_7, LT + M	16.3	116.8	7.19	199.2	806.0	33.5	66.8	33.4	2.00
T_8, CRI + LT + LF	20.8	153.4	7.38	221.8	1,057.9	36.6	92.0	55.1	2.51
T_9, CRI + LJ + LM	20.8	142.0	6.83	196.8	979.3	36.6	83.0	46.5	2.27
T_{10}, LT + LF + LM	20.8	133.0	6.40	183.8	917.4	36.6	77.7	41.1	2.12
T_{11}, CRI + LT + LJ + LF	22.8	184.7	8.10	233.3	1,273.8	41.6	108.0	66.4	2.59
T_{12}, CRI +LT + LJ + LM	22.8	177.2	7.77	220.6	1,222.0	41.6	102.7	61.1	2.47
T_{13}, CRI + LT + LF + LM	22.8	165.3	7.25	209.6	1,139.8	41.6	96.9	55.3	2.33
T_{14}, CRI + LJ + LF + LM	22.8	170.0	7.45	216.7	1,172.4	41.6	99.9	58.3	2.40
T_{15}, CRI + LT + LJ + LF + LM	24.3	184.5	7.60	217.8	1,275.2	43.1	107.8	64.7	2.50

CRI, Crown root initiation; LT, late tillering; LJ, late jointing; LF, late flowering; LM, late milking
Labour wages @ ₹250/man-day; rates per tonnes of wheat grain and straw @ ₹18,500 and ₹3,000 respectively

The higher net returns of T_{11} (4 irrigations at CRI + tillering + late jointing + flowering) might be owing to higher yield and saving of 1 irrigation compared with treatment T_{15}. However, almost equal values of benefit: cost (B: C) ratio under treatment T_6 might be owing lower cost of cultivation and proportionately higher increase in wheat yield. Among 3 irrigations (T_8 to T_{10}), treatment T_8, where irrigations were applied at CRI + tillering + flowering gave the maximum net returns (₹ 55055/ha) and B : C ratio (2.51), whereas, treatment T_6, where 2 irrigations were applied at tillering + flowering stage resulted in the highest net returns and B: C ratio compared with the other treatments with 2 irrigations (T_5, T_6 and T_7). Single irrigation applied at tillering stage (T_3) recoded substantially more net returns (₹ 40,977/ha) and benefit : cost ratio (2.42) than T_2 (irrigation applied at CRI) owing to higher wheat yield and similar cost of cultivation.

On the basis of 2 years study, it was concluded that application of 4 irrigations up to late flowering stage (CRI + late tillering + late jointing + late flowering) holds promise to provide almost similar yield as obtained from 5 irrigations up to the stage of late milking. However, 3 irrigations, CRI + late tillering + late flowering, and two irrigations at late tillering + late flowering and 1 irrigation at late tillering stage provided substantially higher wheat yields than their same levels of irrigation at other physiological stages of irrigation in Vertisols of Central India.

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