International Journal of Chemical Studies

P-ISSN: 2349–8528
E-ISSN: 2321–4902
IJCS 2019; 7(6): 2468-2470

Received: 07-09-2019
Accepted: 09-10-2019

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Effect of moisture regimes on water use efficiency (WUE), water productivity (WP) and yield of wheat (*Triticum aestivum* L.)

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Abstract
An experiment was conducted during *rabi* season of 2017-18 at Agronomy Research Farm of Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya, Uttar Pradesh, India, situated at 260.47^0 North latitude, 80.120^0 East longitude at an altitude of about 113.0 meter from mean sea level. Water management on the basis of soil moisture regimes and critical growth stages was used as strategy in this quest to harness water use efficiency, water productivity and yield of wheat crop. The experiment was comprised of eight (8) treatments of moisture regimes viz. (i) 0.8 IW/CPE ratio (ii) 1.0 IW/CPE ratio (iii) 1.2 IW/CPE ratio (iv) two irrigations each at CRI & LJS (v) three irrigations each at CRI, LJS & MKS (vi) four irrigations each at CRI, TRS, LJS, & FRS (vii) five irrigations each at CRI, TRS, LJS, FRS & MKS (viii) six irrigations each at CRI, TRS, LJS, FRS, MKS & DS. The experiment was framed in Randomized Block Design (RBD) with four replications. The wheat variety PBW-502 was used for sowing. The crop was fertilized with recommended dose of NPK and other cultural operations were performed accordingly. The result revealed that irrigations provided in the crop either at soil moisture regimes (IW/CPE ratio) or at critical growth stages of crop did not recognized any significant difference. The treatment provided six irrigations either at 1.0 IW/CPE ratio or at critical growth stages (CRI, TRS, LJS, FRS, MKS & DS) recorded maximum yield potential (45.40 to 46.00 qha^{-1} grain yield and 65.83 to 66.29 qha^{-1} straw yield), highly remunerative in terms of net return (net return Rs.65097.0 to 66278.0 ha^{-1}) and B:C ratio (1.85 to1.88). Five irrigation given at CRI, TRS, LJS, FRS & MKS recorded significantly *at par.*

Keywords: Moisture regimes, water use efficiency, water productivity, yield, economics, wheat

Introduction
Wheat (*Triticum aestivum* L.) is one of the three most important cereals cultivated worldwide. It ranks first in the world among the cereals both in respect of area (225.07 m ha) and production (736.98 mt) (USDA, 2017) [1]. In India, total area under wheat is 29.57 million ha, with the production and productivity of 99.70 million tones and 3.37 tonnes ha^{-1}, respectively, during the year 2017-18 (Department of Agriculture Cooperation & Farmers Welfare, India, 2018-19). In India, wheat crop is grown mainly in the northern states, with Uttar Pradesh being the top most contributor of wheat with a total production of 30.06 million tonnes, followed by Madhya Pradesh 17.94 million tonnes and Punjab 16.44 million tonnes during 2016-17. The average productivity of Uttar Pradesh is 26.91 qha^{-1} which is considered low as compared to state like Punjab with productivity of 45.31 qha^{-1} and Haryana with 40.66 qha^{-1}. Water is an important factor for realizing high wheat productivity, however, it is becoming the most limiting factor for crop production in most of the north western parts of India (Hira, 2009) [5]. Irrigation water is a major constraint for crop production. To grow wheat economically and successfully the evapo-transpirative demand must be balanced with supply of available soil moisture. Proper scheduling of irrigation is an important component of water saving techniques and application of irrigation water at right time. Lack of moisture at heading, grain formation and dough stage significantly reduce the yield of wheat grain. There is a positive correlation between grain yield and irrigation frequencies. Irrigation in wheat can be scheduled mainly by three approaches viz., soil moisture depletion approach, climatic approach (IW/CPE ratio) and critical growth stages. Among them the climatological approach is very scientific and useful being recognized widely among the scientist and research workers throughout the word. It is well know that evapotranspiration by a full crop cover is closely associated with evaporation from an open pan (Dastane, 1967) [4]. Parihar *et al.*, (1974) [9] suggested a

relatively more practical meteorological approach of IW/CPE, the ratio between fixed amount of irrigation water (IW) and as a basis for irrigation scheduling of crops. This IW/CPE approach merits special consideration on account of its simplicity of operation and high water use efficiency. From above point in view, the present study was undertaken to assess suitable moisture regime on growth and to maximize the production and productivity of wheat.

Materials and Methods

Field experiment was conducted during *rabi* season of 2017-18 at Agronomy Research Farm of Acharya Narendra Deva University of Agriculture & Technology, Kumarganj, Ayodhya, Uttar Pradesh, India. The experimental site belongs to sub humid and sub tropical climate of indo-gangetic plains (IGP) having alluvial calcareous soil and located at 260.47^0 North latitude, 80.120^0 East longitude at an altitude of about 113.0 meter from mean sea level. The field experiment was comprised of eight (8) treatments of moisture regimes viz. (i) 0.8 IW/CPE ratio (ii) 1.0 IW/CPE ratio (iii) 1.2 IW/CPE ratio (iv) two irrigations each at CRI & LJS (v) three irrigations each at CRI, LJS & MKS (vi) four irrigations each at CRI, TRS, LJS, & FRS (vii) five irrigations each at CRI, TRS, LJS, FRS & MKS (viii) six irrigations each at CRI, TRS, LJS, FRS, MKS & DS were laid out in a Randomized Block Design (RBD) and replicated four times. The soil of experimental field was silt loam in texture with 25.53% sand, 52.22% silt and 22.25% clay having the pH of 8.23. It was moderately fertile being medium in organic carbon (0.42%), low in nitrogen (165.53 Kgha^{-1}), medium in phosphorus (17.78 Kgha^{-1}) and high in potassium (265.27 Kgha^{-1}). The wheat variety PBW-502 was sown timely on 15 November, 2017. The other management operations performed as per standard recommendation. The mean weekly meteorological weather observation recorded during the season of study revealed that the maximum temperature 39.2^{0}C, minimum 4.7^{0}C, maximum relative humidity (RH) 86.8%, and minimum 41.9% and total rainfall 00.0 mm. and winter rainfall recorded negligible (1.0 mm) in the fourth SMW (Standard Meteorological Weeks) during 22-28 January 2018. The crop experienced an average maximum wind speed 7.3 Km/hr and minimum wind speed 1.0 km /hr and average evaporation rate 5.34 mm/week during the crop growing season. Crop responses to the treatments were measured in terms of predetermined quantitative Indices. The observations so recorded were subjected to statistical analysis. Valid comparisons between various treatments were drawn using the respective CD (Critical difference) values.

Results and Discussion

Growth and yield attributing characteristics

Among eight moisture regimes tested, 1.0 IW/CPE ratio was registered significantly better growth and yield attributing characteristics. Significantly maximum growth viz. plant height (92.0 cm), effective shoots (405.0 m^{-2}) and leaf area index (5.78) and yield attributing characteristics viz. length of spike (9.50 cm) and number of grains spike^{-1} (44.80) were recorded under moisture regime with 1.0 IW/CPE ratio as compared to rest of moisture regimes, while, being *at par* with 1.2 IW/CPE ratio, six irrigations each at CRI, TRS, LJS, FRS, MKS & DS and five irrigations each at CRI, TRS, LJS, FRS & MKS. Days to 50% flowering, days to maturity and test weight were found nonsignificant. Similar research findings had also been reported by Prashar and Thaman (2005) [8], Idnani and Kumar (2012) [6].

Yield

The grain yield of wheat was influenced significantly under different irrigation levels at different moisture regimes as well as critical growth stages. The minimum grain yield (27.00 qha^{-1}) recorded under two irrigations each at CRI & LJS. It was improved significantly and maximum grain yield (46.00 qha^{-1}) recorded under 1.0 IW/CPE ratio (six irrigations) moisture regime. The grain yield increased to the tune of 29.62%, 49.62%, 54.81%, 62.96%, 67.40%, 68.14% and 70.37% under three irrigations, four irrigations,0.8 IW/CPE ratio (four irrigations), five irrigations, 1.2 IW/CPE ratio (seven irrigations), six irrigations and 1.0 IW/CPE ratio (six irrigations) moisture regimes, respectively. The straw yield showed similar trend. The harvest index evaluated significantly *at par*. Similar research findings were reported by Nadeem *et al*. (2007) [7] and Behera and Sharma (2014) [3].

Water use efficiency and water productivity

The water use efficiency (Kg/ha-mm) and water productivity (Rs.m^{-3}) markedly decreased with increasing number of irrigations at different levels. The control treatment (two irrigations each at CRI & LJS) recorded maximum WUE (22.50 Kg/ha-mm) and minimum WUE (10.76 Kg/ha-mm) was recorded under 1.2 IW/CPE ratio (seven irrigations). The higher WUE in limited irrigation may be due to precise use of water under restricted irrigation and decreased under plenty irrigation water. The water productivity showed similar trend of variations with WUE. The maximum water productivity (38.25 Rs.m^{-3}) was computed under two irrigations each at CRI & LJS (control). Three, four, five irrigations recorded 32.98, 28.56 and 24.82 Rs.m^{-3} water productivity, respectively. The minimum water productivity (18.19 and 21.59 Rs.m^{-3}) recorded under seven and six irrigations at 1.2 and 1.0 IW/CPE ratio, respectively. The findings of Sun *et al*. (2006) [11] elaborated similar trend of result.

Economics

The economics of treatments influenced with number of irrigations given under different treatments which increased cost of treatments accordingly. The minimum gross return (Rs. 60,075.0 ha^{-1}) and net return (Rs 28,952.0 ha^{-1}) recorded under only two irrigations treatment. The gross return and net return was increased with increasing irrigation due to increased yield. The maximum gross return (Rs.1,01,401.0 ha^{-1}) and net return (Rs.66,278.0 ha^{-1}) recorded under 1.0 IW/CPE ratio regime (six irrigations) treatment. The moisture regime 1.0 IW/CPE ratio recorded more gross return (Rs.41,326.0 ha^{-1}) and net return (Rs.37,326.0 ha^{-1}) compared to control treatment (only two irrigations). The data on B:C ratio exhibited that control treatment recorded no benefit (0.93 ratio), while 1.0 IW/CPE ratio treatment recorded benefit of Rs.1.88 by investing Rs.1.0. Similar findings were reported by Pandey *et al* (2017) [10].

Table 1: Effect of moisture regimes on growth characters and yield attributes of wheat

Treatments	Plant height (cm)	Effective shoots (m^{-2})	LAI (at 90 DAS)	Days to 50% flowering	Days to maturity	Length of spike (cm)	No. of grains spike^{-1}	Test weight (g)
0.8 IW/CPE ratio moisture regime	83.61	371.5	4.49	67.00	120.00	8.60	40.30	39.00
1.0 IW/CPE ratio moisture regime	92.00	405.0	5.78	68.80	123.00	9.50	44.80	41.00
1.2 IW/CPE ratio moisture regime	91.60	396.0	5.73	68.00	121.00	9.15	43.60	40.25
Two Irrigation at CRI & LJS	71.00	227.0	4.83	66.10	118.00	7.10	34.00	37.5
Three Irrigation at CRI, LJS & MS	73.20	321.0	5.05	66.50	118.80	7.50	35.00	38.5
Four Irrigation at CRI, TRS, LJS & FRS	83.20	370.1	4.38	66.60	119.00	7.90	36.90	38.75
Five Irrigation at CRI, TRS, LJS, FRS &MKS	90.80	395.0	5.61	67.50	120.60	9.05	42.90	39.75
Six Irrigation at CRI, TRS, LJS, FRS, MKS & DS	91.60	400.0	5.74	68.10	122.00	9.40	43.80	40.75
SEM $_-^+$	2.21	10.78	0.12	1.85	3.52	0.26	1.15	1.46
CD at 5%	6.49	31.69	0.35	NS	NS	0.75	3.37	NS

IW- Irrigation water (Depth of water); CPE- Cumulative pan evaporation; LAI- Leaf area index; CRI- Crown root initiation; TRS- Tillering stage; LJS- Late jointing stage; FRS- Flowering stage; MKS- Milking stage; DS- Dough stages.

Table 2: Effect of moisture regimes on yield, water use efficiency and water productivity of wheat

Treatments	Grain yield (qha^{-1})	Straw yield (qha^{-1})	Harvest index (%)	WUE (Kg/ha-mm)	WP (Rs./m^3)	Gross return (Rs.ha^{-1})	Net return (Rs.ha^{-1})	B:C ratio
0.8 IW/CPE ratio moisture regime	41.80	60.55	40.84	17.41	29.58	92252.0	59129.0	1.78
1.0 IW/CPE ratio moisture regime	46.00	66.29	40.96	12.77	21.59	101401.0	66278.0	1.88
1.2 IW/CPE ratio moisture regime	45.20	65.58	40.80	10.76	18.19	99793.0	63670.0	1.76
Two Irrigation at CRI & LJS	27.00	40.50	40.00	22.50	38.25	60075.0	28952.0	0.93
Three Irrigation at CRI, LJS & MS	35.00	52.15	40.16	19.44	32.98	77752.0	45629.0	1.42
Four Irrigation at CRI, TRS, LJS & FRS	40.40	60.10	40.20	16.83	28.56	89715.0	56592.0	1.70
Five Irrigation at CRI, TRS, LJS, FRS &MKS	44.00	63.80	40.81	14.66	24.82	97130.0	63007.0	1.84
Six Irrigation at CRI, TRS, LJS, FRS, MKS & DS	45.40	65.83	40.81	12.61	21.42	100220.0	65097.0	1.85
SEM $_-^+$	1.25	1.86	1.10	-	-	-	-	-
CD at 5%	3.69	5.46	NS	-	-	-	-	-

IW- Irrigation water (Depth of water); CPE- Cumulative pan evaporation; CRI- Crown root initiation; TRS- Tillering stage; LJS- Late jointing stage; FRS- Flowering stage; MKS- Milking stage; DS- Dough stages; WUE- Water use efficiency; WP- Water productivity; B:C- Benefit cost ratio.

Conclusion

Based on above findings of results limited irrigations (two irrigations each at CRI & LJS) found uneconomical though recorded maximum water productivity. Similarly three, four, five & seven irrigations either given at different critical growth stages or at different moisture regimes (IW/CPE ratio) recorded less yielding capacity in terms of grain yield and straw yield of wheat. The treatment provided six irrigations either at 1.0 IW/CPE ratio or at different critical growth stages recorded maximum yield potential (45.40 to 46.00 qha^{-1} grain yield and 65.83 to 66.29 qha^{-1} straw yield), most remunerative in terms of net return (Rs.65097.0 to 66278.0 ha^{-1}) and B:C ratio (1.85 to 1.88).

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