Vol. 49, No. 3, pp 163-171, 2021
Indian Journal of Soil Conservation

Effect of irrigation levels and nitrogen management on water, nitrogen and radiation use efficiency of wheat in a semi-arid tropical environment

K.K. Bandyopadhyay[1,*], Sanatan Pradhan[2], Debashis Chakraborty[1] and P. Krishnan[1]

[1]*Division of Agricultural Physics, ICAR-Indian Agricultural Research Institute, New Delhi;* [2]*ICAR-Indian Institute of Water Management, Bhubaneswar, Odisha.*

*Corresponding author:
E-mail: kk.bandyopadhyay@gmail.com (K.K. Bandyopadhyay)

ARTICLE INFO

DOI : 10.59797/ijsc.v49.i3.184

Article history:
Received : June, 2021
Revised : December, 2021
Accepted : December, 2021

Key words:
Partial factor productivity of N
Radiation use efficiency
Water use efficiency
Wheat

ABSTRACT

A field experiment was carried out in a sandy loam soil at Indian Agricultural Research Institute, New Delhi for four years to study the effect of irrigation schedule and nitrogen source on water, nitrogen and radiation use efficiency (RUE) of wheat. Wheat (*cv.* PBW 502) was grown in a split plot design with four irrigation levels as main plot factor and three nitrogen management strategies as subplot factor. It was observed that grain yield of wheat with irrigation at 0.8 IW/CPE irrigation level was statistically similar with that at 1.0 IW/CPE irrigation level and there was no significant difference in the grain yield of wheat due to sole urea @ 120 kg Nha^{-1} and integrated use of urea @ 60 kg Nha^{-1} and FYM @ 60 kg Nha^{-1}. Irrigation at 0.8 IW/CPE also registered equivalent water use efficiency (WUE) and partial factor productivity of nitrogen (PFPN) as that of irrigation at 1.0 IW/CPE level. The WUE, RUE and partial factor productivity of wheat due to sole urea was statistically similar to integrated use of urea and FYM. Therefore, wheat may be grown with integrated use of urea and FYM with an irrigation level of 0.8 IW/CPE to save irrigation water compared to 1.0 IW/CPE and 50% urea compared to 100% sole urea treatment, respectively.

1. INTRODUCTION

In India wheat is the second most important cereal crop after rice, which contributes nearly one third to the total food grain production. Though there is a quantum jump in wheat production from 12.65 M t in1965-1966 to 99.87 M t in 2018-2019, the biggest challenge is to increase the productivity by efficient use of resources in the face of shrinking land resources, degradation of soil health and increasing population pressure. Water and nitrogen are key inputs in agriculture, which interact synergistically in influencing growth and yield of crops (Lenka *et al.,* 2009; Pradhan *et al.,* 2018). Non-judicious use of these inputs has degraded soil, water and environmental quality besides raising the cost of production (Pradhan *et al.,* 2013). So, these inputs should be used efficiently to sustain agricultural productivity at higher level. Increased crop growth due to water and nitrogen management results in increased leaf area index and radiation interception, which lead to higher radiation use efficiency (RUE) and crop productivity.

Indiscriminate use of water and nitrogen, especially high analysis synthetic fertilizers and non-use or low use of organic sources of nutrients has resulted in depletion of soil organic matter and degradation of soil health (Ranjan *et al.,* 2015; Chatterjee *et al.,* 2016). Soil organic matter plays a vital role in improving physical, chemical and biological quality of soil, which ultimately contributes to improved resource use efficiency. It has been reported that continued application of organic manures like farmyard manure (FYM) and green manure has increased soil organic matter and crop productivity under different soil and cropping systems (Kundu *et al.,* 2002). However, neither sole use of inorganic fertilizer nor organic manures alone can sustain agricultural productivity (Prasad, 1996). So, judicious conjunctive use of organic manures and inorganic fertilizers or integrated nutrient management is essential to safeguard soil health and augment agricultural productivity and resource use efficiency (Bandyopadhyay *et al.,* 2010). In the face of limited availability of irrigation due to groundwater depletion and competing demands from other sectors, there is a need to optimize the irrigation schedule in wheat under different nitrogen management strategies (*i.e.* organic, inorganic and integrated nutrient management) for achieving higher yield and resource use efficiency.

Though WUE, nitrogen use efficiency and RUE in wheat under different management practices have been studied in isolation, there is very limited study where all these three efficiency have been studied simultaneously under varied nutrient and water management. It has been hypothesized that optimum irrigation schedule under integrated nutrient management will improve crop yield and water, nitrogen and RUE in wheat. To test this hypothesis, a field experiment was conducted with the following objectives: (i) To find out the optimum irrigation schedule for improving productivity of wheat under different nitrogen sources and (ii) To study the effect of irrigation schedule and nitrogen source on water, nitrogen and RUE of wheat.

2. MATERIALS AND METHODS

Soil and Climate of the Experimental Site

Field experiments were carried out during the years 2010-2011 to 2013-2014 at the research farm of the Indian Agricultural Research Institute, New Delhi (28°37' to 28° 39' N latitudes and 77°90' to 77°11' E longitudes and at an altitude of 228.7 m above mean sea level). This region is characterized by extreme temperatures in summer and the annual maximum temperature goes as high as 45°C, whereas in winter the minimum temperature dips to as low as 1°C. There is occasional occurrence of frost in December and January. The mean summer and mean winter temperatures were 33.0°C and 17.3°C, respectively. The mean annual rainfall is around 750 mm of which a substantial amount (85%) is received during July to September. The monthly weather situation during wheat growth for the four years is presented in Table 1.

The soil of the experimental site is sandy loam (*Typic Haplustept*) with medium to angular blocky structure, non-calcareous and slightly alkaline in reaction. The soil (0-15 cm) has sand, silt and clay, 64.0, 16.8 and 19.2%, respectively, bulk density 1.56 Mg m^{-3}; hydraulic conductivity (saturated) 1.05 cm h^{-1}, saturated water content 0.42 $m^3 m^{-3}$; pH (1:2.5 soil / water suspension) 7.4; EC 0.34 dS m^{-1}; organic C 3.0 g kg^{-1}; total N 0.031%; available (Olsen) P 6.9 kg ha^{-1}; available K 279.0 kg ha^{-1}. The soil moisture at 0.033 MPa suction ranged from 25-28% and at 1.5 MPa suction ranged from 8-10% in different layers of 0-90 cm soil depth.

Crop Culture

Wheat (*cv* PBW 502) was grown in a split plot design with four levels of irrigation *viz*., I_1: 0.4 IW/CPE, I_2: 0.6 IW/CPE, I_3: 0.8 IW/CPE and I_4: 1.0 IW/CPE (IW = 6 cm) as

Table: 1
Weather condition during the study period

	Max T (°C)	Min T (°C)	Mean T (°C)	Max RH (%)	Min RH (%)	Mean RH (%)	Rain (mm)	SSH (hr)	EP (mm)
2010-11									
Nov	26.6	13.4	20.0	92.7	48.3	70.5	10.6	3.3	2.8
Dec	21.1	6.1	13.6	89.5	45.0	67.3	0.7	3.0	2.2
Jan	18.1	5.3	11.7	88.1	46.4	67.3	0.0	3.8	2.8
Feb	23.1	9.5	16.3	91.6	47.7	69.7	49.9	5.4	2.9
Mar	29.2	13.0	21.1	85.1	38.5	61.8	2.3	6.9	4.4
April	35.0	17.8	26.4	65.3	24.2	44.8	2.2	7.9	6.3
2011-12									
Nov	28.8	12.6	20.7	86.5	34.8	60.7	0.0	4.2	2.9
Dec	22.6	5.7	14.2	91.5	42.9	67.2	0.0	3.2	2.2
Jan	18.7	5.5	12.1	91.3	53.9	72.6	14.8	3.4	2.1
Feb	22.6	7.9	15.3	76.3	32.5	54.4	0.0	6.6	4.2
Mar	29.9	12.7	21.3	75.5	25.3	50.4	19.2	6.8	5.5
April	35.4	19.3	27.4	68.3	39.9	54.1	9.0	7.4	7.1
2012-13									
Nov	27.3	9.9	21.1	89.0	61.9	75.5	0.0	3.4	2.4
Dec	21.7	7.5	14.6	84.3	49.3	66.8	8.6	4.2	2.4
Jan	18.0	4.7	11.4	92.0	66.0	79.0	40.8	3.7	2.8
Feb	22.1	9.6	15.8	91.7	52.1	71.9	102.4	5.1	2.7
Mar	29.9	13.7	21.8	87.0	35.0	61.0	12.6	8.1	4.7
April	36.1	19.5	27.7	67.0	28.0	47.0	11.6	8.4	7.1
2013-14									
Nov	26.9	9.9	21.1	90.9	48.3	69.6	0.4	4.9	3.1
Dec	22.4	7.1	14.7	93.8	55.9	74.8	1.9	4.1	2.1
Jan	18.6	6.8	12.7	96.6	66.5	81.6	18.6	2.3	1.9
Feb	21.4	7.5	14.5	96.0	63.1	79.5	63.5	4.4	2.6
Mar	27.2	12.7	20.0	90.0	48.1	69.0	63.5	6.4	3.7
April	34.8	17.9	26.3	73.4	40.1	56.8	16.4	8.5	6.8

main-plot factor and three nitrogen management strategies (N_1: 120 kg Nha^{-1} as urea, N_2: 60 kg Nha^{-1} as urea + 60 kg Nha^{-1} as FYM and N_3:120 kg Nha^{-1} as FYM) as subplot factor to optimize irrigation schedule and N management for wheat (*cv* PBW 502) for improving water, nitrogen and RUE. 50% of urea was applied as basal application and rest 50% urea was applied in two equal splits at crown root initiation and flowering stage in N_1 and N_2 treatments whereas FYM was applied as basal dose before sowing of the crops in N_2 and N_3 treatments. FYM contained 0.55% N, 0.28% P and 0.52% K. Recommended dose of P (60 kg P_2O_5 as single super phosphate) and K (60 kg K_2O ha^{-1} as muriate of potash) was applied as basal application to all the treatments. Irrigation was applied as per treatment in measured amount using parshall flume. Surface irrigation method was adopted for all the experimental plots. Irrigation water depth was kept constant at 6 cm. The irrigation was applied when the cumulative pan evaporation reached 150 mm, 100 mm, 75 mm and 60 mm for 0.4 IW/CPE, 0.6 IW/CPE, 0.8 IW/CPE and 1.0 IW/CPE irrigation treatments, respectively.

Water and Nitrogen Use Efficiency

Soil moisture content of the profile (0-120 cm) was determined gravimetrically at 15 days interval during the crop growth period to study the distribution and redistribution of soil water in the profile.

Evapotranspiration (ET) was computed by water balance method using the following equation:

$$ET = P + I + Cp - Dp - Rf - \Delta S \qquad ...(1)$$

$$ET = P + I - (Sf - Si) \qquad ...(2)$$

Where, P is precipitation, I is depth of irrigation, Cp is contribution through capillary rise from the water table, Dp is deep percolation loss, Rf is runoff, ΔS is change in soil moisture storage in the profile for the period considered. Sf is the final moisture storage in the profile and Si is initial moisture storage in the profile for the period considered. Runoff was assumed to be negligible as the field plots were bunded to a sufficient height of 30 cm and in no case bund overflow was observed. The water table was below 8 m depth and therefore capillary rise (Cp) was assumed to be negligible. The deep percolation loss (Dp) beyond 120 cm soil depth was assumed negligible.

Grain water use efficiency (WUEg, kg ha^{-1} mm) = GY/ET ...(3)

Biomass water use efficiency (WUEb, kg ha^{-1} mm) = BY/ET ...(4)

Where, GY is the grain yield and BY is above ground biomass yield of wheat (kg ha^{-1}).

The partial factor productivity of nitrogen (PFPN) was computed using the following formula:

$$PFPN = \frac{Grain\ yield,\ kg\ ha^{-1}}{N\ applied,\ kg\ ha^{-1}} \qquad ...(5)$$

Radiation Interception and RUE

Incoming and outgoing photosynthetically active radiation (PAR) were measured periodically at the top and bottom of the wheat canopy throughout the season using line quantum sensor LI-191SA (LICOR Inc., Lincoln, NE, USA). These observations were taken at regular intervals on clear days between 11.00 and 12.00 hrs Indian Standard Time when disturbances due to leaf shading and leaf curling and solar zenith angle were minimum. The intercepted photosynthetically active radiation (IPAR) for a particular day was computed as the difference between PAR at the top and bottom of canopy. The fraction intercepted photosynthetically active radiation (fIPAR) for a particular day is the ratio between intercepted PAR and total incident PAR on that day (Pradhan *et al.,* 2014, 2018). Values for fIPAR for the days when actual observation was not recorded between the actual measurements were interpolated by linear interpolation throughout the crop season. Daily incoming solar radiation was calculated by the procedure described in Allen *et al.* (1998) using daily bright sunshine hours observation. The daily incoming solar radiation was multiplied by a factor 0.48 (Monteith, 1972) to get incoming incident PAR. Then the daily incident PAR values were multiplied by corresponding daily fIPAR values to compute daily intercepted PAR (IPAR). The daily IPAR was added for the whole crop season to get total IPAR (TIPAR). The RUE was calculated by dividing total aboveground biomass (g m^{-2}) with the total IPAR (TIPAR, MJ m^{-2}) for the whole crop duration (Pradhan *et al.,* 2014, 2018).

Radiation use efficiency (RUE, g MJ^{-1}) = Total above ground biomass (g m^{-2}) / TIPAR (MJ m^{-2}) ...(6)

Statistical Analysis

The data were statistically analyzed using analysis of variance (ANOVA) as applicable to split plot design (Gomez and Gomez, 1984). The significance of the treatment effects was determined using F-test. The difference between the means were estimated using least significance difference and Duncan's multiple range tests at 5% probability level. Regression analyses were performed using the data analysis tool pack of MS Excel.

3. RESULTS AND DISCUSSIONS

Weather

Mean monthly maximum and minimum air temperature, relative humidity, sunshine hours, pan evaporation and rainfall during the growth period of wheat crop for the four years of study are presented in Table 1. It was observed that minimum temperature and mean air temperature was less in the month of February during the year 2011-2012 and 2013-

2014 compared to other two years. However, in the year 2012-2013 (126.6 mm) and 2013-2014 (143.4 mm), unusually high rainfall was received during the months of February, March and April leading to aeration stress of the crops. The sunshine hours in the month of February (6.6 hrs) was also maximum for the year 2011-2012 compared to other years. February month coincides with the booting, flowering and milk stage of wheat. The mean RH during the month of February and March during the year 2011-2012 was minimum compared to other years, which implies that the wheat crop during the year 2011-2012 experienced relatively drier environment during milk and grain filling stage. As a whole, the wheat crop during the year 2011-2012 experienced cool and moist weather during the vegetative stage and warm and dry weather with longer bright sunshine hours during the reproductive period, compared to other years, which is highly congenial environment for the growth and development of wheat (Prasad, 2004).

Grain and Biomass Yield of Wheat

Grain yield of wheat increased significantly with the increase in the irrigation levels in all the four years of study (Table 2). However, there was no significant difference (p70.05) in the grain yield of wheat due to 0.8 and 1.0 IW/CPE irrigation levels. This indicates that irrigation at 0.8 IW/CPE was sufficient for achieving equivalent grain yield as that of 1.0 IW/CPE with saving of valuable irrigation water in this region. Grain yield of wheat with irrigation at 0.8 and 1.0 IW/CPE was significantly higher than that of 0.4 IW/CPE across the years but there was no significant difference in the grain yield of wheat between 0.4 and 0.6 IW/CPE irrigation levels across the years. The increased grain yield with the increased levels of irrigation can be ascribed to better water and nutrient availability, greater canopy coverage, higher radiation interception and extended green crop duration (Pradhan *et al.,* 2018b). This finding is in agreement with Pradhan *et al.* (2014) in Inceptisol and Hati *et al.* (2001); Mandal *et al.* (2006) and Bandyopadhyay *et al.* (2010) in Vertisol. The grain yield of wheat was significantly influenced by nutrient management (p70.05) with minimum wheat yield being recorded under sole FYM treatment in all the four years of study. In two out of four years (2011-2012 and 2012-2013), the grain yield of wheat due to sole urea was statistically similar to that of integrated use of urea and FYM treatment. Thus integrated use of urea and FYM could save 50% of urea fertilizer without significant reduction in grain yield of wheat. The poor grain yield of wheat due to sole FYM treatment may be due to lower nitrogen mineralization and availability under this treatment compared to the crop demand (Pradhan *et al.,*

Table: 2
Grain yield and biomass yield of wheat as influenced by irrigation and nitrogen management

Treatment	Grain yield (Mg ha^{-1})					Biomass yield (Mg ha^{-1})				
	2010-11	2011-12	2012-13	2013-14	Pooled	2010-11	2011-12	2012-13	2013-14	Pooled
Irrigation levels										
I_1:0.4 IW/CPE	3.34^{B}*	5.14^{B}	2.46^{B}	2.08^{C}	3.25	9.36^{D}*	14.78A	8.49^{B}	8.46^{B}	10.27
I_2:0.6 IW/CPE	3.28^{B}	5.39^{AB}	2.70^{B}	2.25^{BC}	3.40	10.76^{C}	15.28A	10.19^{A}	8.70^{B}	11.23
I_3:0.8 IW/CPE	3.92^{A}	5.58^{A}	3.45^{A}	2.52^{AB}	3.87	11.51^{B}	15.11A	11.04^{A}	9.02^{B}	11.67
I_4:1.0 IW/CPE	3.97^{A}	5.74^{A}	3.47^{A}	2.72^{A}	3.97	11.99^{A}	15.83A	11.50^{A}	10.70^{A}	12.50
Nutrient sources										
N_1:$Urea_{100\%N}$	4.47^{A}	6.22^{A}	3.28^{A}	2.77^{A}	4.18	13.62^{A}	17.58^{A}	12.43^{A}	10.60^{A}	13.56
N_2:$Urea_{50\%N}$ + $FYM_{50\%N}$	3.75^{B}	6.13^{A}	3.26^{A}	2.41^{B}	3.89	11.12^{B}	17.13^{A}	10.63^{B}	9.30^{B}	12.04
N_3:$FYM_{100\%N}$	2.66^{C}	4.04^{B}	2.53^{B}	2.00^{C}	2.81	7.98^{C}	11.04^{B}	7.85^{C}	7.75^{C}	8.66
Irrigation × Nutrient interaction										
I_1N_1	4.53^{a}	5.79^{a}	2.77^{a}	2.28^{a}	3.84	12.71^{a}	16.83^{a}	10.96^{a}	10.00^{a}	12.63
I_1N_2	3.23^{a}	6.00^{a}	2.50^{a}	2.06^{a}	3.45	9.04^{a}	17.00^{a}	8.32^{a}	8.25^{a}	10.65
I_1N_3	2.27^{a}	3.63^{a}	2.11^{a}	1.90^{a}	2.48	6.33^{a}	10.50^{a}	6.18^{a}	7.13^{a}	7.53
I_2N_1	3.61^{a}	5.71^{a}	2.99^{a}	2.75^{a}	3.76	12.63^{a}	17.00^{a}	11.59^{a}	10.17^{a}	12.85
I_2N_2	3.41^{a}	5.83^{a}	2.85^{a}	2.44^{a}	3.63	11.29^{a}	16.67^{a}	10.73^{a}	9.67^{a}	12.09
I_2N_3	2.81^{a}	4.63^{a}	2.26^{a}	1.57^{a}	2.82	8.89^{a}	12.17^{a}	8.24^{a}	6.25^{a}	8.89
I_3N_1	4.98^{a}	6.67^{a}	3.73^{a}	2.76^{a}	4.54	14.42^{a}	18.17^{a}	13.17^{a}	9.89^{a}	13.91
I_3N_2	4.19^{a}	6.42^{a}	3.70^{a}	2.69^{a}	4.25	12.02^{a}	17.33^{a}	11.52^{a}	8.95^{a}	12.46
I_3N_3	2.58^{a}	3.67^{a}	2.92^{a}	2.12^{a}	2.82	8.36^{a}	9.83^{a}	8.43^{a}	8.22^{a}	8.71
I_4N_1	4.73^{a}	6.71^{a}	3.62^{a}	3.27^{a}	4.58	15.13^{a}	18.33^{a}	14.01^{a}	12.33^{a}	14.95
I_4N_2	4.18^{a}	6.25^{a}	3.98^{a}	2.46^{a}	4.22	12.14^{a}	17.50^{a}	11.94^{a}	10.33^{a}	12.98
I_4N_3	3.00^{a}	4.25^{a}	2.83^{a}	2.42^{a}	3.12	8.71^{a}	11.67^{a}	8.53^{a}	9.42^{a}	9.58

**Numbers in a column followed by same letter are not significantly different at $p<0.05$. Capital letters are used to differentiate the main effect whereas the small letters are used to differentiate the interaction effect.*

2013; Rautaray *et al.,* 2020). Pooled over the years, the I4 treatment registered 3%, 17%, and 22% higher grain yield than the I3, I2, and I1 treatments, respectively. Similarly, the N1 treatment registered 8% and 49% higher grain yield than the N2 and N3 treatments, respectively.

Biomass yield of wheat also increased significantly with the increase in irrigation levels in three years of study whereas in 2011-12 the effect of irrigation treatments on biomass yield of wheat was not statistically significant (Table 2). The biomass yield of wheat due to different nutrient management treatments followed the trend similar to the grain yield of wheat. In all the years, significantly minimum biomass yield of wheat was recorded in sole FYM treatment (p70.05). Except the year 2011-12, the biomass yield of wheat under sole urea was significantly higher than integrated use of urea and FYM treatment. However, in the year 2011-12, the biomass yield of wheat due to sole urea was statistically similar to integrated use of urea and FYM. Pooled over the years, the I4 treatment registered 7%, 11%, and 12% higher biomass yield than the I3, I2, and I1 treatments, respectively. Similarly, the N1 treatment registered 13% and 57% higher biomass yield than the N2 and N3 treatments, respectively.

In all the years of study, the effect of water and nutrient management interaction was not significant on grain and biomass yield of wheat. Among the years, the maximum grain and biomass yield of wheat was recorded in the year 2011-2012 due to relatively congenial weather experienced by the crop during this year (Prasad, 2004). The harvest index of wheat was maximum for 0.8 IW/CPE irrigation level across the years (0.326). Among the nutrient management treatments, maximum harvest index was recorded in sole FYM treatment (0.320), which was similar to that of integrated use of urea and FYM (0.315) but higher than that of sole urea treatment (0.301). Among the years, the maximum harvest index of wheat was recorded during the year 2011-2012.

Seasonal ET and WUE of Wheat

Among the four years, maximum seasonal ET was recorded in the year 2012-2013 (394.5 mm) followed by the years 2011-2012 (385.1 mm), 2010-2011 (378.3 mm) and 2013-2014 (375.2 mm) due to highest rainfall received during the year 2012-2013 (Fig. 1). The seasonal ET of wheat increased with the increase in the irrigation levels in all the four years. Among the nutrient management practices, maximum seasonal ET was recorded under sole urea application.

Mean grain water use efficiency (WUEg) of wheat for the years 2010-2011, 2011-2012, 2012-2013 and 2013-2014 were 9.6, 14.5, 7.4 and 6.5 kg ha^{-1} mm, respectively (Table 3). The correlation between grain yield and WUEg of wheat (r = +0.92) was higher than the correlation between ET and

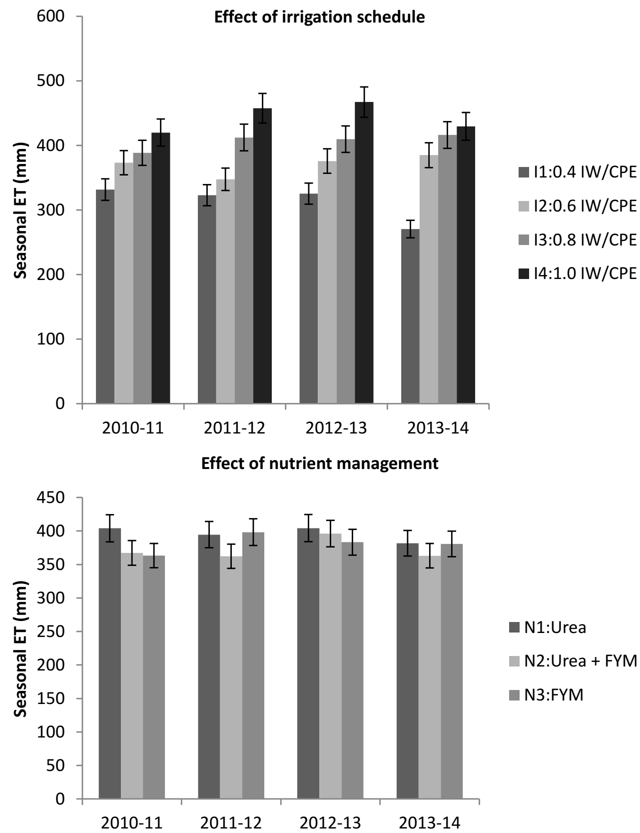

Fig. 1. Seasonal evapotranspiration of wheat as influenced by irrigation schedule and nutrient management

WUE of wheat (r = -0.18). This indicates that grain yield of wheat has more dominant effect than ET on WUE of wheat. WUEg of wheat decreased with the increase in the irrigation level in all the four years of study (Table 3). This may be attributed to loss of water at higher irrigation levels. Also the yield increase with the increase in the irrigation level was not in the same proportion as the increase in ET at higher level of irrigation, which resulted in decrease of WUE at higher irrigation levels. This finding is in agreement with Bandyopadhyay *et al.* (2009) and Pradhan *et al.* (2014b). Among the nutrient management practices, there was no significant difference in the WUEg of wheat due to sole urea and integrated use of urea and FYM. But these treatments registered significantly higher WUEg than sole FYM application. This was attributed to higher grain yield registered under sole urea and integrated use of urea and FYM than sole FYM application. Thus by practicing integrated urea and FYM, 50% urea can be saved without sacrificing the WUEg of wheat. The interaction between irrigation and N source on WUEg was not significant in all the years of study except 2013-2014. During the year 2013-2014, the maximum WUEg was recorded in I1N2 treatment.

Mean biomass water use efficiency (WUEb) of wheat for the years 2010-2011, 2011-2012, 2012-2013 and 2013-2014 were 28.9, 40.5, 26.2 and 25.3 kg ha^{-1} mm, respectively

Table: 3
Grain and biomass water use efficiency of wheat as influenced by irrigation and nitrogen management

Treatment	Grain water use efficiency (kg grain ha^{-1}mm)					Biomass water use efficiency (kg biomass ha^{-1} mm)				
	2010-11	2011-12	2012-13	2013-14	Pooled	2010-11	2011-12	2012-13	2013-14	Pooled
Irrigation levels										
I_1:0.4 IW/CPE	10.2^{A}*	15.9^{A}	7.5^{A}	7.8^{A}	10.4	28.6^{A}*	45.8^{A}	25.9^{A}	31.7^{A}	33.0
I_2:0.6 IW/CPE	8.8^{A}	15.5^{A}	7.2^{B}	5.8^{B}	9.3	29.3^{A}	43.9^{AB}	27.0^{A}	22.6^{B}	30.7
I_3:0.8 IW/CPE	9.9^{A}	13.9^{B}	8.4^{AB}	6.1^{B}	9.6	29.6^{A}	37.7^{BC}	27.1^{A}	21.9^{B}	29.1
I_4:1.0 IW/CPE	9.4^{A}	12.6^{C}	7.4^{AB}	6.3^{B}	8.9	28.3^{A}	34.8^{C}	24.6^{A}	24.9^{B}	28.1
Nutrient sources										
N_1:Urea$_{100\%N}$	11.2^{A}	15.9^{A}	8.1^{A}	7.3^{A}	10.6	34.3^{A}	45.2^{A}	30.9^{A}	28.2^{A}	34.6
N_2:Urea$_{50\%N}$ + FYM$_{50\%N}$	10.2^{A}	17.1^{A}	8.2^{A}	7.0^{A}	10.6	30.3^{B}	47.8^{A}	27.0^{B}	27.0^{A}	33.0
N_3:FYM$_{100\%N}$	7.3^{B}	10.5^{B}	6.6^{B}	5.3^{B}	7.4	22.2^{C}	28.7^{B}	20.6^{C}	20.6^{B}	23.0
Irrigation × Nutrient interaction										
I_1N_1	14.1^{a}	17.2^{a}	8.1^{a}	7.9^{ab}	11.8	39.7^{a}	50.0^{a}	31.9^{a}	34.5^{a}	39.0
I_1N_2	10.0^{a}	19.4^{a}	8.0^{a}	9.1^{a}	11.6	28.2^{bc}	54.9^{a}	26.6^{bc}	36.7^{a}	36.6
I_1N_3	6.4^{a}	11.2^{a}	6.6^{a}	6.4^{cde}	7.7	17.9^{e}	32.6^{a}	19.3^{e}	24.0^{bcd}	23.4
I_2N_1	8.7^{a}	16.1^{a}	6.2^{a}	6.5^{cde}	9.4	30.5^{b}	47.9^{a}	27.4^{cd}	24.2^{bcd}	32.5
I_2N_2	9.9^{a}	16.7^{a}	6.8^{a}	6.7^{bcde}	10.0	32.8^{b}	47.7^{a}	29.7^{c}	26.7^{bc}	34.2
I_2N_3	7.8^{a}	13.7^{a}	5.6^{a}	4.2^{g}	7.8	24.6^{cd}	36.0^{a}	24.0^{de}	16.8^{f}	25.3
I_3N_1	11.5^{a}	16.3^{a}	9.5^{a}	7.2^{bcd}	11.1	33.4^{b}	44.4^{a}	33.4^{a}	25.9^{bcd}	34.3
I_3N_2	11.0^{a}	17.6^{a}	8.8^{a}	6.5^{cde}	11.0	31.6^{b}	47.6^{a}	27.3^{bc}	21.6^{de}	32.0
I_3N_3	7.3^{a}	7.9^{a}	7.1^{a}	4.7^{fg}	6.8	23.7^{cd}	21.3^{a}	20.4^{de}	18.1^{ef}	20.9
I_4N_1	10.5^{a}	14.1^{a}	7.9^{a}	7.5^{bc}	10.0	33.6^{b}	38.4^{a}	30.7^{ab}	28.3^{b}	32.7
I_4N_2	9.9^{a}	14.7^{a}	8.1^{a}	5.5^{efg}	9.6	28.7^{bc}	41.0^{a}	24.5^{cd}	22.9^{cd}	29.3
I_4N_3	7.8^{a}	9.1^{a}	6.2^{a}	6.0^{def}	7.3	22.6^{de}	24.9^{a}	18.7^{e}	23.5^{cd}	22.4

**Numbers in a column followed by same letter are not significantly different at $p<0.05$. Capital letters are used to differentiate the main effect whereas the small letters are used to differentiate the interaction effect.*

Table: 4
Radiation use efficiency of wheat (g MJ^{-1}) as influenced by irrigation and nitrogen management

Treatment	2011-12	2012-13	2013-14	Pooled
Irrigation levels				
I_1:0.4 IW/CPE	2.83^{A}*	1.64^{B}	2.02^{A}	2.16
I_2:0.6 IW/CPE	2.79^{A}	1.99^{A}	1.88^{A}	2.22
I_3:0.8 IW/CPE	2.59^{A}	2.04^{A}	1.82^{A}	2.15
I_4:1.0 IW/CPE	2.74^{A}	1.91^{AB}	2.06^{A}	2.24
Nutrient sources				
N_1:Urea	2.77^{A}	2.13^{A}	2.10^{A}	2.33
N_2:Urea + FYM	2.97^{A}	1.92^{B}	1.94^{AB}	2.28
N_3:FYM	2.46^{B}	1.64^{C}	1.80^{B}	1.97
Irrigation × Nutrient Interaction				
I_1N_1	2.80^{a}	1.96^{bcd}	2.23^{a}	2.33
I_1N_2	3.35^{a}	1.67^{cd}	2.02^{abc}	2.34
I_1N_3	2.35^{a}	1.28^{e}	1.82^{cd}	1.82
I_2N_1	2.69^{a}	1.99^{bc}	2.11^{abc}	2.26
I_2N_2	2.81^{a}	1.98^{bcd}	2.04^{abc}	2.28
I_2N_3	2.86^{a}	1.99^{bc}	1.51^{e}	2.12
I_3N_1	2.80^{a}	2.35^{a}	1.94^{abc}	2.36
I_3N_2	2.73^{a}	2.11^{ab}	1.66^{de}	2.17
I_3N_3	2.23^{a}	1.67^{cd}	1.86^{bcd}	1.92
I_4N_1	2.81^{a}	2.21^{ab}	2.12^{ab}	2.38
I_4N_2	3.01^{a}	1.91^{bcd}	2.07^{abc}	2.33
I_4N_3	2.40^{a}	1.62^{d}	2.01^{abc}	2.01

**Numbers in a column followed by same letter are not significantly different at $p<0.05$. Capital letters are used to differentiate the main effect whereas the small letters are used to differentiate the interaction effect.*

(Table 3). The correlation between biomass yield and WUEb of wheat (r = 0.85) was higher than the correlation between ET and WUEb of wheat (r = -0.29). This indicates that biomass yield of wheat has more dominant effect than ET on WUEb of wheat. Similar to the WUEg, the WUEb also decreased with the increase in the irrigation levels (Table 5). Among the nutrient management practices, the maximum WUEb was observed in sole urea application and minimum WUEb was observed under sole FYM application in all the four years of study. In two out of the four years of study *i.e.* 2011-2012 and 2013-2014, there was no significant difference in the WUEb due to sole urea and integrated use of urea and FYM. However, in the other two years, the WUEb due to sole urea was significantly higher than that of the integrated nutrient management. The interaction between irrigation and nitrogen sources were significant in all the years of study except 2011-12. In 2010-2011, 2012-2013 and 2013-2014, the maximum WUEb was recorded in I1N1 treatment. But in 2012-2013 WUEb of I1N1, I3N1 and I4N1 treatments were statistically similar.

Seasonal TIPAR and RUE of Wheat

The mean total intercepted photosynthetically active radiation (TIPAR) was maximum for the year 2011-2012 (554 MJ) followed by the year 2012-2013 (539 MJ) and 2013-2014 (472 MJ). The TIPAR increased with the increase in the irrigation levels (Fig. 2). This followed the

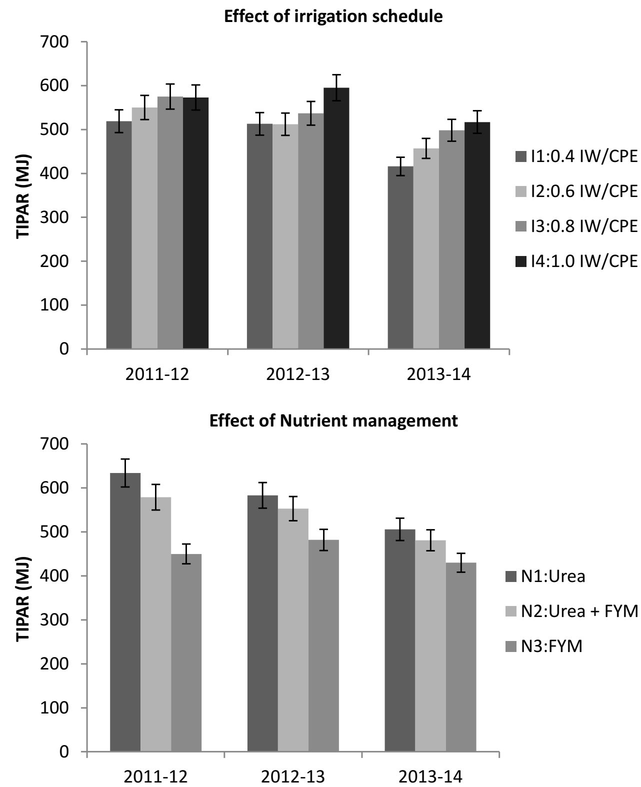

Fig. 2. Total intercepted photosynthetically active radiation in wheat as influenced by irrigation scheduling and nutrient management

Table: 5
Partial factor productivity of N in wheat (kg grain kg^{-1} N) as influenced by irrigation and nitrogen management

Treatment	2010-11	2011-12	2012-13	2013-14	Pooled
Irrigation levels					
I_1:0.4 IW/CPE	27.8^{B}*	42.8^{B}	20.5^{B}	19.0^{A}	27.5
I_2:0.6 IW/CPE	27.3^{B}	44.9^{AB}	22.5^{B}	19.9^{A}	28.7
I_3:0.8 IW/CPE	32.6^{A}	46.5^{A}	28.8^{A}	21.0^{A}	32.2
I_4:1.0 IW/CPE	33.1^{A}	47.8^{A}	28.9^{A}	22.6^{A}	33.1
Nutrient sources					
N_1:Urea	37.2^{A}	51.8^{A}	27.3^{A}	23.2^{A}	34.9
N_2:Urea + FYM	31.3^{B}	51.0^{A}	27.1^{A}	20.1^{AB}	32.4
N_3:FYM	22.2^{C}	33.7^{B}	21.1^{B}	18.6^{B}	23.9
Irrigation × Nutrient Interaction					
I_1N_1	37.6^{a}	48.3^{a}	23.1^{a}	22.0^{a}	32.8
I_1N_2	26.9^{a}	50.0^{a}	20.8^{a}	17.1^{a}	28.7
I_1N_3	18.9^{a}	30.2^{a}	17.6^{a}	17.8^{a}	21.1
I_2N_1	30.1^{a}	47.6^{a}	24.9^{a}	22.9^{a}	31.4
I_2N_2	28.4^{a}	48.6^{a}	23.7^{a}	20.3^{a}	30.3
I_2N_3	23.4^{a}	38.5^{a}	18.8^{a}	16.4^{a}	24.3
I_3N_1	41.5^{a}	55.6^{a}	31.1^{a}	23.0^{a}	37.8
I_3N_2	34.9^{a}	53.5^{a}	30.8^{a}	22.4^{a}	35.4
I_3N_3	21.5^{a}	30.6^{a}	24.4^{a}	17.7^{a}	23.6
I_4N_1	39.4^{a}	55.9^{a}	30.1^{a}	24.9^{a}	37.6
I_4N_2	34.8^{a}	52.1^{a}	33.1^{a}	20.5^{a}	35.1
I_4N_3	25.0^{a}	35.4^{a}	23.6^{a}	22.4^{a}	26.6

**Numbers in a column followed by same letter are not significantly different at $p<0.05$. Capital letters are used to differentiate the main effect whereas the small letters are used to differentiate the interaction effect.*

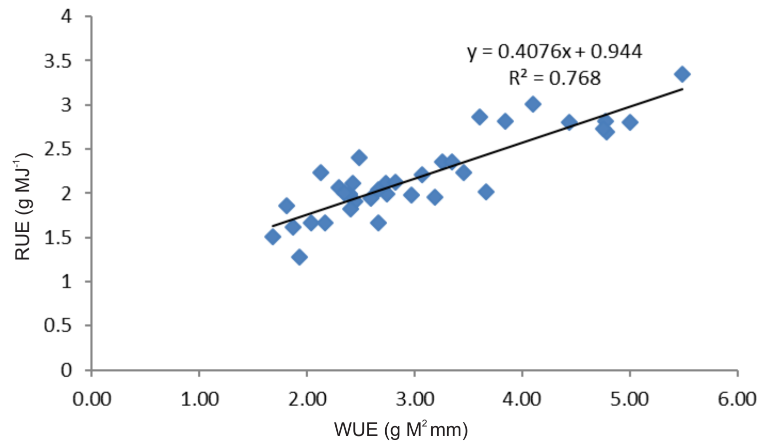

Fig. 3. Relationship between radiation use efficiency (RUE) and water use efficiency (WUE) of wheat (pooled over three years)

similar trend as the above ground biomass production of wheat. Among the nutrient management treatments, maximum TIPAR was recorded under sole urea followed by integrated use of urea and FYM (INM) and sole FYM application. It could be attributed to better crop development and canopy coverage under sole urea than that of INM and sole FYM application. The relationship between TIPAR and aboveground biomass production of wheat (Y = 36.268x - 7337.4, R^2 = 0.599) showed that TIPAR could account for ~ 60% variation in the plant biomass production. This indicated that increased interception of radiation is one of the major driving forces of crop biomass production.

The RUE of wheat was maximum for the year 2011-2012 (2.74 g MJ^{-1}) among the three years (Table 4). The correlation between biomass yield and RUE of wheat (r = 0.89) was higher than the correlation between TIPAR and RUE of wheat (r = 0.41). This indicates that biomass yield of wheat has more dominant effect than TIPAR on RUE of wheat. Han *et al.* (2008) and Pradhan *et al.* (2014b) also observed significant positive correlation between RUE and crop yield of wheat. There was no significant difference in the RUE of wheat due to irrigation levels during the year 2011-2012 and 2013-2014 but during the year 2012-2013, the RUE of wheat due to 0.8 and 0.6 IW/CPE irrigation level was significantly higher than that of 0.4 IW/CPE irrigation level. Pandey *et al.* (2004) also observed higher RUE of wheat under higher moisture regimes compared to moisture stress conditions. This may be due to higher biomass production and higher radiation interception at higher irrigation levels. Across the years, maximum RUE was recorded under sole urea application and minimum RUE was recorded under sole FYM application. In two out of three years (2011-2012 and 2013-2014) there was no significant difference in the RUE of wheat due to sole urea and integrated use of urea and FYM treatment whereas during the year 2012-2013, significantly higher RUE was recorded under sole urea than integrated use of urea and FYM. Interaction of irrigation levels and nutrient management was not significant on RUE of wheat during the year 2011-2012. However, during the year 2012-2013, significantly higher RUE was recorded under irrigation at 0.8 IW/CPE and sole urea application (I3N1) (2.35 g MJ^{-1}), which was at par with I3N2 whereas during the year 2013-2014 significantly higher RUE was recorded under irrigation at 0.4 IW/CPE and sole urea application (I1N1) (2.23 g MJ^{-1}), which was at par with I1N2, I2N1, I2N2, I3N1, I4N1, I4N2, and I4N3 treatments.

It was observed that RUE of wheat was significantly positively correlated with the WUEb (r = 0.88) (Fig. 3). The RUE could account for 76.8% variation in the WUEb. The regression equation showed that per unit increase in the WUEb, the RUE of wheat increased by 0.407 unit. Narayanan *et al.* (2013) also reported positive correlation between RUE and WUE of sorghum.

Partial Factor Productivity of Nitrogen (PFPN) of Wheat

PFPN of wheat followed the trend similar to the grain yield of wheat. Among the four years of study, the maximum mean PFPN was recorded in the year 2011-2012 (Table 5). This was attributed to higher grain yield obtained during this year. Except the year 2013-2014, the PFPN increased significantly with the increase in the irrigation level. This is attributed to synergetic interaction between water and nitrogen for improving wheat yield. During the year 2013-2014, the effect of irrigation levels was not significant on PFPN of wheat. In all the four years of study, there was no significant difference in the PFPN of wheat due to 0.8 and 1.0 IW/CPE irrigation levels. So in this region, irrigation at 0.8 IW/CPE may be practiced for wheat without any significant reduction in PFPN. Among the nutrient management practices, maximum PFPN was recorded under sole urea application and minimum PFPN was recorded under sole FYM application in all the four years of study. Pooled over the four years, PFPN of wheat due to sole urea was higher than that of INM and sole FYM by 7.7 and 46%, respectively. Similarly, the PFPN of wheat due to INM was higher than sole FYM by 35.6%. In three out of four years of study, there was no significant difference in the PFPN of wheat due to sole urea and integrated use of urea and FYM. So, integrated use of urea and FYM may be practiced for wheat to save 50% urea without significant reduction in PFPN compared to sole urea in this region. In all the four years of study, interaction between irrigation levels and nutrient management was not significant on PFPN of wheat.

4. CONCLUSIONS

Thus from this study it may be concluded that grain yield of wheat with irrigation at 0.8 IW/CPE irrigation level was statistically similar with that at 1.0 IW/CPE irrigation level and there was no significant difference in the grain yield of wheat due to sole urea and integrated use of urea and FYM. Irrigation at 0.8 IW/CPE also registered equivalent WUE and PFPN of wheat as that of irrigation at 1.0 IW/CPE level. There was no significant difference in the WUE, RUE and partial factor productivity of wheat due to sole urea and integrated use of urea and FYM. Therefore, wheat may be grown with integrated use of urea and FYM with an irrigation level of 0.8 IW/CPE to save irrigation water compared to 1.0 IW/CPE and 50% urea compared to sole urea treatment, respectively. This treatment also registered equivalent RUE, PFPN, grain yield and WUE compared to 1.0 IW/CPE irrigation and sole urea application. Therefore, integrated use of urea and FYM with an irrigation level of 0.8 IW/CPE is recommended for wheat in Inceptisols of the Indogangetic plain region.

ACKNOWLEDGEMENTS

The logistic support received from the Director, ICAR-Indian Agricultural Research Institute, New Delhi during the study period is thankfully acknowledged.

REFERENCES

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. Crop evapotranspiration-guidelines for computing crop water requirements, No. 56. FAO, Rome, FAO Irrigation and Drainage Paper.

Bandyopadhyay, K.K., Misra, A.K., Ghosh, P.K., Hati, K.M., Mandal, K.G. and Mohanty, M. 2010. Effect of irrigation and nitrogen application methods on input use efficiency of wheat under limited water supply in a Vertisol of Central India. *Irrig. Sci.,* 28: 285-299.

Bandyopadhyay, K.K., Ghosh, P.K., Hati, K.M. and Misra, A.K. 2009. Efficient utilization of limited available water in wheat through proper irrigation scheduling and integrated nutrient management under different cropping systems in a Vertisol. *J. Indian Soc. Soil Sci.,* 57(2): 121-128.

Bandyopadhyay, K.K., Misra, A.K., Ghosh, P.K. and Hati, K.M. 2010. Effect of integrated use of farmyard manure and chemical fertilizers on soil physical properties and productivity of soybean. *Soil Till. Res.,* 110: 115-125.

Chatterjee, S., Bandyopadhyay, K.K., Pradhan, S., Singh, R. and Datta, S.P. 2016. Influence of irrigation, crop residue mulch and nitrogen management practices on soil physical quality. *J. Indian Soc. Soil Sci.,* 64: 351-367.

Gomez, K.A. and Gomez, A.A. 1984. Statistical Procedures for Agricultural Research. John Wiley and Sons, New York.

Han, H., Li, Z., Ning, T., Zhang, X., Shan, Y. and Bai, M. 2008. Radiation use efficiency and yield of winter wheat under deficit irrigation in North China. *Plant Soil Environ.,* 54: 313-319.

Hati, K.M., Mandal, K.G., Misra, A.K., Ghosh, P.K. and Acharya, C.L. 2001. Effect of irrigation regimes and nutrient management on soil water dynamics, evapotranspiration and yield of wheat in vertisols. *Indian J. Agric. Sci.,* 71: 581-586.

Kundu, S., Ved Prakash, Ghosh, B.N., Singh, R.D. and Shrivastava, A.K. 2002. Quantitative relationship between annual carbon inputs and soil organic carbon build-up in soybean (*Glycine max*)-wheat (*Triticum aestivum*) cropping sequence. In: Proceedings of the 2nd International Agron. Congress, New Delhi, India, November 26-30, pp 108-110.

Lenka, S., Singh, A.K. and Lenka, N.K. 2009. Water and nitrogen interaction on soil profile water extraction and ET in maize -wheat cropping system. *Agric. Water Manage.,* 96: 195-207.

Mondal, K.G., Hati, K.M., Misra, A.K. and Bandyopadhyay, K.K. 2006. Assessment of irrigation and nutrient effects on growth, yield and water use efficiency of Indian mustard (*Brassica juncea*) in central India. *Agric. Water Manage.,* 85: 279-286.

Monteith, J.L. 1972. Solar radiation and productivity in tropical ecosystems. *J. Appl. Ecol.,* 9: 747-766.

Narayanan, S., Aiken, Robert M., Vara Prasad, P.V., Xin, Z. and Yu, J. 2013. Water and radiation use efficiency of sorghum. *Agron. J.,* 105(3): 650-656.

Pandey, V., Chaudhari, G.B., Patel, H.R., Vadodaria, R.P., Bhatt, B.K. and Shekh, A.M. 2004. Radiation interception and light use efficiency in wheat crop at Anand. *J. Agrometeor.,* 6: 43-46.

Pradhan, S., Chopra, U.K., Bandyopadhyay, K.K., Singh, R., Jain, A.K. and Chand, I. 2014a. Effect of deficit irrigation and nitrogen levels on water productivity and nitrogen use efficiency of wheat (*Triticum aestivum*) in a semi-arid environment. *Indian J. Agron.,* 84(7): 887-891.

Pradhan, S., Sehgal, V.K., Sahoo, R.N., Bandyopadhyay, K.K. and Singh, R. 2014b. Yield, water, radiation and nitrogen use efficiencies of wheat (*Triticum aestivum*) as influenced by nitrogen levels in a semi-arid environment. *Indian J. Agron.,* 59: 267-275.

Pradhan, S., Sehgal, V.K., Bandyopadhyay, K.K., Panigrahi, P., Parihar, C.M. and Jat, S.L. 2018a. Radiation interception, extinction coefficient and use efficiency of wheat crop at various irrigation and nitrogen levels in a semiarid location. *Indian J. Plant Physio.*, 23: 416-425.

Pradhan, S., Sehgal, V.K., Sahoo, R.N., Bandyopadhyay, K.K. and Singh, R. 2018b. Yield, water radiation use efficiency of wheat as influenced by irrigation levels in a semi-arid environment. *J. Agrometeor.,* 20: 31-36.

Pradhan, S., Bandyopadhyay, K.K., Sahoo, R.N., Sehgal, V.K., Singh, R., Joshi, D.K. and Gupta, V.K. 2013. Prediction of wheat grain and biomass yield under different irrigation and nitrogen management practices using canopy reflectance spectra model. *Indian J. Agric. Sci.,* 83: 1136-1143.

Pradhan, S., Sehgal, V.K., Das, D.K., Jain, A.K., Bandyopadhyay, K.K., Singh, R. and Sharma, P.K. 2014c. Effect of weather on seed yield and radiation and water use efficiency of mustard cultivars in a semi-arid environment. *Agric. Water Manage.,* 139: 43-52.

Prasad, R. 2004. Text book of field crops production. Directorate of Information and Publication of Agriculture, Indian Council of Agricultural Research, Krishi Anusandhan Bhavan, Pusa, New Delhi.

Prasad, R. 1996. Cropping systems and sustainability of agriculture. *Indian Farm.,* 46: 39-45.

Ranjan, R., Chopra, U.K., Sahoo, R.N., Pramanik, M., Singh, A.K., Pradhan, S. and Alam, N.M. 2015. Resource conservation in wheat under different water and nitrogen stress levels. *Indian J. Soil Cons.,* 43: 159-165.

Rautaray, S.K., Pradhan, S., Mohanty, S., Dubey, R., Raychaudhuri, S., Mohanty, R.K., Mishra, A. and Ambast, S.K. 2020. Energy efficiency, productivity and profitability of rice farming using Sesbania as green manure-cum-cover crop. *Nut. Cycling Agroecosys.,* 116: 83-101.