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Research Paper

Moisture and nutrient management strategies to magnify the productivity, nitrogen use efficiency and optimize nutrient acquisition in wheat under IGP region of India

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ABSTRACT

A field study was carried out during 2021–22 and 2022–23 at CRC, Sardar Vallabhbhai Patel University of Agriculture & Technology, Modipuram, Meerut, Uttar Pradesh to see the outcomes of integrated nutrient management (INM) and moisture regimes on yield and nitrogen use efficiency of wheat. The experiment was designed as a split plot design and replicated 3 times. It consisted of 3 different moisture levels assigned to the main plots, *viz.* I_1, irrigation at 0.7 IW/CPE ratio; I_2, irrigation at 0.9 IW/CPE ratio and I_3, 5 irrigations at critical stages (crown root initiation, late tillering, late jointing, flowering and milking stage) and six INM modules, *viz.* N_1, control; N_2, 100% recommended dose of fertilizer (RDF) (150:75:60 kg NPK/ha); N_3, 125% RDF; N_4, 50% RDF + poultry manure (PM) @ 2.5 t/ha; N_5, 50% RDF + PM @ 2.5 t/ha + *Azotobacter* + phosphorus solubilizing bacteria (PSB) + potassium mobilizing bacteria (KMB); N_6, 50% RDF + PM @ 2.5 t/ha + NPK Consortia in sub plots. Mean data of 2 years indicated that grain and straw yield, NPK uptake, partial factor productivity (PFP_N), agronomic efficiency (AE_N) and recovery efficiency (RE) were significantly higher under I_3 ~ 13.3, ~ 11.3, ~ 16.5, ~ 13.8, ~ 18.6 and ~ 25.7%, respectively being over I_1 during both the years of experimentation. A significantly higher grain (5.12 and 5.08 t/ha) and straw yield (6.83 and 6.86 t/ha) was noted with N_6 treatment. The highest HI (42.9 and 43.2) and grain: straw ratio (0.75 and 0.76) were noted under control during 2021–22 and 2022–23, respectively. N_5 had the highest NPK uptake and RE_N, being significantly ~ 2.6, ~ 22.6%, respectively superior over N_3. PFP_N (34.1 and 33.9 kg/kg) and AE_N (18.8 and 18.9 kg/kg) was higher in N_6 but physiological efficiency (PE_N) was higher with N_3 in 1st and N_2 in 2nd year.

***Key words*:** Agronomic efficiency, Harvest index, NPK consortia, Poultry manure and Yield

Wheat ranks as second most important cereal crop and playing a pivotal role for food and nutritional security of India. It accounts 14% area (31.1 mha) and 13% production (109.8 mt) of globe. However, its productivity is frequently constrained by various environmental factors, such as moisture availability and nutrient deficiencies, which significantly impact yield potential and nutrient uptake efficiency. In recent years, as the challenges of climate change loom larger and agricultural resources face mounting pressure, understanding the interplay between moisture regimes and nutrient management has become imperative for sustainable wheat production. Despite being cultivated under enhanced production practices the factor productivity of water and fertilizers has decreased over the years (Hasanain *et al*., 2021). Precision water management has a viable option to improve crop yield and resource use efficiency (Rajanna *et al*., 2018). Utilizing water resources optimally for irrigation endeavours to maximize crop production benefits. Providing water based on the Irrigation Water: Crop Water Productivity ratio proves more advantageous than alternative criteria, resulting in improved crop yields and water utilization efficiency. In recent times, there has been an excessive application of chemical fertilizers, particularly nitrogen fertilizers, in intensive farming regions of developing nations (Zhang *et al.,* 2012). The accumulative use of synthetic fertilizers has undoubtedly resulted as a remarkable surge in the food production but prolonged cultivation of crops using chemical fertilizers

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alone have caused decline in soil fertility and overall soil health. Optimum nutrient dose and their source significantly contribute to increasing wheat crop productivity. Integrated nutrient management practices aim to minimize nutrient losses due to leaching, runoff, volatilization, emissions and immobilization, thereby enhancing nutrient-use efficiency (Zhang *et al.,* 2012). Moreover, it intent to enhance soil physical, chemical, biological and hydrological properties, with the goal of increasing crop productivity and alleviating land degradation (Esilaba *et al.,* 2004). There is growing recognition that integrated nutrient management can enhance crop productivity while also effectively conserving soil resources. Hence, utilizing a blend of organic, inorganic and biological sources for plant nutrients could offer a favourable strategy for sustaining crop productivity while, concurrently enhancing both nutrient utilization efficiency and soil fertility (Haque and Ali, 2020). As a result, the present research was devised and executed to examine the impact of different moisture regimes and integrated nutrient management modules on the yield, nutrient uptake and efficiency of wheat.

MATERIALS AND METHODS

The field study was carried out during *rabi* seasons of 2021–22 and 2022–23 at Crop Research Centre, SVPUA&T, Meerut, Uttar Pradesh. The study soil was sandy loam with slight alkaline *p*H (7.83) and EC (0.33 dS/m). Soil exhibited low levels of OC (0.34 %) and available N (203.3 kg/ha) while, available P (20.8 kg/ha) and K (223.0 kg/ha) in medium level. The experiment was arranged in split-plot design having 18 treatment combinations with 3 replications. The main plot included 3 moisture regimes*,* viz. I_1, irrigation at 0.7 IW/CPE ratio; I_2, irrigation at 0.9 IW/CPE ratio and I_3, 5-irrigations at critical stages (Crown root initiation, Late tillering, Late Jointing, Flowering and Milking stage). Six INM modules, viz. N_1, control; N_2, 100% RDF (150 : 75 : 60 kg NPK/ha); N_3, 125% RDF; N_4, 50% RDF + PM @ 2.5 t/ha; N_5, 50% RDF + PM 2.5 @ t/ha + *Azotobacter* + PSB + KMB; N_6, 50% RDF + PM @ 2.5 t/ha+ NPK consortia were consisted in sub plots. In experimental field, PM @ 2.5 t/ha (on dry weight basis) was applied as per the treatments by spreading uniformly in the plots and thoroughly mixing up to top 15 cm soil depth, before one week of sowing. The chemical composition of the poultry manure was 2.97, 2.54, 1.37 and 39.5% NPK and OC, respectively. The recommended amount of N, P and K were supplied through urea, NPK mixture, and muriate of potash, respectively. The full dose P, K along with half dose of total N was applied as basal during sowing and remaining half amount of N was top dressed in two equal splits, at the time of first irrigation and flowing stage during experimentation. The wheat seeds inoculated with *Azotobacter chroococcum*, PSB (*Pseudomonas fluorescens*), KMB (*Bacillus*) and NPK consortia (*Rhizobium, Azotobacter, Acetobacter*, *Pseudomonas* and *Bacillus*) each @ 20 ml/kg seed as per treatments before sowing. Other agronomic operations were conducted following the standard package of practices for wheat cultivation, with the exception of irrigation. The irrigation water was applied up to 7 cm depth, as per treatment as in I_1 (0.7 IW/CPE ratio) when cumulative pan evaporation reading was reached at 100 mm and in the I_2 (0.9 IW/CPE ratio) when cumulative pan evaporation reaches at 77.8 mm, while in I_3, irrigation water was applied at five critical stages *i.e*., crown root initiation, late tillering, late jointing, flowering and milking stages. The entire biomass from each designated plot area was collected and subsequently processed using a Pullman thresher following sun drying. The harvested grains were cleaned and sun-dried for a period of 4 to 5 days. Subsequently, the moisture content was adjusted to 14% and then the grains were weighed. The final yield was explicated in tons per hectare (t/ha). The straw yield of wheat was calculated by deducting the grain yield from each net plot from the biological yield. This was then expressed in tons per hectare (t/ha). Whereas, harvest index (HI) was calculated by dividing the grain yield by the total biomass yield and then expressed as a percentage.

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

Nitrogen (N) content was analysed using the modified Kjeldahl method, while phosphorus (P) content was determined through the vanadomolybdophosphoric acid yellow colour method with a wavelength of 420 nm on a UV-VIS spectrophotometer, and potassium (K) content was measured via flame photometry. The uptake of N, P, and K was computed using the provided formula:

N, P and K uptake (kg/ha) in grain/straw = [% N/P/K in grain/straw × grain/straw yield (kg/ha)/100]

The partial factor productivity (PFP) of N (kg grain yield/kg N applied)**,** agronomic efficiency (AE) of N (kg grain yield increase/kg N applied), physiological efficiency of N (PE_N) (kg biological yield increase/kg N uptake increase) and recovery efficiency (RE) (Dobermann, 2007) were worked out as:

Partial factor productivity = Y/N; Agronomic efficiency = $(Y_N-Y_0)/N$; Physiological efficiency = $(Y_N-Y_0)/U_N-U_0$; Recovery efficiency = $[(U_N- U_0)/N] \times 100$

Where, Y, Grain yield (kg/ha); Y_N, Grain yield (kg/ha) with N; Y_0, Grain yield (kg/ha) without N; U_N, N uptake (kg/ha) with N; U_0, N uptake (kg/ha) without N; N, Amount of nitrogen applied (kg/ha)

The data recorded for various parameters over the two experimental years underwent statistical analysis using the analysis of variance (ANOVA) technique for a split-plot design, employing the F-test. The results were presented at a significance level of 5% ($p \leq 0.05$).

RESULTS AND DISCUSSION

Yield and yield parameters

In current study, yield of grain and straw in wheat were significantly influenced however, harvest index and grain: straw ratio did not differ by various moisture regimes (Table 1). A noticeably higher grain (4.89 and 4.84 t/ha) and straw yield (6.51 and 6.45 t/ha) were recorded ($p \leq 0.05$) with I_3 which was statistically *on par* with I_2 and significantly superior over I_1 during study. The magnitude of increasing grain yield under I_3 had 14.8 and 8.7 and 15.8 and 8.0% higher over I_1 and I_2 during first and second year, respectively. The highest harvest index (42.8 and 42.9) and grain: straw ratio (0.75 and 0.74) was noted with I_3 followed by I_1 and I_2 during course of study. A higher yield of grain and straw when irrigation is applied at critical stages may be due to improved photosynthetic translocation towards the sink from the source, as well as from the generation of higher growth and yield-related characteristics that prevent moisture stress when the crop reaches maturity (Idnani *et al*., 2013 Goswami *et al.,* 2020). Critical irrigation stages coincide with key growth phases that significantly contribute to final yield determination, such as grain filling in cereal crops like wheat. Higher yield potential during these stages often corresponds to increased nutrient requirements by the plant to support grain development and fill. Therefore, ensuring adequate water availability through irrigation is crucial for meeting the plant's heightened nutrient demands during these critical stages (Kumar *et al*., 2020). The reduced grain and straw yield in the second year compared to the first year may be caused by a comparatively higher rate of evaporation between 50% of the blooming and active grain development period (5.0 and 4.1 mm/day, respectively), which in turn slowed down the overall crop's growth and development (Rajanna *et al*., 2018). Yield of grain and straw in wheat were significantly affected by different INM modules, however, harvest index and grain: straw ratio did not differ significantly (Table 1). The highest grain 5.12 t/ha (2021–22) and 5.08 t/ha (2022–23) t/ha and straw yield 6.83 t/ha (2021–22) and 6.86 t/ha (2022–23) was noted with N_6, which was statistically *on par* with N_2, N_3, N_4 and N_5, while being significantly higher over N_1 during study. The highest value of harvest index (42.9 and 43.2%) and grain: straw ratio varied between (0.75 and 0.76) were seen with N_1 than remaining other INM options during experimentation. The improvement in the yield might be caused to the combined use of biofertilizers and poultry manure over and above 50% chemical fertilizer supplied the nutrient particularly N at initial stages of crop growth, whereas the poultry manures show beneficial effect after their proper decomposition and

Table 1. Effect of various moisture regimes and INM modules on yield, harvest index and grain: straw ratio of wheat

Treatment	Yield (t/ha)				Harvest index (%)		Grain: Straw ratio	
	Grain		Straw					
	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23
Moisture regimes								
I_1	4.26	4.18	5.78	5.72	42.7	42.4	0.75	0.74
I_2	4.50	4.48	6.15	6.10	42.3	42.4	0.73	0.74
I_3	4.89	4.84	6.51	6.45	42.8	42.9	0.75	0.75
SEm±	0.09	0.09	0.13	0.13	0.03	0.08	0.008	0.016
CD (P=0.05)	0.41	0.38	0.59	0.57	NS	NS	NS	NS
INM modules								
N_1	2.30	2.25	3.09	2.96	42.9	43.2	0.75	0.76
N_2	4.84	4.77	6.53	6.46	42.6	42.5	0.74	0.74
N_3	5.04	5.01	7.00	6.83	41.9	42.3	0.72	0.73
N_4	4.90	4.88	6.58	6.60	42.7	42.4	0.74	0.73
N_5	5.08	5.03	6.83	6.83	42.7	42.4	0.75	0.74
N_6	5.12	5.08	6.85	6.86	42.8	42.6	0.75	0.74
SEm±	0.11	0.11	0.15	0.13	0.08	0.08	0.023	0.024
CD (P=0.05)	0.32	0.33	0.43	0.38	NS	NS	NS	NS

I_1: irrigation at 0.7 IW/CPE ratio, I_2: irrigation at 0.9 IW/CPE and I_3: five irrigations at critical stages (Crown root initiation, Late tillering, Late Jointing, Flowering and Milking stage) and six INM modules, viz. N_1: control, N_2: 100% RDF (150:75:60 NPK/ha), N_3: 125% RDF, N_4: 50% RDF+ PM @ 2.5 t/ha, N_5: 50% RDF+PM 2.5 @ t/ha+ *Azotobacter* + PSB+KMB, N_6: 50% RDF+PM @ 2.5 t/ha+ NPK Consortia.

mineralization, its supplied available nutrients directly to the plant at later stages through slow and steady release of nutrients and biofertilizers increasing the availability of nutrients near the plant root zone (Fazily *et al.*, 2021). It is easy to absorb nutrients which increased the photosynthetic activities and translocation of photosynthates from source to sink in reproductive stages of the crop. it also enhanced the organic matter and water retention capacity of soil throughout the entire growth period, thereby promoting in better root growth, leaf area expansion and photosynthesis, ultimately greater plant growth and development, reflected from higher values of yield attributing characters of wheat (Yadav *et al.*, 2017).

Nutrient Uptake

The nutrient uptake (NPK) of wheat was significantly influenced by various moisture regimes and INM modules (Fig. 1a, 1b, 2a, 2b, 3a, 3b)). The results showed that, among the various moisture regimes, the nitrogen uptake of grains (94.1 and 94.7 kg/ha) and straw (29.2 and 29.9 kg/ha) was significantly higher with I_3 irrigation option which was significantly higher over I_1 and I_2 moisture regimes during first and second year, respectively (fig.1a). Similarly, a significantly greater uptake of phosphorus (P) and potassium (K) in both grains and straw was observed under moisture regime I_3 being higher ~ 16.3, ~ 14.9, ~ 17.0 ~ 14.6%, respectively compared to I_1 which was statistically *on par* with I_2 in study of both years (Fig. 2a and 3a). This could be ascribed to the sufficient moisture supply during reproductive phase of plant growth, which enhances the availability of nutrients in the soil solution. This, in turn, promotes their absorption by the plant roots and facilitates their translocation to the site of action, ultimately

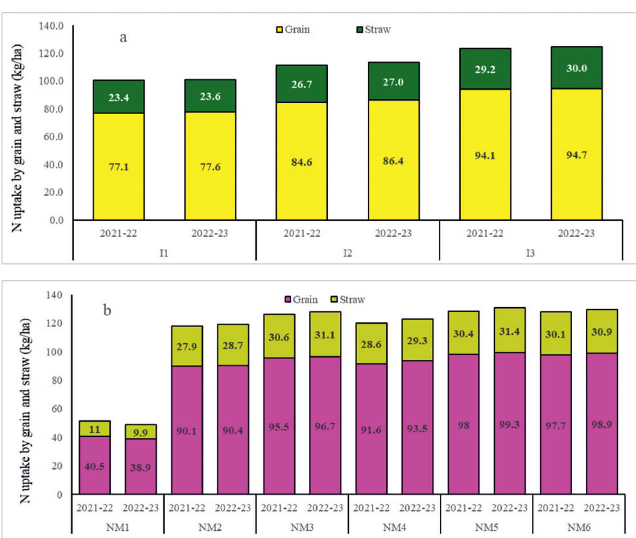

Fig. 1a. N uptake in grain and straw influenced due to MR and 1b. N uptake in grain and straw influenced due to INM

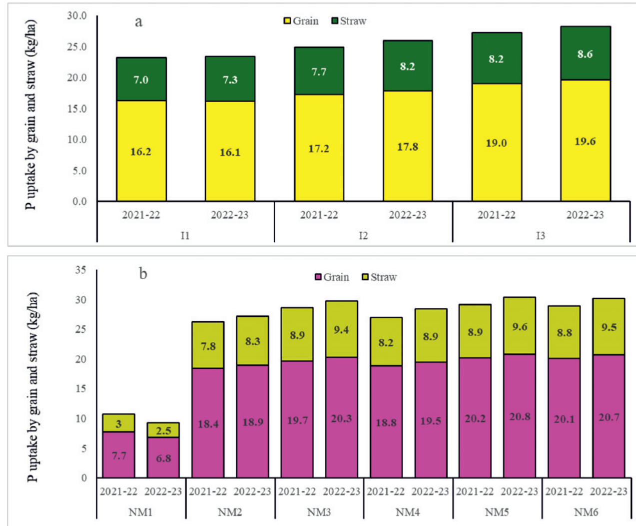

Fig. 2a. P uptake in grain and straw influenced due to MR and 2b. P uptake in grain and straw influenced due to INM

resulting in the highest yield and nutrient uptake. Optimal soil moisture levels promote root growth and activity, which in turn enhances the plant's capacity to extract the nutrients from the soil. Conversely, well-timed irrigation can stimulate root growth and increase the surface area available for nutrient absorption, facilitating greater nutrient uptake by the plant (Kumar *et al.*, 2020). In the various INM modules N, P, and K uptake in grains and straw being highest under N_5 (98.7, 30.9, 20.5, 9.3, 23.1 and 113.4 kg/ha, respectively) fallowed by N_3, N_4 and N_6 treatment however, significantly superior over than remain treatment during experimentation, except potassium accumulation in straw during first year, it was significantly higher with N_3 than N_1 and N_2 (fig. 1b, 2b and 3b). Results further indicated that the super optimal dose and combined use of PM @ 2.5 t/ha and biological sources over and above 50 % RDF were recorded statistically alike to each other during both the years (fig. 1b, 2b and 3b). This increase was concerned through integrated use of chemical fertilizers, organic manure and biofertilizers enhance the root growth and balanced nutrition which resulted greater water and nutrient absorption through the wheat (Chhetri and Sinha, 2020). INM has ensures a balanced and adequate supply of essential nutrients during the crop growth stages, meeting the specific requirements of wheat crop. The availability of nutrients in the suitable proportion and right time promotes optimal crop growth, development, and ultimately, higher yield (Kakraliya *et al.,* 2017).

Nitrogen use efficiency

Nitrogen use efficiency in terms of PFP, AE, PE, and RE were influenced significantly due to various moisture regimes and INM modules during study (Table 2). The PFP_N,

Table 2. Effect of various moisture regimes and integrated nutrient management practices on PFP, AE, PE and RE of wheat

Treatment	PFP (kg grain yield/kg nitrogen applied)		AE (kg grain yield increase/kg nitrogen applied)		PE (kg yield increase/kg nitrogen uptake)		RE (%)	
	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23	2021–22	2022–23
Moisture regimes								
I_1	24.9	24.4	13.4	12.4	83.6	77.9	32.7	34.9
I_2	26.3	26.4	14.1	14.7	72.0	66.6	38.7	44.1
I_3	28.7	28.5	15.6	16.1	66.4	67.7	44.8	46.3
SEm±	0.6	0.5	0.4	0.4	2.3	1.6	1.2	1.4
CD (P=0.05)	2.6	2.2	1.6	1.9	10.5	7.4	5.5	6.1
INM modules								
N_1	-	-	-	-	-	-	-	-
N_2	32.2	31.9	16.9	16.8	90.0	87.2	44.5	50.6
N_3	26.9	26.7	14.6	14.7	90.6	84.6	39.7	42.2
N_4	32.7	32.5	17.3	17.5	89.6	87.1	46.1	49.3
N_5	33.9	33.5	18.5	18.5	86.0	81.8	51.3	54.6
N_6	34.1	33.9	18.8	18.9	87.9	83.8	50.9	54.0
SEm±	0.7	0.7	0.7	0.7	2.2	2.0	1.9	2.2
CD (P=0.05)	2.1	2.1	2.1	2.2	6.2	5.7	5.3	6.3

I_1: irrigation at 0.7 IW/CPE ratio, I_2: irrigation at 0.9 IW/CPE and I_3: five irrigations at critical stages (Crown root initiation, Late tillering, Late Jointing, Flowering and Milking stage) and six INM modules, viz. N_1: control, N_2: 100% RDF (150:75:60 NPK/ha), N_3: 125% RDF, N_4: 50% RDF+ PM @ 2.5 t/ha, N_5: 50% RDF+PM 2.5 @ t/ha+ *Azotobacter* + PSB+KMB, N_6: 50% RDF+PM @ 2.5 t/ha+ NPK Consortia.

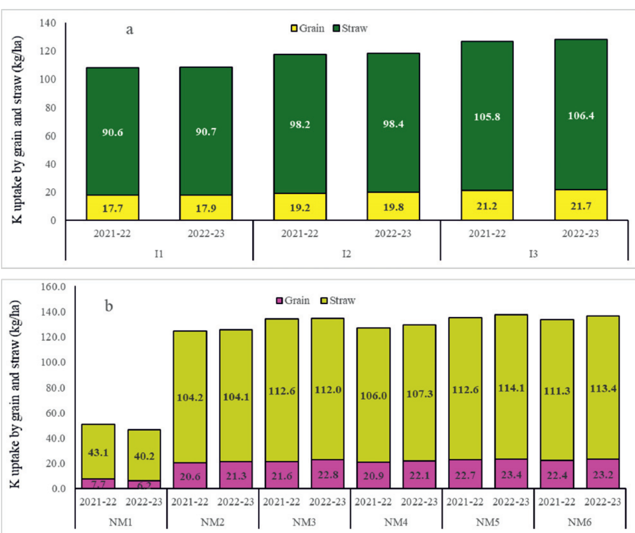

Fig. 3a. K uptake in grain and straw influenced due to MR and 3b. K uptake in grain and straw influenced due to INM

I_1, irrigation at 0.7 IW/CPE ratio; I_2: irrigation at 0.9 IW/CPE and I_3: five irrigations at critical stages (Crown root initiation, Late tillering, Late Jointing, Flowering and Milking stage) and six INM modules, viz. N_1: control, N_2: 100% RDF (150:75:60 NPK/ha), N_3: 125% RDF, N_4: 50% RDF+ PM @ 2.5 t/ha, N_5: 50% RDF+PM 2.5 @ t/ha+ *Azotobacter* + PSB+KMB, N_6: 50% RDF+PM @ 2.5 t/ha+ NPK Consortia.

was significantly higher with I_3 (28.7 and 28.5 kg grain yield/kg N applied), and significantly ~ 13.8% higher over I_1 but did not differ significantly over I_2 during course of study. Likewise, the AE_N (15.6 and 16.1 kg grain yield increase kg N applied) and RE_N (44.8 and 46.3 %) were noted significantly higher with I_3, which was significantly superior over I_1 but did not differ significantly over I_2 during both the years (Table 2). Similarly, PE_N was significantly higher with I_1 (83.6 and 77.9 kg grain yield increase/kg N uptake), which was significantly superior over I_2 and I_3 during both the year of study (Table 2). This may be the result of sufficient moisture supplies increasing crop availability and solubility of nutrients (Kumar *et al*., 2020). Among the INM practices, the PFP_N (34.1 and 33.9 kg grain yield/kg N applied) and AE_N (18.8 and 18.9 kg grain yield increase/kg N applied) was significantly higher with N_6 and significantly superior over N_3 but *on par* with N_5, N_4 and N_2 treatment during study (Table 2). The PE_N was significantly higher with N_3 in first year and N_2 in second year. The RE_N was significantly maximum under N_5, which was significantly higher over N_3, while, remain treatments did not influence significantly during study (Table 2). This might be result of integrated use of manures and biofertilizers along with sub-optimal dose of RDF produce more biomass and nutrient uptake in grains and straw of wheat (Limon *et al*., 2000). PFP, AE and RE decreased significantly with increased fertilizers level. By combining use of nutrient from organic and inorganic sources, INM maximizes the nutrient use efficiency of wheat crop. Organic sources gradually release nutrients, thus decreasing the likelihood of nutrient leaching and runoff. This balanced approach minimizes nutrient losses and ensures that wheat crop have access to nutrients when they are most needed, resulting in enhance nitrogen use efficiency (Kakraliya *et al.,* 2017).

The outcomes of the present study highlight a promising approach to enhance wheat production through a combination of strategic irrigation, specific nutrient application, and organic matter incorporation. Result from the present study clearly exhibit that higher yield, nutrient uptake and nutrient use efficiency of wheat can be achieved by the integration of irrigation applied at critical stages along with application of 50% RDF + poultry manure @ 2.5 t/ha + NPK consortia.

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