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Nutrient use efficiency and growth analysis of wheat crop under precision nitrogen management techniques and growth regulators application

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Abstract

Nitrogen occupies a significant position in plant metabolism as an essential component of proteins, which are associated with all vital and metabolic processes in the plant system. Nitrogen fertilization in wheat is more complex, and the results are more flexible than in any other field crop. The objective of this study was to determine how nitrogen dose variation interacts with growth regulators and their impact on crop lodging and the yield of wheat. The experiment was conducted during the Rabi season 2019-20 to assess these effects, involving various treatment combinations of different nitrogen doses, use of growth regulators, including precision nitrogen management using leaf color charts, GreenSeeker, and decision-support tools such as Nutrient Expert. The results showed that precision nitrogen management techniques resulted in higher harvest index and nitrogen use efficiency compared to other treatments. Balanced supply of major nutrients, viz., N, P, and K, led to better nutrient uptake compared to treatments where only nitrogenous fertilizer was applied. The use of growth regulators increased the total number of days to achieve physiological maturity, thereby increasing values of growing degree days and heliothermal units. Therefore, it is suggested that nitrogenous fertilizer alone should not be applied in wheat crops to avoid soil nutrient imbalance and potential toxicity disruptions in the food cycle.

Keywords: Chlormequat chloride, Growth regulators, Nitrogen, Nutrient expert, Nutrient use efficiency, Precision nutrient management, Tebuconazole.

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Contents

Contribution of this paper to the literature
This study contributes to the existing literature on the application of nitrogen, along with growth regulators and precision nutrient management. It demonstrates the relevance of balanced nutrients, especially nitrogen application in crops. Although the integrated use of growth regulators can also help achieve higher yield targets and improve soil nutrient status.

1. Introduction

Wheat (*Triticum aestivum L.*) is a universal staple food for 40% of the human population in the world and is the second most important cereal after rice [1]. The massive importance of wheat can be understood from the figures of a grown area of 215.48 Mha, with an annual production of 731.46 Mt and a productivity of 33.9 q/ha during 2018-19 worldwide [2]. In India, a significant portion of total cultivation is devoted to this crop, covering nearly 29.14 million hectares with an annual production of 102.19 million tonnes, carrying an average productivity of 3,506.8 kg/ha in the year 2018-19 [3] but Unfortunately, the productivity of Bihar and Uttar Pradesh is 44% and 34%, respectively, which is less than the productivity of Punjab [4]. On a deeper level, these yield gaps can be somewhat related to the nutrient ($N+P_2O_5+K_2O$) consumption per unit of gross cropped area in each individual state.

Nitrogen is an indispensable protein component required in all dynamic processes of plants. Excessive N causes "luxuriant" growth, resulting in the plant being attractive to insects and diseases. The excessive growth can also reduce the strength of stems, which induces lodging at the time of flowering and grain filling. Therefore, deciding the optimum dose of nitrogen for crops is a matter of great concern for better yield. On one hand, high-yielding varieties require more inputs like nitrogenous fertilizers for their better performance, but on the other hand, more nitrogen application causes problems like lodging, which reduces their yield [5]. Therefore, it becomes quite important to know whether nitrogen management could reduce lodging risk without reducing the yield potential [6]. Plant growth regulators are chemical substances that can alter growth and developmental processes, helping to increase yield, improve grain quality, or facilitate harvesting [7]. The chemicals used are most commonly gibberellin inhibitors that block the early stages of gibberellin synthesis, thereby inhibiting cell elongation and growth, which results in shorter, lodging-tolerant plants. Some examples include Chlormequat chloride, Trinexapac-ethyl, Ethephon, Peclobutrazol, etc.

The blanket recommendations of nitrogenous fertilizers for larger areas have helped to serve the purpose of producing optimum yield, but these recommendations are not always helpful in increasing N use efficiency beyond a certain limit [8]. In general, nitrogen use efficiency (NUE) or recovery is only 30-50%. The concept of Site-Specific Nutrient Management can help to improve production per unit of nutrient supply. Site-Specific Nutrient Management is a method to adjust soil nutrient supply over time and space to match the crop's requirements through four key principles: Right Rate, Right Product, Right Time, and Right Place. Many instruments, *viz.* LCC (Leaf Colour Chart), optical sensors, and decision support systems like Nutrient Expert can be used for this purpose [9].

2. Materials and Methods

The Centre N. E. Borlaug Crop Research Centre of Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, is situated at 29°N latitude and 79.50°E longitude, at an elevation of 243.8 meters above mean sea level. The climate of the region is subtropical, with winters that are extremely cold, and the average temperature ranges from 4°C to 35.4°C. The soil at the experimental site is silty clay loam with a neutral pH of 7.4. It contains medium organic carbon content (0.73%), low available nitrogen (217.16 kg/ha), medium available phosphorus (21.4 kg/ha), and potassium (139.1 kg/ha) (Figure 1).

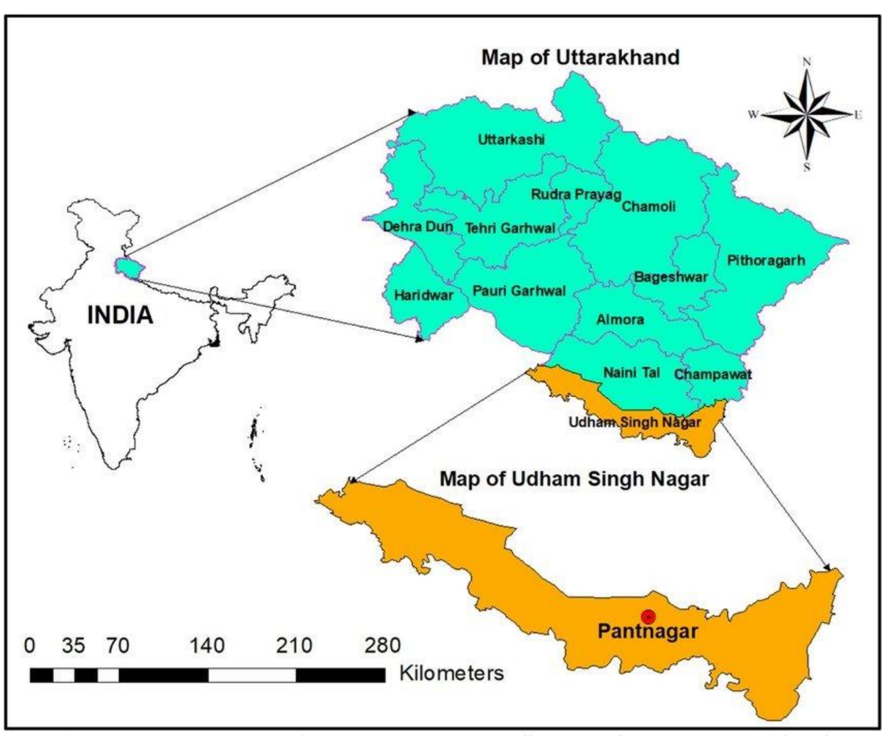

Figure 1. Location map of Pantnagar, District Udham Singh Nagar, Uttarakhand.

The experiment was laid out in a randomized block design with 13 treatments and 3 replications. The treatments included an absolute control, 50% N (recommended dose of N) (75 kg N/ha), 75% N (112.5 kg N/ha), 100% N (150 kg N/ha), 125% N (187.5 kg N/ha), 150% N (225 kg N/ha), 100% RDF (150:60:40 kg N P_2O_5 K_2O / ha). Three treatments involved growth regulator spray with Chlormequat chloride (Lihocin) @ 0.2% of the commercial product dose and tebuconazole (Folicur 430 SC) @ 0.1% of the commercial product at the first node and boot leaf stage, along with application of 125% N, 150% N, and 150% RDF in respective treatments. Additionally, three precision nutrient management treatments were included. N management by LCC (Apply 45kg N/ha if LCC<4 and 35kg N/ha if LCC≥ 4) (135 kg N/ha), N management by green seeker (116.5 Kg N/ha) and N management by Nutrient Expert (125: 71: 89 Kg N P_2O_5 K_2O / ha). N was applied in 3 split doses (1/3rd basal + 1/3rd at 1st irrigation + 1/3rd at 2nd irrigation) in only N-containing treatments. Full dose of P and K and 1/3rd of N was applied at the time of sowing, and the remaining 2/3rd of N was applied as 1/3rd at first irrigation and 1/3rd at second irrigation. In LCC-based N management, a full dose of P, K, and 1/3rd N was applied as basal, and 1/3rd N at the time of the first irrigation. The readings of LCC were taken at the time of the second irrigation, and 35 kg N/ha was applied as the LCC reading was 4. Similarly, in Green Seeker-based N management treatment, 1/3rd N and full P and K were applied as basal, and 1/3rd at the time of the first irrigation. The remaining N was applied based on Green Seeker NDVI readings taken at the time of the third irrigation. In the case of Nutrient Expert-based N management, the fertilizer doses were determined through the SSNM Nutrient Expert software with a yield target of 8 t/ha.

Wheat variety WH 1105 was sown at a row spacing of 20 cm on 14th November 2019. Other management practices, including irrigation, weeding, and hoeing, were adopted as per the package of practices for the wheat crop.

Crop growth rate and relative growth rate during different time intervals were calculated using the following formula [10].

$$\text{CGR} = \frac{W2 - \text{W1}}{T2 - T1}$$

Where,
W2 = dry weight of plant/m^2 recorded at time T2.
W1 = dry weight of plant/m^2 recorded at time T1.

$$\text{RGR} = = \frac{lnW2 - \text{lnW1}}{T2 - T1}$$

Where,
ln = Natural log.
W2 = dry weight of plant/m^2 recorded at time T2.
W1 = dry weight of plant/m^2 recorded at time T1.

The collected grain and straw samples, after harvest, were oven-dried at 70 ± 1 °C for 72 hours and ground to estimate the nitrogen content (%) in the samples, which was then converted to kg/ha.

$$\text{Nitrogen uptake by grain (kg/ha)} = \frac{\text{Nitrogen conc.in grain (\%)} \times \text{Grain yield (kg/ha)}}{100}$$

$$\text{Nitrogen uptake by straw (kg/ha)} = \frac{\text{Nitrogen conc.in straw (\%)} \times \text{Straw yield (kg/ha)}}{100}$$

Total nitrogen uptake (kg/ha) = Nitrogen uptake by grain + Nitrogen uptake by straw

Plant samples were analyzed for phosphorus concentration (%) in grain and straw. Plant samples were dried in a dryer at 70 ± 1°C for 72 hours and followed by wet digestion using the vanado-molybdo-phosphoric acid yellow color method [11]. The total phosphorus uptake was calculated as described below.

$$\text{Phosphorus uptake by grain (kg/ha)} = \frac{\text{Phosphorus conc.in grain (\%)} \times \text{Grain yield (kg/ha)}}{100}$$

$$\text{Phosphorus uptake by straw (kg/ha)} = \frac{\text{Phosphorus conc.in straw (\%)} \times \text{Straw yield (kg/ha)}}{100}$$

Total Phosphorus uptake (kg/ha) = Phosphorus uptake by grain + Phosphorus uptake by straw.

Plant samples were analyzed for potassium concentration (%) with the help of a flame photometer, and the total potassium uptake by grain and straw was calculated separately. Total potassium uptake (kg/ha) was determined as follows.

$$\text{Potassium uptake by grain(kg/ha)} = \frac{\text{Potassium conc.in grain (\%)} \times \text{Grain yield (kg/ha)}}{100}$$

$$\text{Potassium uptake by straw (kg/ha)} = \frac{\text{Potassium conc.in straw (\%)} \times \text{Straw yield (kg/ha)}}{100}$$

Total Potassium uptake = Phosphorus uptake by grain + Phosphorus uptake by straw.

Partial factor productivity and Agronomic efficiency of N were calculated by formula [12].

$$\text{Partial factor productivity (kg/kg N)} = \frac{Grainyield\ (kg/ha)}{amountofnutrientapplied\ (kg/ha)}$$

$$\text{Agronomic efficiency (\%)} = \frac{Y_N - Y_0}{N} \times 100$$

Where,
Y_N = Crop yield (kg/ha) with applied nutrient.
Y_0= Crop yield (kg/ha) without nutrients.
N = Amount of nutrient applied (kg/ha).

Weekly weather observations were recorded at the meteorological observatory situated at the research centre, and growing degree days and heliothermal units were calculated using the following formula [13].

$$\text{GDD (°C days)} = \Sigma \frac{\text{T max} + \text{T min}}{2} - \text{base temp.}$$

The base temperature for wheat was taken as 5 °C.

$$\text{HTU} = \Sigma \left[\text{GDD X bright (Actual) sunshine hrs} \right]$$

Observations on different growth and yield parameters were taken, and the data were statistically analyzed with the help of the statistical program OPSTAT.

3. Results and Discussion

3.1. Crop Growth Rate (g/m²/ Day)

Different treatments had shown no significant effect on CGR values during 90-120 DAS, while a significant effect was reported during the early stages of the crop (Figure 2). CGR increased slowly at early stages of growth and reached the peak at booting to heading stage; thereafter, it declined. The mean value of CGR was lowest in the absolute control during 30-60 DAS, while achieving the highest value in 100% RDF and 125% N during 60-90 DAS. These results are in accordance with the results obtained by Sugár et al. [14]. This was due to the maximum production of dry matter at vegetative stages and indicates that dry matter production increases throughout the life cycle, but at a slow rate in later stages. Crop growth rate (CGR) is an index of agricultural productivity of land in terms of the plant biomass produced per unit area. It represents the net result of photosynthesis, respiration, and canopy area interception [15].

3.2. Relative Growth Rate (g/g/Day)

Relative growth rate (RGR) is used to express growth in terms of the rate of increase in size per unit of size. There was no significant effect of nitrogen doses on RGR values during 90-120 DAS, but a significant effect was observed during the initial stages until 90 DAS (Figure 3). The values of RGR were maximum during 60- 90 DAS, and after that, RGR values declined. Sugár et al. [14] reported similar results. The observed decline in RGR with increasing size is accompanied by systematic changes in physiology, morphology, and allocation [16] often referred to as ontogenetic drift. The RGR values at later stages decrease for several reasons: non-photosynthetic biomass (roots and stems) increases, the top leaves of a plant begin to shade lower leaves, and soil nutrients can become limiting. As RGR is a total function of plant biomass change with time, it indicates that in later stages of plant growth, biomass increases but at a relatively slower rate compared to the initial period.

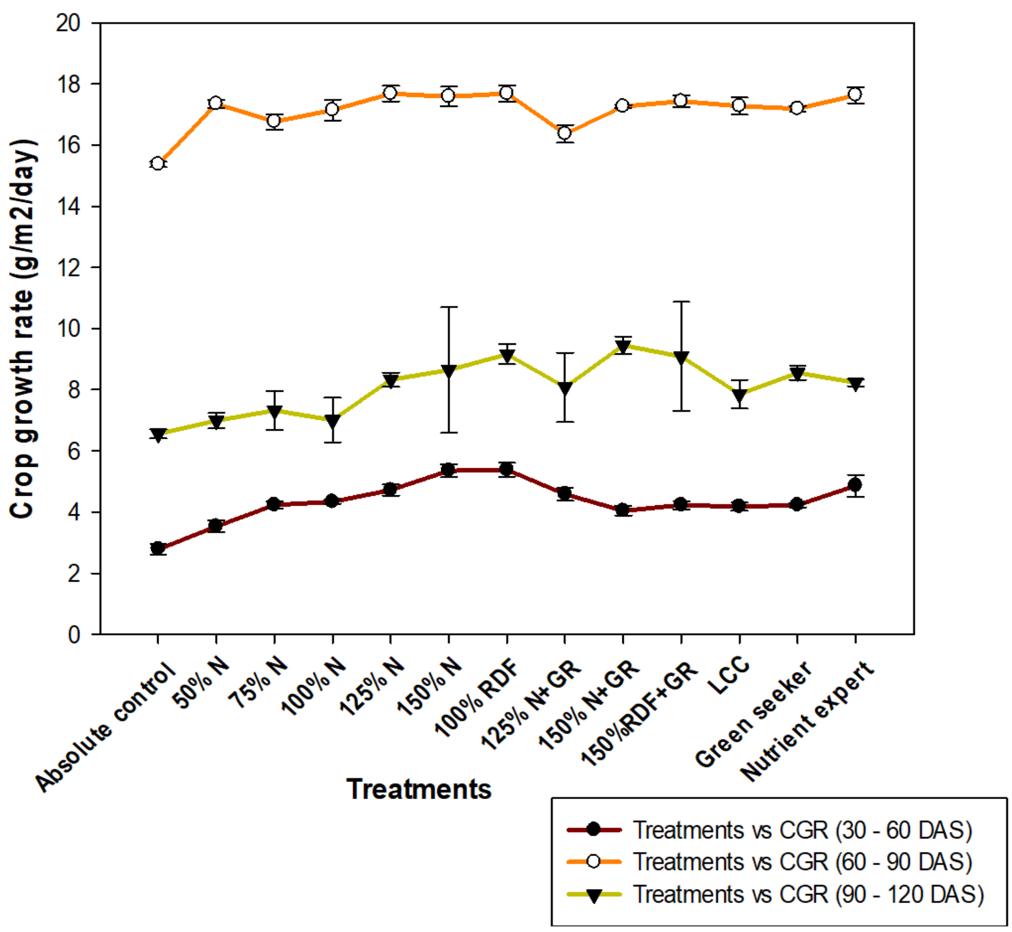

Figure 2. Effect of different treatments on Crop growth rate (g/m²/day) at different intervals.

3.3. Harvest Index (%)

There was no significant difference observed in harvest index due to different treatments (Figure 4). The maximum harvest index was recorded from Green Seeker-based N management, followed by the application of 50% N. While a minimum harvest index was observed from the application of 150% N. A Low harvest index means that there is less translocation of assimilates from the source to the sink, which results in less development of seeds. When the harvest index is high, it means that more assimilates were translocated from the source to the grains, which results in improved development and filling [17]. The more nitrogen present, the greater the vegetative growth and development, but only up to a certain limit. Beyond that limit, it can cause toxicity to the plant and have adverse effects on yield and yield parameters. Therefore, N doses exceeding 125% resulted in a low harvest index [18].

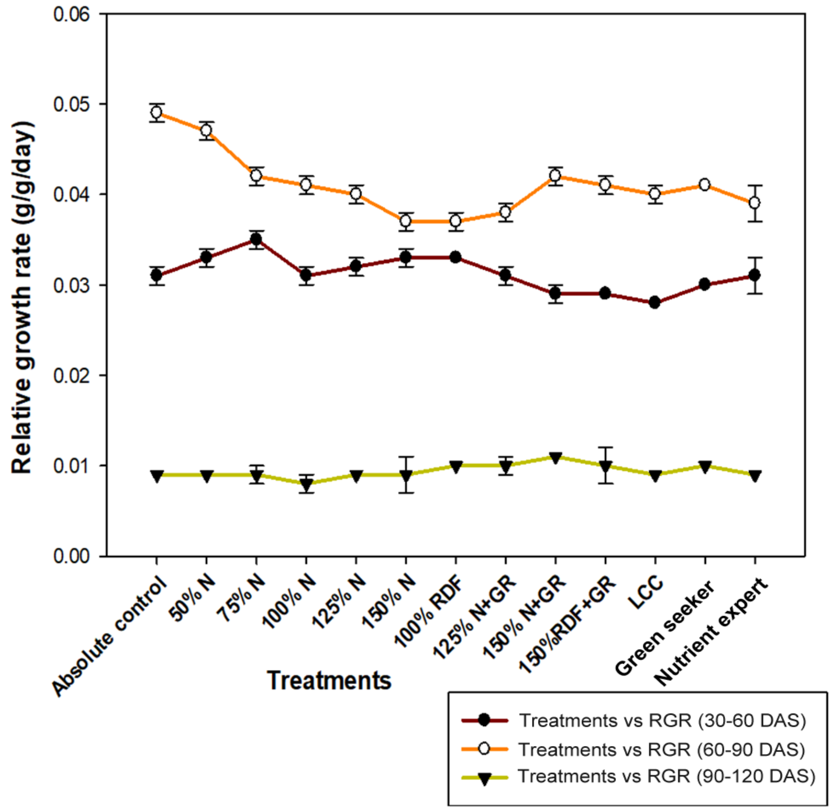

Figure 3. Effect of different treatments on the Relative growth rate (g/g/day).

3.4. Nitrogen Content (%) and Uptake in Grain and Straw

A gradual and significant increase in nitrogen content in grain and straw was observed with an increase in the dose of nitrogen (Table 1). N content in grain varies from 1.18% in the absolute control to 2.01% in 150% RDF + GR. This may be the effect of increased availability of nitrogen to the plants due to higher application amounts. As proper availability of K was present under 150% RDF, and K plays a very important role in the translocation of nutrients in the plants, therefore, N% in grain was higher in this treatment [19]. Similarly, maximum N content in straw was observed with the application of 125% N+GR and nutrient expert-based nitrogen management. The application of growth regulators has a positive impact on grain and straw nitrogen content. Under similar N application, treatments with growth regulator application showed higher values of grain and straw nitrogen content. Belete et al. [20] and Singh et al. [21] reported similar results. Nutrient Expert gave the best results among all precision nitrogen management practices. As nutrients were applied at the right dose and the right time with the help of a software system, the availability of nitrogen content was increased to the plants.

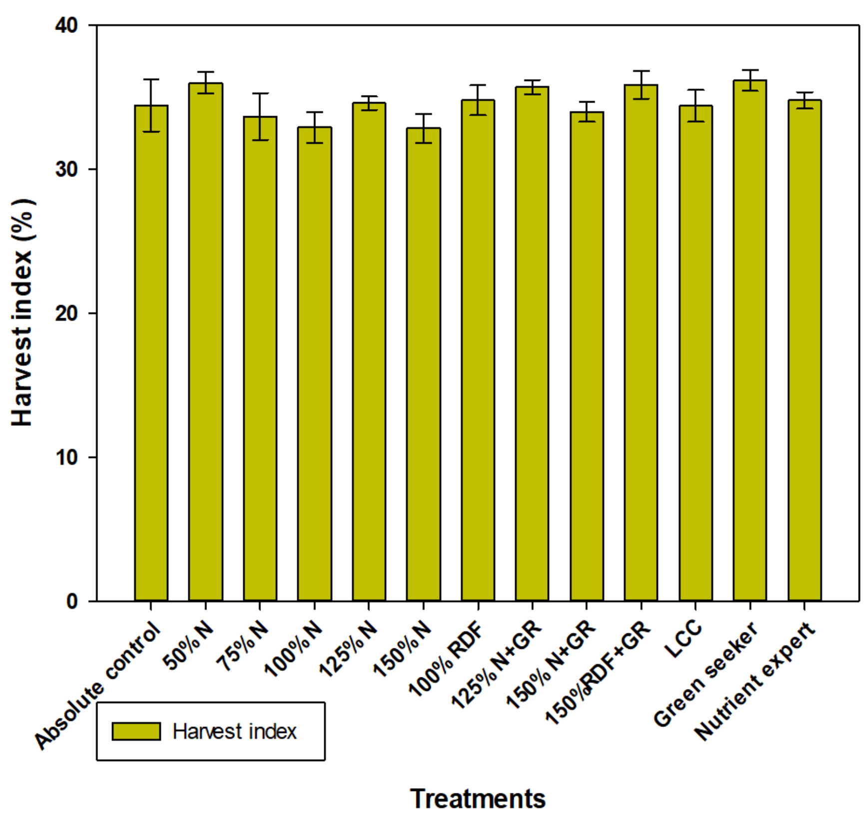

Figure 4. Effect of different treatments on Harvest index (%).

Significant effects of different nitrogen doses and plant growth regulators were observed in the uptake of nitrogen by the crop. N uptake in grain and straw was significantly increased with an increase in the dose of nitrogen. Maximum N uptake in grain was obtained from the application of 150% RDF + GR, followed by 100% RDF, while maximum N uptake in straw was recorded in Nitrogen management by Nutrient Expert. Eytoo [22] reported similar results. Total N uptake is directly related to the grain and straw yield obtained from the particular treatment and is found to be maximum with the application of 150% RDF + GR. The balanced supply of major nutrients, *viz.* N, P, and K might have resulted in better development of the active root system, which efficiently helps in better absorption of nutrients from the soil, producing higher biomass and nutrient concentration, resulting in higher nutrient uptake [20].

Table 1. Effect of different treatments on N content (%) and uptake in grain and straw.

Sr. No	Treatment	N content (%)		N uptake (kg/ha)		
		Grain	Straw	Grain	Straw	Total
1	Absolute control	1.18	0.30	28.9	13.9	42.8
2	50% N	1.20	0.38	51.8	29.3	81.1
3	75% N	1.37	0.40	62.9	36.9	99.8
4	100% N	1.77	0.44	82.9	42.3	125.2
5	125% N	1.86	0.46	92.2	43.2	135.4
6	150% N	1.87	0.41	87.2	39.2	126.4
7	100% RDF	1.99	0.49	102.5	47.3	149.9
8	125% N+GR	1.89	0.50	98.8	47.5	146.3
9	150% N+GR	1.90	0.42	93.2	40.3	140.2
10	150%RDF+GR	2.01	0.49	106.1	46.3	152.8
11	LCC	1.66	0.48	79.2	43.5	122.7
12	Green seeker	1.62	0.49	76.6	41.2	117.8
13	Nutrient expert	1.85	0.50	94.5	48.2	142.7
	SE(m) ±	0.04	0.01	2.9	2.1	4.2
	C.D. (P = 0.05)	0.11	0.03	8.6	6.1	12.4

3.5. Phosphorus Content (%) and Uptake in Grain and Straw

There was a significant difference observed in grain and straw P content due to different nitrogen doses (Table 2). The maximum value of grain P content was obtained with the application of 150% RDF + GR, followed by nutrient expert-based N management. However, P content in straw was maximum under both nutrient expert and 150% RDF + GR, followed by 100% RDF. The reason behind the higher P content in these two treatments may be the application of a higher amount of P, which has increased the availability of P to plants. N also plays an important role in the uptake of other nutrients. It encourages the uptake and utilization of other nutrients, including potassium and phosphorus, and controls the overall growth of the plant [23]. Treatments in which only N was applied without P and K showed a decrease in P content (%) in grain and straw with an increase in the dose of N. As no P was applied, the application of more N resulted in increased plant growth, and due to the dilution of available phosphorus, less content was observed.

Total P uptake in plants depends on P content (%) in grain and straw as well as grain and straw yield, and it was found to be maximum with the application of 150% RDF + GR. P uptake in grains ranged from 8.1 kg/ha in the absolute control to 26.3 kg/ha in 150% RDF + GR. P uptake in straw ranged from 6.3 kg/ha in the absolute control to 16.6 kg/ha in Nutrient Expert-based N management. The amount and timing of application of P in the above two treatments, *viz.* 150% RDF + GR and Nutrient Expert played an important role in increasing the availability and uptake of P by the crop.

Table 2. Effect of different treatments on P content (%) and uptake in grain and straw.

Sr. No.	Treatment	P content (%)		P uptake (kg/ha)		
		Grain	Straw	Grain	Straw	Total
1	Absolute control	0.33	0.13	8.1	6.3	14.3
2	50% N	0.32	0.13	13.8	9.7	23.5
3	75% N	0.32	0.12	14.7	11.2	26.0
4	100% N	0.31	0.11	14.6	10.3	24.9
5	125% N	0.31	0.11	15.2	10.0	25.3
6	150% N	0.30	0.10	14.0	9.5	23.5
7	100% RDF	0.45	0.16	23.1	15.8	38.9
8	125% N+GR	0.30	0.12	15.9	11.3	27.1
9	150% N+GR	0.29	0.10	14.4	9.8	24.2
10	150%RDF+GR	0.50	0.17	26.3	16.1	42.4
11	LCC	0.44	0.15	21.0	13.5	34.5
12	Green seeker	0.42	0.15	20.0	12.8	32.8
13	Nutrient expert	0.49	0.17	24.9	16.6	41.4
	SE(m) ±	0.01	0.01	0.8	0.8	1.1
	C.D. (P = 0.05)	0.02	0.02	2.4	2.3	3.3

3.6. Potassium Content (%) and Uptake in Grain and Straw

Significant differences were observed in potassium content (%) in grain and straw due to different treatments containing various N doses (Table 3). More amount of potassium in grains and straw was obtained from the treatments in which basal application of potassium was done. Maximum K content in grains was recorded at 150% RDF + GR, followed by Nutrient Expert, while maximum K content in straw was obtained at 150% RDF + GR, followed by 100% RDF.

Remaining precision nitrogen management treatments, *viz.* LCC and Green Seeker-based N management have shown better values of K content in both grains and straw compared to other treatments in which only nitrogen was applied.

Table 3. Effect of different treatments on K content (%) and uptake in grain and straw.

Sr. No.	Treatment	K content (%)		K uptake (kg/ha)		
		Grain	Straw	Grain	Straw	Total
1	Absolute control	0.43	0.97	10.6	45.3	55.9
2	50% N	0.42	0.97	18.2	74.2	92.3
3	75% N	0.42	0.96	19.2	87.8	106.9
4	100% N	0.41	0.95	19.4	91.0	110.4
5	125% N	0.40	0.95	20.0	89.6	109.6
6	150% N	0.40	0.93	18.6	88.9	107.5
7	100% RDF	0.63	1.47	32.2	143.1	175.3
8	125% N+GR	0.41	0.97	21.6	91.1	112.7
9	150% N+GR	0.39	0.94	19.3	89.6	108.9
10	150%RDF+GR	0.65	1.53	34.4	144.6	179.0
11	LCC	0.62	1.30	29.3	117.7	147.1
12	Green seeker	0.61	1.20	28.8	99.7	128.5
13	Nutrient expert	0.64	1.37	32.8	130.7	163.5
	SE(m) ±	0.01	0.09	1.0	9.8	9.8
	C.D. (P = 0.05)	0.03	0.26	2.9	28.9	28.6

Significant effects of different treatments were observed in grain and straw potassium (K) uptake. Higher values of potassium uptake were observed from the treatments with application of potassium compared to the treatments in which only nitrogen was applied. The highest potassium uptake in grains was recorded at 150% RDF+GR, followed by Nutrient Expert. The highest potassium uptake in straw was obtained with 150% RDF+GR, followed by 100% RDF. The improved grain and stover (straw) yield also enhanced potassium uptake in the crop, which was also confirmed in the findings of Shivay et al. [24].

3.7. Partial Factor Productivity of Nitrogen (kg/kg N)

Partial factor productivity of N is a useful measure of nitrogen use efficiency as it provides an integrative index that quantifies total economic output relative to the use of nutrient resources in the system [25]. There was a significant difference observed in the partial factor productivity of nitrogen due to different treatments (Figure 5). It was observed that with an increase in the level of nitrogen, partial factor productivity decreased. Significantly, the maximum (57.6 kg/kg N) and minimum (20.7 kg/kg N) PFP were observed with the application of 50% RDN and 150% RDN, respectively. Panayotova and Kostadinova [26] reported similar results. Precision nutrient management treatments consisting of N management by Green Seeker and Nutrient Expert show better partial factor productivity of N compared to the remaining treatments. The fertilizer efficiency increases when suitable sources of nutrients are applied at the exact rate, time, and place, which increases the yield, decreases the loss of nutrients, and improves soil fertility. Nitrogen utilization efficiency (NUE), or N uptake per unit N applied, is greatest where the yield response to N is highest. Therefore, NUE is generally greatest with low levels of applied N and decreases as the amount of N applied increases [27, 28].

3.8. Agronomic Efficiency of Nitrogen (%)

Agronomic efficiency of nitrogen was significantly affected by different treatments. With an increase in the level of nitrogen, agronomic efficiency decreased (Figure 5). Maximum (24.9%) and minimum agronomic efficiency (9.8%) were obtained from treatments with application of 50% N and 150% N, respectively. Similar results are reported by Ayadi et al. [29]. Similar to PFP of N, better agronomic efficiency of nitrogen is obtained from precision nutrient management treatments in which N was applied on the basis of nutrient expert and green seeker.

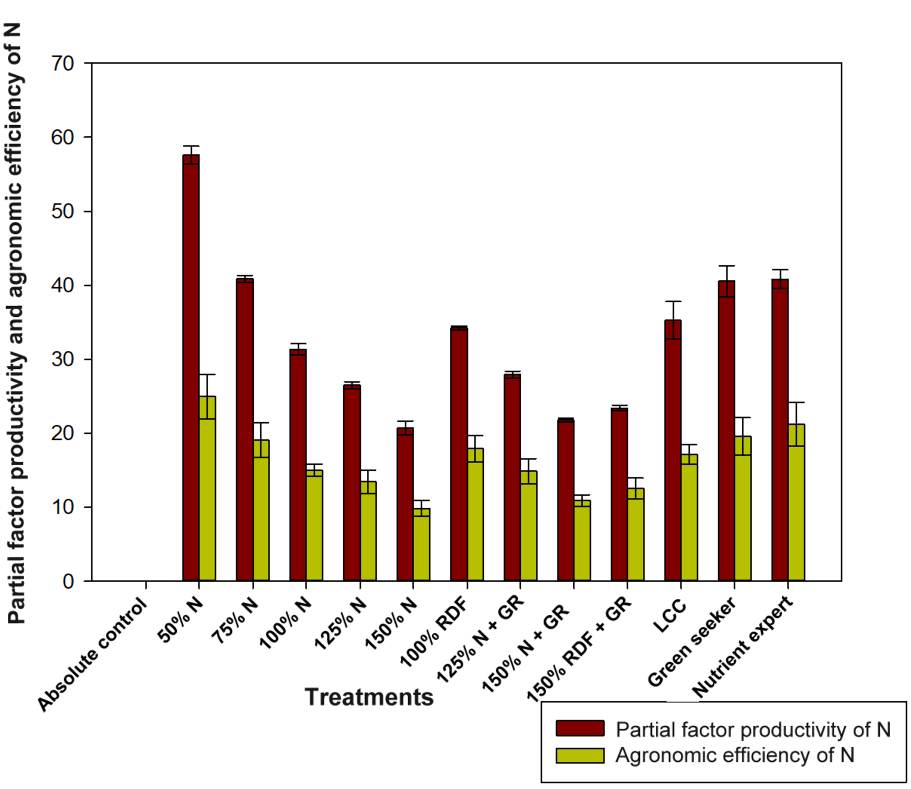

Figure 5. Effect of different treatments on Partial factor productivity (kg/kg N) and Agronomic efficiency (%).

3.9. Growing Degree Days (°C days) and Helio Thermal Units

The relationship between temperature and the length of different growth stages of crops can be well understood with the help of growing degree days. The accumulated GDD, taken from the date of sowing to the physiological maturity of wheat for different treatments, is presented in Figure 6. Wheat crop supplied with higher nitrogen doses accumulated more growing degree days for attaining physiological maturity. The GDD values for different treatments range from 1303 in the absolute control to 1543 in the treatment with application of 150% N with growth regulator. Similar results related to the effect of nitrogen doses on GDD are reported by Sidhu and Raj [30]. Due to the application of more nitrogen, the vegetative phase of the crop was enhanced, which resulted in the accumulation of more growing degree days [31]. Application of plant growth regulators also increases the GDD accumulation to attain maturity as the total growing period length increases. Similarly, the accumulated heliothermal units required to attain physiological maturity differed greatly among different nitrogen doses and growth regulator applications. Maximum and minimum values of heliothermal units were recorded from the application of 150% N + GR and absolute control, respectively. The higher values of heliothermal units may be due to the longer duration of the wheat crop in 150% + GR as compared to lower levels of nitrogen doses. The findings confirmed the results of Kaur et al. [31].

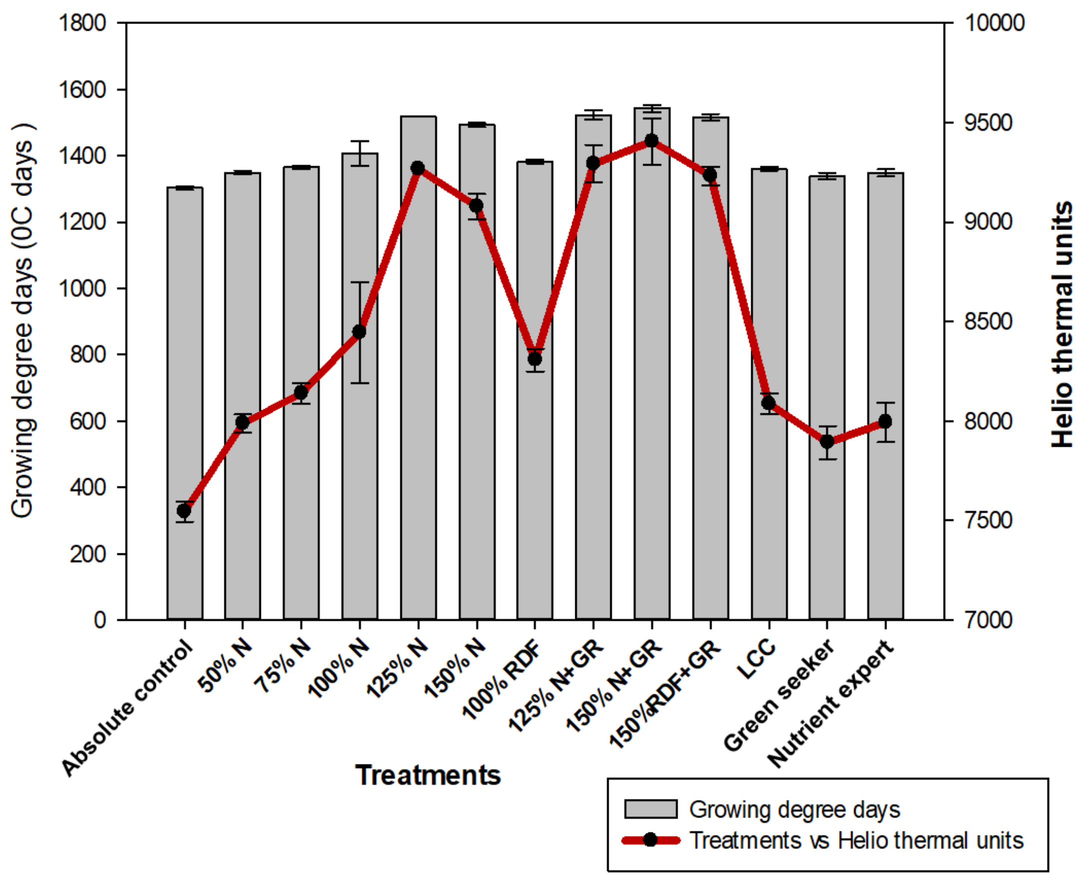

Figure 6. Effect of different treatments on growing degree days (°C days) and Helio thermal units.

4. Conclusion

From the conducted research, it can be concluded that a balanced application of nutrients (NPK) is key to achieving better yield of wheat crops in terms of both quality and quantity. The application of only nitrogenous fertilizer should not be recommended, as it leads to a lower harvest index, nitrogen use efficiency, and nutrient uptake in plants. Precision nitrogen management techniques have significant potential to increase nitrogen use efficiency and crop yield with reduced use of nitrogenous fertilizer.

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