PLANT SCIENCE TODAY
Vol 13(sp1): 1-8
https://doi.org/10.14719/pst.13123

eISSN 2348-1900

RESEARCH ARTICLE

Optimization and validation of leaf color chart, SPAD meter and GreenSeeker thresholds for precise nitrogen management in wheat cv. Karan Vandana

Vivek Bhagat[1*], Meenakshi Gupta[1], Rajeev Bharat[2], Banti[1], Ankita Kumari Bhagat[1], Dhamni Patyal[1], Vijay Kumar[3] & Kanav Sharma[1]

[1]Division of Agronomy, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Chatha 180 009, Jammu and Kashmir, India
[2]Division of Plant Breeding & Genetics, Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, Chatha 180 009, Jammu and Kashmir, India
[3]School of Agriculture, Abhilashi University, Mandi, Chail Chowk, Mandi 175 028, Himachal Pradesh, India

*Correspondence email - vivek25bb@gmail.com

Received: 08 December 2025; Accepted: 10 January 2026; Available online: Version 1.0: 30 January 2026

Cite this article: Vivek B, Meenakshi G, Rajeev B, Banti, Ankita KB, Dhamni P, Vijay K, Kanav S. Optimization and validation of leaf color chart, SPAD meter and GreenSeeker thresholds for precise nitrogen management in wheat cv. Karan Vandana. Plant Science Today. 2026; 13(sp1): 1-8. https://doi.org/10.14719/pst.13123

Abstract

Nitrogen inefficiency in cereal cropping systems leads to suboptimal yields, environmental pollution and reduced fertilizer recovery rates. Non-destructive tools, including the leaf color chart (LCC), Soil plant analysis development meter (SPAD) and GreenSeeker, enable real-time assessment of canopy nitrogen status and site-specific fertilizer recommendations. Therefore, field experiments were conducted at Research farm of Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu during rabi season 2023–24 and 2024–25 with 14 treatments on sandy clay loam soil in randomized block design (RBD) and 3 replications. The results revealed that significantly higher growth, yield attributes, yield and N uptake were found with the application of LCC ≤ 5 at 20 kg N ha^{-1} (T_6) which was statistically at par with LCC ≤ 4 at 20 kg N ha^{-1} (T_4), GreenSeeker-directed N application ≤ 0.8 normalized difference vegetation index (NDVI) at 20 kg N ha^{-1} (T_{14}) and sufficiency index-based N application ≤ 95 % at 20 kg N ha^{-1} (T_{10}) during both the years. Linear regression analysis conducted over 2 years demonstrated that the LCC value had a significant positive correlation with grain yield (GY) at 5 % significance level with an average correlation coefficient of 0.92.

Keywords: GreenSeeker; nitrogen; precision; SPAD meter; wheat; yield

Introduction

In India, wheat (*Triticum aestivum* L.) is a major staple crop, ranking second after rice. It accounts for nearly one third of the total cereal production and plays a vital role in ensuring the nation's food and nutritional security. Globally, India is the second largest producer of wheat, contributing 12 % to the world's total wheat output. Worldwide, wheat cultivation covers approximately 220.60 million hectares, producing about 789.50 million tonnes with an average yield of 3.58 tonnes per hectare (1). In India, the crop occupies 30.47 million hectares with a total production of 106.84 million tonnes and an average productivity of 3.50 tonnes per hectare (2). Agronomic practices viz., sowing method, sowing time, irrigation, fertilizer application etc are of immense importance for wheat cultivation. Of these nitrogen (N) management plays a crucial role in its production. However, to wheat production there is an urgent need to increase its nutrient use efficiency particularly in N use efficiency. Nitrogen plays vital role in plant metabolism, being an essential constituent of proteins (3). Consequently, N application is indispensable for increasing wheat production. It not only boosts yield but also improves food quality by enhancing grain protein content. Nitrogen is an important component of chlorophyll, the primary molecule responsible for photosynthesis and nucleic acids (4). Wheat requires a balanced supply of N for vigorous growth and development processes. Fertilizers are not effectively utilized by plant if applied at wrong time or in the wrong place (5). Such practices lead to low N use efficiency. Therefore, it is essential to enhance N use efficiency by ensuring maximum nitrogen uptake during critical growth stages. Tools like leaf color chart (LCC), SPAD meter and GreenSeeker facilitate this by assessing plant N needs in real time. These tools have been successfully used in wheat to improve both productivity and profitability. This approach enhances N use efficiency while minimizing environmental pollution. It is based on the rapid assessment of leaf N content which serves as a sensitive indicator of the crop's changing N needs throughout its growth cycle. These tools also measure leaf chlorophyll content by analysing the spectral properties of light absorbed, transmitted or reflected by the leaves which provides a quick and accurate evaluation (6). Therefore, this study was conducted to evaluate effectiveness of real time N diagnostic tools for enhancing wheat productivity under actual field conditions.

Materials and Methods

Experimental site and treatment details

A field experiment was performed during the rabi (winter) season of 2023–24 and 2024–25 at the Research farm of Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu. Geographically, the site is situated at 32˚39'33" N to 74˚48'45" E longitude at an elevation of 293 m above mean sea level (amsl) and falls within the subtropical zone of the Shivalik Himalayas in the agro-climatic region of Jammu & Kashmir. The soil of experimental field was sandy clay loam in texture with slightly alkaline pH (7.5) and electrical conductivity (EC) (0.18 dS m^{-1}). The soil was low in organic carbon (4.40 g kg^{-1}) and available N (221.56 kg ha^{-1}) but moderate in phosphorus (P) (15.18 kg ha^{-1}) and potassium (K) (148.67 kg ha^{-1}). The experiment was laid out in randomized block design (RBD) with 3 replications. Leaf color chart, SPAD meter and GreenSeeker served as non-destructive diagnostic tools; LCC matched leaf greenness against color standards (≤ 4 or ≤ 5), SPAD measured chlorophyll via dual-wavelength transmittance (650/940 nm) and GreenSeeker computed normalized difference vegetation index (NDVI) from active red (660 nm)/NIR (780 nm) canopy reflectance. Fourteen treatments were laid viz., T_1: Control (No - N applied); T_2: Recommended dose of N, P & K; T_3: LCC ≤ 4 at 10 kg N ha^{-1}; T_4: LCC ≤ 4 at 20 kg N ha^{-1}; T_5: LCC ≤ 5 at 10 kg N ha^{-1}; T_6: LCC ≤ 5 at 20 kg N ha^{-1}; T_7: Sufficiency index based N application ≤ 90 % at 10 kg N ha^{-1}; T_8: Sufficiency index based N application ≤ 90 % at 20 kg N ha^{-1}; T_9: Sufficiency index based N application ≤ 95 % at 10 kg N ha^{-1}; T_{10}: Sufficiency index based N application ≤ 95 % at 20 kg N ha^{-1}; T_{11}: GreenSeeker directed N application ≤ 0.7 NDVI value at 10 kg N ha^{-1}; T_{12}: GreenSeeker directed N application ≤ 0.7 NDVI value at 20 kg N ha^{-1}; T_{13}: GreenSeeker directed N application ≤ 0.8 NDVI value at 10 kg N ha^{-1}; T_{14}: GreenSeeker directed N application ≤ 0.8 NDVI value at 20 kg N ha^{-1} in the experiment. An N-rich reference plot was established by applying 150 % of the recommended nitrogen dose for wheat, while P and K were applied at the recommended rates (150 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1} and 25 kg K_2O ha^{-1}) and was used to calculate the sufficiency index. The net plot size was 3.8 m × 2 m (7.6 m^2). A uniform dose of N, phosphorus (P_2O_5) and potassium (K_2O) was applied to all treatments. Nitrogen was applied as per treatments full doses of P and K were applied as basal at sowing in all the treatments.

Weather data

Weather data was acquired from the meteorological observatory located close to the experimental site at Research farm, Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu. Average daily minimum and maximum temperatures during the wheat growing season (November–May) ranged from 5.17 to 15.49 °C and 13.47 to 32.11 °C, respectively in 2023–24, whereas in the year of 2024–25 these values were 5.83 to 15.79 °C and 20.68 to 34.02 °C. The mean daily relative humidity varied between 95.11 to 41.26 % in 2023–24 and 94.49 to 30.74 % in 2024–25. During 2023–24 and 2024–25, the total rainfall received in the crop growing season was 342.00 mm and 225.60 mm, respectively (Table 1).

Crop husbandry

Wheat variety DBW 187 (Karan Vandana) was sown using Kera method on 22 November in both 2023 and 2024 with a row spacing of 20 cm and a seed rate of 100 kg ha^{-1}. Only 2 irrigation was given to the crop first at crown root initiation and second at maximum tillering as the water received from rainfall at various growth stages was sufficient for the crop during both the years of study. The crop was harvested in the last week of April during both the years on attainment of physiological maturity. Harvesting was carried out manually with the help of sickle. Immediately after harvest, the crop was bundled, tagged and left in the respective plots for sun drying. Following adequate drying, threshing was performed using drum and seed yield was recorded plot wise using an electronic balance.

Observation recorded and methodology

Plant height

Five plants were randomly tagged per plot for observation. Plant height was measured from the base to the tip of the last fully expanded leaf at 30, 60, 90, 120 DAS (days after sowing) and from the ground to the top of the ear head at harvest and expressed in centimeter.

Dry matter accumulation

Plant samples for dry matter estimation were collected from the penultimate row at 30, 60, 90, 120 DAS and at harvest. Plants were cut near the soil surface, sun-dried and then oven dried at 65 ± 5 °C to constant weight for recording dry matter accumulation and expressed in gram per square meter.

Number of effective tillers

The number of effective tillers per square meter were counted at harvest from each plot and expressed as per square meter.

Spike length

Five spikes were randomly selected per plot and their length was measured and expressed in centimeter.

Number of grains spike^{-1}

Five randomly selected spikes were threshed, cleaned and counted individually. The mean was expressed as grains per spike.

Test weight

From each net plot, 1000 grains were counted using an electronic grain counter, weighed and expressed as gram.

Table 1. Meteorological data during crop growing season

Month	2023-24					2024-25				
	Temperature (°C)		Relative humidity (%)		Rainfall (mm)	Temperature (°C)		Relative humidity (%)		Rainfall (mm)
	Maximum	Minimum	Morning	Evening		Maximum	Minimum	Morning	Evening	
November	24.39	9.58	91.57	54.14	18.00	25.73	8.51	92.71	45.36	0.00
December	21.68	6.60	95.31	55.11	21.20	21.84	4.71	92.98	44.36	31.60
January	13.47	5.17	95.11	75.23	28.80	20.68	5.83	94.49	56.26	6.40
February	20.81	6.02	92.44	52.62	99.20	23.34	7.43	91.40	51.14	87.60
March	25.98	10.43	88.73	48.53	72.60	27.33	10.40	87.26	46.86	65.40
April	32.11	15.49	78.26	41.26	102.20	34.02	15.79	70.76	30.74	34.60

Grain yield

Net plots from each treatment were harvested, sun dried for 1–2 days, threshed and cleaned. Grain yield (GY) was recorded as kilogram per plot and converted to megagram per hectare.

Straw yield

Straw yield per net plot was calculated by subtracting grain weight from total biomass per treatment and expressed as megagram per hectare.

N content and uptake

Total N concentration in grain and straw samples was determined by modified Kjeldahl method, involving digestion with concentrated H_2SO_4 and K_2SO_4, $FeSO_4$ and $CuSO_4$ (20:2:1) (7). N concentration was expressed as percentage and uptake (kg ha^{-1}) calculated using the standard formula.

$$\text{N uptake (kg ha}^{-1}\text{) in grain/straw} = \frac{\text{Nitrogen content (\%) in grain/straw}}{\text{Grain/straw/stover yield (kg ha}^{-1}\text{)}}$$

$$\text{Total uptake of N (kg ha}^{-1}\text{)} = \text{N uptake in grain} + \text{N uptake in straw}$$

Statistical analysis

The mean data for each parameter over 2 years (2023–24 and 2024–25) were subjected to statistical analysis using analysis of variance (ANOVA). Fisher's test of significance was applied to determine differences among treatment means at the 5 % probability level. All the statistical analyses were carried out using R software version 4.2.2. (R Core Team, 2022), developed by the R Foundation for Statistical Computing, Vienna, Austria. Mean comparisons were carried out using the least significant difference (LSD) test where significant treatment effects were detected.

Results and Discussion

Growth parameters

Growth attributes, viz., plant height and dry matter accumulation were significantly affected by various nitrogen treatments during 2023–24 and 2024–25 cropping seasons (Fig. 1). Maximum plant height (103.65 ± 5.49 and 106.56 ± 3.88 cm) was recorded with the application of LCC ≤ 5 at 20 kg N ha^{-1}(T_6) which was at par with LCC ≤ 4 at 20 kg N ha^{-1}(T_4) (97.57 ± 6.37 and 100.12 ± 5.73 cm), GreenSeeker-directed N application ≤ 0.8 NDVI at 20 kg N ha^{-1}(T_{14}) (96.67 ± 4.94 and 99.13 ± 3.99 cm) and sufficiency index-based N application ≤ 95 % at 20 kg N ha^{-1}(T_{10}) (96.66 ± 5.30 and 99.15 ± 4.78 cm) during both the years of experimentation. Control (T_1) treatment consistently exhibited lowest plant height across all crop growth stages compared to other treatments. The observed increase in plant height under enhanced nitrogen supply can be attributed to the fundamental role of nitrogen in regulating cell division and tissue organization. Nitrogen facilitates the activation and progression of the cell cycle thereby accelerating both cell division and expansion which ultimately contributes to greater shoot elongation. Precision nitrogen management tools such as LCC, GreenSeeker and sufficiency index-based applications ensure that nitrogen availability is closely aligned with crop demand resulting in improved plant growth (8–10).

Higher dry matter accumulation (1147.56 ± 24.97 and 1192.03 ± 44.98 g m^{-2}) was observed under the treatment LCC ≤ 5 at 20 kg N ha^{-1}(T_6) which was statistically at par with LCC ≤ 4 at 20 kg N ha^{-1}(T_4) (1119.18 ± 33.36 and 1160.37 ± 25.80 g m^{-2}), GreenSeeker-directed N application ≤ 0.8 NDVI at 20 kg N ha^{-1}(T_{14}) (1095.42 ± 51.83 and 1134.92 ± 33.83 g m^{-2}) and sufficiency index-based N application ≤ 95 % at 20 kg N ha^{-1}(T_{10}) (1066.85 ± 39.87 and 1105.66 ± 13.08 g m^{-2}) whereas lowest dry matter production was recorded in (T_1) control during both the years of study. The effectiveness of precision nitrogen management in enhancing biomass production and physiological growth by ensuring an adequate and timely supply of nitrogen during critical developmental stages. Sufficient nitrogen availability improves photosynthetic capacity and delays leaf senescence thus promoting sustained dry biomass (11, 12).

Yield attributes and yield

The yield attributes of wheat such as number of effective tillers, spike length, number of grains per spike and test weight were significantly affected by various nitrogen treatments (Table 2). Significantly higher number of effective tillers (381.80 ± 10.66 and

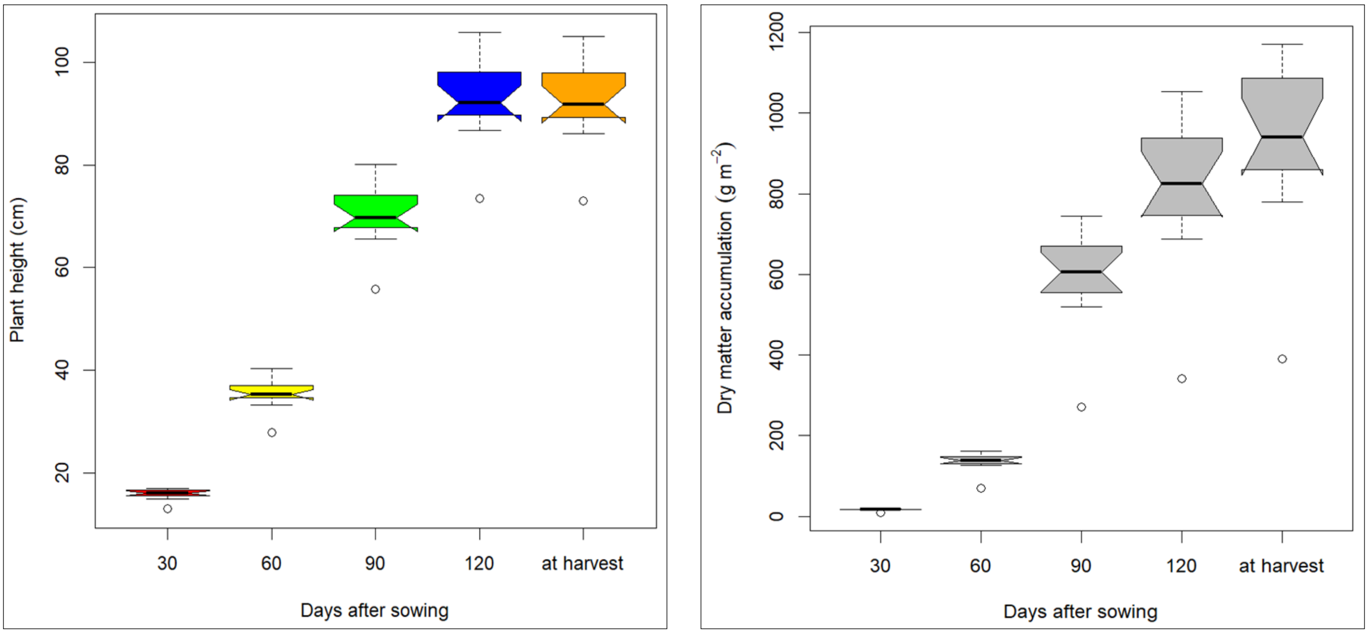

Fig. 1. Effect of leaf color chart, sufficiency index and GreenSeeker-based nitrogen application on plant height and dry matter accumulation of wheat.

Table 2. Effect of leaf color chart, sufficiency index and GreenSeeker based nitrogen application on yield attributes and yield of wheat

Treatment	Number of effective tillers m^{-2}		Spike length (cm)		Number of grains $spike^{-1}$		Test weight (g)		Grain yield (Mg ha^{-1})		Straw yield (Mg ha^{-1})	
	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25
T_1	281.37^{d} ± 14.06	286.67^{d} ± 19.57	7.58^{e} ± 0.46	7.86^{g} ± 0.29	27.85^{h} ± 1.84	28.37^{h} ± 0.39	31.11^{d} ± 0.42	31.70^{d} ± 0.59	1.82^{c} ± 0.03	1.85^{c} ± 0.28	2.83^{d} ± 0.14	2.89^{e} ± 0.10
T_2	301.05^{cd} ± 4.42	307.13^{cd} ± 12.64	10.18^{d} ± 0.71	10.58^{f} ± 0.71	32.55^{gh} ± 0.74	33.21^{gh} ± 2.06	37.04^{c} ± 1.98	37.79^{c} ± 0.70	4.50^{b} ± 0.30	4.59^{b} ± 0.09	6.43^{c} ± 0.45	6.56^{d} ± 0.30
T_3	308.90^{cd} ± 15.35	315.37^{cd} ± 18.95	10.34^{d} ± 0.11	10.76^{ef} ± 0.27	33.00^{g} ± 2.06	33.69^{g} ± 2.02	37.09^{c} ± 0.53	37.87^{c} ± 1.67	4.52^{b} ± 0.18	4.61^{b} ± 0.25	6.47^{c} ± 0.34	6.60^{d} ± 0.42
T_4	375.58^{a} ± 17.06	385.41^{a} ± 6.56	12.28^{ab} ± 0.13	12.91^{ab} ± 0.18	44.79^{ab} ± 2.54	45.96^{ab} ± 2.33	43.05^{a} ± 1.43	44.18^{a} ± 1.28	5.44^{a} ± 0.12	5.59^{a} ± 0.35	7.46^{ab} ± 0.44	7.66^{ab} ± 0.17
T_5	327.52^{c} ± 18.90	335.33^{bc} ± 8.73	11.17^{bcd} ± 0.23	11.69^{cdef} ± 0.36	40.39^{bcde} ± 2.58	41.35^{bcde} ± 2.50	37.64^{b} ± 0.94	38.54^{bc} ± 0.95	4.74^{b} ± 0.23	4.86^{b} ± 0.16	6.68^{bc} ± 0.34	6.84^{bcd} ± 0.27
T_6	381.80^{a} ± 10.66	392.52^{a} ± 23.96	12.40^{a} ± 0.59	13.07^{a} ± 0.15	46.02^{a} ± 1.15	47.31^{a} ± 1.00	43.34^{a} ± 0.92	44.56^{a} ± 2.45	5.94^{a} ± 0.16	6.11^{a} ± 0.30	7.75^{a} ± 0.11	7.97^{a} ± 0.13
T_7	312.79^{cd} ± 11.84	319.53^{cd} ± 17.38	10.49^{d} ± 0.68	10.93^{ef} ± 0.50	33.93^{fg} ± 1.85	34.66^{fg} ± 2.39	37.10^{c} ± 1.83	37.90^{c} ± 0.97	4.59^{b} ± 0.29	4.68^{b} ± 0.20	6.54^{bc} ± 0.42	6.69^{d} ± 0.07
T_8	319.20^{cd} ± 19.33	326.45^{cd} ± 7.10	10.86^{d} ± 0.21	11.34^{ef} ± 0.35	38.21^{def} ± 2.01	39.08^{def} ± 1.09	37.20^{c} ± 0.76	38.04^{bc} ± 2.65	4.67^{b} ± 0.10	4.77^{b} ± 0.19	6.61^{bc} ± 0.26	6.76^{cd} ± 0.34
T_9	324.77^{c} ± 14.60	332.38^{c} ± 5.50	11.02^{cd} ± 0.26	11.52^{def} ± 0.53	38.84^{cde} ± 0.74	39.75^{cdef} ± 2.13	37.37^{c} ± 2.14	38.25^{bc} ± 0.43	4.71^{b} ± 0.27	4.82^{b} ± 0.24	6.65^{bc} ± 0.08	6.80^{bcd} ± 0.48
T_{10}	368.79^{ab} ± 5.06	378.29^{ab} ± 16.64	12.08^{abc} ± 0.15	12.69^{abcd} ± 0.33	42.72^{abcd} ± 0.69	43.82^{abcd} ± 1.62	39.43^{abc} ± 0.76	40.45^{abc} ± 2.32	5.39^{a} ± 0.21	5.53^{a} ± 0.06	7.42^{ab} ± 0.20	7.61^{abc} ± 0.52
T_{11}	317.73^{cd} ± 4.66	324.81^{cd} ± 5.84	10.73^{d} ± 0.49	11.20^{ef} ± 0.48	37.05^{efg} ± 0.63	37.88^{efg} ± 1.68	37.13^{c} ± 0.70	37.96^{c} ± 1.19	4.60^{b} ± 0.27	4.70^{b} ± 0.28	6.57^{bc} ± 0.39	6.72^{d} ± 0.17
T_{12}	322.30^{c} ± 9.00	329.72^{cd} ± 14.82	10.98^{cd} ± 0.66	11.47^{ef} ± 0.17	38.38^{def} ± 0.64	39.26^{def} ± 0.39	37.20^{c} ± 1.27	38.06^{bc} ± 2.18	4.67^{b} ± 0.05	4.78^{b} ± 0.10	6.63^{bc} ± 0.09	6.78^{cd} ± 0.15
T_{13}	330.14^{bc} ± 16.71	338.15^{bc} ± 5.60	11.25^{bcd} ± 0.25	11.78^{bcde} ± 0.20	40.91^{bcde} ± 1.68	41.90^{bcde} ± 1.35	37.83^{bc} ± 1.29	38.75^{bc} ± 1.61	4.76^{b} ± 0.26	4.87^{b} ± 0.08	6.76^{bc} ± 0.40	6.92^{bcd} ± 0.04
T_{14}	374.37^{a} ± 9.21	383.89^{a} ± 17.80	12.22^{ab} ± 0.28	12.83^{abc} ± 0.63	43.45^{abc} ± 1.52	44.55^{abc} ± 1.64	41.81^{ab} ± 2.65	42.87^{ab} ± 2.27	5.42^{a} ± 0.15	5.56^{a} ± 0.14	7.43^{ab} ± 0.45	7.62^{abc} ± 0.44
LSD (p≤0.05)	38.77	43.07	1.14	1.17	4.73	5.22	4.12	4.84	0.62	0.58	0.92	0.86

T_1: Control (No- N applied); T_2: Recommended dose of N, P & K; T_3: LCC ≤ 4 at 10 kg N ha^{-1}; T_4: LCC ≤ 4 at 20 kg N ha^{-1}; T_5: LCC ≤ 5 at 10 kg N ha^{-1}; T_6: LCC ≤ 5 at 20 kg N ha^{-1}; T_7: Sufficiency index based nitrogen application ≤ 90 % at 10 kg N ha^{-1}; T_8: Sufficiency index based nitrogen application ≤ 90 %at 20 kg N ha^{-1}; T_9: Sufficiency index based nitrogen application ≤ 95 %at 10 kg N ha^{-1}; T_{10}: Sufficiency index based nitrogen application ≤ 95 %at 20 kg N ha^{-1}; T_{11}: GreenSeeker directed N application ≤ 0.7 NDVI value at 10 kg N ha^{-1}; T_{12}: GreenSeeker directed N application ≤ 0.7 NDVI value at 20 kg N ha^{-1}; T_{13}: GreenSeeker directed N application ≤ 0.8 NDVI value at 10 kg N ha^{-1}; T_{14}: GreenSeeker directed N application ≤ 0.8 NDVI value at 20 kg N ha^{-1}.

392.52 ± 23.96 m^2), spike length (12.40 ± 0.59 and 13.07 ± 0.15 cm), number of grains $spike^{-1}$ (46.02 ± 1.15 and 47.31 ± 1.00) and test weight (43.34 ± 0.92 and 44.56 ± 2.45 g) were recorded under LCC ≤ 5 at 20 kg N ha^{-1} (T_6) which remained at par with LCC ≤ 4 at 20 kg N ha^{-1} (T_4), GreenSeeker-directed N application ≤ 0.8 NDVI at 20 kg N ha^{-1} (T_{14}) and sufficiency index-based N application ≤ 95 % at 20 kg N ha^{-1} (T_{10}) during both the years. This can be attributed to the precise synchronization of nitrogen availability with critical crop demand periods. In contrast to conventional application of nitrogen, precision approaches enable split nitrogen applications which ensure gradual and sustained supply during peak physiological stages such as tillering and heading. This optimized timing is particularly important as it directly influences key yield components including the number of effective tillers and grains $spike^{-1}$ (13, 14).

Significantly highest grain (5.94 ± 0.16 and 6.11 ± 0.30 Mg ha^{-1}) and straw yield (7.75 ± 0.11 and 7.97 ± 0.13 Mg ha^{-1}) were observed in LCC ≤ 5 at 20 kg N ha^{-1}(T_6) which was statistically similar with LCC ≤ 4 at 20 kg N ha^{-1}(T_4), GreenSeeker-directed N application ≤ 0.8 NDVI at 20 kg N ha^{-1}(T_{14}) and sufficiency index-based N application ≤ 95 % at 20 kg N ha^{-1}(T_{10}) whereas lowest value of grain and straw was recorded under control (T_1) treatment during both the years of experimentation. This improvement could be attributed to close synchronization between nitrogen supply and crop demand which enhances photosynthetic efficiency and facilitates the translocation of assimilates and nutrients towards the reproductive organs. As a result, it leads to increased formation of yield contributing structures, a higher number of productive plants and ultimately improved crop yield (15, 16). The linear regression graph in Fig. 2, which depicted the mean values from both years of experimentation, shows a positive mean correlation between LCC value and GY (0.92) at 5 % significance level. Previous study found a strong and significant positive linear relationship between LCC and GY in wheat (r^2= 0.87, p < 0.01), with optimal LCC 5.0 at 60 DAS and flag leaf yielding 4.87 t ha^{-1} at 120 kg N ha^{-1} (12).

N content and uptake

Nitrogen management treatments have major effect on N content and N uptake of wheat. Maximum value of N concentration in grain (1.50 and 1.54 %) and straw (0.57 and 0.59 %) was recorded with the application of LCC ≤ 5 at 20 kg N ha^{-1}(T_6) which was closely followed by LCC ≤ 4 at 20 kg N ha^{-1}(T_4) (Fig. 3). Similarly, significantly higher N uptake in grain (89.02 ± 3.75 and 94.09 ± 2.94 kg ha^{-1}) and straw (44.47 ± 1.91 and 47.00 ± 1.65 kg ha^{-1}) was recorded in LCC ≤ 5 at 20 kg N ha^{-1}(T_6) which was statistically similar with LCC ≤ 4 at 20 kg N ha^{-1}(T_4), GreenSeeker-directed N application ≤ 0.8 NDVI at 20 kg N ha^{-1}(T_{14}) and sufficiency index-based N application ≤ 95 % at 20 kg N ha^{-1}(T_{10}) during both the years (Table 3). Enhanced nutrient uptake registered under optimized fertilization regimes can be attributes to elevated nitrogen concentration in wheat which are closely linked to higher in key plant parts. This increased accumulation reflects the plant's greater capacity to assimilates essential nutrients thereby supporting greater biomass production and improved grain filling. Ultimately the improvement in N uptake efficiency promotes superior growth, yield and grain quality in wheat (17, 18).

Correlation studies

Fig. 4 presents a correlation matrix accompanied by scatter plots and histograms, which provides a comprehensive visualization of the interrelationships among key agronomic parameters including plant height (PH), dry matter (DM), number of effective tillers (NE), spike length (SL), number of grain $spike^{-1}$ (GPS), test weight (TW), GY and straw yield (SY). The matrix reveals strong positive correlations between GY and various growth and yield attributes such as PH, DM, NE, SL, GPS and SY with correlation coefficient of 0.96, 0.97, 0.82, 0.97, 0.86, 0.92 and 0.99, respectively (p ≤ 0.05). This strong association likely results from precision N management using tools like LCC, SPAD meter and GreenSeeker which enable real time assessment of plant N status to optimize chlorophyll content, biomass accumulation and partitioning to reproductive sinks during critical growth stages in wheat.

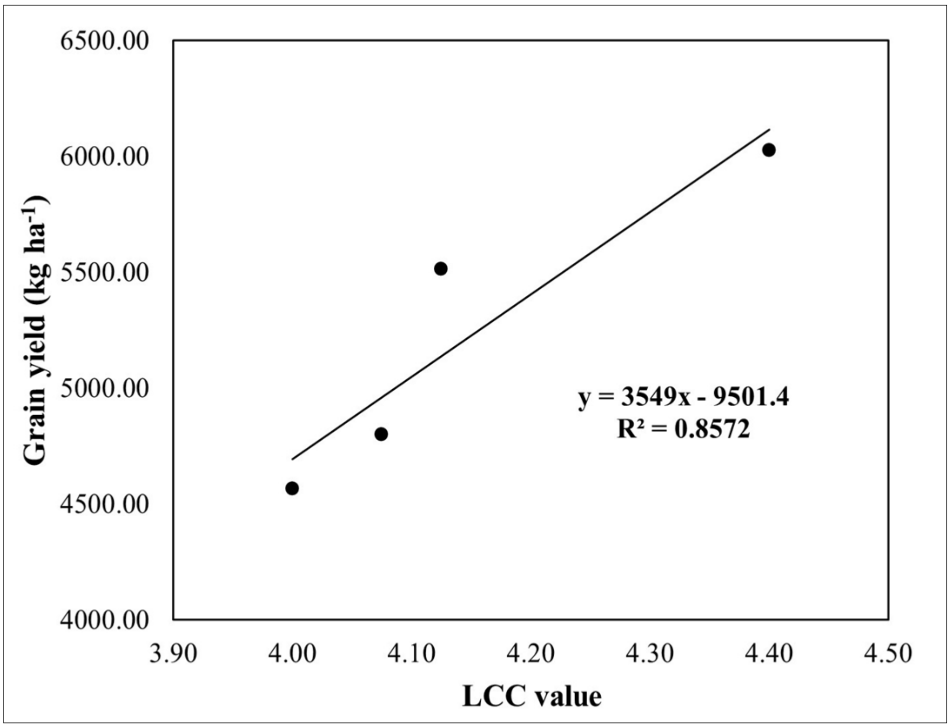

Fig. 2. Linear regression analysis between leaf color chart value and grain yield.

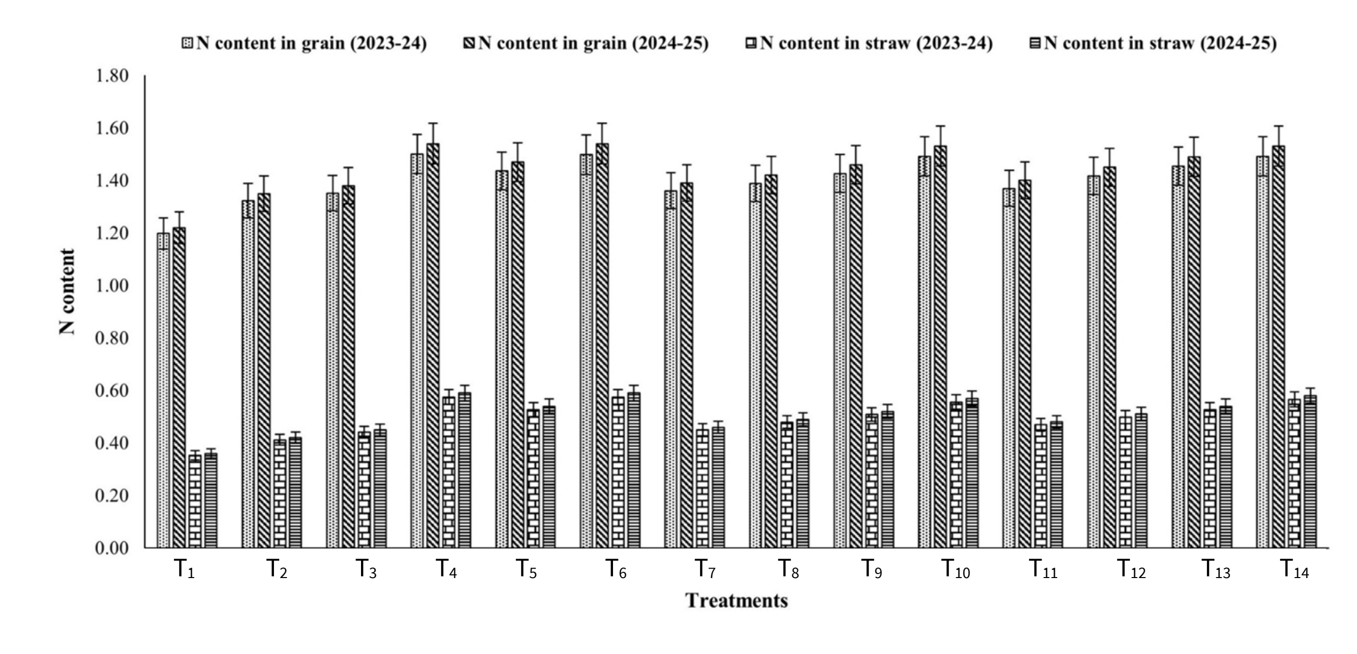

Fig. 3. Effect of leaf color chart, sufficiency index and GreenSeeker based nitrogen application on nitrogen content in wheat; T_1: Control (No- N applied); T_2: Recommended dose of N, P & K; T_3: leaf color chart ≤ 4 at 10 kg N ha^{-1}; T_4: leaf color chart ≤ 4 at 20 kg N ha^{-1}; T_5: leaf color chart ≤ 5 at 10 kg N ha^{-1}; T_6: leaf color chart ≤ 5 at 20 kg N ha^{-1}; T_7: Sufficiency index based nitrogen application ≤ 90 % at 10 kg N ha^{-1}; T_8: Sufficiency index based nitrogen application ≤ 90 % at 20 kg N ha^{-1}; T_9: Sufficiency index based nitrogen application ≤ 95 % at 10 kg N ha^{-1}; T_{10}: Sufficiency index based nitrogen application ≤ 95 % at 20 kg N ha^{-1}; T_{11}: GreenSeeker directed N application ≤ 0.7 NDVI value at 10 kg N ha^{-1}; T_{12}: GreenSeeker directed N application ≤ 0.7 NDVI value at 20 kg N ha^{-1}; T_{13}: GreenSeeker directed nitrogen application ≤ 0.8 NDVI value at 10 kg N ha^{-1}; T_{14}: GreenSeeker directed nitrogen application ≤ 0.8 NDVI value at 20 kg N ha^{-1}.

Table 3. Effect of leaf color chart, sufficiency index and GreenSeeker based nitrogen application on nitrogen uptake of wheat

Treatment	N uptake (kg ha^{-1})				Total N uptake (kg ha^{-1})	
	Grain		Straw			
	2023–24	2024–25	2023–24	2024–25	2023–24	2024–25
T_1	21.73^{d} ± 0.64	22.56^{d} ± 1.51	10.01^{g} ± 0.53	10.39^{f} ± 0.15	31.74^{h} ± 1.74	32.95^{h} ± 1.44
T_2	59.49^{c} ± 1.63	61.92^{c} ± 2.58	26.46^{f} ± 1.25	27.54^{e} ± 1.58	85.95^{g} ± 1.48	89.46^{g} ± 2.25
T_3	61.07^{bc} ± 1.94	63.66^{bc} ± 1.84	28.50^{ef} ± 0.84	29.71^{de} ± 1.17	89.57^{fg} ± 2.68	93.37^{fg} ± 2.89
T_4	81.69^{a} ± 4.87	86.02^{a} ± 5.33	42.89^{a} ± 0.67	45.17^{a} ± 2.52	124.58^{ab} ± 4.29	131.19^{b} ± 5.98
T_5	68.12^{bc} ± 4.64	71.40^{bc} ± 3.58	35.24^{b} ± 1.18	36.94^{b} ± 0.44	103.36^{cd} ± 5.82	108.34^{c} ± 3.38
T_6	89.02^{a} ± 3.75	94.09^{a} ± 2.94	44.47^{a} ± 1.91	47.00^{a} ± 1.65	133.49^{a} ± 3.25	141.09^{a} ± 1.67
T_7	62.39^{bc} ± 2.33	65.11^{bc} ± 3.14	29.47^{def} ± 0.99	30.75^{de} ± 1.73	91.86^{efg} ± 2.03	95.86^{efg} ± 2.73
T_8	64.79^{bc} ± 3.65	67.76^{bc} ± 2.31	31.66^{bcde} ± 2.22	33.12^{cd} ± 1.10	96.45^{cdef} ± 1.98	100.88^{cdef} ± 2.59
T_9	67.16^{bc} ± 3.65	70.35^{bc} ± 4.19	33.78^{bc} ± 0.56	35.38^{bc} ± 0.82	100.94^{cde} ± 4.21	105.73^{cd} ± 3.85
T_{10}	80.40^{a} ± 4.41	84.59^{a} ± 3.32	41.21^{a} ± 2.40	43.36^{a} ± 0.70	121.61^{b} ± 6.57	127.95^{b} ± 2.72
T_{11}	62.93^{bc} ± 0.89	65.76^{bc} ± 3.73	30.84^{cde} ± 1.44	32.23^{cd} ± 1.51	93.77^{defg} ± 1.26	97.99^{defg} ± 4.08
T_{12}	66.23^{bc} ± 1.07	69.32^{bc} ± 4.56	33.04^{bcd} ± 0.77	34.58^{bc} ± 0.36	99.27^{cdef} ± 1.34	103.90^{cde} ± 4.39
T_{13}	69.21^{b} ± 3.70	72.61^{b} ± 1.55	35.62^{b} ± 1.08	37.37^{b} ± 0.90	104.83^{c} ± 2.79	109.98^{c} ± 2.36
T_{14}	80.90^{a} ± 3.10	85.07^{a} ± 1.93	42.05^{a} ± 1.17	44.21^{a} ± 1.55	122.95^{b} ± 3.36	129.28^{b} ± 2.52
LSD ($p \leq 0.05$)	9.56	9.59	4.04	3.65	10.31	9.71

T_1: Control (No- N applied); T_2: Recommended dose of N, P & K; T_3: LCC ≤ 4 at 10 kg N ha^{-1}; T_4: LCC ≤ 4 at 20 kg N ha^{-1}; T_5: LCC ≤ 5 at 10 kg N ha^{-1}; T_6: LCC ≤ 5 at 20 kg N ha^{-1}; T_7: Sufficiency index based nitrogen application ≤ 90 % at 10 kg N ha^{-1}; T_8: Sufficiency index based nitrogen application ≤ 90 % at 20 kg N ha^{-1}; T_9: Sufficiency index based nitrogen application ≤ 95 % at 10 kg N ha^{-1}; T_{10}: Sufficiency index based nitrogen application ≤ 95 % at 20 kg N ha^{-1}; T_{11}: GreenSeeker directed N application ≤ 0.7 NDVI value at 10 kg N ha^{-1}; T_{12}: GreenSeeker directed N application ≤ 0.7 NDVI value at 20 kg N ha^{-1}; T_{13}: GreenSeeker directed N application ≤ 0.8 NDVI value at 10 kg N ha^{-1}; T_{14}: GreenSeeker directed N application ≤ 0.8 NDVI value at 20 kg N ha^{-1}.

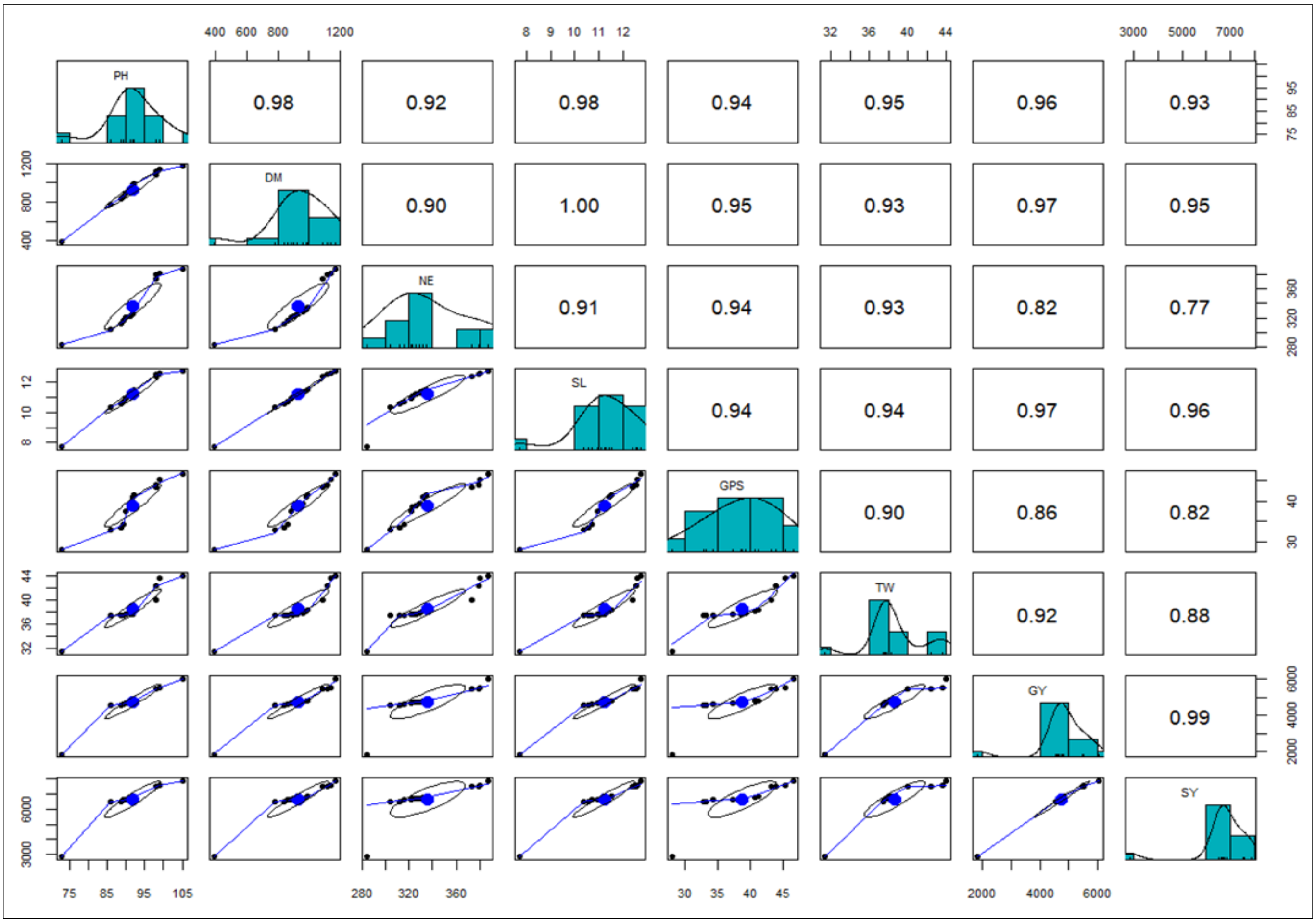

Fig. 4. Correlation matrix and scatter plots illustrating the relationship between various growth and yield attributes, yield and nutrient uptake including the plant height (PH), dry matter (DM), number of effective tillers (NE), spike length (SL), number of grain spike^{-1} (GPS), test weight (TW), grain yield (GY) and straw yield (SY) based on the mean values in both the years of experimentation, $p < 0.05$ (significant).

Conclusion

Nitrogen management based on the leaf color chart proved effective in enhancing the growth, yield attributes, GY and N uptake of wheat. Among the treatments, LCC ≤ 5 at 20 kg N ha^{-1}(T_6) performed the best and was statistically comparable with LCC ≤ 4 at 20 kg N ha^{-1}(T_4), GreenSeeker-directed N application ≤ 0.8 NDVI at 20 kg N ha^{-1}(T_{14}) and sufficiency index-based N application ≤ 95 % at 20 kg N ha^{-1}(T_{10}). The close similarity among these treatments indicates that both optical sensing tools and LCC can accurately assess the crop's real time N demand. Moreover, the strong positive correlation (r = 0.92) between LCC values and grain yield confirms LCC as a reliable, low cost and farmer friendly diagnostic tool. Hence, LCC guided N scheduling can serve as an effective strategy for improving N use efficiency and sustaining wheat productivity under field conditions.

Authors' contributions

VB, MG and RB designed and conducted the experiment and wrote the manuscript. B, AKB and DP reviewed the manuscript. VK and KS participated in the sequence alignment. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. United States Department of Agriculture. The world agriculture production [Internet].
2. Ministry of Agriculture & Farmers Welfare, Government of India. Agricultural statistics at a glance [Internet].
3. Bhagat V, Kumar S, Gupta M, Bharat R, Kumar V, Jamwal S, et al. Optimizing nitrogen splitting and herbicide use for weed suppression and yield enhancement in wheat (*Triticum aestivum* L.). Plant Science Today. 2025;12(3):1-9.
4. Bhagat V, Kumar S, Kaur K, Singh SK. Response of nitrogen scheduling and weed management on growth and yield attributes of wheat (*Triticum aestivum* L.). Environment Conservation Journal. 2023;24(4):88-95. https://doi.org/10.36953/ECJ.14482441
5. Bhagat V, Kumar S, Patyal D, Kaur K, Manhas T, Thakur S. Weed dynamics and yield of wheat as influenced by N-scheduling and weed management practices. Biological Forum–An International Journal. 2023;15(12):242-6.
6. Diacono M, Rubino P, Montemurro F. Precision nitrogen management of wheat: a review. Agronomy for Sustainable Development. 2013;33(1):219-41. https://doi.org/10.1007/s13593-012-0111-z
7. Jackson ML. Soil chemical analysis. New Delhi: Prentice Hall of India Private Limited; 1973.
8. Luo L, Zhang Y, Xu G. How does nitrogen shape plant architecture? Journal of Experimental Botany. 2020;71(15):4415-27. https://doi.org/10.1093/jxb/eraa187
9. Gautam S, Tiwari U, Sapkota B, Sharma B, Parajuli S, Pandit NR, et al. Field evaluation of slow-release nitrogen fertilizers and real-time nitrogen management tools to improve grain yield and nitrogen use efficiency of spring maize in Nepal. Heliyon. 2022;8(6):e09566. https://doi.org/10.1016/j.heliyon.2022.e09566

10. Jiang Y, Li H, Ma W, Yu W, Chen J, Gao Y, et al. A meta-analysis of the effects of nitrogen fertilizer application on maize (*Zea mays* L.) yield in Northwest China. Frontiers in Plant Science. 2025;15:1485237. https://doi.org/10.3389/fpls.2024.1485237

11. Barad BB, Mathukia RK, Bodar KH, Der HN. Real time nitrogen fertilization using precision tools for enhancing productivity of wheat (*Triticum aestivum* L.). International Journal of Pure and Applied Bioscience. 2018;6(2):434-40. https://doi.org/10.18782/2320-7051.6352

12. Kumar B, Shaloo, Bisht H, Meena MC, Dey A, Dass A, et al. Nitrogen management sensor optimization, yield, economics and nitrogen use efficiency of different wheat cultivars under varying nitrogen levels. Frontiers in Sustainable Food Systems. 2023;9(7):1228221. https://doi.org/10.3389/fsufs.2023.1228221

13. Singh B. Long-term fertilizer nitrogen management in crop production and soil health–a rethinking. Agricultural Research Journal. 2023;60(5):779-81. https://doi.org/10.5958/2395-146X.2023.00111.4

14. Krishnakumar S, Haefele S. Integrated nutrient management and LCC based nitrogen management on soil fertility and yield of rice (*Oryza sativa* L.). Scientific Research and Essays. 2013;8(41):2059-67. https://doi.org/10.5897/SRE2013.5643

15. Timilsina D, Marahatta S. Evaluating leaf color chart-based nitrogen management and tillage methods for improved maize yield, nitrogen use efficiency and economic returns in Chitwan, Nepal. Turkish Journal of Agriculture–Food Science and Technology. 2025;13(8):2048-55. https://doi.org/10.24925/turjaf.v13i8.2048-2055.7625

16. Fayaz S, Kanth RH, Bhat TA, Dar EA, Shah ZA, Bashir M, et al. Estimation of yield and nitrogen use efficiencies in hybrid maize varieties through site specific nitrogen management based on leaf color chart. Scientific Reports. 2025;15(1):4686. https://doi.org/10.1038/s41598-025-89393-3

17. Ram KV, Raj AD, Patel KH. Effect of nitrogen, phosphorus and potassium on yield, quality, nutrient content and uptake on hybrid maize (*Zea mays* L.). Agricultural Science Digest–A Research Journal. 2023;43(3):295-300. https://doi.org/10.18805/ag.D-5546

18. Singh B, Singh V, Singh Y, Kumar A, Vashistha M, Thind HS, et al. Fertilizer nitrogen management in irrigated transplanted rice using dynamic threshold greenness of leaves. Agricultural Research. 2016;5(2):174-81. https://doi.org/10.1007/s40003-016-0213-y

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.