International Journal of Plant & Soil Science

Volume 38, Issue 2, Page 350-357, 2026; Article no.IJPSS.153970
ISSN: 2320-7035

Effect of Nitrogen Dose and Application Timing on Nutrient Dynamics and Soil Fertility in Spring Maize (*Zea mays* L.)

Kailash Chand Verma [a*], Ashok Kumar [b], Manoj Kumar [c] and Ram Dhan Jat [b]

[a] *Department of Agronomy, SKN Agriculture University, Jobner-Jaipur, Rajasthan, India.*
[b] *Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana, India.*
[c] *Department of Agronomy, Agriculture University, Jodhpur, Rajasthan, India.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i25988

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/153970

Original Research Article

Received: 26/12/2025
Published: 05/03/2026

Abstract

Maize requires high nitrogen for optimum yield. However, inappropriate nitrogen dose and timing reduce nutrient content, uptake, and soil health. Hence, evaluate the effect of nitrogen dose and time of nitrogen application on nutrient dynamics and soil fertility in spring maize (*Zea mays* L.). This field experiment was conducted at Regional Research Station, Uchani, Karnal, of CCS Haryana Agricultural University. The experiment consisted of four nitrogen doses (N_1-150, N_2-165, N_3-180 and N_4-195 kg N ha^{-1}) assigned to main plots and four application timing, S_1 -50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation), S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf +

**Corresponding author: E-mail: mahawatkai@gmail.com;*

Cite as: *Verma, K. C., Kumar, A., Kumar, M., & Jat, R. D. (2026). Effect of Nitrogen Dose and Application Timing on Nutrient Dynamics and Soil Fertility in Spring Maize (Zea mays L.). International Journal of Plant & Soil Science, 38(2), 350–357. https://doi.org/10.9734/ijpss/2026/v38i25988*

silking), S_3 -20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) and S_4 - 20% + 30% + 40% + 10% (2 leaf+ 6 leaf +tassel initiation + grain formation) assigned to subplots. The treatments were arranged in a split-plot design with three replications. Results revealed that both nitrogen dose and application timing significantly influenced N, P and K contents in grain and stover as well as their uptake by maize. The highest NPK contents and uptake were recorded with N_4 (195 kg N ha^{-1}), which was statistically at par with N_3 (180 kg N ha^{-1}) and superior to N_2 (165 kg N ha^{-1}) and N_1 (150 kg N ha^{-1}). Among the application timing of nitrogen, S_4 and S_3 (unequal split applications) resulted in higher NPK contents in grain and stover. However, nitrogen uptake by both grain and stover was highest under S_2 (four equal splits) followed by S_1. The highest phosphorus and potassium uptake was recorded under S_4, which was statistically at par with S_2. Application of 195 kg N ha^{-1} recorded the highest residual available nitrogen in soil, which was statistically comparable to 180 kg N ha^{-1}. Available soil phosphorus decreased under higher nitrogen doses (195 and 180 kg N ha^{-1}) compared to lower dose (150 and 165 kg N ha^{-1}). Among application timing, S_3 and S_4 recorded significantly higher available nitrogen and phosphorus than other treatments.

Keywords: Nitrogen dose; application timing; NPK content; uptake; available NPK; spring maize.

1. Introduction

Maize widely referred to as the queen of cereals is one of the most extensively grown and high-yielding staple crops worldwide (Sanodiya *et al.,* 2023). In India, it is cultivated on 10 million hectares, produced about 33.6 million tonnes during 2022–23, with an average productivity of 3349 kg ha^{-1} and contributed 2% to global maize production (GOI, 2023). Despite its high yield potential, maize performance is greatly dependent on soil fertility and the balanced supply of essential nutrients, particularly nitrogen which is most limiting nutrient in Indian soils (Rathwa & Bhanvadia, 2023). Nitrogen is a vital constituent of chlorophyll, amino acids protein and nucleic acid, and plays a key role in photosynthesis, vegetative development, dry matter production and crop productivity (Fathi, 2022). Its deficiency is recognized as one of the major constraints to crop production globally (Fathi & Zeidali, 2021). Moreover, nitrogen in the soil undergoes several transformations and losses through processes such as volatilization, leaching, denitrification and immobilization (Karthika & Vageesh, 2014). These complex dynamics make both the rate and timing of nitrogen application critical for nutrient availability with crop demand while reducing environmental losses (Jassal *et al.,* 2016). The application nitrogen up to 120 kg ha^{-1} significantly increased the uptake of nitrogen and phosphorus by grain which was found at par with 100 kg N ha^{-1} (Sharma *et al.*, 2017). Similarly, application of 120 kg N ha^{-1} significantly improved nutrient uptake and grain yield. Splitting this dose into four equal applications at sowing, 30, 45 and 60 days after sowing increased nitrogen content, uptake and also improved residual soil nitrogen after harvest, whereas, available soil P_2O_5 and K_2O were not significantly influenced (Madagoudra *et al.,* 2021). In another study, maximum total nitrogen uptake was recorded when nitrogen was applied in two splits-25% as a basal dose during seedbed preparation and 75% as top dressing at the V9 stage, which was statistically similar to a 50% basal and 50% V9 split (Niaz *et al.* 2014). In view of the importance of improving NPK contents in grain, straw and uptake. The present investigation was designed to examine the effect of nitrogen dose and application timing on nutrient dynamics and soil fertility in maize (*Zea mays* L.).

2. Materials and Methods

The experiment was conducted during the spring seasons of 2013 and 2014 at the Regional Research Station, Uchani, Karnal, which is part of Chaudhary Charan Singh Haryana Agricultural University. The station is located in a semi-arid, sub-tropical region at 29°43′ N latitude and 76°58′ E longitude with an altitude of 245 m above mean sea level. Mean weekly meteorological data were recorded during the crop seasons (March to July) for both years. The two-year mean weekly maximum temperature ranged from 25.75 °C to 44.55 °C, while the minimum temperature varied between 11.3 °C and 27.75 °C. Total rainfall received during the crop seasons was 169.6 mm in 2013 and 178.8 mm in 2014. The experimental field soil was sandy loam in texture and slightly alkaline in reaction (pH 8.10). It was low in organic carbon (0.36%) and available nitrogen (149.0 kg ha^{-1}), and medium in available phosphorus (11.0 kg ha^{-}

^{1}) and potassium (175.0 kg ha^{-1}). This experiment was laid out in a split plot design with four nitrogen doses in main plots (N_1-150 kg ha^{-1}, N_2-165 kg ha^{-1}, N_3-180 kg ha^{-1} and N_4-195 kg ha^{-1}) and four application timing of nitrogen (S_1-50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation), S_2-25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking), S_3-20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) and S_4-20% + 30% + 40% + 10% (2 leaf+ 6 leaf +tassel initiation + grain formation) in sub plots. The sixteen treatments were comprised with three replications for each treatment. Nitrogen in the form of urea (46% N) was used for the study. Nitrogen was applied at different dose and time based on treatments. Pre-sowing irrigation was applied to the field to facilitate preparatory tillage and seed germination. The seed bed was prepared by two harrowing followed by cultivator twice followed by planking and then opening of furrows in dry condition for dibbling of maize manually. The maize variety HQPM-1 was sown on 5 March and 10 March 2013 and 2014, respectively. Crop was sown using 20 kg ha^{-1} seed by dibbling method on dry ridges apart 60 cm with plant to plant spacing of 20 cm followed by irrigation up to half of the ridge to ensure proper soil moisture for better germination of seed. The recommended rate of phosphorus and potassium nutrients (60 kg ha^{-1}) was applied uniformly to all plots at the time of sowing. SSP and MOP were used as a source of phosphorous and potassium in the form of P_2O_5 and K_2O. The following chemical studies were undertaken during the course of the experiments.

2.1 NPK Contents in Grain and Stover (%)

Representative samples of grain and stover were taken separately from each plot for the estimation of N, P and K content and these samples were oven dried at 70 ºC for 48 hours and powdered by mechanical grinder. Oven dried sample weighed 0.2 g for grain and 0.5 g for stover was digested in diacid mixture of H_2SO_4 and $HClO_4$ in the ratio of 9:1 for NPK estimation. After digestion, a known volume was made with distilled water and filtered through Whatman's filter paper No. 42. Nitrogen content in digested plant material was determined by Modified Kjeldahl's method (Jackson, 1973). Phosphorus and potassium content were determined by Vanadomolybdo phosphoric acid yellow colour method (Koenig & Johnson, 1942) and flame photometric method (Jackson, 1973), respectively.

2.2 NPK Uptake by Grain and Stover (kg ha^{-1})

The N, P and K uptake by maize grain and stover were calculated by using following formula.

$$Nutrient\ uptake\ (kg\ ha-1) = \frac{\text{Nutrient content (\%)} \times \text{ Yield (kg ha} - 1)}{100}$$

2.3 NPK Status of Soil (kg ha^{-1})

The soil samples were collected from 0-15 cm soil profile at the initial and at the end of experimentation period. The soil samples were air dried ground and passed through 2 mm mesh sieve and were analysed for available N, P and K. The available N was estimated by alkaline $KMnO_4$ method suggested by Subbiah and Asija (1956) and expressed in Kg ha^{-1}. The available P content in soil was estimated by Olsen's method (Olsen *et.al*., 1954). Available K was determined using neutral normal ammonium acetate extraction (flame photometer) method as described by Jackson (1973) and expressed in Kg ha^{-1}.

2.4 Statistical Analyses

The data recorded for different parameters were analysed with the help of analysis of variance (ANOVA) technique (Gomez and Gomez, 1983) for split plot design using SAS 9.1 software (SAS Institute, Cary, NC). The Tukey procedure was used where ANNOVA was significant and results are presented at 5% level of significance (P=0.05).

3. Results and Discussion

The results of the present study along with the relevant discussion are summarized under the following headings:

3.1 NPK Contents in Grain and Stover (%)

The data pertaining to NPK contents in grain and stover of maize at harvest differed significantly due to nitrogen dose and application timing during both the years (Table 1). The treatment of N_4 (195 kg N ha^{-1}) was recorded maximum content of N (1.60, 1.57 % in grain and 0.78, 0.75% in stover), P (0.21, 0.17% in grain and 0.15, 0.13% in stover) and K (0.33, 0.31% in grain and 1.49, 1.45% in stover) and it was statistically at par with N_3 (180 kg N ha^{-1}) except in K content than other treatments. Similar findings were reported by Madagoudra *et al.* (2021) and Aulakh *et al.* (2012) reported that higher nitrogen content in grain and stover with higher nitrogen dose. Weisler *et al*. (2001) and Miller *et al.* (1987) and Ghafoor *et al.* (2022) who reported that N, P and K content in maize were higher in high than low nitrogen treatment. The effect of application timing was also significant on NPK content in grain and stover during both the years. NPK content was significantly higher in treatment S_4 - 20% + 30% + 40% + 10% (2 leaf+ 6 leaf +tassel initiation + grain formation) which was at par with treatment of S_3 - 20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) followed by S_2 and S_1. These results corroborated with the findings of Amanullah (2004). Avasthe (2011) reported that nutrient concentrations were influenced by nitrogen fertilization with significant variation between different application schedules.

3.2 NPK uptake by grain and stover (kg ha^{-1})

Nitrogen dose significantly influenced N, P and K uptake in grain and stover during both the years of experimentation (Table 2). The uptake of N, P and K increased with increase in nitrogen dose from N_1 (150 kg N ha^{-1}) to N_4 (195 kg ha^{-1}). The highest uptake of N, P and K by both grain and stover was recorded under N_4 (195 kg ha^{-1}), which was statistically at par with N_3 (180 kg N ha^{-1}). However, both these treatments were significantly superior to N_2 (162 kg N ha^{-1}) and N_1 (150 kg N ha^{-1}). The increased uptake at higher nitrogen levels may be attributed to enhanced vegetative growth, greater dry matter production, improved root proliferation and increased nutrient absorption and translocation from source to sink. Adequate nitrogen availability might have promoted better metabolic activity and nutrient use efficiency, resulting in higher accumulation of N, P and K in both grain and stover. These findings are in close conformity with the results reported by Madagoudra *et al.* (2021) and Sharma *et al.* (2017) for nitrogen and phosphorus uptake.

Table 1. Effect of nitrogen dose and application timing on NPK contents in grain and stover of spring maize

Treatments	NPK content in grain (%)						NPK content stover (%)					
	N content		P content		K content		N content		P content		K content	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Nitrogen dose (kg ha^{-1})												
N_1-150	1.42	1.40	0.16	0.12	0.30	0.27	0.71	0.70	0.11	0.11	1.28	1.25
N_2-165	1.55	1.53	0.18	0.14	0.31	0.28	0.74	0.72	0.13	0.12	1.35	1.32
N_3-180	1.59	1.56	0.20	0.16	0.33	0.30	0.77	0.75	0.14	0.13	1.40	1.38
N_4-195	1.60	1.57	0.21	0.17	0.33	0.31	0.78	0.75	0.15	0.13	1.49	1.45
SEm±	0.01	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.03	0.02
C.D. (0.05)	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.04	0.06
Application timing of nitrogen												
S_1	1.50	1.49	0.17	0.12	0.29	0.27	0.72	0.71	0.12	0.10	1.25	1.22
S_2	1.54	1.50	0.18	0.13	0.31	0.29	0.74	0.72	0.12	0.11	1.33	1.30
S_3	1.56	1.53	0.20	0.17	0.33	0.29	0.76	0.73	0.14	0.13	1.46	1.43
S_4	1.57	1.54	0.21	0.17	0.34	0.30	0.77	0.75	0.15	0.14	1.48	1.45
SEm±	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.02
C.D. (0.05)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.05	0.07

S_1 - 50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation), S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking), S_3 - 20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) and S_4 - 20% + 30% + 40% + 10% (2 leaf+ 6 leaf +tassel initiation + grain formation)

Application timing of nitrogen was also significantly influenced on N, P and K uptake by grain and stover of maize during both years (Table 2). The highest uptake of nitrogen by both grain and stover was recorded with four equal split of nitrogen (S_2) followed by S_1, S_4 and S_3 treatment. The highest P and K uptake were recorded with four unequal split of nitrogen (S_4) which was statistically at par with S_2. However, both these treatments were significantly superior to S_1 and S_3. These findings are in close conformity with the results reported by Madagoudra *et al.* (2021) who observed a significant improvement in nitrogen and phosphorus uptake with higher nitrogen levels and four equal split applications. Sunitha and Reddy (2012) reported that nitrogen and phosphorus uptake significantly influenced by split application of nitrogen. Singh *et al.* (2025) reported that nitrogen use efficiency increased with split application as compared to single based application.

3.3 Available NPK Status of Soil after Harvest (kg ha^{-1})

The available NPK status of soil after harvest was significantly influenced by different nitrogen dose and application timing except in the case of available potassium (K), which remained non-significant after two-year study (Table 3). Among nitrogen doses, application of N_4-195 kg N ha^{-1} recorded higher residual available nitrogen (156.17 kg ha^{-1}), which was statistically at par with N_3-180 kg N ha^{-1} (155.09 kg ha^{-1}) but significantly superior to N_2-165 kg N ha^{-1} (153.44 kg ha^{-1}) and N_1-150 kg N ha^{-1} (152.61 kg ha^{-1}). The increase in residual nitrogen with higher N dose may be attributed to greater addition of nitrogen to the soil system and comparatively lower depletion relative to supply. These findings are in conformity with Madagoudra *et al.* (2021), Niaz *et al.* (2014) and Hassan *et al.* (2010) who reported that total soil nitrogen increased with increasing nitrogen levels. Wang et *al.,* 2024 and Singh *et al.,* 2025 reported that higher nitrogen inputs enhanced residual soil nitrogen status under maize. In contrast, available phosphorus content was lower under higher nitrogen dose (N_4-195 and N_3-180 kg ha^{-1}) compared to lower dose (N_1-150 and N_2-165 kg ha^{-1}).

Similarly, Brar and Bhajansing (1984) observed that total phosphorus status declined where nitrogen alone was applied, while phosphorus buildup occurred with its direct application. Madagoudra *et al.* (2021) reported that varying nitrogen levels did not exert any significant effect on the available phosphorus and potassium status of the soil after harvest of the crop. In case of application timing of nitrogen, treatment S_3 recorded significantly higher available nitrogen

Table 2. Effect of nitrogen dose and application timing on NPK uptake by grain and stover of spring maize

Treatments	NPK uptake in grain (kg ha^{-1})						NPK uptake in stover (kg ha^{-1})					
	N uptake		P uptake		K uptake		N uptake		P uptake		K uptake	
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Nitrogen dose (kg ha^{-1})												
N1-150	68	65	8	6	14	12	49	46	8	7	88	81
N2-165	79	75	9	7	16	14	55	50	10	8	100	92
N3-180	90	85	11	9	19	17	59	55	11	10	108	101
N4-195	93	89	12	10	19	18	62	56	12	10	118	109
SEm±	1.3	1.4	0.3	0.3	0.2	0.4	1.2	0.7	0.4	0.2	2.70	2.2
C.D. (0.05)	4.1	4.2	1.0	1.0	0.5	1.0	3.5	2.0	1.2	0.5	8.0	6.0
Application timing of nitrogen												
S1	83	81	9	7	16	15	55	53	9	7	96	91
S2	87	82	10	7	18	16	58	55	11	10	104	99
S3	76	72	10	8	16	14	53	47	10	8	101	91
S4	82	78	11	9	18	15	57	52	11	10	111	101
SEm±	1.1	0.5	0.2	0.1	0.1	0.1	0.7	0.6	0.2	0.3	2.8	1.2
C.D. (0.05)	3.0	1.4	0.5	0.3	0.4	0.3	2.0	1.6	0.50	0.80	8.0	3.5

S_1 - 50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation), S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking), S_3 - 20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) and S_4 - 20% + 30% + 40% + 10% (2 leaf+ 6 leaf +tassel initiation + grain formation)

Table 3. Effect of nitrogen dose and application timing on available NPK status in soil after two year of study

Treatments	Available N (kg ha^{-1})	Available P (kg ha^{-1})	Available K (kg ha^{-1})
Nitrogen dose (kg ha^{-1})			
N_1-150	152.61	19.89	233.89
N_2-165	153.44	19.09	233.45
N_3-180	155.09	17.44	233.11
N_4-195	156.17	16.11	233.09
SEm±	0.51	0.65	0.70
C.D. (0.05)	1.65	2.10	NS
Application timing of nitrogen			
S_1	154.23	18.04	233.29
S_2	153.55	17.31	232.56
S_3	154.97	18.79	234.04
S_4	154.56	18.39	233.64
SEm±	0.33	0.28	0.55
C.D. (0.05)	1.00	0.87	NS

S_1 - 50% + 25% + 25 % (sowing+ 8 leaf + tassel initiation), S_2 - 25% + 25% + 25% + 25% (sowing+ 4 leaf + 8 leaf + silking), S_3 - 20% + 30% + 40% + 10% (sowing+ 6 leaf + flowering + grain formation) and S_4 - 20% + 30% + 40% + 10% (2 leaf+ 6 leaf +tassel initiation + grain formation)

and phosphorus (154.97 and 18.79 kg ha^{-1}, respectively), which was statistically at par with S_4 (154.56 and 18.39 kg ha^{-1}) and S_1 (154.23 and 18.04 kg ha^{-1}). However, these treatments were significantly superior to S_2 which recorded the lowest available nitrogen and phosphorus (153.55 and 17.31 kg ha^{-1}). These results were agreed with the findings of Madagoudra *et al.* (2021), Hassan *et al.* (2010) and Zheng *et al.* (2023).

4. Conclusion

Based on the findings of the study, it is recommended that nitrogen be applied at doses of 180-195 kg N ha^{-1} to achieve higher nitrogen content in grain and stover along with enhanced total N, P, and K uptake by grain and stover of maize crop. The application of 195 kg N ha^{-1} is effective in improving the available nitrogen status of the soil after harvest. Furthermore, application timing of nitrogen in four unequal splits (S_4 and S_3) recommended to enhancing nitrogen content in grain and stover. The nutrient uptake and available soil nitrogen after harvest, S_2 and S_3 split application strategies were advisable.

Disclaimer

This paper is an extended version of a Thesis document of the same author.

The Thesis document is available in this link: https://krishikosh.egranth.ac.in/server/api/core/bitstreams/f1bf630d-a471-4743-b652-3a9fc302e132/content

[As per journal policy, preprint /repository article can be published as a journal article, provided it is not published in any other journal].

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Acknowledgement

This work is part of my Ph. D research (K. C. Verma), I gratefully acknowledge all the authors whose work has contributed to this study. I am sincerely thankful to CCS Haryana Agricultural University for providing the necessary infrastructural facilities and support during the course of my research.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Amanullah. (2004). *Physiology, partitioning of assimilates and yield of maize as affected by plant density, rate and time of nitrogen application* (Ph.D. thesis). Department of Agronomy, University of Agriculture Faisalabad.

Aulakh, G. S., Vashist, K. K., Sharma, S., & Mahal, S. S. (2012). Productivity, quality and water expense efficiency of late kharif sown hybrid maize (*Zea mays* L.). *Journal of Crop and Weed*, 8(2), 139–142. https://cropandweed.com/assets/upload/upload_files/2012/09/2012_8_2_139-142.pdf

Avasthe, R. (2011). Response of rainfed maize (*Zea mays*) to nitrogen management in mid hill acidic soil of Sikkim. *Indian Journal of Agronomy*, 56, 232–236. https://doi.org/10.59797/ija.v56i3.4684

Brar, S. P. S., & Bhajansingh. (1984). Effect of long term application of N, P, K and zinc on crop and soil in a maize-wheat rotation. *Journal of Research*, 21(3), 349–360.

Fathi, A. (2022). Role of nitrogen (N) in plant growth, photosynthesis pigments, and N use efficiency: A review. *Agrisost*, 28, 1–8. https://doi.org/10.5281/zenodo.7143588

Fathi, A., & Zeidali, E. (2021). Conservation tillage and nitrogen fertilizer: A review of corn growth, yield and weed management. *Central Asian Journal of Plant Science Innovation*, 1(3), 121–142. https://doi.org/10.22034/CAJPSI.2021.03.01

Ghafoor, Q., Rahman, M. H. U., Hasnain, M. U., Ikram, R. M., Khan, M. A., Iqbal, R., Hussain, M. I., & Sabagh, A. E. (2022). Effect of slow release nitrogenous fertilizers on dry matter accumulation, grain nutritional quality, water productivity and wheat yield under an arid environment. *Scientific Reports*, 12, 14783. https://doi.org/10.1038/s41598-022-18867-5

Gomez, K. A., & Gomez, A. A. (1983). *Statistical procedures for agricultural research* (2nd ed.). An International Rice Research Institute book.

GoI, (2023). Economic Survey 2022-23. *Government of India, Statistical Appendise*, 37–39. https://www.indiabudget.gov.in/economicsurvey/doc/Statistical-Appendix-in-English.pdf

Hassan, S. W., Oad, F. C., Tunio, S., Candahi, A. W., Siddiqui, M. H., Oad, S. M., & Jagirani, A. W. (2010). Effect of N application and N splitting strategy on maize N uptake, biomass production and physio-agronomic characteristics. *Sarhad Journal of Agriculture*, 26(4), 551–558. E:\00. Ankita\00. GP\GP\Pending\SDI__8\Galley Proof_2026_IJPSS_153970\Contact supdtsja@aup.edu.pk for a free scan copy of articles published before December 2014 (as per Sarhad Journal of Agriculture archive information)

Jackson, M. L. (1973). *Soil chemical analysis*. Prentice Hall of India Pvt. Ltd., New Delhi.

Jassal, R. K., Singh, A., Kang, J. S., & Singh, T. (2016). Response of fodder maize to different levels of nitrogen under various planting methods. *Indian Journal of Agricultural Research*, 50(4), 340–344. https://doi.org/10.18805/ijare.v0iOF.10780

Karthika, K. S., & Vageesh, T. S. (2014). Effect of different levels of nitrogen on leaf chlorophyll content and performance of maize under varying soil nitrogen status in rainfed Alfisols of Karnataka. *Environment and Ecology*, 32(2), 477–480. https://environmentandecology.com/

Koenig, R., & Johnson, C. (1942). Colorimetric determination of phosphorus in biological materials. *Industrial & Engineering Chemistry Analytical Edition*, *14*(2), 155-156. https://pubs.acs.org/doi/pdf/10.1021/i560102a026

Madagoudra, Y. B., Chaithanya, J., Terin, P., & Lokesh, R. (2021). Effect of rate and time of nitrogen application on nutrient content and uptake in summer maize (*Zea mays* L.) and soil nutrient status after harvest. *International Journal of Economic Plants*, 8(2), 57–61. https://ojs.pphouse.org/index.php/IJEP/article/view/4667

Miller, M. H., Mitchell, W. A., Sathya, M., & Barry, D. A. (1987). Effects of nutrient availability and sub soil density on corn yield and nutrient absorption. *Canadian Journal of Soil Science*, 67, 281–292.

Niaz, A., Yaseen, M., Arshad, M., & Ahmad, R. (2014). Variable nitrogen rates and timing effect on yield, nitrogen uptake and economic feasibility of maize production. *Journal of Agricultural Research*, 52(1), 77–89.

Olsen, B. C., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). *Estimation of available phosphorus in soil by extraction with* *sodium carbonate* (USDA Circular No. 939, pp. 19).

Rathwa, M. K., & Bhanvadia, A. S. (2023). Impact of irrigation scheduling and nitrogen management through drip irrigation system on nutrient content and uptake of rabi maize (*Zea mays* L.). *International Journal of Plant & Soil Science*, 35(23), 345–355.

Sanodiya, P., Tiwari, P., & Gupta, C. (2023). Maize (*Zea mays* L.) – The future potential cereal crop of an indispensable significance in agro-forestry system. *Maize Journal*, 12(2), 61–71. https://www.researchgate.net/publication/373700000_Maize_Zea_mays_L_-The_future_potential_cereal_crop_of_an_indispensable_significance_in_agro-forestry_system

Sharma, R., Choudhary, R., & Jat, B. L. (2017). Effect of nitrogen and zinc fertilization on growth and productivity of maize. *International Journal of Agricultural Sciences*, 13(2), 161–176. https://doi.org/10.15740/HAS/IJAS/13.2/161-176

Singh, A., Uppal, R. S., Singh, B., & Kaur, V. (2025). Effect of split application of nitrogen on growth and yield of maize. *International Journal of Environmental Sciences*, 11(14S), 70–79. https://doi.org/10.64252/qakppx72

Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, 25(8), 259–260.

Sunitha, N., & Reddy, P. M. (2012). Effect of graded nutrient levels and timing nitrogen application on yield and quality of sweet corn (*Zea mays* L.). *Madras Agricultural Journal*, 99(4–6), 240–243. https://doi.org/10.29321/MAJ.10.100055

Wang, N., Ai, Z., Zhang, Q., Leng, P., Qiao, Y., Li, Z., Tian, C., Cheng, H., Chen, G., & Li, F. Impacts of nitrogen (N), phosphorus (P) and potassium (K) fertilizers on maize yields, nutrient use efficiency, and soil nutrient balance: Insights from a long-term diverse NPK omission experiment in the North China Plain. *Field Crops Research*, 318, 109616. https://doi.org/10.1016/j.fcr.2024.109616

Weisler, F., Behrens, T., Horst, W. J., Galloway, J. N., Cowling, E. B., Erisman, J. W., Wisniewski, J., & Joden. (2001). The role of nitrogen efficient cultivars in sustainable agriculture. www.thescientificworld.com

Zheng, Y., Ji, J., & Liu, S. (2023). Effect of topdressing time on spring maize yield and nitrogen utilization in black soil of northeast China. *Scientific Reports*, 13, 11841. https://doi.org/10.1038/s41598-023-38999-x

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2026): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Peer-review history:
The peer review history for this paper can be accessed here:
https://pr.sdiarticle5.com/review-history/153970