
*Journal of Experimental Agriculture International*

***Volume 46, Issue 7, Page 599-609, 2024; Article no.JEAI.118996***
***ISSN: 2457-0591***
*(Past name: American Journal of Experimental Agriculture, Past ISSN: 2231-0606)*

# Role of Nitrogen in Wheat Production System and Nitrogen for Improving Wheat Yield and Quality: A Review

**Akshay Markad [a*]**

[a] *Department of Agronomy, School of Agriculture, Lovely Professional University, Phagwara, Punjab-144002, India.*

***Author's contribution***

*The sole author designed, analysed, interpreted and prepared the manuscript.*

***Article Information***

DOI: https://doi.org/10.9734/jeai/2024/v46i72613

**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://www.sdiarticle5.com/review-history/118996

***Review Article***

***Received: 12/04/2024***
***Accepted: 17/06/2024***
***Published: 24/06/2024***

## ABSTRACT

Wheat is the staple food across the different parts of the world. To increase the wheat productivity by utilizing the fertilizers. Nitrogen plays a key role in increasing productivity and the quality of the crops. In this review article, we studied the relationship between nitrogen and wheat parameters, the impact of excessive nitrogen used in wheat, NUE (Nitrogen use efficiency) in wheat production, and examined various nitrogen management strategies aimed at enhancing both yield and quality. Different nitrogen application techniques, such as broadcast and side-dressing, have been evaluated, with the rate of nitrogen showing a significant influence on wheat parameters. Key components influencing NUE in wheat farming, including soil characteristics, nitrogen application timing and rate, environmental factors, and crop genetics, are discussed. Furthermore, innovative nitrogen management practices such as precision farming techniques, cover cropping, and the use of biofertilizers as effective strategies for improving NUE and promoting sustainable wheat production. The abstract underscores the importance of balancing nitrogen application to meet crop demands at different growth stages while minimizing nitrogen losses and environmental risks. By

---

**Corresponding author: E-mail: akshaymarkad302@gmail.com;*

***Cite as:*** *Markad , Akshay. 2024. "Role of Nitrogen in Wheat Production System and Nitrogen for Improving Wheat Yield and Quality: A Review". Journal of Experimental Agriculture International 46 (7):599-609. https://doi.org/10.9734/jeai/2024/v46i72613.*

integrating advanced technologies, agronomic practices, and scientific insights, farmers can optimize nitrogen use efficiency in wheat production systems, thereby enhancing both yield and quality outcomes.

*Keywords: Nitrogen use efficiency (NUE); wheat production; nitrogen management; yield improvement; quality enhancement.*

## 1. INTRODUCTION

Wheat is a cornerstone of global food security and is cultivated in 89 countries to feed around 2.5 billion people one-fifth of the total world population. it belongs to the family Poaceae, tribe Triticeae, and is considered to be the first ever domesticated crop [1]. India has witnessed a significant transformation in its agricultural sector over the past few decades, with wheat playing a crucial role in the nation's food security and economy [2-5]. The country ranks second globally in wheat production, accounting for approximately 14% of the world's wheat output [6]. Notably, the state of Haryana has shown a positive growth rate in wheat production, particularly from 1980 to 1989, and is recognized for its wheat yield sustainability, ranking second after Punjab [7].

In the upcoming century, climate changes are predicted to occur that will create problems for food security and crop production. As the world grapples with escalating food demands, understanding the nuances of wheat cultivation [8]. The need of the time is to increase the productivity of arable land by utilizing fertilizer supplies for crop cultivation. The application of fertilizers (NPK) is essential to restore the soil nutrients and to reduce the yield gap particularly the role of nitrogen (N), which becomes paramount [9]. Nitrogen, an essential nutrient in plant biology, enhances photosynthetic capacity, growth rates, and seed production, directly influencing wheat yield and quality [10].

Nitrogen (N) is a critical macronutrient for cereal crops, playing a pivotal role in plant growth, development, and yield [11]. It is a key component of amino acids, proteins, chlorophyll, and nucleic acids, which are essential for plant cellular functions and metabolism [12]. Nitrogen use efficiency (NUE) is a measure of how effectively plants utilize available nitrogen, and it is a significant factor in agricultural sustainability and productivity [13]. Nitrogen use efficiency (NUE) is a crucial metric in agriculture that measures the effectiveness of nitrogen utilization in crop production. It involves understanding the relationship between the total nitrogen input and the nitrogen output, focusing on factors like uptake, metabolism, and redistribution of nitrogen within plants. NUE calculations typically consider the ratio of nitrogen output (e.g., grain yield) to nitrogen input (e.g., nitrogen supply from soil, organic manure, and inorganic applications). Achieving high NUE is essential for improving efficiency, profitability, and sustainability in farming practices [14].

The effect of nitrogen use efficiency (NUE) on wheat production is multifaceted, with studies demonstrating that improved NUE can lead to increased wheat yields and sustainability in agricultural systems. Efficient nitrogen management practices, such as precision fertilization and integration with organic amendments, have been shown to enhance wheat yields and NUE parameters [15,16]. Additionally, varietal differences in wheat also influence NUE, with certain varieties exhibiting higher N uptake and utilization efficiencies under varying nitrogen supply conditions [17].

This review aims to synthesize existing literature on wheat cultivation with a focus on optimizing nitrogen use. We will explore mechanisms through which nitrogen efficiency can be enhanced in wheat production, assess the environmental impacts of nitrogen overuse, and discuss sustainable practices that could mitigate adverse outcomes. By integrating findings from key studies (e.g., [10]), this paper will contribute to a nuanced understanding of nitrogen's dual role as both a vital nutrient and an environmental challenge in the context of modern agriculture.

## 2. RELATIONSHIP BETWEEN NITROGEN APPLICATION AND WHEAT CHARACTERISTICS

The relationship between nitrogen (N) application and wheat characteristics is multifaceted, with studies demonstrating that appropriate N fertilization can significantly enhance wheat growth, yield, and nutrient uptake. Controlled-release nitrogen fertilizers (CRNF), such as polymer-coated urea (PCU) and sulfur-coated urea (SCU), have been shown to synchronize nitrogen release with the wheat's nitrogen demand, improving nitrogen use efficiency (NUE) and grain yield when applied twice, at pre-sowing and re-greening stages [18]. Additionally, nitrogen application rates and water quality under water-limited conditions have been found to affect yield productivity and plant growth, with optimal ratios of low-quality water (LQW) and high-quality water (HQW) not significantly decreasing yield when nitrogen is adequately applied [19].

Different nitrogen application techniques, such as broadcast and side-dressing, have been evaluated, with the rate of nitrogen showing a significant influence on wheat parameters, particularly at higher doses up to 180 kg N/ha [20]. Moreover, crop residue management practices combined with nitrogen levels have been observed to increase wheat growth and yield attributes, with the application of 120 kg N/ha yielding the highest growth and nutrient uptake [21]. The interactive effects of tillage and nitrogen fertilization methods have also been studied, revealing that no-tillage combined with nitrogen fertilization significantly increases soil quality attributes and wheat productivity [22].

Sensor-based nitrogen application has been shown to improve plant height and tiller density in wheat crops [23], while a rational application of nitrogen fertilizers, including a reduction in N fertilizer dose and replacement with organic manure, has been found to maintain crop yield and enhance soil biological properties without significant changes in N uptake [24]. However, nitrogen fertilization can also increase the uptake of undesirable elements such as cadmium (Cd) in wheat, indicating a need for careful management of N application rates [25]. Furthermore, the interaction between seed rate and nitrogen fertilization has been studied, with optimal rates of both factors leading to the highest yield and growth parameters in wheat [26]. Lastly, potassium fertilization has been shown to influence the accumulation of macronutrients in wheat, including nitrogen, suggesting that nutrient management should consider the combined effects of multiple fertilizers [27].

## 3. IMPACT OF NITROGEN ON WHEAT YIELD

Increased nitrogen levels, coupled with higher crop densities, were found to suppress weed biomass and improve wheat competitiveness, leading to increased grain yield and spikes per square meter [28], optimal nitrogen rates were associated with increased yields in different tillage practices [29] and genotypic responses to nitrogen application also showed marked significance in yield optimization [30]. However, excessive nitrogen can lead to increased susceptibility to diseases such as powdery mildew and stripe rust, which negatively correlate with yield [31].

Contradictions arise when considering the environmental impact and efficiency of nitrogen use. While higher nitrogen levels generally correlate with increased yield [32], there is a point beyond which no further yield benefits are observed and may even negatively impact nitrogen use efficiency (NUE) and grain quality [33]. Moreover, excessive nitrogen fertilization contributes to greenhouse gas emissions, although certain management strategies can mitigate these effects while maintaining yield benefits [34].

In conclusion, nitrogen fertilization is a critical factor in optimizing wheat yield, with studies indicating that yields improve with increased nitrogen application up to a certain threshold [28,30,20]. However, the relationship between nitrogen and yield is complex, influenced by factors such as crop density, tillage practices, genotype, and disease pressure [28,30,31]. Additionally, the environmental impact and efficiency of nitrogen use must be considered, as excessive nitrogen can lead to diminished returns and increased environmental costs [34]. Therefore, a balanced approach to nitrogen fertilization, tailored to specific conditions and wheat varieties, is essential for sustainable wheat production [30,35,36].

## 4. NUE IN WHEAT PRODUCTION

Nitrogen use efficiency (NUE) in wheat production is a critical factor for optimizing grain yield and quality while minimizing environmental impacts. Studies have shown significant genetic variability in NUE among wheat cultivars, with some genotypes demonstrating superior efficiency in utilizing applied nitrogen [37,38,39]. Nitrogen remobilization efficiency (NRE) and nitrogen utilization efficiency (NUtE) are key components of NUE, with NRE playing a dominant role in cultivars under both low and high nitrogen conditions [39]. Additionally, NUpE and NUtE are important traits contributing to

NUE, with efficient genotypes showing stability across environments [37].

Contradictory findings suggest that while NUE generally increases under low nitrogen conditions, certain traits such as NUtE may decrease as nitrogen supply is increased, stabilizing at a certain threshold [37,39]. Moreover, the relationship between nitrogen accumulation, transport, and yield indicates that improving NUE for grain and biomass production is essential under both irrigated and rainfed conditions [40]. Interestingly, tall wheat varieties have shown higher N uptake and NUE for dry matter production, whereas dwarf cultivars excel in NUE for grain production [41].

In conclusion, enhancing NUE in wheat production involves selecting genotypes with improved NUE traits, particularly under low nitrogen conditions. The identification of genotypes with high NUE is crucial for sustainable wheat production, as it can lead to stable yields across varying environmental conditions and reduce the need for excessive nitrogen fertilization [37,38,40]. Future research should focus on the genetic basis of NUE and the development of breeding strategies that incorporate NUE-related traits to improve wheat cultivars [42].

## 5. LOSS OF NITROGEN USE EFFICIENCY IN WHEAT

Nitrogen use efficiency (NUE) in wheat crops is influenced by various pathways through which nitrogen can be lost, including volatilization, leaching, denitrification, and surface runoff [43]. Gaseous nitrogen loss from wheat plants has been identified, particularly between anthesis and post-anthesis stages, with significant losses occurring in this period [44]. Additionally, the study of winter wheat systems revealed that NUE is higher when wheat is harvested for forage before anthesis, as opposed to grain, due to the avoidance of large nitrogen losses after flowering [45].

Interestingly, while the physiological and molecular mechanisms underlying NUE are being unraveled, such as the identification of differentially expressed genes (DEGs) related to carbon and nitrogen metabolism in wheat genotypes with contrasting NUE [46], the translation of scientific knowledge into farm practice remains limited [47]. Moreover, spatial and temporal variations in NUE have been observed, with state-level NUE in winter wheat showing an increasing trend in recent decades, potentially reducing nitrogen loss from agricultural production [48].

In summary, NUE losses in wheat crops are primarily due to nitrogen volatilization, leaching, and denitrification, with significant losses occurring after the anthesis stage [43,44]. While molecular insights are providing a deeper understanding of NUE [46], there is a gap in applying this knowledge to practical farming to mitigate NUE losses [47]. Efforts to improve NUE should consider the timing of nitrogen applications and the selection of wheat varieties with higher NUE [44,45].

## 6. SUSTAINABLE APPROACHES TO NITROGEN MANAGEMENT IN WHEAT FARMING

Sustainable nitrogen management in wheat farming is a critical concern, given the environmental and economic implications of nitrogen use. The literature suggests that conservation agriculture (CA) practices, including minimal soil disturbance, crop residue retention, and crop rotation, can enhance nitrogen use efficiency and reduce environmental impacts [49,50]. Additionally, integrated farming systems (IFS) that recycle waste as inputs and precision farming techniques that optimize resource use are also highlighted as effective strategies for sustainable nitrogen management [51,52]. Conservation tillage and soil health improvement practices play integral roles in sustainable nitrogen management in wheat farming systems [53].

Interestingly, while conservation agriculture has been shown to reduce ammonia volatilization in wheat [49], it is also associated with increased nitrogen-cycling bacterial communities, which can improve soil health and crop productivity [54]. Furthermore, the integration of eco-friendly agricultural practices, such as biological crop protection and the use of resistant varieties, can contribute to high and sustainable wheat yields, potentially reducing the need for synthetic nitrogen inputs [55].

Sustainable nitrogen management in wheat farming can be achieved through a combination of conservation agriculture, integrated farming systems, and precision farming. These approaches not only improve nitrogen use efficiency but also contribute to the overall sustainability of agricultural systems by enhancing soil health, reducing environmental impacts, and optimizing resource use [49], [51,55,50,54,52]. Adopting such practices is essential for the transition towards more resource-efficient and environmentally friendly agricultural systems.

## 7. BALANCING NITROGEN APPLICATION TO OPTIMIZE YIELD AND QUALITY

Balancing nitrogen (N) application is crucial for optimizing both yield and quality in crop production. Studies indicate that while N is essential for plant growth, its over-application can lead to environmental harm and inefficient use, with only about 50% of applied fertilizer being taken up by plants [56]. Conversely, insufficient N can compromise yield and quality, leading to economic losses [57]. Precision management tools such as leaf color charts and sensor-based technologies can assist in predicting crop N needs, thereby enhancing N use efficiency without reducing yield [56]. Long-term experiments in arid regions have shown that balanced fertilizer treatments, particularly with manure amendments, can stabilize yields and improve N use efficiency [58]. Additionally, optimizing water and N management at the grid scale can contribute to low-carbon agriculture by reducing carbon emissions and improving resource use efficiency [59].

However, there are contradictions in the optimal N application rates for different outcomes. For instance, a study found that 80 kg N $ha^{-1}$ maximized yield performance and maintained acceptable N use efficiency, while 160 kg N $ha^{-1}$ improved grain quality but reduced yield and efficiency [60]. Similarly, strategic N management based on plant available water and soil N can enhance yield, grain quality, and profitability, but the optimal rates vary with soil type and environmental conditions [61]. The interaction between tillage and N fertilization methods also influences soil properties and yield, with no-tillage combined with N fertilization showing promising results [62].

The synchronization of crop demand with N supply using precision tools is key to minimizing N losses and maximizing use efficiency and productivity [56]. Balanced fertilizer treatments, especially those incorporating organic amendments, are recommended for arid regions to ensure yield stability and soil N retention [63]. Regional water and N management approaches can further support carbon neutrality goals in agriculture [59]. Ultimately, the choice of N application rate and method must consider the specific crop, soil, and climatic conditions to achieve the best economic and environmental outcomes [61,57,60,62]. Adopting advanced fertilization methods like surface drip fertilization and optimizing planting density can further enhance yield and resource utilization efficiency [64].

## 8. INNOVATIVE NITROGEN MANAGEMENT PRACTICES FOR MAXIMIZING WHEAT PRODUCTIVITY

Innovative nitrogen management practices are crucial for maximizing wheat productivity while minimizing environmental impacts. The meta-analysis in [65] suggests that nitrogen input and irrigation significantly increase nitrogen partial factor productivity in winter wheat, with the best results achieved under specific nitrogen and irrigation regimes. Wang et al. [66] supports the notion that nitrogen addition improves wheat yield, grain protein content, and water productivity, with the optimal nitrogen rate being 100–200 kg/ha. Chawla and Balasaheb [67] emphasizes the importance of integrated irrigation and nitrogen management strategies for improving wheat crop yields and water use efficiency, highlighting the role of climate, soil, and crop management practices.

Zhang et al. [68] presents the CERES-Wheat model as a tool for evaluating management practices, finding that a nitrogen application of 180 kg $ha^{-1}$ with a specific plant density can optimize yield and nitrogen use under limited irrigation. [69] discusses the benefits of integrated rotation-tillage management on wheat productivity and the farmland environment, while [63] demonstrates that nitrogen fertilizer precision management can significantly reduce nitrogen input and increase yield.

Xin and Tao [70] offers insights into optimizing Genotype × Environment × Management interactions to enhance productivity and eco-efficiency in the North China Plain, recommending specific nitrogen application rates and irrigation levels. [71] highlight the potential of exploiting genotype by management interactions to increase wheat yield potential. suggests that no-tillage, crop residue mulch, and appropriate nitrogen and irrigation management can improve yield and water productivity. Lastly, [72] indicate that urea management with neem formulations or biofertilizers can enhance nitrogen use efficiency in wheat.

The collective information indicates that innovative nitrogen management practices that maximize wheat productivity involve optimizing nitrogen rates, integrating nitrogen with irrigation strategies, considering site-specific factors, and potentially utilizing stabilizing agents like biofertilizers or neem extracts. These practices not only increase yield but also contribute to sustainable agriculture by improving nitrogen use efficiency and reducing environmental risks [71,67,63,69,65,72,66,70].

## 9. INTEGRATING TECHNOLOGY FOR PRECISE NITROGEN APPLICATION IN WHEAT FIELDS

Integrating technology for precise nitrogen application in wheat fields is a critical aspect of modern agriculture, aiming to optimize crop yield and minimize environmental impact [73]. Highlight the economic benefits of sensor-based, site-specific nitrogen application systems over uniform pre-planting applications, demonstrating potential cost savings and yield improvements Similarly, [74] explore precision agriculture methods in grain fields, although the differences in nitrogen doses did not significantly affect yields in the study [75]. Emphasize the role of digital technology in precision agriculture, which includes variable fertilizer dose application, potentially enhancing the efficiency of nitrogen use in wheat fields.

Contradictions arise in the effectiveness of these technologies, as seen in [74], where precision agriculture methods did not lead to significantly different yield results. However, the potential for improved nitrogen application efficiency is supported by the findings in [73] and the technological advancements discussed in [75]. Additionally, [76] suggest that big data analytics and machine learning techniques can further refine precision agriculture practices, potentially improving nitrogen application strategies.

In summary, the integration of technology for precise nitrogen application in wheat fields offers economic and environmental benefits [73,75], although the effectiveness can vary depending on specific conditions and implementation strategies [74]. The advancement of data analytics and machine learning presents opportunities for further optimization of nitrogen application [76]. Overall, the adoption of these technologies in wheat cultivation is a promising step towards more sustainable and productive agricultural practices.

## 10. FUTURE DIRECTIONS IN NITROGEN MANAGEMENT RESEARCH FOR WHEAT PRODUCTION

Future research in nitrogen management for wheat production should focus on optimizing nitrogen use efficiency (NUE) and recovery efficiency of N (REN) to balance crop productivity with environmental sustainability. Studies have highlighted the potential of integrated nutrient management strategies, including the use of organic matter, biofertilizers, and precision nitrogen application, to improve soil health and crop yields [77]. Additionally, advancements in molecular biology may offer avenues for enhancing NUE through breeding strategies that modulate N-responsive growth-metabolism coordination [78].

Contradictory findings suggest that while some nitrogen management practices have a significant impact on wheat yields and NUE parameters [79], others do not show a substantial reduction in N-fertilizer use, although they promote site-specific management [80]. Furthermore, the effectiveness of conservation agriculture (CA) in improving soil nitrogen fractions and wheat yields indicates that CA combined with appropriate nitrogen management can be a viable approach for sustainable wheat production [81].

## 11. CONCLUSION

In conclusion, future research should integrate agronomic practices with technological innovations and molecular breeding to develop sustainable nitrogen management strategies. Emphasis should be placed on practices that enhance NUE and REN without compromising yields, as well as on policies that support the adoption of these practices [82,67,83]. Understanding the interplay between genetic factors and nitrogen management will be crucial for achieving sustainable wheat production in the face of global challenges such as climate change and resource scarcity [84,85].

Overall, a balanced and well-planned nitrogen management approach is crucial for optimizing wheat production, improving grain quality, and ensuring environmental sustainability.

## 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 manuscripts.

## COMPETING INTERESTS

Author has declared that no competing interests exist.

## REFERENCES


1. Mastrangelo AM, Cattivelli L. What makes bread and durum wheat different?. Trends in plant science. 2021;26(7):677-684.
2. Yadav G, Anshuman K, Singh A, Yadav S, Singh P. Impact of Azotobacter and Nitrogen on Growth and Productivity of Wheat (*Triticum aestivum* L.). Int. J. Plant Soil Sci. 2023;35(5):109-15.
[Accessed on: 2024 Jun. 11]
Available:https://journalijpss.com/index.php/IJPSS/article/view/2826
3. Gebreslasie N, Shimgabr T, Alene H, Tsegay N, Haftu W. Effects of Nitrogen on Yield and Yield Components of Wheat (*Triticum aestivum* L.) under NPSB Blended Fertilizer in Tsegedie and Welkait Districts Westren Zone Tigray, Ethiopia. AJSSPN. 2020;6(1):31-8.
Available:https://journalajsspn.com/index.php/AJSSPN/article/view/119
[Accessed on: 2024 Jun. 11]
4. Hawkesford MJ. Reducing the reliance on nitrogen fertilizer for wheat production. Journal of Cereal Science. 2014;59(3):276-83.
5. Basso B, Fiorentino C, Cammarano D, Schulthess U. Variable rate nitrogen fertilizer response in wheat using remote sensing. Precision Agriculture. 2016;17:168-82.
6. Madhukar A, Dashora K, Kumar V. Spatial analysis of yield trends and impact of temperature for wheat crop across Indian districts. International Journal of Plant Production. 2021;15(2):325-335.
7. Devi M, Kumar J, Malik DP, Mishra P. Forecasting of wheat production in Haryana using hybrid time series model. Journal of Agriculture and Food Research. 2021;5:100175.
8. Gupta AK, Agrawal M, Yadav A, Yadav H, Mishra G, Gupta R, Singh P. The Effect of Climate Change on Wheat Production: Present Patterns and Upcoming Difficulties. International Journal of Environment and Climate Change. 2023;13(11):4408-4417.
9. Salim N, Raza A. Nutrient use efficiency (NUE) for sustainable wheat production: A review. Journal of Plant Nutrition. 2020;43(2):297-315.
10. Jensen ES, Carlsson G, Hauggaard-Nielsen H. Intercropping of grain legumes and cereals improves the use of soil N resources and reduces the requirement for synthetic fertilizer N: A global-scale analysis. Agronomy for Sustainable Development. 2020;40(1):5.
11. Fortunato S, Nigro D, Lasorella C, Marcotuli I, Gadaleta A, de Pinto MC. The Role of Glutamine Synthetase (GS) and Glutamate Synthase (GOGAT) in the Improvement of Nitrogen Use Efficiency in Cereals. Biomolecules. 2023;13(12):1771.
12. Zuluaga DL, Sonnante G. The use of nitrogen and its regulation in cereals: Structural genes, transcription factors, and the role of miRNAs. Plants. 2019;8(8):294.
13. Bharati A, Mandal PK. Strategies for Identification of Genes Toward Enhancing Nitrogen Utilization Efficiency in Cereals. Nutrient Dynamics for Sustainable Crop Production. 2020;157-187.
14. Congreves KA, Otchere O, Ferland D, Farzadfar S, Williams S, Arcand MM. Nitrogen use efficiency definitions of today and tomorrow. Frontiers in Plant Science. 2021;12:637108.
15. Li S, Li Z, Bi X, Feng B, Wang Z, Wang F, Liu K. Nitrogen fertilizer management on wheat yield and nitrogen utilization. Journal of Plant Nutrition. 2022;45(13):1953-1960.
16. Rehim A, Khan M, Imran M, Bashir MA, Ul-Allah S, Khan MN, Hussain M. Integrated use of farm manure and synthetic nitrogen fertilizer improves nitrogen use efficiency, yield and grain quality in wheat. Italian Journal of Agronomy. 2020;15(1):29-34.
17. Singh VP, Arora A. Intraspecific variation in nitrogen uptake and nitrogen utilization efficiency in wheat (*Triticum aestivum L.*). Journal of Agronomy and Crop Science. 2001;186(4):239-244.
18. Ma Q, Wang M, Zheng G, Yao Y, Tao R, Zhu M, Zhu X. Twice-split application of controlled-release nitrogen fertilizer met

the nitrogen demand of winter wheat. Field Crops Research. 2021;267:108163.
19. Mahdy AM, Fathi NO, Hafez M. Yield Productivity and Nitrogen Uptake of Wheat Crop Are Highly Dependent on Irrigation Water Availability and Quality under Water-Limited Conditions. Communications in Soil Science and Plant Analysis. 2023; 54(6):836-854.
20. Ullah G, Khan EA, Awan IU, Khan MA, Khakwani AA, Baloch MS, Ullah MM. Wheat response to fertilizer application techniques and nitrogen levels: II. Crop growth and yield attributes. Pakistan Journal of Nutrition. 2013;12(7):636.
21. Shah KA, Tandel BM, Bhimani GJ. Growth, yield and nutrient contents and uptake by wheat as influenced by different residue management practices and nitrogen levels. Intl J Forestry Crop Improv. 2015;6:64-70.
22. Yuan J, Sadiq M, Rahim N, Li G, Yan L, Wu J, Xu G. Tillage strategy and nitrogen fertilization methods influences on selected soil quality indicators and spring wheat yield under semi-arid environmental conditions of the loess plateau, China. Applied Sciences. 2022;12(3):1101.
23. Patel M, Singh M, Kothari M, Chhipa Brij. Importance of sensor-based nitrogen application and effect of growth parameters in wheat crop. International Journal of Agricultural Sciences. 2024;20: 68-74.
DOI: 10.15740/HAS/IJAS/20.1/68-74.
24. Guan GUAN, TU SX, Yang JC, Zhang JF, Li YANG. A field study on effects of nitrogen fertilization modes on nutrient uptake, crop yield and soil biological properties in rice-wheat rotation system. Agricultural Sciences in China. 2011;10(8): 1254-1261.
25. Mitchell LG, Grant CA, Racz GJ. Effect of nitrogen application on concentration of cadmium and nutrient ions in soil solution and in durum wheat. Canadian Journal of Soil Science. 2000; 80(1):107-115.
26. Sarker KK, Hoque M, Chowdhury AP. Combined Effect of Nitrogen Fertilization and Seeding Rate on Regional Wheat Yield and Yield Components in Bangladesh. Asian Research Journal of Agriculture. 2022;15(4):77-85.
27. Kubar G. Effect of potassium (K+) on growth, yield components and macronutrient accumulation in Wheat crop. Pure and Applied Biology. 2018;7(4).
28. Banisaeidi AK, Zand E, Modhj A, Lak S, Baghestani MA. Influence of nitrogen and crop density on spring wheat (*Triticum aestivum L.*) yield, yield components and wild oat (*Avena ludoviciana L*.) suppression; 2014.
29. Feng Y, Ning T, Li Z, Han B, Han H, Li Y, Zhang X. Effects of tillage practices and rate of nitrogen fertilization on crop yield and soil carbon and nitrogen; 2014.
30. Hnizil O, Baidani A, Khlila I, Nsarellah N, Amamou A. Assessing the Impact of Nitrogen Fertilization, Variety Selection, Year and Their Interaction on Wheat Yield and Yield Components. Nitrogen. 2024;5 (2):266-287.
31. Luo X, Keenan TF, Chen JM, Croft H, Colin Prentice I, Smith NG, Zhang Y. Global variation in the fraction of leaf nitrogen allocated to photosynthesis. Nature Communications. 2021;12(1):4866.
32. Bibi S, Saifullah Naeem A, Dahlawi S. Environmental impacts of nitrogen use in agriculture, nitrate leaching and mitigation strategies. Soil Science: Agricultural and Environmental Prospectives. 2016:131-157.
33. Boulelouah N, Berbache MR, Bedjaoui H, Selama N, Rebouh NY. Influence of nitrogen fertilizer rate on yield, grain quality and nitrogen use efficiency of durum wheat (*Triticum durum* Desf) under Algerian semiarid conditions. Agriculture. 2022;12 (11):1937.
34. Guo C, Liu X, He X. A global meta-analysis of crop yield and agricultural greenhouse gas emissions under nitrogen fertilizer application. Science of the Total Environment. 2022;831:154982.
35. Sun Y, Zhu S, Yang X, Weston MV, Wang K, Shen Z, Chen L. Nitrogen diagnosis based on dynamic characteristics of rice leaf image. Plos One. 2018;13(4): e0196298.
36. Yin X, Gu J, Dingkuhn M, Struik PC. A model-guided holistic review of exploiting natural variation of photosynthesis traits in crop improvement. Journal of Experimental Botany. 2022; 73(10):3173-3188.
37. Aga TG, Abera FA, Tufa TB, Abebe KA, Abeyo BG, Ayana NG. Nitrogen use efficiency and genotype-by-environment interaction in durum wheat genotypes under varying nitrogen supply. Archives of Agronomy and Soil Science. 2024;70(1):1-18.

38. Silva CLD, Benin G, Bornhofen E, Todeschini MH, Dallo SC, Sassi LHS. Characterization of Brazilian wheat cultivars in terms of nitrogen use efficiency. Bragantia. 2014;73:87-96.
39. Todeschini MH, Milioli AS, Trevizan DM, Bornhofen E, Finatto T, Storck L, Benin G. Nitrogen use efficiency in modern wheat cultivars. Bragantia. 2016;75:351-361.
40. Jinwen YANG, Yugang SH, Huawei SHI, Yubin WANG, Wanghui GUAN, Xue YAN, Daizhen S. UN. Screening of wheat (*Triticum aestivum L*.) varieties with high nitrogen use efficiency under rainfed and irrigated conditions. Turkish Journal of Field Crops. 2019;24(2):121-131.
41. Singh VP, Arora A. Intraspecific variation in nitrogen uptake and nitrogen utilization efficiency in wheat (*Triticum aestivum L*.). Journal of Agronomy and Crop Science, 2001;186(4):239-244.
42. Guttieri MJ, Frels K, Regassa T, Waters BM, Baenzige PS. Variation for nitrogen use efficiency traits in current and historical great plains hard winter wheat. Euphytica. 2017;213(4):1-18.
43. Govindasamy P, Muthusamy SK, Bagavathiannan M, Mowrer J, Jagannadham PTK, Maity A, Tiwari G. Nitrogen use efficiency—a key to enhance crop productivity under a changing climate. Frontiers in Plant Science. 2023;14: 1121073.
44. Kanampiu FK, Raun WR, Johnson GV. Effect of nitrogen rate on plant nitrogen loss in winter wheat varieties. Journal of Plant Nutrition. 1997;20(2-3):389-404.
45. Thomason WE, Raun WR, Johnson GV. Winter wheat fertilizer nitrogen use efficiency in grain and forage production systems. Journal of Plant Nutrition. 2000; 23(10):1505-1516.
46. Zhang X, Li F, Ding Y, Ma Q, Yi Y, Zhu M, Zhu X. Transcriptome analysis of two near-isogenic lines with different NUE under normal nitrogen conditions in wheat. Biology. 2021;10(8):787.
47. Whetton RL, Harty MA, Holden NM. Communicating nitrogen loss mechanisms for improving nitrogen use efficiency management, focused on global wheat. Nitrogen. 2022;3(2):213-246.
48. Lu C, Zhang J, Cao P, Hatfield JL. Are we getting better in using nitrogen?: Variations in nitrogen use efficiency of two cereal crops across the United States. Earth's Future. 2019;7(8):939-952.
49. Bhaskar KA, Al-Hashimi A, Meena M, Meena VS, Langyan S, Shrivastava M, Singh R. Conservation agricultural practices for minimizing ammonia volatilization and maximizing wheat productivity. Environmental Science and Pollution Research. 2022:1-13.
50. Shrestha JIBAN, Subedi SUBASH, Timsina KP, Chaudhary A, Kandel M, Tripathi S. Conservation agriculture as an approach towards sustainable crop production: A Review. Farming and Management. 2020;5(1):7-15.
51. Kayastha S, Behera A, Sahoo JP, Mahapatra M. Growing Green: Sustainable Agriculture Meets Precision Farming: A Review. Bhartiya Krishi Anusandhan Patrika. 2023;38(4):349-355.
52. Sana N, Mullick S, Bhattacharya K. Integrated farming system-an ecofriendly approach for sustainable agricultural environment. Indian Agriculturist. 2017;61 (3/4):175-180.
53. Six J, Elliott ET, Paustian K. Soil macroaggregate turnover and microaggregate formation: A mechanism for C sequestration under no-tillage agriculture. Soil Biology and Biochemistry. 2004;36(11):1761–1768.
54. Singh U, Choudhary AK, Sharma S. Agricultural practices modulate the bacterial communities, and nitrogen cycling bacterial guild in rhizosphere: Field experiment with soybean. Journal of the Science of Food and Agriculture. 2021;101 (7):2687-2695.
55. Rebouh NY, Khugaev CV, Utkina AO, Isaev KV, Mohamed ES, Kucher DE. Contribution of eco-friendly agricultural practices in improving and stabilizing wheat crop yield: A review. Agronomy. 2023;13(9):2400.
56. Bhusal D, Thaku DP. Precision nitrogen management on crop production: A review. Archives of Agriculture and Environmental Science. 2022;7(2):267-271.
57. Fernandes APG., Machado J, Fernandes TR, Vasconcelos MW, Carvalho SMP. Water and nitrogen fertilization management in light of climate change: Impacts on food security and product quality. Plant Nutrition and Food Security in the Era of Climate Change. 2022:147-178.
58. Li S, Li Z, Bi X, Feng B, Wang Z, Wang F, Liu K. Nitrogen fertilizer management on

wheat yield and nitrogen utilization. Journal of Plant Nutrition. 2022;45(13):1953-1960.
59. Fan Y, He L, Liu Y, Wang S. Spatiotemporally optimize water-nitrogen management of crop planting in response to carbon emissions mitigation. Journal of Cleaner Production. 2022;380, 134974.
60. Ierna A, Lombardo GM, Mauromicale G. Yield, nitrogen use efficiency and grain quality in durum wheat as affected by nitrogen fertilization under a Mediterranean environment. Experimental Agriculture. 2016;52(2):314-329.
61. Fabbri C, Basso B, Napoli M, Dalla Marta A, Orlandini S, Martinez-Feria RA. Developing a tactical nitrogen fertilizer management strategy for sustainable wheat production. European Journal of Agronomy. 2023;144:126746.
62. Yuan J, Sadiq M, Rahim N, Li G, Yan L, Wu J, Xu G. Tillage strategy and nitrogen fertilization methods influences on selected soil quality indicators and spring wheat yield under semi-arid environmental conditions of the loess plateau, China. Applied Sciences. 2022;12(3):1101.
63. Li S, Wang X, Kou C, Lv J, Gao J. Crop Yield, Nitrogen Recovery, and Soil Mineral Nitrogen Accumulation in Extremely Arid Oasis Cropland under Long-Term Fertilization Management. Atmosphere. 2022;13(5):754.
64. Wu L, Zhang G, Yan Z, Gao S, Xu H, Zhou J, Wang K. Optimizing Maize Yield and Resource Efficiency Using Surface Drip Fertilization in Huang-Huai-Hai: Impact of Increased Planting Density and Reduced Nitrogen Application Rate. Agronomy. 2024;14(5):944.
65. Liu BY, Zhao X, Li SS, Zhang XZ, Virk AL, Qi JY, Zhang HL. Meta-analysis of management-induced changes in nitrogen use efficiency of winter wheat in the North China Plain. Journal of Cleaner Production. 2020;251:119632.
66. Wang Y, Peng Y, Lin J, Wang L, Jia Z, Zhang R. Optimal nitrogen management to achieve high wheat grain yield, grain protein content, and water productivity: A meta-analysis. Agricultural Water Management. 2023;290:108587.
67. Chawla R, Balasaheb KS. Optimizing Water Use Efficiency and Yield of Wheat Crops through Integrated Irrigation and Nitrogen Management: A Comprehensive Review. International Journal of Environment and Climate Change. 2023; 13(11):4059-4067.
68. Zhang D, Wang H Li D, Li H, Ju H, Li R, and Li Y. DSSAT-CERES-Wheat model to optimize plant density and nitrogen best management practices. Nutrient Cycling in Agroecosystems. 2019;114:19-32.
69. Li T, Zhao D, Li Y, Wang Z, Wen X, Liao Y. Assessment of the effects of integrated rotation-tillage management on wheat productivity in the Loess Plateau region. European Journal of Agronomy. 2023;149: 126906.
70. Xin Y, Tao F. Optimizing genotype-environment-management interactions to enhance productivity and eco-efficiency for wheat-maize rotation in the North China Plain. Science of the Total Environment. 2019;654:480-492.
71. Adak S, Bandyopadhyay K, Sahoo RN, Krishnan P, Sehgal VK, Kumar SN, Yeasin MD. Interactive effect of tillage, residue, nitrogen, and irrigation management on yield, radiation productivity and water productivity of winter wheat in semi-arid climate. Journal of Agrometeorology. 2023; 25(3):383-391.
72. Sarwar N, Wasaya A, Saliq S, Reham A, Farooq O, Mubeen K, Ghani A. Use of natural nitrogen stabilizers to improve nitrogen use efficiency and wheat crop yield; 2019.
73. Biermacher JT, Epplin FM, Wade Brorsen B, Solie JB, Raun WR. Maximum benefit of a precise nitrogen application system for wheat. Precision Agriculture. 2006;7:193-204.
74. Vrindts E, Reyniers M, Darius P, Gilot M, Sadaoui Y, Frankinet M, Destain MF. Analysis of soil and crop properties for precision agriculture for winter wheat. Biosystems Engineering. 2003;85(2):141-152.
75. Pandey H, Singh D, Das R, Pandey D. Precision farming and its application. Smart Agriculture Automation Using Advanced Technologies: Data Analytics and Machine Learning, Cloud Architecture, Automation and IoT. 2021:17-33.
76. Song C, Ma W, Li J, Qi B, Liu B. Development trends in precision agriculture and its management in china based on data visualization. Agronomy. 2022;12(11):2905.
77. Panhwar QA, Ali A, Naher UA, Memon MY. Fertilizer management strategies for enhancing nutrient use efficiency and

sustainable wheat production. In Organic farming. Woodhead Publishing. 2019:17-39
78. Li S, Huang YZ, Liu XY, Fu XD. Genetic improvement of nitrogen use efficiency in crops. Yi chuan= Hereditas. 2021;43(7): 629-641.
79. Santillano-Cázares J, Núñez-Ramírez F, Ruíz-Alvarado C, Cárdenas-Castañeda ME, Ortiz-Monasterio I. Assessment of fertilizer management strategies aiming to increase nitrogen use efficiency of wheat grown under conservation agriculture. Agronomy. 2018;8(12):304.
80. Ji-Ping D, Jing-Han L, Jia-Huan L, Wei-Feng Z, Xiang-Ping J. ICT-based agricultural advisory services and nitrogen management practices: A case study of wheat production in China. Journal of Integrative Agriculture. 2022;21(6):1799-1811.
81. Thammaiah MK, Sharma VK, Parihar CM, Barman M, Dey A, Chakraborty D. Long term conservation agriculture impact on soil nitrogen fractions and wheat (*Triticum aestivum*) yield in subtropical Inceptisol. The Indian Journal of Agricultural Sciences. 2023;93(8):930-935.
82. Bai N, Mi X, Tao Z, Kang J, He G, Wang Z. China’s nitrogen management of wheat production needs more than high nitrogen use efficiency. European Journal of Agronomy. 2022;139:126557.
83. Grzebisz W, Gaj R, Sassenrath GF, Halloran JM. Fertilizer use and wheat yield in Central and Eastern European countries from 1986 to 2005 and its implication for developing sustainable fertilizer management practices. Communications in Soil Science and Plant Analysis. 2012; 43(18):2358-2375.
84. Gad AB, Shalaby MM, Hassanein HG, Ali EA, Said MT. Effect of preceding crop, rates and splitting of nitrogen fertilizer on bread wheat production and nitrogen use efficiency. Journal of Plant Production. 2018;9(8):663-669.
85. Yu Y, Yang L, Hou P, Xue L, Odindo AO. Nitrogen management in the rice–wheat system of China and South Asia. Sustainable Agriculture Reviews 32: Waste Recycling and Fertilisation. 2018;135-167.



*Peer-review history:*
*The peer review history for this paper can be accessed here:*
*https://www.sdiarticle5.com/review-history/118996*