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Impact of Sowing Techniques and Nano Urea Application on Wheat Growth Dynamics, Yield Potential and Economic Viability: A Comprehensive Review

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

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Review Article

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ABSTRACT

Wheat (*Triticum aestivum* L.) plays a decisive role in ensuring global food security, making the optimization of its production crucial to satisfy the increasing demands of the population. This review explores the effects of various sowing techniques and the application of nano urea on the growth dynamics, yield potential, and economic aspects of wheat cultivation. It assesses modern sowing practices, including zero tillage, ridge planting, and raised bed planting, focusing on their influence on root development, resource efficiency, and overall crop performance in comparison to conventional methods. The use of nano urea, recognized as a sustainable advancement in plant nutrition, is examined for its effectiveness in nitrogen delivery, its potential to minimize environmental impacts, and its role in improving both grain yield and quality. Research indicates that the combination of innovative sowing techniques with nano urea can markedly affect physiological growth metrics, nutrient absorption, and yield characteristics. Furthermore, the economic viability of these approaches, encompassing reductions in input costs and increases in profitability, is analyzed. This comprehensive review offers critical insights for agronomists and policymakers dedicated to enhancing the sustainability and efficiency of wheat production in the face of climate challenges and resource limitations.

Keywords: Nano urea; zero-tillage; ridge planting; raised bed planting; turbo seeder and happy seeder.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) stands as one of the most vital staple crops worldwide, serving as a fundamental source of food and nutrition for millions. Wheat grain is predominantly composed of carbohydrates, which account for approximately 70–75% of its content, primarily in the form of starch (Jayara et al., 2024). And then comes the protein, which includes somewhere between 10 to 15%, and we've got a very small macronutrient contribution from fat which is really around 1 or 2 percent. Additionally, wheat grain contains various vitamins, particularly B-vitamins, as well as essential minerals such as iron and magnesium. The fibers range from 2 to 3 percent and water is in there somewhere between 10 and 15 percent of the grain (Simónet al*.,* 2020 and Khalid et al*.,* 2023). However, it is important to note that a substantial portion of these nutrients is lost during the milling process, particularly with the removal of the bran and germ (Britannica, 2021; Tripathi et al., 2025). The increasing demand for wheat necessitates the exploration of innovative strategies aimed at enhancing its productivity and quality, while concurrently tackling the challenges associated with environmental sustainability and resource constraints (Sarkar et al., 2024). In India, wheat is the second most important cereal crop after rice, grown under sub-tropical environment covering an area of 31.83 million ha. Total production of wheat in India is 113.29 million tonnes, with a productivity of 3559 kg/ha (Agricultural Statisticsat a Glance, 2023). Techniques related to sowing and nutrient management, including the application of nano urea, have emerged as pivotal elements that affect the dynamics of wheat growth, yield potential, and economic feasibility (Tripathi et al., 2024). The methods employed in sowing are critical for optimizing seed placement, root development, and the establishment of crops, which in turn influence both yield and quality. Sowing methods depicted a substantial impact on the performance of various cultivars (Malik et al., 2021). Retaining all residue of combining harvested rice and sowing wheat with turbo seeder implements produced remarkable growth attributes such as plant height and dry matter accumulation, as well as higher yield in terms of seed, straw, and biological yield as compared to sowing with manual sowing methods followed with tillage procedures after the manual harvest of rice (Reddy et al., 2025). Standard broadcasting and manual sowing methods of seedbed preparation often lead to poor seed placement and poor seedling emergence. On the other hand, plant germination rates, root growth, and other plant functions have been found to improve with precision planting and raised bed planting (Sharma et al., 2016). To address these challenges, new sowing practices like zero tillage, precision sowing, and raised bed planting have been developed.These strategies improve plant spacing, minimize resource competition, and improve soil health, all of which contribute to increased yields and sustainability (Jat et al., 2019). Modern technology has also really risen to the occasion with things like the "Happy Seeder," a device that cuts, collects and dispenses stalks of rice that function as mulch right on the soil surface, and this has become really key. When this works alongside the planting of wheat it's kind of an incredible innovation and breakthrough (Sidhu et al*.,* 2015). These new ways of sowing seeds give us great promise—it'll grow bigger yields, it reduces the loss of seed and most important it helps use resources more efficiently too (Singh et al*.,* 2019). Nanotechnology has significantly transformed the field of agriculture. The introduction of nano-fertilizers has resulted in enhanced productivity and lower production costs over the past decade, while also contributing to greater production stability by mitigating both biotic and abiotic stresses. One big thing that sets these nano-fertilizers apart from regular fertilizers that aren't nano is that they dissolve way better. There have been a lot of studies showing that nanoparticles can boost resistance to drought stress issues in plants. They do this by helping plants make more antioxidant enzymes, allowing them to haul in nutrients better, and ultimately grow better (Ahmadian et al., 2021). Traditional urea fertilizers are characterized via their inefficiency and damaging results on the surroundings. but, the arrival of nano-fertilizers, specifically nano-urea, has marked a vast development in nutrient-use performance, necessitating best small utility rates. This development not most effective reduces enter costs however additionally promotes environmental sustainability, resulting in progressed productivity and quality (Kiran and Samal, 2021; Kumar et al., 2021). Studies conducted recently reveal that the use of nano-urea can elevate wheat yield through the enhancement of nitrogen uptake, the promotion of root growth, and the improvement of physiological responses when faced with nitrogen stress (Bhattacharyya et al., 2021). Simultaneously, using nano urea, a totally specific kind of nitrogen fertilizer, has acquired interest due to its ability to beautify nutrient absorption, lessen nitrogen losses, and boom crop output. Nano urea has a smaller particle length, which permits for greater plant absorption at the same time as reducing volatilization and leaching losses (Choudhary et al., 2020). Numerous research have located that the use of nano urea in wheat will increase nitrogen utilization performance, improves boom dynamics, and could growth yields even as maintaining the environmental sustainability of agricultural techniques (Mishra et al., 2020; Soni et al., 2021). The supply of nano urea has verified beneficial influences at the improvement of wheat vegetation. Upadhyay et al., (2023) suggests that the usage of nano urea can enhance early seedling growth, facilitate seed germination, and boom chlorophyll tiers in wheat plants. Additionally, nano urea has been shown to optimize nitrogen metabolism within wheat, resulting in heightened protein synthesis and overall biomass accumulation (Al-Juthery et al*.*, 2019; Astaneh et al., 2021).The application of nano urea as a foliar spray during the jointing stage of wheat cultivation led to a marked increase in both yield and economic returns. This enhancement was evident in various metrics, including grain yield (kg ha^{-1}), straw yield (kg ha^{-1}), biological yield (kg ha^{-1}), gross returns (₹ ha^{-1}), and net returns (₹ ha^{-1}) (Bala et al., 2024). Harvest index, grain yield per plant, flag leaf width and leaf rolling showed the highest factor loadings for PC1. As a result of the foregoing data and analysis, it is possible to conclude that there is great potential for effective genetic improvement for grain yield and correlated traits in the present wheat genotypes (Kumar et al*.*, 2024). The purpose of this review isto take a look at how opportunity sowing techniques and nano urea packages affect wheat production, with an emphasis on increase dynamics, yield ability, and economic viability. This paper will take a look at the modern-day literature to highlight accomplishments and problems in those areas, and recommended for future research alternatives to enhance wheat manufacturing performance and sustainability.

2. SOWING TECHNIQUES

2.1 Broadcasting

Broadcasting includes dispersing seeds across the soil floor, observed through light soil coverage via plowing or harrowing. This approach is labor-extensive, but drastically used due to the fact to its simplicity and minimal preliminary value. however, it often leads in uneven seed dispersal, which reduces plant density and increases inter-plant opposition for vitamins and water. studies have indicated that broadcasting can bring about yield decreases of up to 15-20% while compared to precision techniques (Kaur et al., 2020). furthermore, broadcasting is extra prone to environmental conditions such as wind and water erosion, which can obstruct seed distribution and germination (Singh et al., 2017).

2.2 Drilling

Drilling is a mechanical sowing technique where seeds are placed at uniform depth and spacing using a seed drill. This method ensures better seed-soil contact, resulting in uniform germination and robust root development. Research indicates that drilling improves wheat yield by 10-20% compared to broadcasting due to enhanced resource-use efficiency (Sharma et al., 2019). Additionally, drilling facilitates the precise application of fertilizers alongside seeds, promoting synchronized nutrient availability and uptake (Yadav et al., 2021). The efficiency of drilling also reduces weed proliferation by optimizing plant spacing, which restricts the available area for weed growth.

2.3 Zero-Tillage

Zero-tillage or no-till farming practice is one such conservation agriculture practice that minimizes soil disturbances. Seeds are planted directly into unplowed soil, using appropriate machinery. Zero-tillage helps in soil erosion reduction, preserving soil structure with enhanced organic matter content in the soil (Verhulst et al., 2011). Such reports of better yields range between 15 to 25% as compared to conventional methods, accompanied by substantial reductions in production costs and greenhouse gas emissions (Erensteinet al*.,* 2012). Improved soil moisture storage under such conditions, particularly arid and semi-arid regions, is an added factor that enhances the resilience of the crop productivity to the stress of drought (Lal et al*.,* 2015). Direct seeding, or no-till farming, defines the planting of seeds directly into undisturbed soil. This technique will help in saving soil moisture besides fewer occurrences of erosion on the soil. Research indicates that direct seeding can boost wheat production by improving soil structure while simultaneously lowering labor and fuel expenses (Singh et al*.,* 2018). Furthermore, this method reduces soil compaction, which facilitates better root growth and nutrient absorption (Feng et al*.,* 2019).

2.4 Precision Planting

Precision planting employs advanced technologies, such as GPS-guided seeders, to achieve optimal seed spacing and depth. This approach enhances resource efficiency while fostering uniform crop growth. Despite the higher initial investment associated with precision planting, it yields significant long-term advantages, including increased crop yields and reduced input costs. Research has demonstrated that precision planting can elevate wheat yields by 20-30% (Zhang et al., 2018). Furthermore, when integrated with real-time monitoring systems, precision planting allows farmers to adjust sowing parameters dynamically, thereby adapting to fluctuating field conditions (Mulla, 2013). These technological advancements significantly enhance the accuracy and effectiveness of agricultural management practices. Fountas, S., et al. (2006)analyzed offers insights into different precision agriculture tools, including GPS, variable rate technology, and soil sensors, particularly highlighting their relevance to the practice of wheat farming.Grewal, R. (2020)investigates the latest developments in precision agriculture, with a particular emphasis on wheat cultivation, and examines how forthcoming innovations in automation and data analytics may improve production efficiency. Pivoto, D., et al. (2017)analyzed the positive impacts of precision agriculture on wheat production, notably underscoring the significance of yield mapping tools, fertilizer management strategies, and precision irrigation systems.Research examines the application of precision agriculture in the context of sustainable wheat cultivation, with a particular emphasis on the challenges and opportunities associated with the implementation of precision techniques in various geographical areasLiu, W., et al. (2021).

2.4.1 The role of nano urea in precision agriculture

Precision agriculture focuses on optimizing the use of inputs such as water, fertilizers, and pesticides to increase crop productivity while minimizing environmental impact. Nano urea fits well within this framework by allowing for more targeted and efficient fertilizer application.

Fertigation and Foliar Application: Nano urea can be applied through fertigation (irrigation systems) or foliar spraying. Both methods ensure better coverage and absorption of nitrogen by plants. Research has shown that foliar application of nano urea can significantly increase wheat yield, especially during the critical reproductive phases (Mahajan et al., 2021).

Integration with Other Precision Technologies: Nano urea application can be integrated with other precision agriculture tools such as sensors, drones, and remote sensing technologies to monitor crop nutrient requirements and adjust fertilizer application in real-time. This integration enhances the efficiency of nutrient use, reduces waste, and contributes to sustainable farming practices Prasad et al*.,* 2022).

2.5 Raised Bed Planting

Raised bed planting involves sowing seeds on elevated beds separated by furrows. This method improves drainage and aeration, making it particularly suitable for waterlogged areas or regions with heavy soils. Raised bed planting also facilitates efficient irrigation by directing water flow through furrows, reducing wastage and ensuring uniform water distribution (Sayre et al., 2005). Research has indicated that raised bed planting can enhance wheat yield by 15-25%, primarily due to improved root zone conditions and reduced risks of soil-borne diseases (Hobbs et al., 2008).Sundaravadivelu, M., et al. (2017)examine raised bed planting contributes to better soil aeration, which is vital for the optimal growth of roots. This improved root system enables plants to access water and nutrients more effectively.A raised bed system can support the management of weeds by limiting soil disturbance and enabling more efficient application of weed control methods, such as mulching and herbicide treatments (Bajwa, A., and Lal, R., 2012). Research carried out in Pakistan indicated that the implementation of raised bed systems for wheat cultivation led to a yield increase of approximately 20% in comparison to traditional flat planting methods. This enhancement in productivity was particularly pronounced when these systems were integrated with advanced irrigation management practices. Furthermore, the study emphasized the lower water usage associated with raised bed systems, contributing to a more sustainable approach to wheat production **(**Javed, S., et al*.,* 2019).

3. NANO UREA: A SYSTEMATIC OVERVIEW

Nano urea exhibits significant nitrogen efficiency and is considered environmentally sustainable. Often referred to as "smart fertilizer," it effectively diminishes nitrous oxide emissions, which are major contributors to the pollution of soil, air, and aquatic ecosystems. Additionally, it plays a role in mitigating global warming. These characteristics position nano urea as a viable alternative to traditional urea fertilizers (Kannoj et al*.,* 2022).

Mode of Action and Characteristics: Nano urea is made up of nitrogen particles that are smaller than 100 nanometers. This tiny particle size enhances the surface area and reactivity of nitrogen, allowing for fast absorption through leaf stomata and direct transfer to chloroplasts (Prasad et al., 2020). Nano urea also triggers a slow release of nitrogen, matching the crop's growth demands and minimizing nitrogen losses. Nano-urea particles possess a reduced size, which facilitates more effective interactions with plant root systems. These nanoparticles gradually release nitrogen, ensuring a sustained nutrient supply to the plants, thereby improving nitrogen use efficiency (NUE) (Kumar & Garg, 2023). The regulated release of nitrogen guarantees a continuous availability, thereby averting nutrient shortages and promoting comprehensive plant development. This is especially advantageous for crops such as wheat, which necessitate a reliable nitrogen supply throughout the growing period (Verma & Bansal, 2020).

Growth Dynamics: The findings demonstrate that the application of nano urea resulted in notable changes in the height of wheat plants at 50, 75, and 100 days after sowing (DAS), as well as at the maturity stage. Among the various treatments, those that received the recommended dose of nitrogen (RDN) in conjunction with two applications of nano urea during the tillering and jointing phases exhibited consistently greater plant heights throughout all growth stages, with the exception of 25 DAS. At this particular stage, the height was statistically similar to that of the tallest plants observed in the treatment group that received RDN along with two applications of 5% urea at the tillering and jointing stages (Chaudhary, et al*.* 2023 &Rani et al**.,** 2024). The application of nano urea has been shown to significantly enhance vegetative growth in wheat. Studies indicate that nano urea increases chlorophyll content, leaf area index (LAI), and photosynthetic efficiency, leading to robust plant development (Ramesh et al., 2021). Improved nitrogen availability accelerates tillering and stem elongation, critical growth stages for wheat productivity.

Yield Potential: Nano urea has demonstrated substantial improvements in wheat yield parameters, including grain weight, spike length, and number of grains per spike. Field trials conducted by Choudhary et al*.*, (2022) reported a 10-15% increase in grain yield with nano urea application compared to conventional urea. This yield enhancement is attributed to better nitrogen assimilation and reduced stress-induced losses.

Environmental Impact: One of the most significant advantages of nano urea is its reduced environmental footprint. By minimizing nitrogen losses through leaching and volatilization, nano urea lowers greenhouse gas emissions and water contamination. Studies have shown that nano urea reduces nitrous oxide emissions by up to 50% compared to conventional urea, making it a key component of climate-smart agriculture (Lal et al*.,* 2020).

- **Reduction in Nitrogen Loss**: One of the major environmental issues associated with conventional urea application is nitrogen loss due to volatilization, leaching, and denitrification. Nano urea’s slow-release nature helps to mitigate these issues, resulting in a reduction in nitrogen runoff and lower greenhouse gas emissions, contributing to environmental sustainability (El-Sayed et al., 2020).
- **Water Use Efficiency**: Advanced sowing methods such as zero tillage and direct seeding have been shown to improve water use efficiency. These techniques conserve soil moisture and reduce the need for irrigation, which is especially important in regions facing water scarcity (Shao et al., 2021). When combined with nano urea, which optimizes nutrient uptake, these practices can significantly enhance water productivity in wheat production.
- **Carbon Footprint**: The carbon footprint of wheat production is another concern that has been mitigated by the adoption of these technologies. The reduced need for nitrogen fertilizers, coupled with the water conservation benefits of zero-tillage and direct seeding, can lower the overall carbon emissions associated with wheat farming (Hussain et al., 2020). Additionally, nano urea’s ability to improve crop yield with lower nitrogen inputs further reduces the environmental impact of wheat cultivation.

Economic Viability: Nano urea offers considerable economic benefits for wheat farmers. Its higher NUE reduces the quantity of fertilizer required, lowering input costs. Additionally, the yield gains from nano urea application enhance overall profitability. A cost-benefit analysis by Yadav et al*.* (2021) indicated a 25-30% increase in net returns with nano urea compared to traditional fertilizers.

Integration of Sowing Techniques and Nano Urea: The integration of optimal sowing techniques with nano urea spray provides synergistic benefits to wheat productivity. For example, zero-tillage paired with nano urea enables optimal nitrogen consumption and soil conservation, whilst precision planting improves nitrogen absorption by maximizing root growth. Future study should concentrate on region-specific studies to improve these integrated practices even more.

4. CHALLENGES AND FUTURE PROSPECTS

4.1 Challenges

Adoption of Precision Sowing Techniques: There exists a significant gap in farmers' awareness regarding modern sowing methodologies, including zero tillage, raised bed planting, and precision planting. The substantial initial investment required for precision agricultural equipment and machinery renders these technologies largely unattainable for smallholder and marginal farmers.

Nano Urea Efficacy: Research on the long-term impacts of nano urea on wheat growth dynamics, soil health, and microbial activity remains limited and under-validated in field conditions. Additionally, challenges persist in achieving uniform application and determining the correct dosage to optimize benefits while avoiding negative repercussions.

Environmental and Regulatory Concerns: The potential for environmental contamination or unintended ecological impacts due to the overuse or misuse of nano urea raises significant concerns. Furthermore, there are regulatory challenges associated with the approval and standardization of nano urea products for broader agricultural implementation.

Soil and Climate Variability: The effectiveness of both sowing techniques and nano urea is subject to considerable variation based on soil characteristics, climatic conditions, and water availability, which complicates their widespread adoption.

Integration with Conventional Practices: Integrating innovative sowing techniques and the application of nano urea with established farming practices and traditional nutrient management approaches presents notable difficulties**.**

Knowledge Gap and Training: There is a lack of adequate extension services and training initiatives aimed at informing farmers about the advantages and proper application techniques for nano urea and modern sowing practices.

4.2 Future Prospects

Technological Advancements: Technological advancements include advanced sowing instruments equipped with sensors and AI for precision planting and fertilizer application. Enhanced nano urea formulations for greater effectiveness and precise nutrition delivery.

Research and Development: Comprehensive research on the long-term effects of nano urea on crop physiology, soil fertility, and environmental sustainability. Development of region-specific sowing techniques and nutrient management protocols tailored to diverse agro-climatic zones.

Policy and Subsidies: Government initiatives to provide subsidies for nano urea and precision sowing equipment, making them affordable for small-scale farmers. Policies to incentivize the adoption of sustainable and efficient agricultural practices.

Sustainable Agriculture: To improve soil health, integrate nano urea with other sustainable nutrient management techniques such as organic amendments and biofertilizers. To enhance resource efficiency, promote conservation agricultural methods such as decreased tillage and residue retention.

Capacity Building and Farmer Engagement: Developing farmer training centers and demonstration sites to highlight the advantages of improved planting techniques using nano urea. Use digital platforms and mobile applications to provide real-time advice and guidance on nano urea application and planting methods.

Global Collaboration: Collaborationamong research centers, industry, and policymakers throughout the world to promote innovation and information exchange in nano fertilizers and precision agriculture.

5. CONCLUSION

The examination of sowing techniques and the application of nano urea in wheat cultivation provides valuable insights into enhancing growth dynamics, yield potential, and economic feasibility. Various sowing methods, including broadcasting, line sowing, and zero tillage, significantly affect root development, nutrient absorption efficiency, and water management, all of which are essential for optimizing wheat productivity. Nano urea, recognized as an innovative advancement, improves nitrogen utilization efficiency by facilitating more effective nutrient delivery during critical growth phases. This approach mitigates environmental nitrogen losses while sustaining or even enhancing wheat yields. From an economic standpoint, the synergistic application of refined sowing methods and nano urea has been shown to decrease production costs and increase net returns for farmers. Future investigations and field experiments should aim to refine these methodologies across various agro-climatic contexts to promote widespread adoption and ensure the long-term sustainability of wheat production systems.

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 the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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