***Review Article***

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

**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

**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 is a significant source of various nutrients, comprising approximately 70% carbohydrates, 10-12% protein, 2.0% fat, 1.8% minerals, 12% water, and 2.2% crude fiber. Additionally, it contains vitamins such as thiamin, riboflavin, niacin, and trace amounts of vitamin A. 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). 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. In India, wheat is the second most important cereal crop after rice, grown under sub-tropical environment covering an area of 30.47 million ha. Total production of wheat in India is 106.84 million tonnes, with a productivity of 3507 kg/ha (Anonymous, 2022).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. 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. (Malik *et al*., 2021) studies that sowing methods showed a substantial impact on the performance of various cultivars. Sowing wheat with turboseeder after retaining all of the residue of combine harvested rice resulted in significantly higher growth attributes (plant height, dry matter accumulation) and yield (seed, straw, and biological yield) than sowing with conventional tillage conditions after manual harvested rice. Conventional sowing practices, such as broadcasting and manual sowing, frequently result in uneven seed distribution and suboptimal emergence rates. Conversely, contemporary methods like precision planting and the utilization of raised beds have demonstrated improvements in germination rates, root development, and overall plant performance (Sharma *et al*., 2016). Advanced sowing techniques, including as precision sowing, zero tillage, and raised bed planting, have evolved as solutions to these difficulties. 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 such as the "Happy Seeder" to cut, carry, and dump the rice straw on the soil surface as mulching material while combined with wheat crop planting, has emerged as an essential alternative (Sidhu *et al*., 2015).These innovative sowing practices hold the promise of maximizing yield, minimizing seed loss, and enhancing the efficiency of resource utilization (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. A key characteristic of these nano-fertilizers is their superior solubility compared to conventional non-nano fertilizers. Various studies have indicated that the use of nanoparticles can bolster plant resistance to drought stress by stimulating antioxidant enzyme activity, improving nutrient uptake, and promoting overall plant growth (Ahmadian *et al*., 2021).Conventional urea fertilizers are characterized by their inefficiency and detrimental effects on the environment. However, the advent of nano-fertilizers, particularly nano-urea, has marked a significant improvement in nutrient-use efficiency, necessitating only small application rates. This development not only reduces input costs but also promotes environmental sustainability, resulting in improved 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, the use of nano urea, a unique type of nitrogen fertilizer, has received interest due to its potential to boost nutrient absorption, reduce nitrogen losses, and increase crop output. Nano urea has a smaller particle size, which allows for greater plant absorption while reducing volatilization and leaching losses (Choudhary *et al*., 2020). Several research have found that using nano urea in wheat increases nitrogen usage efficiency, improves growth dynamics, and increases yields while maintaining the environmental sustainability of agricultural techniques (Mishra *et al*., 2020; Soni *et al*., 2021).The application of nano urea has demonstrated beneficial impacts on the development of wheat crops. Research conducted by Upadhyay *et al*. (2023) indicates that the utilization of nano urea can enhance early seedling growth, facilitate seed germination, and increase chlorophyll levels 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).The purpose of this review is to look at how alternative sowing procedures and nano urea applications affect wheat production, with an emphasis on growth dynamics, yield potential, and economic viability. This paper will examine the current literature to highlight accomplishments and problems in these areas, as well as recommend future research options to improve wheat production efficiency and sustainability.

**Sowing Techniques**

**1. Broadcasting**

Broadcasting involves dispersing seeds across the soil surface, followed by light soil coverage via plowing or harrowing. This approach is labor-intensive, yet extensively used because to its simplicity and minimal initial cost. However, it frequently leads to uneven seed dispersal, which reduces plant density and increases inter-plant competition for nutrients and water. Studies have indicated that broadcasting can result in yield decreases of up to 15-20% when compared to precision approaches (Kaur *et al*., 2020). Furthermore, broadcasting is more vulnerable to environmental conditions such as wind and water erosion, which can impede seed distribution and germination (Singh *et al*., 2017).

**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.

**3. Zero-Tillage**

Zero-tillage, or no-till farming, is a conservation agriculture practice that minimizes soil disturbance. Seeds are directly sown into unplowed soil using specialized machinery. Zero-tillage preserves soil structure, reduces erosion, and improves soil organic matter content (Verhulst *et al*., 2011). Studies have reported yield gains of 15-25% with zero-tillage compared to conventional methods, along with significant reductions in production costs and greenhouse gas emissions (Erenstein*et al*., 2012). Additionally, zero-tillage has been shown to improve soil moisture retention, particularly in arid and semi-arid regions, thereby enhancing crop resilience to drought stress (Lal *et al*., 2015).Direct seeding, also known as no-till farming, refers to the practice of planting seeds directly into undisturbed soil. This approach is beneficial for conserving soil moisture, mitigating soil erosion, and enhancing the organic matter content of 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).

**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).

**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).

**Integrationwith 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).

**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).

**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.

**Challenges and Future Prospects:-**

**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.

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

**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.

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