REVIEW ARTICLE

Impact of zero tillage and nutrient management practices on productivity of wheat in indo gangetic plains: An overview

Deovrat Singh*, Ambreesh Singh Yadav, Saba Siddiqui, Shipra Yadav, and Sanket Kumar

DOI: 10.18811/ijpen.v11i01.05

Abstract

Wheat cultivation is a basis of agricultural systems of India predominantly in the Indo-Gangetic Plains (IGP) or the Great Plains of North India, which is crucial for food security in South Asia. The primary constraints to wheat grain production include inefficient tillage operations, bed preparation, production of late-maturing paddy cultivars, scarcity of water, insufficiency of labor, high fertilizer costs, and suboptimal crop management operations. Tillage is a pivotal agricultural tool for soil manipulation and crop yield enhancement. Various tillage methods are employed in paddy-wheat cropping systems, viz., intensive, traditional, deep and conservation tillage practices such as zero and minimum tillage, etc. Zero tillage provides an efficient and manageable planting method that enables well-timed wheat cultivation, eliminates the requirement for tillage operations, and enhances crop or biomass residue management. This approach reduces production costs and maintains environmental cleanliness. Specifically, zero tillage reduces operational costs for wheat planting by 50 to 60% compared to conventional sowing methods. The main factor driving the adoption of zero tillage technology is expense minimization. Moreover, ensuring an effective nutrient management strategy through the combined use of chemical fertilizers, organic amendments, and biological resources is critical. However, advancing knowledge about the importance of essential nutrients in crop physiology and their impact on qualitative and quantitative components of cereal crops, particularly in wheat, is necessary. Balanced fertilizer application is critical for improving wheat yield, quality, and agronomic traits. Thus, integrating zero tillage with appropriate fertilizer management is crucial for optimizing wheat production. This study reviews zero tillage and nutrient management practices in wheat and examines their impacts on growth, quality and yield-related associated indices.

Highlights

- Zero tillage (ZT) conserves 13–35% of irrigation water.
- Yield is increased by 27–31% compared to conventional tillage.
- It improves soil quality and shifts weed dynamics toward broad-leaved species.
- The integrated use of organic inputs enhances soil health, nutrient uptake, and wheat growth, ensuring sustainable productivity.

Keywords: Wheat, Growth, Zero tillage, Integrated nutrient management, Yield.

International Journal of Plant and Environment (2025); **ISSN:** 2454-1117 (Print), 2455-202X (Online)

Introduction

Wheat is a globally significant cereal crop, serving as a primary source of flour, pasta, semolina, pastries, chapatti, cookies, and other processed products. It constitutes approximately 35% of the global population's dietary intake as a staple food (Mohammadi-Joo *et al*., 2015). In 2019-2020, global wheat production was estimated at 765.41 million metric tons (Shabandeh *et al*., 2020). To address the dietary needs and demands of the world's growing population, boosting wheat production is essential. Historically, the Industrial and Green Revolutions drove the extensive use of synthetic fertilizers to enhance crop yields per unit area (Chandini *et al*., 2019). However, indiscriminate fertilizer application has resulted in suboptimal nutrient management.

Studies in the Indo-Gangetic Plains (IGP) revealed a tendency among farmers to overuse nitrogen (N) and phosphorus (P) but overlook potassium (K) along with other essential secondary and micronutrients (Singh *et al*., 2005). This imbalance not only reduces the nutrient use efficiency (NUE) and benefit-cost ratio as well as intensifies environmental dilemmas, including nutrient losses via leaching or gaseous emissions, thereby increasing agriculture's contribution to greenhouse gas (GHG) emissions. Consequently, refining wheat production systems is imperative to achieve higher yields with reduced input costs and minimized environmental impacts through efficient use of land, labor, nutrients, water, and agrochemicals.

Zero tillage (ZT) has emerged as a promising strategy for sustainable wheat production, particularly in intensively cultivated regions such as northwest India. This system, characterized by minimal soil disturbance and efficient crop rotations along with permanent soil cover, addresses critical challenges in intensified wheat systems (Saharawat *et al*., 2010). It enables timely wheat planting after delayed rice harvests and promotes residue retention, which further contributes to

Department of Agriculture, Integral Institute of Agricultural Science and Technology (IIAST), Integral University, Lucknow, Uttar Pradesh, India.

***Corresponding author:** Deovrat Singh, Department of Agriculture, Integral Institute of Agricultural Science and Technology (IIAST), Integral University, Lucknow, Uttar Pradesh, India., Email: deovratsingh1998@gmail.com

How to cite this article: Singh, D., Yadav, A.S., Siddiqui, S., Yadav, S., Kumar, S. (2025). Impact of zero tillage and nutrient management practices on productivity of wheat in indo gangetic plains: An overview. International Journal of Plant and Environment. 11(1), 41-47.

Submitted: 23/11/2024 **Accepted:** 21/02/2025 **Published:** 28/03/2025

soil health improvement (Sharma *et al.*, 2012). Despite these advancements, optimal nutrient management under ZT with varying levels of surface residues remains poorly understood. Addressing these gaps offers a significant opportunity to enhance yield potential, profitability, and nutrient use efficiency within ZT-based wheat systems. Therefore, future exploration should be focussed on refining nutrient management practices tailored to ZT conditions to optimize resource use and bolster the sustainability of wheat production systems.

Zero Tillage in wheat

Rather than plowing, zero tillage keeps crop residues on the soil surface. Instead of plowing, zero tillage leaves crop leftovers on the land surface. Erenstein *et al.,* (2008) characterize zero tillage as "no-till farming, direct seed placement, direct planting, direct sowing and direct drilling". Surface seeding is an uncomplicated method for farmers with constrained resources bypasses the need for both machinery and land preparation. In the IGP, the dominant zero-till technique relies on a tractor-mounted zero-till seed drill to directly plant wheat seeds onto unploughed fields in one pass of the tractor. Despite its benefits, it is still primarily limited to low-lying areas, and excessively wet areas unsuitable for tractors, notably in the Eastern Indo-Gangetic Plains.

In these plains, zero tillage includes three distinctive key aspects making it unique compared to similar approaches in other areas (Erenstein, 2003). The first aspect is a double-cropped system of wheat is generally sown with ZT, whereas the succeeding rice crop continues to involve heavy tillage. Second, because paddy fields are mostly free of weeds at harvest, an increased need for herbicide is not inherently implied by ZT wheat following rice. Third, the retention of crop remainder is not always guaranteed with ZT wheat. Indian zero-tillage seed drills generally demonstrate suboptimal trash handling, but this was not viewed as a major concern given the minimal residue left from the wheat crop after the dominant rice crop and common residue management methods (Erenstein *et al.,* 2007b).\

Effect of zero tillage on water use

Compared to conventional tillage, zero tillage in wheat farming conserves 20 to 35% more irrigation water, equating to a reduction of roughly 10 cm ha^{-1}, or equivalent to nearly 1 million liters per hectare (Hobbs and Gupta, 2003a). Research findings showed a lower yet still significant 13% decrease in tubewell irrigation water usage under the ZT system (Chandra *et al.*, 2007). Cost savings are reasonable with zero tillage, as it enables to seed of wheat immediately after rice harvest, leveraging remaining soil moisture for wheat germination and potentially saving pre-sowing irrigation. Zero tillage can improve soil structure and allow the accumulation of crop residues, all associated with increased water retention, superior infiltration, and lower water demand/ consumption in surrounding areas (Erenstein, 2003). Furthermore, zero tillage allows for a faster turnaround time, allowing for earlier sowing and harvesting of wheat, which potentially eliminates or cuts down the need for late-season irrigation in some places. By adopting zero tillage one irrigation can be conserved for wheat production (Laxmi *et al.*, 2007). Agriculture in the IGP is increasingly constrained by water shortages, driven by rising competition from domestic and industrial demands and declining water use efficiency (Hobbs and Gupta, 2003b).

Utilizing zero tillage in wheat farming optimizes water use, lowers irrigation needs, and conserves essential water supplies. The NW Indo-Gangetic Plains face critical water shortages due to the overuse of groundwater by pumping excessively so this system is crucial in these wheat-growing areas (Malik *et al.*, 2002). It is widely acknowledged that resource-efficient methods, including zero tillage, have the potential to boost field-level irrigation efficiency by minimizing water usage (Jehangir *et al.*, 2007).

Effect of zero tillage on soil quality

Zero tillage significantly boosts soil quality, leading to better soil structure, increased fertility, and improvements in biological traits like microbial activity and organic matter levels, thereby promoting long-term soil health and sustainability (Mohanty *et al.*, 2007). It can also boost organic carbon concentration in the upper soil horizons, improving the stability of soil aggregates (Chauhan *et al.*, 2002). Research shows that the surface layer of soil under zero tillage was relatively soft, remained soft, contained greater moisture, and demonstrated no marked change in bulk density compared to traditional tillage methods (Malik *et al.*, 2002a). Despite the advantages gained from the zero-tillage in wheat crop, these are largely offset by the rigorous and anaerobic tillage practices required for the following rice crop, which typically involves 5-6 tractor passes, including dry and wet plowing as well as wet planking, regardless of whether zero tillage was used for the previous wheat crop (Erenstein *et al.*, 2007). To boost soil structure, the whole cropping approach must shift to aerobic conditions, implement zero-tillage methods, and ensure the proper handling of crop residues.

Effect of zero tillage on weeds, pests, and diseases

It has been observed that weeds are less common in wheat crops after adopting zero tillage practices in wheat farming across the IGP, as noted by Franke *et al.*, (2007). *P. minor* Retz. is the predominant weed affecting wheat in the Indian Indo-Gangetic Plain which demonstrated growing resistance to Isoproturon herbicide in the mid-1990s after decades of continuous and extensive use (Yadav *et al.*, 2005). Mehta and Singh (2005) highlighted that Zero tillage is an effective *P. minor* control method because it reduces soil mobility. The need to combat herbicide-resistant *P. minor* constituted a primary initial motivator for adopting zero tillage in North West IGP, which eventually managed to address the problem in combination with new herbicides. In a survey, farmers agreed that zero tillage helped lower *P. minor* infestation (Kumar *et al.*, 2005a). The early emergence of wheat, combined with limited or no soil disturbance, led to a significant reduction in weed growth and lowered weed density *P. minor*, when zero tillage was implemented. Studies from extended trials and farmer feedback highlighted a shift in weed spectra under zero tillage conditions, with a notable increase in the prevalence of broad-leaved weed species. Additionally, survey data indicated that 51% and 85% of farmers in Haryana and Bihar, respectively reported a reduction in overall weed infestation following the adoption of zero tillage practices. Complementary findings from focus group discussions highlighted perceived improvements in soil quality, a decline in *Phalaris minor* populations, and a concomitant rise in broad-leaved weeds prevalence as reported by Laxmi *et al*., (2007).

Research by Jaipal *et al*., (2005) suggests that zero tillage has been demonstrated to alter the dynamics of specific pests and diseases while having no detrimental effects on soil biology within wheat production systems in the IGP. Scientists found no evidence of wheat pathogen inoculum build-up or significant carry-over between wheat and the subsequent crop cultivated, resulting in additional biotic restrictions. Evidence shows that zero tillage leads to a rise in the earthworm population, as well as the growth of earthworms and the proliferation of diverse natural predators. According to Dabur *et al*., (2002), zero tillage also led to a decrease in the reduction in nematode numbers within wheat crops.

Effect of zero tillage on yield

Practicing zero tillage combined with the retention of crop residues in the wheat field significantly surpasses conventional tillage without residue retention in enhancing crop productivity and preserving soil integrity. Wheat production methods are frequently characterized by late wheat planting (Mehla *et al*., 2000). The phenomenon of terminal heat stress, as described by Hobbs and Gupta (2003a), causes wheat yields to drop by 1 TO 1.5% daily, emphasizing the need for timely sowing practices. Wheat planting delays primarily result from the preceding crop's late harvest and a protracted turn-around period. The delay in the turnaround process often arises from heavy tillage activities, unfavorable soil moisture conditions (either overly wet or excessively dry), limited availability of draft or mechanical power for plowing, and the additional task of storing the rice crop before preparing the land for wheat planting. Zero tillage facilitates quicker wheat establishment by significantly reducing the turnaround time permits, making it possible to sow wheat in a single operation right after harvesting rice, thereby improving the cropping cycle efficiency. Research consistently shows that wheat yields under no-till systems were 27 to 31% superior to those under conventional tillage systems, as reported by Hemmat and Eskandari (2004). The favorable yield outcomes of zero tillage wheat are largely due to (i) the ability to achieve timely sowing and (ii) enhanced efficiency in input utilization along with improved weed management, leading to superior crop results.

Chaudhury *et al*., (2020) observed that zero tillage increases yield to a much greater extent when compared to conventional tillage (Fig. 1).

An integration of zero tillage with straw mulch practices, the soil's moisture retention was significantly improved, benefiting plants, particularly during periods of drought, as observed by Hemmat and Eskandari (2006). Zero tillage makes assessing soil erosion losses caused by crop residue accumulation (López-Bellido *et al*., 2003) easier. The no-till technique best suits places with low rainfall and soil water availability. One of the major benefits of zero tillage for plant growth is maintaining lower temperatures in the upper soil layers, which creates a more optimal environment for roots to grow. A reduction in soil temperature contributes to better organic matter retention, but it also delays seedling emergence and recovery by 1-3 and 4-5 days, respectively, than conventional tillage systems, as noted by Qin *et al*., (2008). Wheat production following rice was higher with lower tillage, crop residues, and nitrogen incorporation (Gangwar *et al*., 2006). Retaining crop leftovers and zero tillage can result in sustainable crop production and a better soil physical environment. Incorporating crop residues caused the inorganic nitrogen to become immobilized, which was initially reduced by using nitrogen as a basal. Despite this, immobilization had no notable effect on wheat yield. Allowing rice residues to remain on the soil surface for wheat cultivation resulted in a 46% increase in nitrate levels, a 29% improvement in nitrogen absorption, and boosted wheat yield by 37%, compared to the alternative practice of burning the residues. 37% improvement in wheat yield as opposed to burning the residues. Zero tillage, when paired with the retention of rice crop residues on the soil surface led to the accumulation of organic matter, which in turn enhanced microbial biomass and increased mineralization processes. Zero tillage, coupled with the retention of crop residues, contributed to improvements in crop yields, boosted microbial activity, enhanced nutrient availability, and minimized soil erosion, as highlighted by Govaerts *et al*., (2007) and Rafi *et al*., (2012).

Integrated nutrient management in wheat

Integrated nutrient management (INM) encompasses the systematic integration of diverse nutrient sources including organic, inorganic, and biological components to foster an ecologically sustainable and economically efficient agroecosystem (Jat *et al*., 2015). However, exclusive reliance on organic manures has been shown to inadequately meet the nutritional requirements of high-demand crops such as wheat, resulting in suboptimal yields (Sheoran *et al*., 2017). Empirical evidence indicates that the integrated use of farmyard manure (FYM) with the recommended dose of chemical fertilizers substantially increases wheat productivity compared to the sole application of chemical fertilizers. The nutrient demands of crops are contingent upon the nutrient accessibility within the soil matrix, and INM practices significantly enhance both nutrient and water use efficiencies (Jat *et al*., 2015). Furthermore, incorporating municipal solid waste manure into a cotton-wheat cropping system demonstrated an increase of about 9% in grain

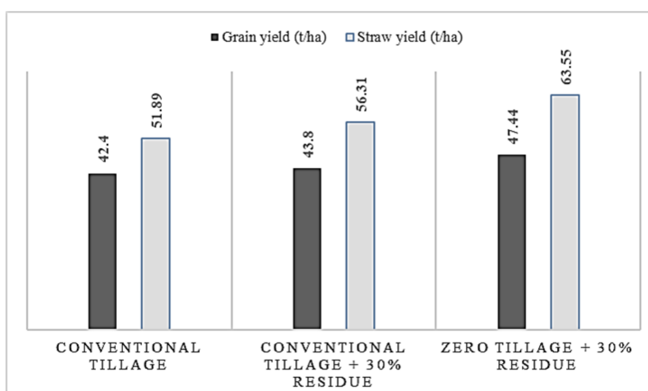

Fig. 1: Effect of conventional and zero tillage on yield of wheat (Chaudhury *et al*., 2020)

and straw yield of wheat (Akram *et al*., 2007). The synergistic application of chemical and organic fertilizers has thus proven to be a pivotal strategy for achieving sustainable agricultural production systems (Yasin *et al*., 2015).

Effect of nutrient management on soil properties

Managing nutrients is a vital aspect that greatly influences wheat sequential cropping systems (Usman *et al*., 2013). According to Chondie (2015), an application of chemical fertilizers and organic manures holds promise for restoring soil health and productivity by mitigating minor deficiencies in secondary and micronutrients, microbial ecosystems, and soil organisms and improving soil's physical and biological attributes. Wheat grain yields have remained stable over the years because of integrated nutrient management (Mehdi *et al*., 2011). Jaga and Upadhyay (2013), observed that chemical fertilizers, when applied at recommended levels to maintain crop yields, fail to enhance soil attributes like soil pH, soil OC, CEC, and available nitrogen and potassium as effectively as the combined application of organic and inorganic fertilizers, potentially endangering soil health. Integration of organic amendments with chemical fertilizers for wheat production can harmonize the degenerative and regenerative dynamics of the soil ecosystem (Ram *et al*., 2014). Factors such as water infiltration, erosion potential, water retention, and nutrient cycling processes are strongly shaped by soil organic matter (Wander and Yang, 2000). To preserve soil productivity necessitates the upkeep of sufficient soil organic matter and the appropriate use of chemical fertilizers. For wheat cultivation, combining 50% nitrogen from organic sources (farm yard and green manures) with NPK @ 50% via chemical fertilizers, resulted in better outcomes for soil organic carbon, nutrient availability (nitrogen, phosphorus and potassium), and soil bulk density compared to other combinations. Jaga and Upadhyay (2013) found that applying FYM to wheat crops reduced bulk density and enhanced soil aeration.

In the context of wheat farming in the North-Western Himalayas, applying various organic manures, such as farmyard manure (FYM), compost, and green manures, combined with increasing levels of chemical fertilizers ranging from 50 to 150% of the recommended NPK dosage, significantly enhanced the soil's physical and hydraulic properties in wheat crop production under this unique agro-climatic conditions. These improvements included better soil bulk density, higher soil moisture content, improved soil water retention, increased plant-available water capacity, and enhanced saturated hydraulic conductivity (Choudhary *et al*., 2008). Lal *et al*., (2014) reported a significant improvement in the availability of essential nutrients such as nitrogen, phosphorus, and potassium in wheat when farmyard manure was applied alongside chemical fertilizers. This synergistic approach not only enriched the soil nutrient profile but also integrated the overall fertility and productivity of the cropping system. Farmyard manure application led to an increase in soil nitrogen and phosphorus, largely because of the gradual release of these nutrients through the decomposition and mineralization of its organic components, which enriched the soil nutrient pool and boosted its fertility. Incorporating farmyard manure (FYM) in wheat fields substantially enhanced soil organic matter content and improved the soil's capacity to retain accessible water, while concurrently reducing soil bulk density, thereby contributing to improved soil structure and overall soil health. When compared to no application of farmyard manure, the application of FYM at rates of 7.5 t/ha and 15 t/ha led to remarkable improvements in soil properties including 3.6 and 10.3% improvement in water holding capacity, a 17.8% and 46.6% rise in organic carbon levels, and a 23.3 and 15.0% reduction in bulk density, showcasing FYM's effectiveness in boosting soil health and long-term sustainability (Shirani *et al*., 2002). The use of 100% NPK alongside 10 tons per hectare of farmyard manure led to notable enhancements in several biological soil parameters. These included enhanced levels of soil microbial biomass carbon (SMBC), soil microbial biomass nitrogen (SMBN), and dehydrogenase activity (DHA), indicating a positive impact on the soil's microbial activity as observed by Katkar *et al*., (2011).

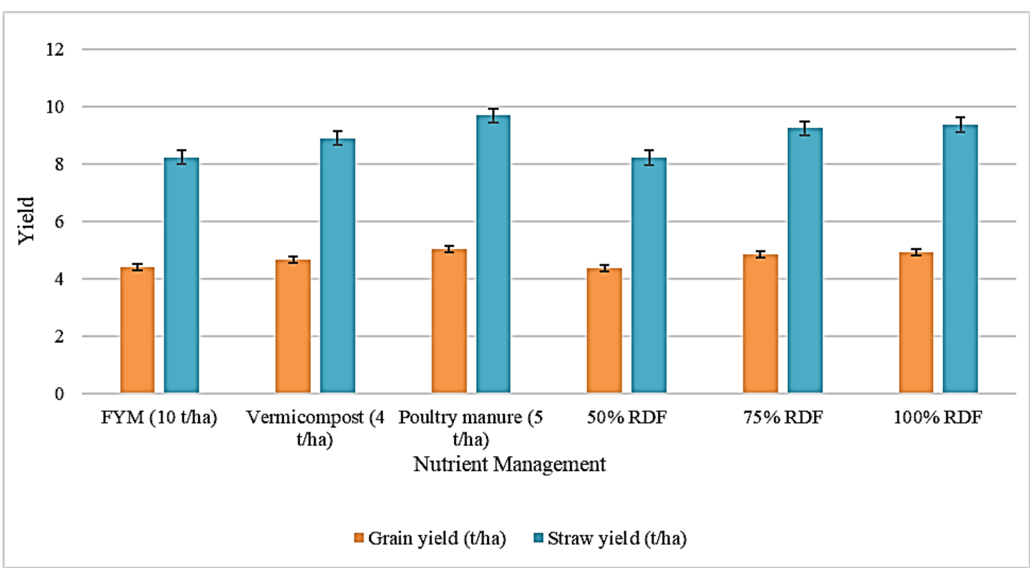

Fig. 2: Effects of organic manures, fertilizer levels and biofertilizers on wheat yield (Chopra *et al*., 2016)

Effect of nutrient management on growth and yield of wheat

Wheat is significantly influenced by the applications of different concentrations of nitrogenous, phosphatic and potassium-based fertilizers. Increased fertilizer rates may improve growth and yield-related attributes like plant height, dry matter accumulation, the number of effective tillers, spike length, leaf area index, test weight and wheat yield (El-Gizawy, 2009).

Crop development can be boosted using organic materials such as organic substances or farm yard manures. Ibrahim *et al.*, (2008) revealed that using organic manure and compost improved wheat growth and output compared to chemical fertilizer. Increasing wheat output by combining organic and inorganic fertilizers is possible. Chopra *et al.*, (2016) study showed various effects of organic manures and fertilizer levels on wheat yield (t ha^{-1}) and found a significant response towards yield (Fig. 2).

The study by Kowsar and Boswal (2015) indicated that FYM application is significantly responsible for improving wheat's physiological characteristics, notably elevated chlorophyll-a and b content and the ability to withstand heat stress. An increased plant height, tiller number, dry matter accumulation and wheat grain production were reported because of higher NPK fertilizer application mixed with FYM (Parewa and Yadav, 2014; Pandey *et al.*, 2024). Majumdar *et al.*, (2008) found a substantial improvement in the production of grain in wheat with the application of chemical fertilizers in combination with FYM.

Effect of INM on nutrient uptake

Adding vermicompost and Phosphorus Solubilizing Bacteria combined with various fertilizer doses increased the crop NPK uptake much more than fertilizer or vermicompost applied alone. Improved nutrient absorption was credited to the abundant availability of nutrients and the development of a strong root system, facilitating more efficient water and nutrient uptake (Devi *et al.*, 2011; Datt *et al.*, 2003). The increased uptake is due to the release of extra native nutrients from the soil and their transfer to the plant system via the synergy via the combination of Sulphur + Boron + FYM and 75% NPK. The application of Sulphur, boron, or FYM individually along with 100% NPK @ 150:60:60, significantly improved total nutrient uptake especially macronutrients, as reported by Reena *et al.*, (2017), and corroborated by Rathar and Sharma (2010). An increase in wheat yield and its related attributes can be credited with the use of S, B, and FYM either independently with the ratio of NPK @150:60,60 or combined with 75% NPK. In addition to this, nutrient concentration in both grain and straw may also be increased in these formulations added alone or with a three-fourth percentage of NPK. As nutrient uptake depends on yield and nutrient concentration, supports this thought, the result aligns with the observations of Natan and Anurag (2011).

Conclusion

To enhance crop productivity and minimize environmental risks associated with agriculture, adopting sustainable and ecologically sound management practices is imperative. Precision agriculture presents a transformative approach by enabling site-specific input applications to the type, amount, timing, and spatial distribution of resources. This strategy addresses within-field variability, a critical determinant of wheat production efficiency, necessitating its quantification and management at both spatial and temporal scales. In the Indo-Gangetic Plain, wheat serves as a pivotal staple crop, underpinning regional food security. However, conventional puddled rice cultivation systems often degrade soil structure and adversely affect the rhizosphere, leading to suboptimal wheat growth and reduced productivity. The adoption of zero-tillage systems, integrated with site-specific nutrient management through the combined application of organic and inorganic amendments, has demonstrated the potential to mitigate these challenges. Zero-tillage improves soil physical properties, enhances nutrient dynamics, and fosters favorable agroecological conditions for wheat development. From an economic and environmental perspective, zero tillage reduces input costs, increases net returns, and contributes to ecological sustainability through reduced fossil fuel use, lower greenhouse gas emissions, and water conservation. Concurrently, INM optimizes soil fertility and nutrient use efficiency, promoting improved plant physiological traits, enhanced yield parameters, and superior disease suppression. The synergistic effects of these practices improve soil organic carbon sequestration and nutrient bioavailability, thereby enhancing soil health and productivity. In summary, the integration of zero tillage with INM represents a scientifically robust, sustainable, and economically viable paradigm for wheat cultivation. This dual approach not only enhances yield potential and farm profitability but also safeguards soil and environmental health, ensuring resilience and sustainability in agroecosystems.

Acknowledgment

The authors express their sincere gratitude to the Head, Department of Agriculture, IIAST, Integral University, Lucknow, for providing University MCN-IU/R&D/2024-MCN0003220 and for offering the necessary facilities and encouragement during this investigation.

Authors' Contribution

Planning of the study, reviewing, drafting the original manuscript and compiling the content by Deovrat Singh. Dr. Ambreesh Singh and Prof. Saba Siddiqui gave supervision and conceptualization of the idea during the study. Dr. Shipra Yadav and Dr. Sanket Kumar contributed to compiling, editing and incorporating corrections in the manuscript.

Conflict of interest

There is no conflict of interest regarding the publication of this article.

References

Akram, M., Qazi, M. and Ahmad, N. (2007). Integrated nutrient management for wheat by municipal solid waste manure in rice-wheat and cotton-wheat cropping systems. *Polish Journal of Environmental Studies*. 16(4):495-503.

Chandini, Kumar, R., Kumar, R. and Prakash, O.M. (2019). The impact of chemical fertilizers on our environment and ecosystem. *Research trends in environmental sciences*, Pp. 69-86.

Chandra, R., Sikka, A., Singh, S., Gupta, R., Upadhyaya, A.K. and Sakthivadivel, R. (2007). Impact of Resource Conserving Technologies on Water Use and Water Productivity in Pabnawa Minor of Bhakra Canal System. RWC Technical Bulletin No. 10. RWC, New Delhi.

Chauhan, B.S., Yadav, A. and Malik, R.K. (2002). Zero tillage and its impact on soil properties: a brief review. In: Malik, R.K., Balyan, R.S., Yadav, A. and Pahwa, S.K. (Eds.), Herbicide Resistance Management and Zero Tillage in Rice–Wheat Cropping System. CCSHAU, Hisar, India, pp. 109–114.

Chondie, Y.G. (2015). Effect of integrated nutrient management on wheat. *Journal of biology, Agriculture and health care*, 5(13): 68-76.

Chopra, R., Sharma, M., Sharma, S.K., Nepalia, V., Jain, H.K. and Singh, A. (2016). Effect of integrated nutrient management on growth and yield of wheat (*Triticum aestivum* L.) in Haplustepts. *International Journal of Science and Nature,* 7(3):622-628.

Choudhary, A.K., Thakur, R.C. and Naveen, K. (2008). Effect of integrated nutrient management on soil physical and hydraulic properties in rice wheat crop sequence in N-W Himalayas. *Indian Journal of Soil Conservation,* 36 (2): 97- 104.

Choudhury, S.R., Dipu, D.K., Mandal, N. and Pathak, S.K. (2020). Yield, Yield Attributes and Economics of Wheat as Influenced by Resources Conservation and Nutrient Management Practices. *International Journal of Inclusive Development*, 6(02): 81-86.

Dabur, K.R., Malik, R.K., Singh, S., Yadav, A. and Banga, R.S. (2002). Impact of zero tillage in wheat on nematodes population under rice–wheat cropping system. In: Malik, R.K., Balyan, R.S., Yadav, A. and Pahwa, S.K. (Eds.), Herbicide Resistance Management and Zero Tillage in Rice–Wheat Cropping System. CCSHAU, Hisar, India, pp. 162–165.

Datt, N., Sharma, R.P. and Sharma, G.D. (2003). Effect of supplementary, use of farmyard manures a long with chemical fertilizers on productivity and nutrient uptake by vegetable pea and nutrient build up to soil fertility in Lahual valley of Himachal Pradesh. *Indian Journal of Agricultural Sciences,* 73:266-68.

Devi, K.N., Singh, M.S., Singh, N.G. and Athokpam, H.S. (2011). Effect of integrated nutrient management on growth and yield of wheat (*Triticum aestivum* L.). *Journal of Crop and Weed*, 7(2):23-27.

El-Gizawy. (2009). Effect of Planting Date and Fertilizer Application on Yield of Wheat under No till System. *World Journal of Agricultural Sciences,* 5 (6): 777- 783.

Erenstein, O. (2003). Smallholder conservation farming in the tropics and subtropics: a guide to the development and dissemination of mulching with crop residues and cover crops. *Agriculture, Ecosystems and Environment,* 100:17–37.

Erenstein, O., Malik, R.K. and Singh, S. (2007). Adoption and Impacts of zero tillage in the irrigated Rice–Wheat systems of Haryana, India. Research Report. CIMMYT India and RWC, New Delhi, India.

Erenstein, O., Sayre, K., Wall, P., Dixon, J. and Hellin, J. (2008). Adapting no-tillage agriculture to the conditions of smallholder maize and wheat farmers in the tropics and sub-tropics. In: Goddard, T., Zoebisch, M., Gan, Y., Ellis, W., Watson, A. and Sombatpanit, S. (Eds.), No-till Farming Systems. Special Publication 3. World Association of Soil and Water Conservation (WASWC), Bangkok, pp. 253–278.

Erenstein, O., Thorpe, W., Singh, J. and Varma, A. (2007b). Crop–Livestock Interactions and livelihoods in the Indo-Gangetic Plains, India: A Regional Synthesis. Crop– Livestock Interactions Scoping Study—Synthesis. CIMMYT-ILRI-RWC, New Delhi, India.

Franke, A.C., Singh, S., McRoberts, N., Nehra, A.S., Godara, S., Malik, R.K. and Marshall, G. (2007). Phalaris minor seedbank studies: longevity, seedling emergence and seed production as affected by tillage regime. *Weed Research,* 47:73–83.

Gangwar, K.S., Singh, K.K., Sharma, S.K. and Tomar, O.K. (2006). Alternative tillage and crop residue management in wheat after rice in sandy loam soils of Indo-Gangetic plains. *Soil and Tillage Research,* 88(1-2): 242-252.

Govaerts, B., Mezzalama, M., Unno, Y., Sayre, K.D., LunaGuido, M., Vanherck, K., Dendooven, L. and Deckers, J. (2007). Influence of tillage, residue management, and crop rotation on soil microbial biomass and catabolic diversity. *Applied Soil Ecology,* 37(1-2): 18-30.

Hemmat, A. and Eskandari, I. (2004). Conservation tillage practices for winter wheat-fallow farming in the temperate continental climate of northwestern Iran. *Field Crops Research,* 89(1): 123-133.

Hemmat, A. and Eskandari, I. (2006). Dryland winter wheat response to conservation tillage in a continuous cropping system in northwestern Iran. *Soil and Tillage Research,* 86(1): 99-109.

Hobbs, P.R. and Gupta, R.K. (2003b). Resource-conserving technologies for wheat in the rice–wheat system. In: Ladha, J.K., Hill, J.E., Duxbury, J.M., Gupta, R.K. and Buresh, R.J. (Eds.), Improving the Productivity and Sustainability of Rice–Wheat Systems: Issues and Impacts. ASA Special Publication Number 65. ASA-CSSA-SSSA, Madison, Wisconsin, USA, pp. 149–172.

Hobbs, P.R. and Gupta, R.K. (2003a). Rice–wheat cropping systems in the Indo-Gangetic Plains: issues of water productivity in relation to new resource-conserving technologies. In: Kijne, J.W., Barker, R. and Molden, D. (Eds.), Water Productivity in Agriculture: Limits and Opportunities for Improvement. CABI Publication, Wallingford, UK, pp. 239–253.

Ibrahim, M., Anwar-ul-Hassan, Muhammad, I. and Ehsan, E.V. (2008). Response of wheat growth and yield to various levels of compost and organic manure. *Pakistan Journal of Botany*, 40(5): 2135- 2141.

Jaga, P.K. and Upadhyay, V.B. (2013). Effect of integrated nutrient management on wheat: A review. *Innovare Journal of Agricultural Sciences,*1(1): 1-3.

Jaipal, S., Malik, R.K., Hobbs, P., Yadav, A. and Singh, S. (2005). Conservation agriculture— IPM issues. In: Abrol, I.P., Gupta, R.K. and Malik, R.K. (Eds.), Conservation Agriculture—Status and Prospects. Centre for Advancement of Sustainable Agriculture, New Delhi, pp. 99–113.

Jat, K., Singh, Y.V., Meena, S.K., Meena, S.K., Parihar, M., Jatav, H.S., Meena, R.K. and Meena, V.S. (2015). Does INM enhance agricultural productivity? *Journal of pure and applied microbiology*, 9 (2): 1211-1221.

Jehangir, W.A., Masih, I., Ahmed, S., Gill, M.A., Ahmad, M., Mann, R.A., Chaudhary, M.R. and Turral, H. (2007). Sustaining Crop Water Productivity in Rice–Wheat Systems of South Asia: A Case Study from Punjab Pakistan. IWMI Working Paper 115. International Water Management Institute, Colombo, Sri Lanka.

Katkar, R.N., Sonune, B.A. and Kadu, P.R. (2011). Long term effect of fertilization on soil chemical and biological characteristics and productivity under sorghum- wheat system in vertisols. *Annals of Plant and Soil Research*, 2: 32-34.

Kowsar, J. and Boswal, M.V. (2015). Effect of bio-fertilizer and organic fertilizer on physiological characteristics of bread wheat (*Triticum aestivum*). *International Journal of Scientific Research and Management,* 3(2): 2073- 2089.

Kumar, R., Singh, B., Bangarwa, S.K., Singh, S. and Yadav, A. (2005a). Farmers' view on the success of zero-tillage—a survey report. In: Malik, R.K., Gupta, R.K., Singh, C.M., Yadav, A., Brar, S.S., Thakur, T.C., Singh, S.S., Singh, A.K., Singh, R. and Sinha, R.K. (Eds.), Accelerating the Adoption of Resource Conservation Technologies in Rice–Wheat System of the Indo-Gangetic Plains, Proceedings of the Project Workshop June 1–2, 2005. Directorate of Extension Education, CCS HAU, Hisar, Haryana, India, pp. 130–136.

Lal, B., Vinod, N., Priyanka, S. and Tedia, K. (2014). Effect of combined application of FYM, fly Ash and fertilizers on soil properties and paddy grown on degraded land. *Current World Environment*, 9(2): 531-535.

Laxmi, V., Erenstein, O. and Gupta, R.K. (2007). Impact of Zero Tillage in India's Rice– Wheat Systems. CIMMYT and Rice–Wheat Consortium for the Indo-Gangetic Plains, New Delhi.

López-Bellido, R.J., López-Bellido, L., Castillo, J.E. and López Bellido, F.J. (2003). Nitrogen uptake by sunflower as affected by tillage and soil residual nitrogen in a wheat-sunflower rotation under rainfed Mediterranean conditions. *Soil and Tillage Research*, 72(1): 43-51.

Majundar, B., Mandal, B., Bandopadhyay, P.K., Gangopadyay, A., Mani, P.K., Kundu, A.L. and Majumdar, D. (2008). Organic amendment influence soil organic pools and crop productivity in nineteen years old rice-wheat agroecosystem. *Soil Science Society of America Journal,* 72: 775-785.

Malik, R.K., Balyan, R.S., Yadav, A. and Pahwa, S.K. (2002). Herbicide resistance management and zero tillage in rice–wheat cropping system. In: Proceedings of International Workshop, March 4–6, 2002. Chaudhary Charan Singh Haryana Agricultural University (CCSHAU), Hisar, India.

Malik, R.K., Yadav, A., Singh, S., Malik, R.S., Balyan, R.S., Banga, R.S., Sardana, P.K., Jaipal, S., Hobbs, P.R., Gill, G., Singh, S., Gupta, R.K. and Bellinder, R. (2002a). Herbicide Resistance Management and Evolution of Zero Tillage—A Success Story. Research Bulletin. CCS Haryana Agricultural University, Hisar, India.

Mehdi, S.M., Sarfraz, M., Abbas, S.T., Shabbir, G. and Akhtar, J. (2011). Integrated nutrient management for rice-wheat cropping system in a recently reclaimed soil. *Soil Environment*, 30(1): 36-44.

Mehla, R.S., Verma, J.K., Gupta, R.K. and Hobbs, P.R. (2000). Stagnation in the Productivity of Wheat in the Indo-Gangetic Plains: Zero-till-seed-cum-fertilizer Drill as an Integrated Solution. Rice–Wheat Consortium Paper Series 8. RWC, New Delhi, India.

Mehta, A.K. and Singh, R. (2005). Transfer of resource conserving technologies through Krishi Vigyan Kendras. In: Abrol, I.P., Gupta, R.K. and Malik, R.K. (Eds.), Conservation Agriculture—Status and Prospects. Centre for Advancement of Sustainable Agriculture, New Delhi, pp. 128–134.

Mohammadi-Joo, S., Mishra, A., Saediabueshaghi, R., Amiri, M. (2015). Evaluation of bread wheat (*Triticum aestivum* L.) based on resistance indices under field conditions. *International Journal of Biosciences*, 6 (2):331-337.

Mohanty, M., Painuli, D.K., Misra, A.K. and Ghosh, P.K. (2007). Soil quality effects of tillage and residue under rice–wheat cropping on a Vertisol in India. *Soil and Tillage Research,* 92: 243–250.

Natan, U.P., Anurag, C.R., 2011. Residual effect of organic and inorganic fertilizer nutrients on sulfur content and uptake in wheat crop under rice-wheat cropping system. Journal of Soil and crop, 21 (10), Pp. 82-88.

Pandey, O. C., Pratap, D., Hasanain, M., Gupta, S. P., Singh, A. K., Siddiqui, S. and Yadav, S. (2024). The Crucial Role of Tillage and Nutrient Management in Enhancing Wheat Production. *International Journal of Plant and Environment*, 10(2): 150-157

Parewa, H.P. and Yadav, J. (2014). Response of fertility levels, FYM and bio inoculants on yield attributes, yield and quality of wheat. *Agriculture for Sustainable Development*, 2(1): 5- 10.

Qin, H.L., Gao, W.S., Ma, Y.C., Ma, L., Yin, C.M., Chen, Z. and Chen, C. (2008). Effects of subsoiling on soil moisture under no-tillage for two years. *Agricultural Sciences in China,* 7(1): 88-95.

Rafi, Q., Riaz, A. and Muhammad, I. (2012). Response of wheat to tillage and nitrogen fertilization in rice-wheat system. *Pakistan Journal of Agricultural Sciences,* 49(3): 243-254.

Ram, M., Davari, M.R. and Sharma, S.N. (2014). Direct residual and cumulative effects of organic manures and biofertilizers on yields, NPK uptake, grain quality and economics of wheat (*Triticum aestivum* L.) under organic farming of rice- wheat cropping system. *Journal of Organic Systems*, 9(1):16- 30.

Rather, S.A. and Sharma, N.L. (2010). Effect of integrated nutrient management (INM) on productivity and nutrient in wheat and soil fertility. *Asian Journal of Soil Science*, 4(2):208-210.

Reena, Pandey, S.B., Tiwari, D.D., Nigam, R.C., Singh, A.K. and Kumar, S. (2017). Effect of Integrated Nutrient Management on Yield and Nutrients Uptake of wheat and Soil Health. *International Archive of Applied Sciences and Technology*, 8(3):25-28.

Saharawat, Y.S., Singh, B., Malik, R.K., Ladha, J.K., Gathala, M., Jat, M.L. and Kumar, V. (2010). Evaluation of alternative tillage and crop establishment methods in a rice-wheat rotation in North Western IGP. *Field Crops Research,* 116:260–267.

Shabandeh, M. (2020). Global wheat production from 2011/2012 to 2019/2020 (in metric tons). Statista.

Sharma, A.R., Jat, M.L., Saharawat, Y.S., Singh, V.P. and Singh, R. (2012). Conservation agriculture for improving productivity and resource-use efficiency: prospects and research needs in Indian context. *Indian Journal of Agronomy,* 57:131–140.

Sheoran, S., Raj, D., Antil, R.S., Mor, V.S. and Dahiya, D.S. (2017). Productivity, seed quality, and nutrient use efficiency of wheat (*Triticum aestivum* L.) under organic, inorganic, and INM practices after 20 years of fertilization. *Cereal Research Communications*, 45 (2): 315-325.

Shirani, H., Hajabbas, M.A., Afyuni, M. and Hemmat, A. (2002). Effects of farmyard manure and tillage systems on soil physical properties and corn yield in central Iran. *Soil and Tillage Research*, 68(2): 101- 108.

Singh, V.K., Dwivedi, B.S., Shukla, A.K., Chauhan, Y.S. and Yadav, R.L. (2005). Diversification of rice with pigeonpea in a rice-wheat cropping system on a Typic Ustochrept: Effect on soil fertility, yield and nutrient use efficiency. *Field Crops Research*, 92 (1):85-105.

Usman, K., Khan, E.A., Khan, N., Khan, M.A., Ghulam, S., Khan, S. and Baloch, J. (2013). Effect of Tillage and Nitrogen on Wheat Production, Economics, and Soil Fertility in Rice-Wheat Cropping System. *American Journal of Plant Sciences,*4: 17-25.

Wander, M.M. and Xueming, Y. (2000). Influence of tillage on the dynamics of loose- and occluded-particulate and humified organic matter fractions. *Soil Biology and Biochemistry*, 32 (8-9): 1151- 1160.

Yadav, A., Malik, R.K., Jaipal, S., Singh, S., Singh, R., Ram, K. and Singh, S. (2005). Sustainability of long-term zero-tillage in wheat and its impact on the productivity of rice. In: Malik, R.K., Gupta, R.K., Singh, C.M., Yadav, A., Brar, S.S., Thakur, T.C., Singh, S.S., Singh, A.K., Singh, R. and Sinha, R.K. (Eds.), Accelerating the Adoption of Resource Conservation Technologies in Rice–Wheat System of the Indo-Gangetic Plains, Proceedings of the Project Workshop June 1–2, 2005. Directorate of Extension Education, CCS HAU, Hisar, Haryana, India, pp. 18–22

Yasin, G.C. (2015). Effect of Integrated Nutrient Management on wheat. *A review journal of Biology, agriculture, and health care*, 5 (13).