REVIEW ARTICLE

The Crucial Role of Tillage and Nutrient Management in Enhancing Wheat Production

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Abstract

Wheat (*Triticum aestivum* L.), the second most vital grain globally, underpins food security for the world's population. The mid-1960s to the present have seen a green revolution driven by high-yielding wheat varieties, improved irrigation, and chemical fertilizers. Despite these advances, food security in key wheat-producing areas faces threats due to a 50% output disparity and recent yield plateaus. This stagnation, alongside biotic and abiotic stresses and resource depletion, is compounded by nutritional deficiencies, leading to declining productivity, profits, and increased environmental impacts. Addressing these challenges necessitates focusing on nutrient management and tillage practices to maximize yields and maintain soil health. Effective tillage practices enhance soil structure and nutrient availability, while appropriate nutrient management ensures that the crop's needs are met using both organic and inorganic sources. This review explores the pros and cons of conventional and modern tillage techniques and nutrient management strategies. It assesses how conservation and conventional tillage impact wheat production across various ecological environments globally and highlights the differing nutrient requirements these methods entail. Tailored nutrient management strategies, aligned with specific tillage practices, are essential to overcoming current production barriers and ensuring sustainable wheat cultivation.

Keywords: Wheat, Grain yield, Integrated nutrient management, Zero tillage, Conventional tillage, Conservation tillage.

Highlights

- Efficient nutrient management is vital for replenishing soil fertility and enhancing nutrient-use efficiency to boost crop productivity for future food and fiber needs.
- Effective tillage practices enhance soil properties, nutrient availability, and water-use efficiency, boosting wheat production by improving root growth and nutrient cycling.
- Agronomic biofortification enhances wheat zinc content, boosting yield and quality, and improving nutrition despite climate challenges.
- Proper nitrogen application at growth stages boosts wheat's physiological processes, enhancing yield and nutrient content.

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Introduction

Increasing crop productivity to meet future food and fiber demands necessitates efficient nutrient management practices that can replenish soil fertility and enhance nutrient-use efficiency (Havlin and Heiniger, 2020). Wheat is a staple cereal crop that plays a significant role in global food security, and its production can be significantly improved through effective tillage and nutrient management strategies (Hussain, 2019). Agronomic biofortification has emerged as a promising approach to enhance the nutritional value of wheat, particularly in terms of zinc (Zn) content (Singh *et al.* 2023). Climate change can pose challenges to the efficiency of these biofortification methods due to their impact on grain-filling stages. Nonetheless, agronomic biofortification can improve zinc content, crop yield, and quality, ultimately benefiting human nutrition and health. Furthermore, the genetics and molecular breeding aspects have been explored in wheat to address the issue of grain iron and zinc biofortification, as these micronutrients play a vital role in sustaining adequate growth and development.

Wheat is an important source of energy, as well as a supplier of various nutrients and micronutrients necessary for a healthy diet (Rosell, 2012). However, wheat processing can significantly affect the nutritional profile of the grain. Emphasis has been placed on improving the nutritional quality of wheat to address the global challenge of malnutrition, particularly with regard to micronutrient deficiencies (Mallick *et al.* 2013). Effective tillage practices can play a crucial role in enhancing wheat production by improving soil physical properties, nutrient availability, and water-use efficiency. Appropriate tillage methods can help create a favorable soil environment for root growth,

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water infiltration, and nutrient cycling, ultimately leading to improved wheat yields and quality (Wani *et al.* 2022). Nutrient management is another critical aspect in optimizing wheat production. Adequate nitrogen (N) application is essential for various physiological processes in wheat, such as protein formation, chlorophyll production, and photosynthesis. Nitrogen application at specific growth stages can significantly influence grain yield, protein content, and nutrient utilization (Wani *et al.* 2022; Khan, 2020; Singh *et al.* 2023; Rosell, 2012).

Different Tillage Systems in Wheat

Conventional tillage enhances seed germination and plant establishment in comparison to zero tillage through the promotion of soil aeration, facilitation of field workability, and reduction of soil compaction (Licht and Al-Kaisi, 2005). Zero tillage is an extensively adopted technology in IGP that functions to mitigate soil erosion, optimize crop sowing, and decrease operational costs. Erenstein *et al.* (2008) and Younis *et al.* (2006) found that zero-tillage wheat cultivation produces higher yield and benefit:cost ratio (BCR) profits in comparison to conventional methods. Farmers' livelihoods are improved, their profits are increased, and destitution is reduced through the implementation of ZT (Bakhsh *et al.* 2005). Farmers are increasingly embracing zero tillage technology due to its reduced production costs and enhanced crop yield in comparison to conventional tillage (de Vita *et al.* 2007). In irrigated conditions, the implementation of deep tillage and the cheerful seeder (zero tillage drill) results in a more substantial increase in wheat production than conventional tillage and the zone disc tiller (Rafi *et al.* 2012). Zero-tillage practices aid in the prevention of soil structural degradation through the mitigation of soil erosion (Tabatabaeefar *et al.* 2009). The composition of soil organic carbon is subject to variation depending on the tillage system employed, which determines the depth of the soil. Soil zero tillage, as opposed to the chisel and mold-board tillage systems, produces increased concentrations of organic carbon solely in the uppermost stratum of the soil profile (Deen and Kataki, 2003). investigated the carbon sequestration impact of conservation tillage. Soil organic carbon (SOC) fluctuations are found to be more conspicuous when long-term tillage techniques are employed, in contrast to short-term tillage practices. An investigation was conducted on the organic carbon content of sediments at depths ranging from 0 to 60 cm. An analysis was conducted to compare zero tillage with conventional farming methods such as chisel plowing and moldboard. In brief, ZT techniques led to a 36 to 62% increase in soil organic carbon (SOC) concentration in comparison to conventional tillage methods. However, this increase was confined to the surface layer and did not permeate the entire soil profile. Within the depth range of 0-5 cm, the organic carbon concentration is at its peak in ZT soil.

Effect of Tillage on Soil Physical Properties

To sustainably increase agronomic output, the physical environment of the soil is vital. Soil conditions are improved for optimal crop emergence and yield through the modification of the soil's physical properties by tilling (Boydas and Turgut, 2007). Due to the increased availability of water and soil organic matter, ZT and residue retention on the soil surface are more sustainable methods for increasing wheat yields than conventional agricultural practices. Zero tillage, which entails the complete elimination of intensive tillage machine usage, is the sole method that can effectively maintain soil productivity (Fabrizzi *et al.* 2005). Zero tillage and residue retention result in reduced soil bulk density, penetration resistance, and infiltration rate when compared to conventional tillage practices (Jat *et al.* 2009). Soil bulk density and resistance to penetration are both diminished as a result of heightened soil perturbation (Osunbitan *et al.* 2005; Pedrotti *et al.* 2005). In wheat, imprudent tillage practices deteriorated the structure of the soil. While ZT does offer a notable advantage in terms of enhancing soil structure, it has been found to exacerbate soil compaction, thereby detrimentally impacting crop development (Ferreras *et al.* 2000). Consistent plowing at a given depth results in compaction of the subsurface, which subsequently impacts the porosity, bulk density, and growth of plant roots. As a consequence of these variables, Rafi *et al.* (2012) observed that the tillage system had an impact on both root length and growth. Nutrient availability is likewise impacted by the physical characteristics of the soil, as diminished root penetration of subsurface soil strata and restricted extraction of soil nutrients and hydration are probable outcomes (Ahmad *et al.* 2009). The physical conditions of the soil beneath wheat crops are enhanced through the retention of crop residues using ZT (Sharma and Bhushan *et al.* 2001). As stated by Czyz and Dexter (2008), the incorporation of agricultural residues into ZT creates a more conducive setting than traditional tillage for improving soil stability, physical properties, and moisture content. The researchers examined soil bulk density, particle size distribution (utilizing the hydrometer method), water content, and two tillage systems (reduced and traditional), in addition to the utilization of wheat straw mulch. In comparison to conventional tillage, they discovered that reduced tillage improved soil stability, bulk density, and water content. In contrast to the traditional methodology, the reduced tillage approach fostered a more conducive setting for the improvement of soil physical characteristics, specifically soil stability. Additionally, Alam and Salahin (2013) examined the impact of varying tillage depths on a range of soil properties (Table 1).

Effect of Tillage on Moisture Retention in Wheat Field

The recognition of the criticality of conserving soil and water for agricultural production is evident in the face of climate change. In this competition, the function of conservation tillage strategies

Table 1: Effect of different tillage depths on various soil properties in wheat (Adopted from Alam and Salahin, 2013)

Depth of tillage (cm)	*Soil properties*		
	Bulk density ($g\ cm^{-3}$)	*Porosity (%)*	*Particle density ($g\ cm^{-3}$)*
0-4	1.49	42.25	2.58
10-12	1.48	42.41	2.57
20-25	1.46	42.75	2.55
CV (%)	2.95	3.62	2.43
SE±	0.008	0.403	0.004

such as minimum and zero tillage becomes crucial. Zero tillage, in contrast to conventional tillage methods, enhanced soil strength, water retention, and transfer through the promotion of soil aggregation, reduction of discharge, and improvement of soil hydrological parameters (Abid and Lal, 2008). Due to water scarcity during the growing season, early soil moisture contents necessary for wheat seed germination are frequently increased. Deposition of crop residues on the surface of the soil acts as a mulch, which increases water infiltration and decreases evaporative water loss (Shipitalo *et al.* 2000). In conjunction with crop residue retention, zero-tillage practices increased soil water content and water use efficiency, leading to an increase in crop yield. In comparison to ZT, water storage was greater in deep tillage at 50 to 100 cm soil depth, whereas water consumption increased in 50 to 100 cm soil depth and decreased in subsoiling at 0 to 50 cm (Qingjie *et al.* 2009). Subsoiling decreased water consumption by 16.8% while increasing output by 18.3%. Liu *et al.* (2008) stated that NT (no tillage) subsoiling is an efficient rotating tillage technique for increasing water use efficiency and retaining more soil moisture. Water was conserved while soil productivity was increased through conservation tilling. It is an effective strategy for enhancing water efficiency and crop yields (Jin *et al.* 2007). Crop yield was increased as a result of conservation tillage and residue retention, which increased soil moisture content and enhanced water usage efficiency. Similarly, ZT containing agricultural residues has the maximum content of soil organic matter, which increases water availability in the soil and improves the distribution of soil pores (Bescansa *et al.* 2006).

Effect of Tillage on Soil Organic Matter Content

Traditional tillage practices result in a reduction in the concentration of organic matter and an increase in the turnover of crop residues as they become incorporated into the soil. Soil erosion and the emission of soil carbon into the atmosphere are consequences of conventional tillage (CT), which also depletes organic matter and the soil's capacity to retain carbon over an extended period of time. Conservation tillage has a substantial impact on soil organic matter, nitrogen, and exchangeable cations in comparison to CT (Balesdent *et al.* 2000). The accumulation of greater quantities of organic matter at the soil surface in ZT has been found to have advantageous effects on soil physical and chemical properties, as well as crop yields. The macroaggregates comprise the majority of soil organic carbon and nitrogen, and their proportion in ZT is more substantial than in CT (Sundermeier *et al.* 2011). Consequently, ZT increased the sequestration of nitrogen and soil organic carbon on the surface soil. Soil carbon losses are augmented when the duration of tillage exceeds one year. Zero-tilled soil, as opposed to conventional tilled soil, sequestered carbon between 67 and 512 kg ha^{-1} annually (McConkey *et al.* 2003). Soil organic carbon provides advantages for both crops and soil production through the application and incorporation of crop residues onto the soil surface. The soil surface was where crop detritus was lost before its sequestration as soil organic carbon (SOC). Consequently, the incorporation of stubbles into soil organic carbon sequestration is merely an illustrative approach. Zero-tillage resulted in greater stocks of SOC at a depth of 0-5 cm compared to CT. However, no-tillage caused superficial accumulation and decomposition of crop detritus on the soil surface, which decreased its concentration in the deeper layers at a depth of 0 to 20 cm.

Effect of Tillage on Crop Yield and Soil Nutrient Level

The improvement of soil physical conditions through tilling is widely acknowledged as a significant factor in generating higher crop yields (Mohanty *et al.* 2007). Deep tillage has been linked to a multitude of advantages, such as increased root depth (Rajkannan and Selvi, 2002), enhanced water storage capacity, and improved infiltration (Sharma *et al.* 2004). These benefits collectively contribute to an overall increase in crop productivity. In contrast to conventional tillage, deep tillage utilizing a chisel plow produced a substantially greater quantity of fertile tillers, according to Khan *et al.* (2013). Furthermore, it was observed that deep-tilled wheat produced a considerably higher quantity of grains per spike, exceeding the yields of conventional tillage, zone disc tiller, and cheerful seeder by 5, 20, and 22%, respectively. Additionally, the wheat biological yield was significantly greater in the deep tillage treatment than in the other tillage techniques. Deep tillage exhibits a substantial and favorable influence on cereal yield.

Maximum water use efficiency values were recorded for zone disc tiller and deep tillage. In comparison to alternative tillage systems, the quantity of fruitful tillers produced was considerably greater with deep tillage. The enhanced grain production resulting from deep tillage can be ascribed to the finer, more aerated, and more profound soil structure, which promotes successful seedling emergence and further supports increased crop yields (Rashidi and Keshavarzpour, 2007). Furthermore, Alijani *et al.* (2012) in a study, revealed that chisel plowing resulted in a greater wheat cereal yield in comparison to rotary tillage and moldboard plowing. In regard to maximal grain yield, (FIRB) (T4) demonstrated statistically significant superiority over all other treatments, as evidenced by the data presented in Table 2 (52.6 q ha^{-1}). T5 performed superiorly to reduced (T2) and roto tillage (T3) throughout the experiment. In comparison to T4 (wheat planted using FIRB) and T5 (wheat sown using conventional tillage), reduced tillage and roto tillage procedures resulted in a 24.6 and 9.1% decrease in grain production, respectively. Conversely, in comparison to the remaining tillage practice sites, the wheat yield enhanced by furrow irrigation in raised beds 18.4%.

Table 2: Effect of various tillage techniques on yield of wheat crop (Adopted from Mahajan, 2018).

Tillage methods	*Grain yield (q ha^{-1})*	*Straw yield (q ha^{-1})*	*Harvest Index (%)*	*Test Weight (g)*
T1 (Zero tillage)	48.7	57.5	45.8	41.2
T2 (Reduced tillage)	41.9	50.9	45.2	39.6
T3 (Roto tillage)	37.4	44.8	45.0	37.4
T4 (Raised bed)	52.6	63.8	45.2	42.3
T5 (Conventional tillage)	43.6	56.6	43.5	40.3
SEm±	0.51	0.53	0.45	0.4
CD (P=0.05)	1.68	1.75	1.45	1.31

Variations in nutrient availability were noted in relation to the profundity of tillage techniques, suggesting that soil distribution significantly influences nutrient dynamics. In contrast, the impact of the tillage technique was more conspicuous in relation to the concentration of phosphorus (P) as opposed to nitrogen (N) and potassium (K) (Qamar *et al*. 2021). Concentrations of N, P, K, and organic matter influence crop yield, whereas penetration resistance has no such effect. The contribution of crop residues and tiller intensity to N dynamics is substantial. Zero tillage is a widely employed method utilized to mitigate water scarcity and enhance soil fertility through erosion control. In comparison to CT, the process of N mineralization during zero tillage reduces N losses and increases N use efficiency. In a similar fashion, conservation tillage strategies increased SOC and other nutrient concentrations through crop residue deposition at the soil surface. As a result of increased N mineralization at the upper soil surface caused by ZT, crop yield gets enhanced. Sainju *et al.* (2006) stated that crop residue and reduced tillage intensity reduce soil erosion and N leaching. The stability of soil macroaggregates in ZT-containing crop residue enhances the levels of SOC and total N, thereby safeguarding the organic matter present in the soil. The administration of N is significantly influenced by the tillage system, which in turn affects NUE, N uptake, and ultimately, crop production. The rate of carbon conversion to plant-available carbon (inorganic carbon) and tillage technique influences the availability of nitrogen in the soil for plant absorption (Verhulst *et al.* 2010). Soil organic matter (SOM) serves as a reservoir for nitrogen; consequently, fluctuations in SOM concentration significantly impact nitrogen cycling. The decline in soil organic matter and total nitrogen is predominantly attributed to conventional tillage methods (Xue *et al.* 2015), which expedite the decomposition of soil organic carbon (Al-Kaisi and Yin, 2005). This, in turn, promotes the mineralization process (Khan *et al.* 2017), which converts the organic form of nitrogen into inorganic forms, including nitrate (NO_3^-), ammonium (NH_4^+), nitrous oxide (N_2O), and nitric oxide (NO), the majority of which is low in the soil profile's nutrient distribution was modified by tilling, and intensive subsoiling increased nutrient loss. ZT exhibits elevated concentrations of SOC and N between 4 and 8 cm of soil depth before declining below 12 cm (Zibilske *et al.* 2002). Likewise, the distribution of organic and inorganic P in the rhizosphere is impacted by tillage. The overall required P was significantly reduced in no-till or ZT conditions compared to CT due to the increased availability of residual P. There has been a 30% increase in residual P availability when no-till or ZT is utilized. The availability of P was subject to the influence of organic P, which comprised the preponderance of total P (Zamuner *et al.* 2008). Soil aggregation has a direct influence on the P dynamics within the soil profile. P storage and sequestration in organic pools increased in tandem with soil aggregation. As a result of intensive cultivation decreasing aggregation size, P accumulation in inorganic fractions increases (Dent and Wright, 2009). Variations in nutrient distribution result from differences in crop rotation and tillage techniques. N and K concentrations were, however, greater in ZT than in CT, whereas the difference in soil P concentrations between the two tillage systems (conventional and zero) was negligible. In the deeper soil profile, nutrient concentrations were found to be lower with ZT as opposed to CT. This can be attributed to the residual retention on the surface caused by zero tillage, which increases mineralization and microbial degradation at the surface and consequently elevates nutrient concentrations their layers (Lupwayi *et al.* 2006).

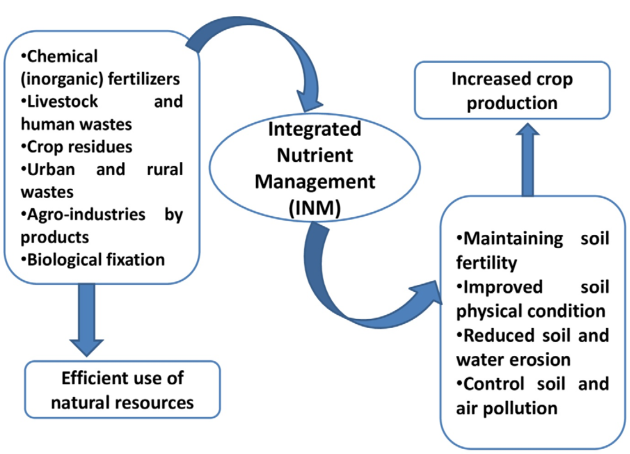

Fig. 1: Schematic representation of various Integrated Nutrient Management components and their role in improving soil productivity and enhancing crop production

Integrated Nutrient Management in Wheat

Integrated nutrient management entails the meticulous blending of all possible nutrient sources or components, including organic, inorganic, and biological sources, to produce an economically viable agricultural system and an environmentally sustainable setting (Jat *et al.* 2015; Fig. 1). Sustained yield and enhanced soil quality are outcomes that can be achieved through the integrated application of inorganic and organic nutrient sources (Brar *et al.* 2015). Ongoing implementation of organic manures enhances physical and chemical conditions through the following mechanisms: provision of a favorable soil structure, augmentation of soil cation exchange capacity, enhancement of plant nutrient quantity and availability, elevation of humus content, and facilitation of microbial activity utilizing a substrate (Bohme and Bohme *et al.* 2006). The utilization of organic manure in isolation resulted in a decrease in wheat yield, suggesting that this particular method is insufficient to supply the necessary nutrients for wheat growth (Sheoran *et al.* 2017). Wheat crop yield was enhanced when FYM and the recommended dose of fertilizers were applied in conjunction, as opposed to when the recommended dose of fertilizers was applied alone (Narwal *et al.* 2003; Brar *et al.* 2015). The accessibility of the soil to the wheat crop influences the amount of fertilizer that is necessary (Krentos and Orphanos, 1979). The nutrient and water use efficiency of INM is greater (Jat *et al.* 2015). According to Akram *et al.* (2007), the application of municipal solid refuse manure to INM in the cotton wheat system resulted in a 9% increase in the production of wheat grain and straw. An advantageous approach to sustainable crop production has been the integrated application of organic and chemical fertilizers (Yasin *et al.* 2015).

Effect of Nutrient Management on Productivity of Soil

In integrated nutrient management, chemical fertilizers blended with organic manure are utilized as inputs *via* the biological process (Jaga and Upadhya, 2013). Organic matter has improved the soil's capacity to retain water and provide nutrients, thereby establishing a favorable soil environment conducive to plant growth. By increasing soil water storage, bulk density, and porosity, soil organic matter enhances water availability and bulk density (Benbi and Nieder, 2003). Existing research suggests that the implementation of specific agricultural practices, such as the integration of organic amendments with chemical fertilizers, yields a multitude of favorable results. An increase in nutrient assimilation by plants, an improvement in the organic carbon content of the soil, and an enhancement in the NPK (nitrogen, phosphorus, and potassium) status were all findings documented by Khan *et al.* (2007). Furthermore, the utilization of manure during a specific year yields advantageous results not only for the crop of that season but also for the subsequent one.

The integration of biofertilizers, chemical fertilizers, farmyard manure, and organic manure leads to enhancements in soil characteristics. According to the findings of Saha *et al.* (2010), the integration of this compound improves the infiltration rate of the soil, aggregate stability, soil organic matter content, and moisture retention capacity, all while reducing bulk density. The consistent application of farmyard manure resulted in a gradual increase of 35.7% in soil organic matter over the years relative to the control. It has also been reported that the consistent application of organic fertilizers enhances the efficacy of chemical fertilizers when applied to the soil. The enhanced nutrient-retaining surface area of organic soil colloids and favorable soil microbial activity is responsible for this (Mana *et al.* 2005). In fields that are consistently fertilized with chemical fertilizers alone, it becomes critical to integrate organic and chemical fertilizers in order to rectify deficiencies in secondary and micronutrients (Chand *et al.* 2006). In addition, the introduction of these fertilizers into the soil fosters a favorable environment for humic acid formation, stimulates the activity of soil microorganisms, and results in a rise in the soil's organic carbon content (Bajpai *et al.* 2006).

Effect of Integrated Nutrient Management on Total Organic Carbon and Total Organic Matter Content

The presence of soil organic carbon (SOC) is of paramount importance in numerous soil processes and ecosystem services. The combination of various organic amendments with NPK leads to an increased reservoir of organic carbon in the soil. The increased productivity of the soil can be ascribed to the effective delivery of advantageous macro and micronutrients (Biswas and Benbi, 1997). According to Bharali *et al.* (2017), the carbon content of NPK + Cow dung (CD) is the highest at 39.36%. This is followed by NPK + green manure (GM) at 38.17%, NPK + Rice husk dried (RHD) at 36.05%, and NPK + Azolla compost (AC) at 14.14%, in comparison to NPK alone. It is considered essential to maintain a minimum soil organic carbon content of approximately 0.9% in soils containing less than 90% silt. An agroecologically appropriate organic carbon level for sandy soils over an extended period is between 1 and 1.5% (Araki *et al.* 1993). Increased levels of organic matter in the soil have been found to have positive effects on soil productivity, microbial activity, aggregation, and nutrient buffering capacity (Jolliff and Snapp, 1988).

The incorporation of organic fertilizers, including farmyard manure (FYM), biofertilizers, and crop residues, into soil processes results in an increase in organic matter content. It is widely recognized that the utilization of organic fertilizers improves soil health and productivity in comparison to inorganic sources, owing to their substantial organic matter content. Hence, the integration of organic and inorganic fertilizer sources is regarded as the most effective method for fulfilling the nutritional needs of plants and enhancing the overall condition of the soil.

Effect of Nutrient Management on Growth of Wheat Crop

The significance of growth parameters for inorganic and organic sources was demonstrated (Joy *et al.* 2018). Wheat was subjected to the following treatments: nitrogen at a rate of 120 kg ha^{-1}, phosphorous at a rate of 60 kg ha^{-1}, potassium at a rate of 40 kg ha^{-1}, farmyard manure at a rate of 10 kg ha^{-1}, and zinc at a rate of the maximum plant height (86.43 cm) and tillers per plant (7.33) were documented 90 days after sowing (Sangma *et al.* 2017). Enhanced nutrient availability and increased photosynthate production result in higher biomass production and yield, as indicated by the presence of more efficient tillers per plant and increased output per plant (Singh *et al.* 2018; Kaur *et al.* 2018). Increased production can result from nitrogen application, as it promotes more productive tillers and 1000-grain weight (Singh *et al.* 2011). Grain production, annual grain yield, and test weight were significantly increased by utilizing 80% of the recommended mineral fertilizer dosage in conjunction with ten tones of FYM per hectare applied with crop residues (Kler *et al.* 2007). Wheat growth and yield were enhanced by the combination of FYM and rice residue as opposed to FYM alone (Davari *et al.* 2012). Organic manures contain, apart from nutrients, microbial load and growth-promoting compounds that stimulate plant growth and metabolic activity.

Effect of Integrated Nutrient Management on Yield Attributing Characters and Yield

Nitrogen is an indispensable and fundamental component that is vital for the development of plants and the augmentation of agricultural output. Empirical evidence, including that of Khan *et al.* (2007), suggested that the integration of organic matter and chemical fertilizers yields favorable results, including increased cereal yield and crop biomass. By employing a synergistic strategy that combines chemical and organic inputs, this method successfully supplies the essential nutrients required for optimal plant development and enhances agricultural output. The application of a sufficient quantity of nitrogen is considered a crucial element in achieving a multitude of bumper harvests of wheat. As a necessary constituent of all proteins, nitrogen is engaged in every stage of plant development. Wheat yield was increased by 27.01% with NPK+ Azolla compost and 24.42% with NPK+ bovine manure (Bharali *et al.* 2017). Adopting improved agronomic techniques and cultivars has the potential to enhance wheat production (Sadat *et al.* 2008). Grain yield was significantly affected by nitrogen application rate; maximum grain yield was achieved with 150 kg N ha^{-1} nitrogen application; however, nitrogen application rates exceeding 100 kg N ha^{-1}

Table 3: Effect of Integrated Nutrient Management (INM) in wheat on yield and nutrient uptake by the crop (Adopted from Brar *et al.* 2015).

Treatment	*Yield (t ha^{-1})*	*Nutrient uptake (kg ha^{-1})*		
		N	*P*	*K*
Control	1.63	40.1	4.6	25.9
RDF[#]	4.69	122.8	16.3	82.0
50% NPK	3.53	83.8	9.4	53.9
150% NPK	5.08	130.1	18.3	81.8
RDF + Zn[$]	4.65	120.5	17.3	81.3
RDF + FYM[*]	5.13	150.8	18.5	92.4

[#]RDF (Recommended dose of fertilizer) = 150, 32.70 and 31.20 N, P and K (kg ha^{-1}), respectively; [$]Zinc sulphate applied @50 kg ha^{-1}; [*]FYM applied @10 t ha^{-1}.

did not generate a substantial increase in grain yield ha^{-1} (Maqsood *et al.* 2000). Additionally, nitrogen fertilizer treatment significantly increased grain yield, according to Ayoub *et al.* (1994). By combining inorganic and organic fertilizers, yield-related metrics including dry matter accumulation, absence of efficient tillers, grain per spike, and test weight increased (Mary *et al.* 2018). According to a study by Brar *et al.* (2015), the wheat crop exhibited enhanced nutrient uptake and yield when FYM was applied in conjunction with the prescribed dose of fertilizer (RDF) (Table 3).

Effect of Integrated Nutrient Management in Reducing Environmental Impact

As the concept of sustainability has gained acceptance, researchers advocate and develop INM approaches based on more than 20 years of research that can lead to significantly improved nutrient use efficiency (NUE), water use efficiency (WUE), and soil health condition while increasing yield and lowering environmental risk (Zhang *et al*. 2012). Nutrient management has always been concerned with optimal economic return, but today, we must consider the possible influence of these nutrients on environmental quality. As the theme of INM is sustainable agricultural production, it focuses on integrating all possible sources of nutrients that preserve soil productivity and promote soil health (Javaria and Khan, 2010). Higher carbon sequestration with better potential to sequester carbon was observed with manure application in the wheat crop (Kukal *et al.* 2009; Ghosh *et al.* 2012; Bharali *et al.* 2017). The expanding need for cereal crops to feed a growing human population necessitates the overuse of inorganic fertilizers to increase crop production (Wu and Baulo, 2015). Most farmers still need to learn about organic fertilizer sources and the INM approach method. The INM technique increases agricultural output while reducing environmental impact. Integrated nutrient management promotes plant performance, resource utilization efficiency, water utilization efficiency, and environmental protection (Wu and Baulo, 2015). Using inorganic fertilizer (NPK) with organic fertilizer enhances crop output by 8 to 150% and increases farmers' economic return (Wu and Baulo, 2015). Because soil is the primary source of nutrients, any loss in soil quality can result in decreased agricultural productivity and unfavorable environmental changes (Yadav *et al.,* 2018). Integrated nutrient management increases soil health, while organic sources with high carbon sequestration availability minimize greenhouse gas emissions. So, applications of organic sources reduce the impact of using an inorganic source of fertilizers on soil and the environment by reducing the emission of greenhouse gases and making the environment sound and clean.

Conclusion

To ensure sustainable agriculture, farmers need an effective cropping system to adapt to changing environmental conditions. Wheat cropping systems are crucial for global agriculture and play a significant role in meeting food security objectives. Adopting appropriate nutrient management practices and a suitable tillage system holds promise for wheat cultivation, improving yields and farm profitability while maintaining soil health. Zero tillage in wheat cropping reduces costs, increases revenue and yield, and has a beneficial environmental impact. Integrated nutrient management (INM) offers a sustainable, eco-friendly, and cost-effective approach to boost soil fertility and reduce the environmental impact of inorganic fertilizers. By integrating conservation tillage with the use of fertilizers and organic sources, wheat productivity can be enhanced while maintaining soil health.

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Authors Contribution

O.C.P. Planning of the study, review, and editing of MS. D.P. correction as per suggestion from reviewer and editor. M.H. Review and editing of MS and correction as per suggestion from reviewer and editor. S.P.G. Conceptualization of idea and writing the original draft of the manuscript. S.S. and A.K.S. Collection of review literature and compilation. S.Y. Conceptualization of idea, administration, and supervision of the study.

Conflict Of Interest

We have no conflicts of interest to disclose.

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