CropSci Publisher©

Field Crop 2024, Vol.7, No.2, 79-92
http://cropscipublisher.com/index.php/fc

Research Insight Open Access

Impact of Integrated Agronomic Practices on Maize Yield and Nutrient Use Efficiency

Lan Zhou ✉, Long Jiang
Colleye of Agriculture, Jilin Agricultural Science and Technology University, Jilin, 132101, Jilin, China
✉ Corresponding email: jilinzhoulan@126.com
Field Crop, 2024 Vol.7, No.2 doi: 10.5376/fc.2024.07.0009
Received: 03 Feb., 2024
Accepted: 14 Mar., 2024
Published: 01 Apr., 2024

Preferred citation for this article:
Zhou L., and Jiang L., 2024, Impact of integrated agronomic practices on maize yield and nutrient use efficiency, Field Crop, 7(2): 79-92 (doi: 10.5376/fc.2024.07.0009)

Abstract The integration of agronomic practices has shown significant potential in enhancing maize yield and nutrient use efficiency (NUE). This study synthesizes findings from multiple studies to evaluate the impact of integrated agronomic practices (IAP) on maize yield and NUE under varying soil fertility conditions. Studies indicate that IAP, which includes optimal planting density, split fertilizer application, and subsoiling tillage, can substantially increase maize grain yield and NUE compared to traditional farmers' practices (FP). The combination of organic and inorganic fertilizers, as part of integrated nutrient management (INM), has also been shown to improve soil fertility and crop productivity, contributing to sustainable agricultural practices. Long-term field studies reveal that integrated soil-crop system management (ISSM) strategies can achieve high maize yields and NUE with reduced environmental costs. Additionally, the integration of weed and nutrient management practices has been found to enhance maize yield, nutrient uptake, and economic returns in rice-maize cropping systems. The application of biochar in conjunction with partial doses of inorganic fertilizers further supports improved crop productivity and sustainability in maize-wheat cropping systems. Overall, the adoption of integrated agronomic practices offers a promising approach to achieving higher maize yields and better nutrient use efficiency, thereby supporting sustainable agricultural intensification.
Keywords Integrated agronomic practices (IAP); Maize yield; Nutrient use efficiency (NUE); Integrated nutrient management (INM); Sustainable agricultural practices

1 Introduction

Maize (*Zea mays* L.) is one of the most important cereal crops globally, serving as a staple food for millions of people and a key component in animal feed and industrial products. It is cultivated extensively across diverse climatic regions, making it a versatile crop with significant economic and nutritional value. In countries like India, maize is the third most important food crop after wheat and rice, with substantial production during both the Kharif and Rabi seasons (Sindhi et al., 2018; Augustine et al., 2021). The global demand for maize continues to rise due to its wide range of uses, necessitating improvements in its production to ensure food security and meet the needs of a growing population (Ramadhan, 2021; Sarwar et al., 2023).

Despite its global significance, maize cultivation faces several challenges that impact yield and sustainability. One of the primary issues is nutrient use efficiency (NUE), which refers to the ability of the crop to utilize available nutrients effectively. Poor NUE can lead to nutrient losses, environmental pollution, and increased production costs. Factors such as soil fertility, inappropriate fertilizer application, and climatic conditions can significantly affect NUE. For instance, unbalanced use of chemical fertilizers can degrade soil health and reduce crop productivity over time (Ghosh et al., 2020; Jalal et al., 2022). Additionally, nutrient deficiencies, particularly in nitrogen (N) and zinc (Zn), are common in many maize-growing regions, further complicating efforts to achieve optimal yields (Zhou et al., 2019; Jalal et al., 2022).

Integrated Agronomic Practices (IAP) offer a promising solution to the challenges of maize cultivation by combining various agronomic techniques to enhance crop performance and nutrient use efficiency. IAP strategies may include optimal planting density, split fertilizer application, subsoiling tillage, and the use of organic amendments such as biochar and farmyard manure (FYM) (Zhou et al., 2019; Sailaza and Kannamreddy, 2020;

Sarwar et al., 2023). These practices aim to improve soil health, increase nutrient availability, and enhance the overall resilience of the cropping system. Studies have shown that IAP can significantly increase maize grain yield and NUE, particularly in fields with varying soil fertility levels (Zhou et al., 2019). For example, the application of biochar in combination with reduced doses of inorganic fertilizers has been found to boost dry matter production, grain yield, and nutrient uptake in maize (Sarwar et al., 2023). Similarly, the use of diazotrophic bacteria and residual Zn fertilization has been shown to improve Zn use efficiency and grain biofortification (Jalal et al., 2022). By integrating these practices, farmers can achieve higher productivity, sustainability, and profitability in maize cultivation (Bhandari et al., 2021; Sarwar et al., 2023).

In conclusion, the adoption of integrated agronomic practices holds great potential for addressing the challenges of maize cultivation, particularly in enhancing nutrient use efficiency and achieving sustainable yield improvements. This study aims to explore the impact of various IAP strategies on maize yield and nutrient use efficiency, drawing insights from recent research findings.

2 Integrated Agronomic Practices (IAP)

2.1 Definition and components of IAP

Integrated Agronomic Practices (IAP) refer to a holistic approach to crop management that combines various agronomic techniques to optimize crop yield and nutrient use efficiency (NUE). The components of IAP typically include optimal planting density, split fertilizer application, subsoiling tillage, and the use of biochar and other organic amendments. These practices are designed to enhance soil fertility, improve plant health, and increase the efficiency of nutrient uptake by crops (Zhou et al., 2019; Sailaza et al., 2020; Yu et al., 2020; Sarwar et al., 2023).

2.2 Historical development and adoption of IAP in maize cultivation

The concept of IAP has evolved over the years as researchers and farmers have sought more sustainable and efficient ways to increase crop productivity. Initially, agronomic practices were often applied in isolation, but the limitations of this approach led to the development of integrated strategies. For instance, the combination of optimal planting density and split fertilizer application has been shown to significantly increase maize yield and NUE under various soil fertility conditions (Zhou et al., 2019). Similarly, the integration of biochar with partial doses of inorganic fertilizers has been found to improve dry matter production and grain yield in maize-wheat cropping systems (Sarwar et al., 2023).

2.3 Adoption of IAP in maize cultivation

The adoption of IAP in maize cultivation has been driven by the need to enhance crop productivity and sustainability. Studies have shown that IAP can lead to substantial increases in maize grain yield and NUE. For example, IAP increased maize grain yield by 25%-37% and improved various NUE metrics compared to traditional farming practices (Zhou et al., 2019). Additionally, integrated nutrient management practices, including the use of farmyard manure and biofertilizers, have been found to be effective in improving maize growth and yield (Sailaza et al., 2020). The adoption of IAP has also been influenced by the need to address environmental concerns, such as reducing nitrogen loss and improving nitrogen balance in cropping systems (Liu et al., 2020).

The development and adoption of IAP in maize cultivation have been driven by the need to improve crop yield, nutrient use efficiency, and sustainability. The integration of various agronomic practices has proven to be an effective strategy for achieving these goals.

3 Impact of IAP on Maize Yield

3.1 Yield improvements with IAP

Integrated Agronomic Practices (IAP) have been shown to significantly enhance maize yield across various studies. For instance, IAP strategies that include optimal planting density, split fertilizer application, and subsoiling tillage have demonstrated yield increases of 25% and 28% in low soil fertility fields and 36% and 37% in high soil fertility fields over two growing seasons (Zhou et al., 2019). Similarly, the application of 100% recommended dose of fertilizer (RDF) combined with farmyard manure (FYM) and biofertilizer consortium resulted in better growth and yield of maize compared to other nutrient management practices. Additionally, integrated soil-crop system management (ISSM) with a combination of inorganic and organic fertilizers achieved a 27% increase in maize yield relative to traditional farmers' practices (Wang et al., 2020).

3.2 Comparison with traditional farming practices (FP)

When compared to traditional farming practices (FP), IAP consistently outperforms in terms of yield. For example, IAP increased maize grain yield by 25-37% compared to FP, with the yield gap attributed to greater dry matter and nitrogen accumulation due to increased leaf area index and root length (Figure 1) (Zhou et al., 2019). In another study, ISSM achieved 97.7% of the yield obtained with high-yielding practices but with significantly lower nitrogen surplus and environmental costs, indicating a more sustainable approach (Wang et al., 2020). Furthermore, integrated weed and nutrient management practices in maize resulted in a 9% higher grain yield compared to chemical weed control alone (Ghosh et al., 2020).

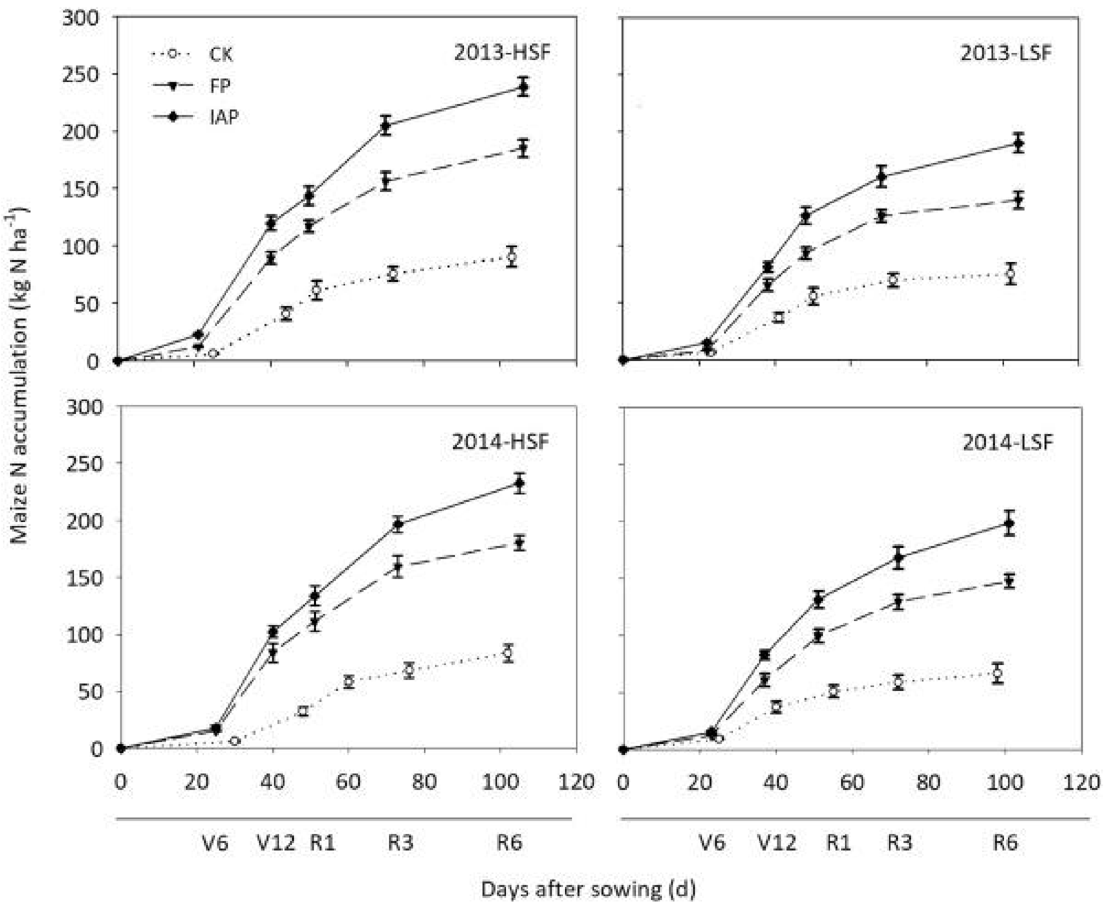

Figure 1 Nitrogen accumulation in maize plants for various treatments in 2013 and 2014 (Adopted from Zhou et al., 2019)

Image caption: HSF, high soil fertility field; LSF, low soil fertility field. CK, control without nitrogen; FP, conventional farmers' practice; IAP, an integrated agronomic practice. V6, 6-leaf stage; V12, 12-leaf stage; R1, silking stage; R3, milk stage; R6, physiological maturity (Adopted from Zhou et al., 2019)

3.3 Factors contributing to yield increase

Several factors contribute to the yield increase observed with IAP. Enhanced nutrient uptake and utilization are primary contributors. For instance, the use of biochar in combination with partial doses of NPK fertilizers improved dry matter production, grain weight, and nutrient uptake, leading to higher yields (Sarwar et al., 2023). The integration of density and fertilizer management also optimized biomass accumulation and nutrient remobilization, further boosting yield (Ren et al., 2020). Additionally, the combination of nitrogen fertilization with iron foliar application improved photosynthetic characteristics and enzyme activities, enhancing photosynthetic nitrogen use efficiency and ultimately increasing yield (Nasar et al., 2022). The use of organic amendments like farmyard manure and biofertilizers also played a significant role in improving soil health and nutrient availability, contributing to better crop performance (Ghosh et al., 2020; Sailaza et al., 2020).

In summary, IAP significantly improves maize yield through optimized nutrient management, enhanced soil health, and better agronomic practices, outperforming traditional farming methods and contributing to sustainable agricultural productivity.

4 Nutrient Use Efficiency (NUE) in Maize

4.1 Definition and importance of NUE

Nutrient Use Efficiency (NUE) in maize refers to the ability of the plant to utilize available nutrients, particularly nitrogen (N), to produce biomass and grain yield. NUE is a critical parameter in agricultural systems as it directly impacts crop productivity and environmental sustainability. High NUE means that a greater proportion of the applied nutrients are taken up and used by the crop, reducing the potential for nutrient losses to the environment through leaching, volatilization, or runoff (Figure 2) (Zhou et al., 2019; Shiade et al., 2023; Yadav et al., 2023).

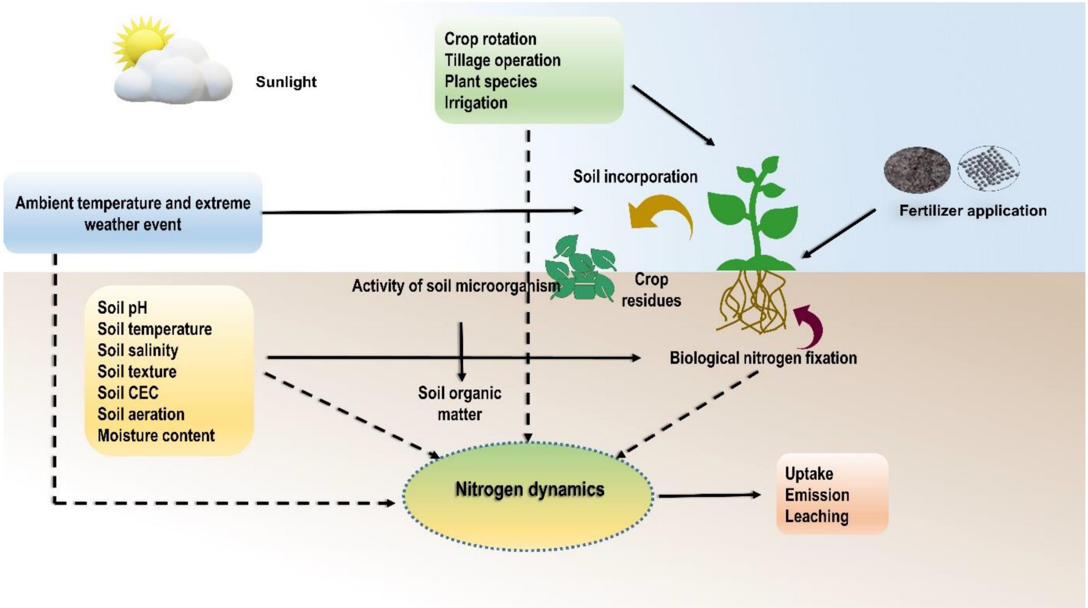

Figure 2 Interactions between nitrogen dynamics and environmental factors (Adopted from Yadav et al., 2023)

Image caption: This diagram illustrates the comprehensive dynamics of soil nitrogen cycling. Sunlight, ambient temperature, and extreme weather events directly impact the nitrogen cycle. Crop rotation, tillage operations, plant species, and irrigation influence nitrogen cycling through soil incorporation and crop residues. Fertilizer application directly adds nitrogen sources, while biological nitrogen fixation converts atmospheric nitrogen into usable forms through microbial activity. Soil pH, temperature, salinity, texture, cation exchange capacity (CEC), aeration, and moisture content affect soil microorganism activity and organic matter decomposition, thus impacting nitrogen dynamics. Ultimately, the nitrogen cycle results in nitrogen uptake, emission, and leaching (Adopted from Yadav et al., 2023)

4.2 Challenges in achieving high NUE

Achieving high NUE in maize is fraught with several challenges. One of the primary issues is the inefficient use of nitrogen fertilizers, which often results in significant environmental pollution and increased greenhouse gas emissions (Yadav et al., 2023). Factors such as soil fertility, climatic conditions, and inappropriate agronomic practices can further complicate the efficient use of nutrients. For instance, excessive or poorly timed fertilizer applications can lead to nutrient losses and reduced NUE (Zhang et al., 2018; Li et al., 2019; Zhou et al., 2019). Additionally, the genetic variability among maize cultivars in their ability to uptake and utilize nutrients poses another challenge (Yadav et al., 2023).

4.3 Strategies for improving NUE

Several strategies have been proposed and tested to improve NUE in maize. Integrated Agronomic Practices (IAP), which include optimal planting density, split fertilizer application, and subsoiling tillage, have been shown to significantly enhance NUE by promoting greater dry matter and nitrogen accumulation. The use of integrated soil-crop system management (ISSM) that combines organic and inorganic fertilizers has also been effective in achieving sustainable high maize yields and improved NUE (Wang et al., 2020).

Moreover, adopting precision farming techniques, such as site-specific nitrogen management and the use of enhanced efficiency fertilizers, can help in optimizing nutrient application and reducing losses (Yadav et al., 2023; Shiade et al., 2023). The integration of crop-livestock systems (ICLS) has also been found to improve nutrient cycling and soil chemical attributes, thereby enhancing NUE in paddy fields (Denardin et al., 2020). Lastly, modern breeding and biotechnological tools, including gene-editing technologies, offer promising avenues for developing maize cultivars with improved nutrient utilization capacities (Yadav et al., 2023).

By implementing these strategies, it is possible to achieve higher maize yields while minimizing the environmental impact of agricultural practices.

5 Effect of IAP on NUE

5.1 Influence of IAP on NUE

Integrated Agronomic Practices (IAP) have been shown to significantly enhance Nitrogen Use Efficiency (NUE) in maize cultivation. The implementation of IAP, which includes optimal planting density, split fertilizer application, and subsoiling tillage, has demonstrated substantial improvements in both maize grain yield and NUE under varying soil fertility conditions. For instance, a study found that IAP increased maize grain yield by 25%-28% in low soil fertility fields and by 36%-37% in high soil fertility fields over two growing seasons. This increase was attributed to greater dry matter and nitrogen accumulation, which were promoted by increased leaf area index and root length, leading to higher soil mineral nitrogen content and post-silking nitrogen accumulation (Zhao et al., 2019).

Moreover, long-term studies have shown that combining inorganic and organic fertilizers under an integrated soil-crop system management (ISSM) strategy can achieve sustainable high maize yields and improved NUE. Over an 11-year period, ISSM increased maize yield by 27% compared to traditional farmers' practices, while also reducing nitrogen surplus and losses, thereby enhancing NUE (Wang et al., 2020). Similarly, integrated nutrient management practices, which include the use of farmyard manure and biofertilizers along with recommended doses of inorganic fertilizers, have been found to improve maize growth and yield significantly (Sailaza and Kannamreddy, 2019).

5.2 Case studies

Several case studies highlight the effectiveness of IAP in improving NUE:

Northeast China: An 11-year field study demonstrated that ISSM, which combines inorganic and organic fertilizers, achieved 97.7% of the yield obtained with high-yielding practices while significantly reducing nitrogen losses and greenhouse gas emissions. This approach resulted in higher NUE and better sustainability compared to traditional practices (Wang et al., 2020).

North China Plain: A four-year study on double cropping of winter wheat and summer maize showed that integrated agronomic practices management (IAPM) improved grain yield and nitrogen balance. The treatment that combined optimized tillage, plant density, and fertilization practices resulted in the highest nitrogen recovery efficiency and reduced nitrogen loss by 39.1%-54.4% compared to other treatments (Liu et al., 2018).

Pakistan: A field study on the maize-wheat cropping system found that integrated nutrient management (INM) with 75% of the recommended dose of NPK fertilizers supplemented with biochar significantly improved dry matter production, grain yield, and nutrient uptake. This approach also enhanced the economic sustainability of the cropping system (Sarwar et al., 2023).

5.3 Mechanisms enhancing NUE

The mechanisms through which IAP enhances NUE are multifaceted and involve several physiological and agronomic factors:

Improved Root Development: IAP promotes greater root length and density, which enhances the plant's ability to uptake nitrogen from the soil. This is particularly effective in high soil fertility conditions where increased root length correlates with higher nitrogen uptake and post-silking nitrogen accumulation (Zhao et al., 2019).

Optimized Fertilizer Application: Split fertilizer application ensures that nitrogen is available to the plant at critical growth stages, reducing nitrogen losses through leaching and volatilization. This method has been shown to increase nitrogen recovery efficiency and agronomic nitrogen efficiency (Zhao et al., 2019; Wang et al., 2020).

Enhanced Soil Fertility: The use of organic fertilizers such as farmyard manure and biochar improves soil structure and increases soil organic carbon content, which in turn enhances the soil's capacity to retain and supply nitrogen to the plants. This integrated approach has been shown to improve nutrient uptake and NUE in various cropping systems (Sailaza and Kannamreddy, 2019; Sarwar et al., 2023).

Balanced Hormone Levels: IAP can regulate the balance of endogenous hormones such as indole-3-acetic acid (IAA), zeatin riboside (ZR), and gibberellin (GA3), which are crucial for grain filling and overall plant growth. Optimized hormone levels lead to improved grain-filling characteristics and higher grain yield, thereby enhancing NUE (Table 1) (Yu et al., 2020).

Table 1 Effects of integrated agronomic practices management on grain flling parameters and yield of summer maize (2016–2017) (Adopted from Yu et al., 2020)

Year	Treatment	Growth curve Parametric equation	Correlation coeffcient	T_{max} (d)	W_{max} (g/100 kernels)	G_{max} (g/100 kernels d^{-1})	P(d)	R_o	Graindry weight (g/100 kernels)	Yield (Mg ha^{-1})
2016	T1	$y=29.81/(1+40.39e^{-0.15x})$	0.9982	25.36 b	14.91 b	1.09 a	41.1 b	0.15 a	30.1 b	9.0 c
	T2	$y=30.81/(1+35.53e^{-0.14x})$	0.9902	25.85 b	15.40 a	1.06 a	43.4 a	0.14 b	31.3 a	10.8 b
	T3	$y=30.05/(1+41.46e^{-0.14x})$	0.997	25.18 b	15.02 ab	1.03 a	43.8 a	0.14 b	30.3 b	13.5 a
	T4	$y=31.02/(1+34.98e^{-0.14x})$	0.9985	27.13 a	15.51 a	1.06 a	43.8 a	0.14 b	31.2 a	11.9 b
	N0	$y=25.16/(1+57.57e^{-0.15x})$	0.9984	30.66 a	12.58 c	0.92 b	41.1 b	0.15 a	27.2 d	9.8 d
	N1	$y=26.27/(1+50.54e^{-0.15x})$	0.9981	26.81 b	13.14 b	0.96 b	41.0 b	0.15 a	29.2 b	12.2 c
	N2	$y=32.47/(1+32.98e^{-0.14x})$	0.9875	25.87 c	16.24 a	1.10 a	44.4 a	0.14 b	32.0 a	13.3 a
	N3	$y=31.89/(1+47.37e^{-0.14x})$	0.9975	26.94 b	15.94 a	1.14 a	41.9 b	0.14 b	30.9 b	12.9 b
2017	T1	$y=27.50/(1+59.02e^{-0.16x})$	0.9983	29.09 a	13.75 d	1.09 a	37.9 d	0.16 a	31.3 c	9.0 c
	T2	$y=30.04/(1+50.32e^{-0.14x})$	0.9951	28.47 b	15.02 b	1.03 a	43.6 b	0.14 c	35.9 a	11.9 b
	T3	$y=28.93/(1+55.21e^{-0.15x})$	0.9962	28.25 b	14.46 c	1.11 a	39.0 c	0.15 b	34.5 b	13.1 a
	T4	$y=31.20/(1+46.84e^{-0.13x})$	0.9935	29.18 a	15.60 a	1.03 a	45.5 a	0.13 d	35.5 a	12.4 b
	N0	$y=24.79/(1+56.89e^{-0.14x})$	0.9895	28.91 a	12.40 d	0.87 c	42.9 b	0.14 a	31.2 c	9.2 d
	N1	$y=27.51/(1+56.97e^{-0.14x})$	0.9977	28.88 a	13.76 c	0.96 b	42.9 b	0.14 a	34.9 b	11.2 c
	N2	$y=31.19/(1+48.74e^{-0.14x})$	0.9957	28.64 a	15.59 a	1.06 a	44.2 a	0.14 a	35.8 a	12.7 a
	N3	$y=30.17/(1+52.47e^{-0.14x})$	0.9962	28.16 a	15.08 b	1.06 a	42.7 b	0.14 a	35.1 ab	12.2 b

Note: T_{max}, days of maximum grain filling; W_{max}, weight of maximum grain-filling rate; G_{max}, maximum grain filling; P, active grain filling period; R_o, initiative value of grain filling. 2) T1, local smallhoder famers practices; T2, based on T1, increase planting density, decrease nitrogen rate, increase phosphorous and potassium rates, change fertilization time and delay harvesting; T3, based on T2, further increase planting density and greater increase fertilize rate to creating high yield; T4, based on T3, decrease planting density and the amount of fertilizer, were employed in a randomized block test design with four replications. N0-N3, 0, 129, 184.5, and 300 kg N ha^{-1}, respectively.Values followed by different small letters within a column are significantly different at the 0.05 probability level (Adopted from Yu et al., 2020)

Reduced Environmental Impact: By minimizing nitrogen surplus and losses, IAP reduces the environmental footprint of maize cultivation. This is achieved through better nitrogen balance and lower greenhouse gas emissions, making IAP a sustainable approach to improving NUE (Liu et al., 2018; Wang et al., 2020).

In conclusion, the implementation of integrated agronomic practices significantly enhances nitrogen use efficiency in maize cultivation through improved root development, optimized fertilizer application, enhanced soil fertility, balanced hormone levels, and reduced environmental impact. These practices not only increase maize yield but also contribute to sustainable agricultural systems.

6 Integrated Nutrient Management (INM)

6.1 Description of INM

Integrated Nutrient Management (INM) is a holistic approach aimed at maintaining or adjusting soil fertility and optimizing plant nutrient supply to achieve sustainable crop productivity. This strategy involves the balanced use of both chemical fertilizers and organic sources such as farmyard manure (FYM), compost, green manures, and biofertilizers. The primary goal of INM is to enhance nutrient availability, improve soil health, and reduce environmental impacts associated with excessive use of chemical fertilizers (Wang et al., 2020; Sarwar et al., 2023).

6.2 Impact on maize yield and NUE

The implementation of INM has shown significant positive impacts on maize yield and nutrient use efficiency (NUE). Studies have demonstrated that combining chemical fertilizers with organic amendments can lead to substantial improvements in crop growth, yield, and nutrient uptake. For instance, the application of 75% of the recommended dose of NPK fertilizers supplemented with biochar resulted in increased dry matter production, grain weight, and grain yield in maize, as well as improved nutrient uptake and economic sustainability. Similarly, integrated agronomic practices, including optimal planting density and split fertilizer application, have been found to increase maize grain yield and NUE, particularly in fields with high soil fertility (Zhou et al., 2019; Ghosh et al., 2020).

Long-term studies have also highlighted the benefits of INM in maintaining soil fertility and achieving sustainable high yields. For example, an 11-year field study in Northeast China showed that INM with a combination of inorganic and organic fertilizers significantly increased maize yield and NUE while reducing nitrogen losses and greenhouse gas emissions. Another long-term experiment in the Indo-Gangetic plains of India revealed that INM practices led to higher sustainable yield indices and better nutrient balance compared to the sole use of chemical fertilizers (Saha et al., 2018).

6.3 Successful INM strategies

Several successful INM strategies have been identified in various studies. One effective approach involves the partial substitution of chemical fertilizers with organic amendments. For example, substituting 50% of the recommended nitrogen dose with farmyard manure or other organic sources has been shown to enhance maize growth and yield parameters. Additionally, the use of biochar as a supplement to chemical fertilizers has proven to be beneficial in improving crop productivity and nutrient uptake (Sarwar et al., 2023).

Another successful strategy is the integration of weed management practices with nutrient management. Combining chemical weed control with mechanical methods, such as hoeing, has been found to reduce weed density and enhance maize grain yield. Furthermore, the adoption of integrated soil-crop system management (ISSM) strategies, which include the use of both inorganic and organic fertilizers, has been shown to achieve sustainable high yields and improved NUE in maize cropping systems (Wang et al., 2020).

In conclusion, INM is a promising approach to enhance maize yield and nutrient use efficiency while maintaining soil health and sustainability. The integration of chemical and organic nutrient sources, along with appropriate agronomic practices, can lead to significant improvements in crop productivity and environmental sustainability.

7 Soil Fertility and IAP

7.1 Importance of soil fertility

Soil fertility is a critical factor in determining crop yield and overall agricultural productivity. It influences the availability of essential nutrients required for plant growth and development. High soil fertility ensures that crops receive adequate nutrients, leading to better growth, higher yields, and improved quality of produce. Conversely, low soil fertility can limit crop productivity and nutrient use efficiency (NUE), necessitating the implementation of effective soil management practices to enhance soil health and fertility (Zhou et al., 2019; Wang et al., 2020; Sailaza and Kannamreddy, 2020).

7.2 Addressing soil fertility issues

Addressing soil fertility issues involves the adoption of integrated nutrient management practices that combine organic and inorganic fertilizers to improve soil health and nutrient availability. For instance, the application of farmyard manure (FYM) along with recommended doses of fertilizers has been shown to enhance soil organic carbon content, increase soil nutrient levels, and improve crop yields (Sailaza and Kannamreddy, 2020; Asaye et al., 2022; Nisar et al., 2022). Additionally, the use of biochar and compost in conjunction with inorganic fertilizers can significantly enhance soil fertility, especially in alkaline soils, by improving soil structure, nutrient retention, and microbial activity (El-Syed et al., 2023). Long-term integrated soil-crop system management (ISSM) strategies that combine organic and inorganic fertilizers have also been effective in maintaining high crop yields and NUE while reducing environmental impacts (Wang et al., 2020).

7.3 Relationship between soil fertility and IAP effectiveness

The effectiveness of Integrated Agronomic Practices (IAP) is closely linked to the underlying soil fertility conditions. Studies have shown that IAP, which includes optimal planting density, split fertilizer application, and subsoiling tillage, can significantly increase maize grain yield and NUE, particularly in fields with high soil fertility (HSF) (Zhou et al., 2019). In HSF conditions, IAP promotes greater dry matter and nitrogen accumulation, leading to higher yields compared to low soil fertility (LSF) fields. However, even in LSF fields, IAP can still enhance crop performance by improving root length and soil mineral nitrogen content, although the yield gains may be less pronounced (Zhou et al., 2019). Furthermore, integrated nutrient management practices that combine organic and inorganic inputs can improve soil fertility over time, thereby enhancing the long-term effectiveness of IAP in various soil conditions (Sailaza and Kannamreddy, 2020; Asaye et al., 2022; Nisar et al., 2022).

By addressing soil fertility issues through integrated nutrient management and adopting IAP, farmers can achieve sustainable increases in crop yield and NUE, contributing to improved food security and environmental sustainability.

8 Environmental Impact of IAP

8.1 Environmental benefits

Integrated Agronomic Practices (IAP) have demonstrated significant environmental benefits, particularly in terms of reducing nitrogen (N) losses and greenhouse gas emissions. For instance, the Nutrient Expert (NE) system, a form of IAP, has been shown to reduce reactive N losses and greenhouse gas emissions by 46.9% and 37.2% for maize, respectively, compared to traditional farmers' practices (FP) (Wang et al., 2020a). Additionally, the Integrated Soil-Crop System Management (ISSM) strategy, which combines inorganic and organic fertilizers, has achieved lower N losses and greenhouse gas emissions while maintaining high maize yields (Wang et al., 2020b). These practices not only enhance nutrient use efficiency but also contribute to a cleaner environment by minimizing the environmental footprint of agricultural activities.

8.2 Long-term Sustainability

The long-term sustainability of IAP is evident from various studies that highlight its ability to maintain high crop yields and improve nutrient use efficiency over extended periods. For example, an 11-year field study in Northeast China demonstrated that ISSM could sustain high maize yields and NUE with significantly lower environmental costs compared to traditional practices. Similarly, the use of biochar integrated with nutrient application has been shown to improve crop productivity and sustainability in a maize-wheat cropping system, enhancing nutrient uptake and reducing the need for chemical fertilizers (Sarwar et al., 2023). These findings suggest that IAP can provide a sustainable solution for long-term agricultural productivity while preserving environmental health.

8.3 Potential environmental challenges

Despite the numerous benefits, IAP also presents potential environmental challenges that need to be addressed. One such challenge is the risk of excessive nutrient accumulation in the soil, which can lead to nutrient imbalances and potential environmental pollution. For instance, while IAP strategies like the NE system have been effective in reducing N losses, there is still a need to monitor and manage soil nutrient levels to prevent long-term accumulation and potential leaching (Wang et al., 2020a). Additionally, the variability in soil fertility conditions can affect the efficiency of IAP, as seen in studies where the benefits of IAP were more pronounced in high soil fertility fields compared to low soil fertility fields (Zhou et al., 2019). Therefore, it is crucial to tailor IAP strategies to specific soil and environmental conditions to mitigate potential challenges and maximize their environmental benefits.

9 Economic Viability of IAP

9.1 Cost-benefit analysis

Integrated Agronomic Practices (IAP) have shown significant potential in enhancing maize yield and nutrient use efficiency (NUE), which directly impacts the economic viability of maize production. For instance, the application of IAP, including optimal planting density, split fertilizer application, and subsoiling tillage, resulted in a 25%-37% increase in maize grain yield compared to farmers' practices (FP) under varying soil fertility conditions (Zhou et al., 2019). This yield improvement translates into higher economic returns due to increased productivity. Additionally, the use of integrated soil-crop system management (ISSM) with a combination of inorganic and organic fertilizers has demonstrated a 27% increase in maize yield relative to FP, while also reducing nitrogen surplus and environmental costs (Wang et al., 2020b). These findings suggest that the initial investment in IAP can be offset by the substantial gains in yield and efficiency, making it a cost-effective strategy for maize production.

9.2 Economic returns

The economic returns from IAP are evident through various studies. For example, the integration of biochar with nutrient management practices in a maize-wheat cropping system resulted in a 60%-63% increase in grain yield and improved economic sustainability (Sarwar et al., 2023). Similarly, the use of integrated weed and nutrient management practices in the rice-maize cropping system of Eastern India not only enhanced maize yield but also maximized net returns and economic efficiency (Ghosh et al., 2020). Furthermore, conservation agriculture combined with precision nutrient management practices in the maize-wheat system significantly increased net returns by 36.8%-40.5% compared to conventional tillage (Jat et al., 2018). These studies highlight the economic benefits of adopting IAP, which include higher yields, improved nutrient use efficiency, and increased profitability.

9.3 Economic case studies

Several case studies illustrate the economic viability of IAP in different regions and cropping systems. In Northeast China, an 11-year field study on ISSM demonstrated sustainable high maize yields and NUE with significantly lower nitrogen losses and greenhouse gas emissions compared to FP (Wang et al., 2020b). In North China Plain, integrated agronomic practices management (IAPM) in double cropping of winter wheat-summer maize resulted in a 33.3% increase in annual grain yield and higher net profit and nitrogen use efficiency (Liu et al., 2018). Additionally, a study in Rajasthan, India, showed that the application of 75% recommended dose of fertilizer (RDF) through chemical fertilizer combined with vermicompost and biofertilizers produced the highest grain yield and net returns, with a benefit-cost ratio of 2.27 (Shekhawat, 2021). These case studies provide concrete evidence of the economic advantages of IAP, demonstrating its potential to enhance productivity and profitability across diverse agricultural settings.

10 Case Study

10.1 Detailed examination

This case study examines the impact of integrated agronomic practices (IAP) on maize yield and nutrient use efficiency (NUE) across various soil fertility conditions. The study spans multiple regions and incorporates diverse agronomic strategies to enhance maize productivity and sustainability.

10.2 Agronomic practices used

The integrated agronomic practices evaluated in this case study include a combination of optimal planting density, split fertilizer application, subsoiling tillage, and the use of organic and inorganic fertilizers. These practices were tailored to different soil fertility conditions to maximize their effectiveness.

Optimal Planting Density and Split Fertilizer Application: The use of optimal planting density and split fertilizer application was a common strategy across several studies. This approach aimed to enhance nutrient uptake and improve crop growth by ensuring that nutrients were available when the plants needed them most (Liu et al., 2018; Wang et al., 2020b; Shekhawat, 2021).

Subsoiling Tillage: Subsoiling tillage was employed to improve soil structure and root penetration, which in turn enhanced nutrient uptake and water retention. This practice was particularly effective in fields with low soil fertility (Shekhawat, 2021).

Combination of Organic and Inorganic Fertilizers: The integration of organic fertilizers (such as poultry manure, vermicompost, and biochar) with inorganic fertilizers was a key component of the IAP. This combination aimed to improve soil fertility, enhance nutrient use efficiency, and increase crop yield (Sailaza and Kannamreddy, 2020; Urmi et al., 2022; Sarwar et al., 2023).

Integrated Weed and Nutrient Management: In some regions, integrated weed and nutrient management practices were implemented to reduce weed competition and enhance nutrient availability for maize. This approach included the use of organic manures and chemical herbicides in a complementary manner (Ghosh et al., 2020).

Conservation Agriculture and Precision Nutrient Management: Conservation agriculture practices, such as reduced tillage and residue management, were combined with precision nutrient management to improve water use efficiency and crop productivity. This approach was particularly effective in regions with water scarcity issues (Jat et al., 2018).

10.3 Results and lessons learned

The implementation of integrated agronomic practices led to significant improvements in maize yield and nutrient use efficiency across various soil fertility conditions. The key findings and lessons learned from this case study are as follows:

Increased Maize Yield: The use of IAP resulted in substantial increases in maize yield compared to traditional farming practices. For instance, in fields with low soil fertility, IAP increased maize grain yield by 25% and 28% in 2013 and 2014, respectively. In fields with high soil fertility, the yield increase was even more pronounced, with gains of 36% and 37% in the same years (Shekhawat, 2021).

Enhanced Nutrient Use Efficiency: IAP significantly improved NUE by increasing nitrogen uptake and reducing nitrogen losses. This was achieved through better root development, increased soil mineral nitrogen content, and optimized fertilizer application timing. The partial factor productivity, agronomic efficiency, and recovery efficiency of applied nitrogen were all higher under IAP compared to traditional practices (Wang et al., 2020b; Shekhawat, 2021; Sarwar et al., 2023).

Improved Soil Fertility and Sustainability: The integration of organic fertilizers with inorganic fertilizers enhanced soil fertility by increasing organic carbon content, total nitrogen, and other essential nutrients. This not only improved crop yield but also contributed to long-term soil health and sustainability (Sailaza and Kannamreddy, 2020; Urmi et al., 2022; Sarwar et al., 2023).

Economic Benefits: The adoption of IAP led to higher net returns and economic efficiency. For example, the use of biochar and partial doses of inorganic fertilizers in a maize-wheat cropping system resulted in higher system productivity and profitability compared to conventional practices (Sarwar et al., 2023).

Environmental Benefits: IAP practices reduced environmental costs by minimizing nitrogen losses and greenhouse gas emissions. The use of conservation agriculture and precision nutrient management further enhanced water use efficiency and reduced the environmental footprint of maize production (Jat et al., 2018).

In conclusion, the case study demonstrates that integrated agronomic practices can significantly enhance maize yield and nutrient use efficiency while promoting soil health and sustainability. The successful implementation of these practices requires a tailored approach that considers local soil fertility conditions and resource availability. The lessons learned from this case study can inform future efforts to improve agricultural productivity and sustainability in maize-growing regions worldwide.

11 Challenges and Limitations

11.1 Common implementation challenges

Implementing integrated agronomic practices (IAP) in maize cultivation faces several challenges. One significant challenge is the variability in soil fertility across different fields, which affects the consistency of IAP outcomes. For instance, while IAP significantly increased maize grain yield and nitrogen use efficiency (NUE) in high soil fertility (HSF) fields, the benefits were less pronounced in low soil fertility (LSF) fields (Zhou et al., 2019). Additionally, the complexity of managing multiple agronomic factors such as planting density, fertilizer application, and tillage methods can be daunting for farmers, especially those with limited resources or technical knowledge (Liu et al., 2018). The need for precise timing and coordination of these practices further complicates their implementation (Xu et al., 2018).

11.2 Observed limitations

Despite the potential benefits, several limitations have been observed in the application of IAP. One major limitation is the environmental impact, particularly in terms of nitrogen losses and greenhouse gas emissions. Although integrated soil-crop system management (ISSM) strategies have shown promise in reducing these environmental costs, they still require careful management to avoid negative impacts (Wang et al., 2020b). Another limitation is the economic feasibility for small-scale farmers. While high-yield management practices can significantly increase grain yield, they often involve higher input costs, which may not be sustainable for all farmers (Xu et al., 2018). Additionally, the long-term sustainability of these practices is still under investigation, with some studies indicating that continuous application may lead to diminishing returns in terms of soil health and crop productivity (Sarwar et al., 2023).

11.3 Potential solutions and further research

To address these challenges and limitations, several potential solutions and areas for further research have been identified. One promising approach is the use of biochar and organic amendments in combination with inorganic fertilizers. This strategy has been shown to improve soil health, enhance nutrient uptake, and increase crop yield, particularly under stress conditions such as drought (El-Syed et al., 2023). Another solution is the development and dissemination of decision-support tools like the Nutrient Expert (NE) system, which helps optimize nutrient management and reduce environmental impacts (Wang et al., 2020a). Further research is needed to refine these tools and make them more accessible to farmers.

Additionally, long-term field studies are essential to evaluate the sustainability of IAP and ISSM strategies. These studies should focus on understanding the interactions between different agronomic practices and their cumulative effects on soil health, crop productivity, and environmental sustainability (Liu et al., 2018; Wang et al., 2020b). Finally, there is a need for more comprehensive training programs to equip farmers with the knowledge and skills required to implement these complex practices effectively (Sailaza and Kannamreddy, 2020).

By addressing these challenges and limitations through targeted research and practical solutions, the potential of integrated agronomic practices to enhance maize yield and nutrient use efficiency can be fully realized.

12 Concluding Remarks

Integrated agronomic practices (IAP) have demonstrated significant potential in enhancing maize yield and nutrient use efficiency (NUE) across various soil fertility conditions. Studies have shown that IAP strategies, which include optimal planting density, split fertilizer application, and subsoiling tillage, can increase maize grain yield by up to 37% in high soil fertility (HSF) fields and 28% in low soil fertility (LSF) fields compared to traditional farmers' practices (FP). The improvements in yield are primarily attributed to increased dry matter (DM) and nitrogen (N) accumulation, greater leaf area index (LAI), and enhanced root length, which collectively promote better post-silking DM and N accumulation.

Long-term studies have further validated the effectiveness of integrated soil-crop system management (ISSM) in achieving sustainable high maize yields and NUE. For instance, an 11-year field study in Northeast China reported a 27% increase in maize yield and significantly lower N losses and greenhouse gas emissions under ISSM compared to FP. Additionally, integrated nutrient management (INM) practices, such as the combined use of organic and inorganic fertilizers, have been shown to improve soil fertility, carbon sequestration, and overall crop productivity.

The findings from these studies underscore the importance of adopting integrated agronomic practices to enhance maize yield and NUE sustainably. Future agricultural practices should focus on the following:

Optimization of Agronomic Practices: Implementing optimal planting densities, split fertilizer applications, and advanced tillage methods can significantly improve crop performance. Tailoring these practices to specific soil fertility conditions can maximize their benefits.

Integration of Organic and Inorganic Fertilizers: Combining organic amendments such as poultry manure, vermicompost, and biochar with inorganic fertilizers can enhance soil health, improve nutrient uptake, and increase crop yields. This approach also contributes to better soil carbon sequestration and reduced environmental impact.

Long-term Sustainability: Long-term field studies highlight the need for sustainable management practices that balance high crop yields with minimal environmental costs. Strategies like ISSM and conservation agriculture, which include crop rotation and residue management, should be promoted for their long-term benefits.

Precision Nutrient Management: Utilizing site-specific nutrient management tools can optimize fertilizer use, improve NUE, and enhance economic returns. This approach ensures that crops receive the right amount of nutrients at the right time, reducing waste and environmental pollution.

The integration of advanced agronomic practices holds great promise for improving maize yield and nutrient use efficiency. By adopting a holistic approach that combines optimal planting techniques, precise nutrient management, and sustainable soil practices, farmers can achieve higher productivity while maintaining soil health and reducing environmental impact. Continued research and field trials are essential to refine these practices and adapt them to diverse agricultural settings, ensuring food security and sustainability for future generations.

Funding

This work was supported by the Science and Technology Development Plan Project of Jilin Province (#20240303004NC) Innovation Capacity Building Project of Jilin Development and Reform Commission (#2023C035-3) and the Science and Technology Development Plan Project of Jilin City (#20230501010).

Acknowledgments

Authors would like to express our gratitude to the two anonymous peer reviewers for their critical assessment and constructive suggestions on our manuscript.

Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

Asaye Z., Kim D., Yimer F., Prost K., Obsa O., Tadesse M., Gebrehiwot M., and Brüggemann N., 2022, Effects of combined application of compost and mineral fertilizer on soil carbon and nutrient content, yield, and agronomic nitrogen use efficiency in maize-potato cropping systems in southern Ethiopia, Land, 11(6): 784.
https://doi.org/10.3390/land11060784

Augustine R., and Kalyanasundaram D., 2021, Effect of agronomic biofortification on growth, yield, uptake and quality characters of maize (Zea mays .L) through integrated management practices under North-eastern region of Tamil Nadu, India, Journal of Applied and Natural Science, 13(1): 278-286.
https://doi.org/10.31018/jans.v13i1.2539

Bhandari M., Regmi N., Sahani H., Sherpa P., and Panthi B., 2021, Integrated nutrient management in maize production–a review, Reviews in Food and Agriculture, 2(1): 27-30.
https://doi.org/10.26480/rfna.01.2021.27.30

Denardin L., Martins A., Carmona F., Veloso M., Carmona G., Carvalho P., and Anghinoni I., 2020, Integrated crop–livestock systems in paddy fields: New strategies for flooded rice nutrition, Agronomy Journal, 112(3): 2219-2229.
https://doi.org/10.1002/agj2.20148

El-Syed N., Helmy A., Fouda S., Nabil M., Abdullah T., Alhag S., Al-Shuraym L., Syaad K., Ayyoub A., Mahmood M., and Elrys A., 2023, Biochar with organic and inorganic fertilizers improves defenses, nitrogen use efficiency, and yield of maize plants subjected to water deficit in an alkaline soil, Sustainability, 15(16): 12223.
https://doi.org/10.3390/su151612223

Ghosh D., Brahmachari K., Brestič M., Ondrisik P., Hossain A., Skalický M., Sarkar S., Moulick D., Dinda N., Das A., Pramanick B., Maitra S., and Bell R., 2020, Integrated weed and nutrient management improve yield, nutrient uptake and economics of maize in the rice-maize cropping system of eastern India, Agronomy, 10(12): 1906.
https://doi.org/10.3390/agronomy10121906

Ghosh S., Kholiya K., Pant R., Kholiya D., and Paul J., 2020, Integrated nutrient management on maize, International Journal of Chemical Studies, 8: 807-810.
https://doi.org/10.22271/chemi.2020.v8.i6l.10868

Jalal A., Oliveira C., Fernandes H., Galindo F., Silva E., Fernandes G., Nogueira T., Carvalho P., Balbino V., Lima B., and Filho M., 2022, Diazotrophic bacteria is an alternative strategy for increasing grain biofortification, yield and zinc use efficiency of maize, Plants, 11(9): 1125.
https://doi.org/10.3390/plants11091125
PMid:35567126 PMCid:PMC9099601

Jat R., Jat H., Nanwal R., Yadav A., Bana A., Choudhary K., Kakraliya S., Sutaliya J., Sapkota T., and Jat M., 2018, Conservation agriculture and precision nutrient management practices in maize-wheat system: effects on crop and water productivity and economic profitability, Field Crops Research, 222: 111-120.
https://doi.org/10.1016/j.fcr.2018.03.025

Li Y., Li Z., Cui S., Chang S., Jia C., and Zhang Q., 2019, A global synthesis of the effect of water and nitrogen input on maize (*Zea mays*) yield, water productivity and nitrogen use efficiency, Agricultural and Forest Meteorology, 268: 136-145.
https://doi.org/10.1016/j.agrformet.2019.01.018

Liu Z., Gao J., Gao F., Dong S., Liu P., Zhao B., and Zhang J., 2018, Integrated agronomic practices management improve yield and nitrogen balance in double cropping of winter wheat-summer maize, Field Crops Research, 221: 196-206.
https://doi.org/10.1016/j.fcr.2018.03.001

Nasar J., Wang G., Ahmad S., Muhammad I., Zeeshan M., Gitari H., Adnan M., Fahad S., Khalid M., Zhou X., Abdelsalam N., Ahmed G., and Hasan M., 2022, Nitrogen fertilization coupled with iron foliar application improves the photosynthetic characteristics, photosynthetic nitrogen use efficiency, and the related enzymes of maize crops under different planting patterns, Frontiers in Plant Science, 13: 988055.
https://doi.org/10.3389/fpls.2022.988055
PMid:36119633 PMCid:PMC9478416

Nisar S., Mavi M., Singh J., and Dey P., 2022, Integrated nutrient management in spring-maize improves yield, nutrient use efficiency and minimizes greenhouse gas intensity, Archives of Agronomy and Soil Science, 69(13): 2522-2536.
https://doi.org/10.1080/03650340.2022.2160977

Ramadhan M., 2021, Yield and yield components of maize and soil physical properties as affected by tillage practices and organic mulching, Saudi Journal of Biological Sciences, 28(12): 7152-7159.
https://doi.org/10.1016/j.sjbs.2021.08.005
PMid:34867018 PMCid:PMC8626335

Ren H., Cheng Y., Li R., Yang Q., Liu P., Dong S., Zhang J., and Zhao B., 2020, Integrating density and fertilizer management to optimize the accumulation, remobilization, and distribution of biomass and nutrients in summer maize, Scientific Reports, 10(1): 11777.
https://doi.org/10.1038/s41598-020-68730-8
PMid:32678188 PMCid:PMC7367288

Saha S., Saha B., Ray M., Mukhopadhyay S., Halder P., Das A., Chatterjee S., and Pramanick M., 2018, Integrated nutrient management (INM) on yield trends and sustainability, nutrient balance and soil fertility in a long-term (30 years) rice-wheat system in the Indo-Gangetic plains of India, Journal of Plant Nutrition, 41(18): 2365-2375.
https://doi.org/10.1080/01904167.2018.1510509

Sailaza N., and Kannamreddy V., 2020, Effect of integrated nutrient management practices on growth and yield of maize, Pharma Innovation, 9(12):105-107.
https://doi.org/10.22271/tpi.2020.v9.i12b.5410

Shekhawat A., 2021, Effect of integrated nutrient management on productivity, quality and economics of maize (*Zea mays* L.) on typic Haplustepts of Rajasthan, Annals of Plant and Soil Research, 23(4): 407-410.
https://doi.org/10.47815/apsr.2021.10092

Shiade S., Fathi A., Kardoni F., Pandey R., and Pessarakli M., 2023, Nitrogen contribution in plants: recent agronomic approaches to improve nitrogen use efficiency, Journal of Plant Nutrition, 47(2): 314-331.
https://doi.org/10.1080/01904167.2023.2278656

Sarwar N., Abbas N., Farooq O., Akram M., Hassan M., Mubeen K., Rehman A., Shehzad M., Ahmad M., and Khaliq A., 2023, Biochar integrated nutrient application improves crop productivity, sustainability and profitability of maize–wheat cropping system, Sustainability, 15(3): 2232.
https://doi.org/10.3390/su15032232

Urmi T., Rahman M., Islam M., Islam M., Jahan N., Mia M., Akhter S., Siddiqui M., and Kalaji H., 2022, Integrated nutrient management for rice yield, soil fertility, and carbon sequestration, Plants, 11(1): 138.
https://doi.org/10.3390/plants11010138
PMid:35009141 PMCid:PMC8747502

Wang Y., Cao Y., Feng G., Li X., Zhu L., Liu S., Coulter J., and Gao Q., 2020b, Integrated soil–crop system management with organic fertilizer achieves sustainable high maize yield and nitrogen use efficiency in Northeast China based on an 11-year field study, Agronomy, 10(8): 1078.
https://doi.org/10.3390/agronomy10081078

Wang Y., Li C., Li Y., Zhu L., Liu S., Yan L., Feng G., and Gao Q., 2020a, Agronomic and environmental benefits of nutrient expert on maize and rice in Northeast China, Environmental Science and Pollution Research, 27: 28053-28065.
https://doi.org/10.1007/s11356-020-09153-w
PMid:32405950

Xu H., Dai X., Chu J., Wang Y., Yin L., Ma X., Dong S., and He M., 2018, Integrated management strategy for improving the grain yield and nitrogen-use efficiency of winter wheat, Journal of Integrative Agriculture, 17(2): 315-327.
https://doi.org/10.1016/S2095-3119(17)61805-7

Yadav M., Kumar S., Lal M., Kumar D., Kumar R., Yadav R., Kumar S., Nanda G., Singh J., Udawat P., Meena N., Jha P., Minkina T., Glinushkin A., Kalinitchenko V., and Rajput V., 2023, Mechanistic understanding of leakage and consequences and recent technological advances in improving nitrogen use efficiency in cereals, Agronomy, 13(2): 527.
https://doi.org/10.3390/agronomy13020527

Yu N., Zhang J., Peng L., Zhao B., and Ren B., 2020, Integrated agronomic practices management improved grain formation and regulated endogenous hormone balance in summer maize (*Zea mays* L.), Journal of Integrative Agriculture, 19(7): 1768-1776.
https://doi.org/10.1016/S2095-3119(19)62757-7

Zhang H., Yu C., Kong X., Hou D., Gu J., Liu L., Wang Z., and Yang J., 2018, Progressive integrative crop managements increase grain yield, nitrogen use efficiency and irrigation water productivity in rice, Field Crops Research, 215: 1-11.
https://doi.org/10.1016/j.fcr.2017.09.034

Zhou B., Sun X., Wang D., Ding Z., Li C., Ma W., and Zhao M., 2019, Integrated agronomic practice increases maize grain yield and nitrogen use efficiency under various soil fertility conditions, The Crop Journal, 7(4): 527-538.
https://doi.org/10.1016/j.cj.2018.12.005