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Review Article

Integrated nutrient management to maintain maize productivity while reducing environmental impacts

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The global imperative of sustaining food production to meet the needs of a growing population requires innovative agricultural approaches that enhance crop productivity while mitigating environmental impacts. This summary delves into the concept of integrated nutrient management (INM) as a comprehensive strategy for maintaining maize productivity while concurrently minimizing environmental footprints. INM entails a careful blend of organic and inorganic fertilizers, cover cropping, and other agronomic techniques to optimize nutrient availability and utilization in maize cultivation. The review examines existing literature and research outcomes on the effects of INM, with a specific focus on its capacity to improve nutrient use efficiency, decrease nutrient runoff, and counteract soil degradation. Through the incorporation of organic nutrient sources like crop residues and green manure with precisely calibrated inorganic fertilizers, INM seeks to enhance soil health, nutrient cycling, and overall agricultural sustainability. The abstract also explores cover cropping as a complementary INM strategy, contributing to soil conservation, weed control, and increased biodiversity. Addressing environmental concerns such as nutrient runoff and greenhouse gas emissions from fertilizer use is crucial in contemporary agriculture. This abstract underscore the potential of INM to tackle these challenges by promoting a balanced nutrient supply, reducing nutrient losses to water bodies, and mitigating the environmental impact associated with excessive fertilizer application. Through a thorough examination of existing literature, the abstract underscores the necessity for further research and the adoption of INM practices to ensure sustained maize productivity while safeguarding the environment. The integration of nutrient management strategies not only boosts crop yields but also aligns with goals of sustainable agriculture, emphasizing the importance of adopting practices that balance economic viability with environmental stewardship for global food security.

Keywords: *cover cropping, integrated nutrient management (INM), mitigating environmental*

Introduction

Maize belongs to the family *Zea* and genus *mays,* recognized globally as highly nutritious crop with substantial production potential, particularly in favorable growing conditions, setting it apart from other major grain crops (Nayak et al., 2012). Plant growth necessitates essential elements such as phosphorous, potassium, and NPK, which are traditionally supplied to the soil through chemical or organic fertilizers to meet crop nutritional needs (Abid et al., 2016; Güereña et al., 2016). Although genetic advancements and the widespread use of chemical fertilizers have led to enhanced crop yields, the excessive dependence on artificial fertilizers has given rise to notable environmental hazards and soil quality deterioration, ultimately causing a decline in corn production over the years (Hepperly et al., 2009). Extensive research indicates that maize-centric intensive agricultural systems are displaying signs of fatigue, evident in stagnant yields (Arif et al., 2016; Güereña et al., 2016). The incorporation of organic fertilizer (OM) in agricultural practices has demonstrated benefits by enhancing both the physical and chemical properties of the soil, thereby boosting crop productivity. OM is considered environmentally friendly, cost-effective, readily available, and capable of providing essential nutrients (Gangwar et al., 2006). However, relying solely on OM may be insufficient to meet the nutritional needs of plants in large areas due to its limited and uneven nutrient content. Moreover, its application demands significant manual effort owing to its bulky nature (Jones & Healey, 2010). On the other hand, introducing metallic elements to the soil can be advantageous in mitigating the adverse effects of excessive metal concentrations and reducing their absorption by crops. The effectiveness of this approach depends on the quality and concentration of these elements in the soil-plant systems (Nayak et al., 2012).

The surging global population, coupled with diminishing available land and resources, poses unprecedented challenges to agriculture and natural ecosystems in meeting the escalating demand for food. Ensuring the availability of food in an ecologically sustainable manner is a critical concern in developing nations, pivotal for poverty reduction. In response to this challenge, agricultural practitioners have increasingly turned to the excessive application of certain substances like chemical fertilizers and pesticides, leading to ongoing environmental degradation. Achieving global sustainability and food safety goals necessitates a substantial increase in food production while concurrently minimizing the ecological impact of farming practices (Foley et al., 2011). In maize agricultural systems, where optimal and sustained crop yields are imperative, the application of an appropriate quantity of integrated fertilizer treatment becomes crucial for ensuring an adequate supply of minerals. Pakistan, a country that relies on imported chemical fertilizers, considers maize as its third most significant cereal crop, following rice and wheat. Maize contributes to over 10% of the total agricultural production in Pakistan and engages 15% of the agricultural workforce, with small landholding farms contributing 50% to these statistics (Shiferaw et al., 2013). Maize cultivation spans 1.016 million hectares, resulting in an annual production of 3.037 million tons, with an average grain yield of 2864 kg ha^{-1}, according to Shiferaw et al.'s 2013 report. Small-scale maize farmers in Pakistan grapple with challenges such as low soil fertility, variable nutrient availability, and disrupted soil characteristics, emerging as primary constraints on crop output (Arif et al., 2016). In contrast, Argentina, with its substantial livestock and poultry population, has easy access to organic meat. This situation creates an opportunity to integrate fertilizer treatments that enhance crop growth in maize-based cropping systems. Therefore, evaluating the impact of integrated nutrient delivery on agricultural yields in real-world conditions becomes essential, encompassing factors such as crop growth, crop and soil characteristics, and specific locations (Abid et al., 2020).

Achieving a reduction in chemical usage and greenhouse gas emissions can be accomplished through the adoption of alternative nutrient management strategies and the practice of balanced fertilization, as suggested by Zhang et al. (2011, 2012). Aligning with future needs, curtailing greenhouse gas (GHG) release through environmentally friendly and sustainable approaches is essential. Despite the considerable advancements in crop genetics resulting from scientific farming research, which have boosted global food production in terms of both quantity and quality (Wu et al., 2014a), the actual yields achieved by farmers often fall approximately one-third short of the predicted yields documented in various field studies (Mueller et al., 2012). Numerous studies suggest that the enhancement in yields for major crop types either declined or remained steady in the early 1990s (Brisson et al., 2010). Furthermore, the increased agricultural productivity in various global regions has been linked to significant depletions of natural resources, including soil nutrient exhaustion and the loss of organic carbon. The negative impact of global change on agricultural regions is on the rise (Bruinsma, 2009). It is crucial to develop strategies that foster sustained and improved agricultural growth to counter prevailing trends. The current agricultural model, marked by extensive use of pesticides, fertilizers, fresh water, and land expansion, is deemed unsustainable due to the rapid depletion of natural resources (Haddad et al., 2010). According to Chen et al. (2011), enhancing crop yield and output without compromising ecological sustainability is unattainable. Therefore, prioritizing the pursuit of sustainable agricultural development becomes imperative. This involves integrating agroecological methods to conserve resources, minimize ecological impact, and address global climate change through adaptation and mitigation strategies. These measures should be an integral part of any agricultural program aiming to boost production.

The impact of INM on plant production maize-based cropping system

Several studies have demonstrated that incorporating integrated nutrient management (INM) practices markedly improves multiple facets of maize productivity and related yield indicators. Dasog et al. (2012) demonstrated that the use of a balanced NPK fertilizer treatment, in conjunction with farmyard manure (FYM) and lime, markedly improved the growth and production of maize crops. A decade-long experimental investigation in Kathalagere, India, indicated that applying 50% nitrogen (N) through farmyard manure (FYM) and 50% NPK through inorganic fertilizers resulted in higher maize yields (Sathish et al., 2011). Another study in Islamabad observed that substituting 25 or 50% of nitrogen (N) with farmyard manure (FYM) and supplementing with 4 kilograms of zinc per hectare (ha) led to increased grain and straw output compared to using 100% N (at a rate of 120 kg/ha) through chemical fertilizers alone. The most substantial maize yield of 5.18 tons per hectare was achieved through a combination of 75% chemical fertilizer (CF) and 25% farmyard manure (FYM), along with 4 kilograms of zinc per hectare. This yield was equivalent to either using 50%

CF and 50% FYM with 4 kg of zinc per hectare or using 75% CF and 25% FYM with 8 kg of zinc per hectare (Sarwar et al., 2012).

Upon further investigation, it was revealed that a combination of 50% organic waste, specifically poultry and farmyard manure, with 50% urea nitrogen resulted in increased crop yields and improved yield components compared to the use of either natural or synthetic nitrogen alone. The application of basic nitrogen or 50% poultry manure led to enhanced maize ear length, grains per ear, grain yield, and biological yield, as reported in Ali et al.'s 2012 study. In Ahmad et al.'s 2013 research, it was found that combining farmyard manure (FYM), constituting 50% of the recommended NPK fertilizers, resulted in the highest maize yields and microbiological activity, comparable to applying 100% NPK fertilizers. In terms of crop performance, the analysis indicated that this approach was comparable to applying 100% NPK fertilizers and utilizing natural resources alongside 50% of the necessary NPK fertilizers maximized net returns.

How INM affects the absorption of nutrients by crops in mechanisms derived from maize

A study conducted in Islamabad revealed that substituting 25 or 50% of nitrogen with farmyard manure (FYM), supplemented with 4 kg of zinc per hectare, led to higher nutrient absorption compared to using synthetic fertilizers alone at the full nitrogen application rate of 120 kg/ha. The maximum nitrogen absorption, reaching 98.7 kg/ha, was observed with a combination of 50% chemical fertilizer and 50% farmyard manure, along with an application of 8 kg of zinc per hectare. Conversely, the highest zinc uptake, measuring 250.7 g/ha, occurred with a combination of 75% chemical fertilizer and 25% fungicide-free treatment, supplemented with 4 kg of zinc per hectare (Sarwar et al., 2012).
The uptake of NPK in maize significantly increases when NPK mineral fertilizer and poultry manure are applied together, surpassing the application of organic and inorganic fertilizers independently. Quansah (2010) reported that combining 60 kilograms of nitrogen from poultry manure with mineral fertilizer at a ratio of 60-40-40 kg ha^{-1} NPK results in higher NPK absorption compared to using organic or inorganic fertilizers alone. The residual effect indicated variations in phosphorus uptake when different sources were used alone, but the combination of industry wastes increased the overall efficiency of resource utilization for crop growth through integrated management. Aslam et al. (2005) discovered that the efficacy of P-fertilizer usage increased by 2.8 to 59.7% when nutrients were combined with chemical fertilizer, as opposed to using chemical fertilizer alone.

Impact of INM on the nutritional condition of the land in systems of agriculture based on maize

The application of comprehensive nutrient management techniques significantly increased the overall nutrient content, encompassing both micronutrients and macronutrients, in the surface of the maize cropping system. Higher maize yields were achieved through meticulous application of NPK fertilizers in conjunction with farmyard manure or agricultural waste, contributing to enhanced soil fertility (Dutta et al., 2013). Integrated nutrient management (INM) practices resulted in higher organic matter content compared to traditional farming methods, and initial soil mineral levels were elevated in maize-wheat and maize-potato cropping systems. The chemical composition of the soil experienced improvement when 25 or 50% of nitrogen was replaced with farmyard manure (FYM), supplemented with 4 kilograms of zinc per hectare (Sarwar et al., 2012). In contrast to relying solely on inorganic fertilizer, the incorporation of 5 tonnes of compost per acre along with inorganic fertilizers (50 kg urea ha^{-1} + 100 kg DAP ha^{-1}) was found to enhance the soil's chemical and physical characteristics in a more sustainable manner, as indicated by Fanuel & Gifole in 2012. Similarly, a study spanning two decades discovered that the application of 50% NPK with inorganic fertilizers and 50% N with farmyard manure (FYM) significantly improved soil fertility, as reported by Sathish et al. in 2011. Research in 2013 demonstrated that including 50% of the recommended NPK fertilizers alongside organic inputs resulted in the highest levels of soil organic matter, total nitrate (N), extracted phosphorous (P), and potassium (K). This implies that the combined use of organic materials with 50% of the recommended NPK fertilizers represents a viable approach for sustainable crop production. By the conclusion of the fourth year of the study, the levels of available nitrogen (N), phosphorus (P_2O_5), potassium (K_2O), and sulfur (S) had increased by 19.0%, 46.3%, 9.6%, and 54.1%, respectively, due to the implementation of comprehensive nutrient management. Conversely, the use of mechanical nutrient management practices led to a decline in micronutrient levels compared to their initial values, as reported by Dasog et al. in 2012.

A comprehensive set of INM approach includes the following critical steps

- Assessing soil nutrient availability and identifying potential deficiencies for agricultural plants is commonly carried out through soil sampling and subsequent laboratory tests. Two primary methodologies exist for recognizing nutrient deficiencies. Initially, visual cues are utilized to identify specific nutrient deficiencies by examining plant symptoms. Additionally, when symptoms are not visibly apparent, a more in-depth analysis of both plant tissues and soil samples can be performed at a testing facility, with the results compared to a reference sample obtained from a healthy plant (Bala et al., 2017).

- Examine the constraints and potentialities within existing methods for soil fertility management and explore their correlation with nutrient diagnostics, such as the inadequate or excessive utilization of nitrogen fertilizers, as discussed by Watson et al. (2006).
- Recognize the agricultural practices and technologies that deliver essential nutrients across diverse climates and soil conditions. The difference between the quantity of fertilizer intake and the actual utilization of fertilizers can be employed to compute the soil nutrient budget for a specific region and period. Once these parameters are established, suitable integrated nutrient management (INM) technologies can be chosen, as discussed by Panta & Parajulee (2021).

Matching soil nutrients with crop demand in space and time

Integrated Nutrient Management (INM) involves aligning the quantity and timing of fertilizer applications with the specific nutrient requirements of crops, with the goal of optimizing yields and improving fertilizer use efficiency, as emphasized by Cassman et al. in 2002. The strategic utilization of small, frequent doses of nitrogen fertilizers during periods of heightened crop demand has the potential to reduce nitrogen losses, simultaneously enhancing crop quality and overall production (Witt & Dobermann, 2004). This method of nitrogen application results in a lack of synchronization between nitrogen availability in the soil and crop demand, leading to an excess of organic nitrogen precisely when it is needed for rapid crop growth (Chen et al., 2006)

Reduced n losses while increasing crop output

The excessive use of nitrogen fertilizers can lead to increased nitrate leaching into groundwater and heightened emissions into the atmosphere. Integrated Nutrient Management (INM) aims to boost agricultural productivity while reducing nitrogen losses and minimizing negative environmental impacts (Gruhn et al., 2000). The use of nitrogen inhibitors has proven effective in reducing N_2O emissions, particularly as these emissions mainly occur during the nitrification processes following fertilizer application (Ma et al., 2010).

Conclusion

Integrated Nutrient Management (INM) practices offer notable financial and environmental benefits for farmers. A comprehensive review of multiple research papers has identified various methodologies and highlighted existing opportunities that could be further optimized through the implementation of enhanced site-specific INM practices. The future strategic expansion of INM is poised to be guided by the following factors: (i) Integration of soil and plant testing, (ii) Customization to align with local climate conditions, (iii) Incorporation of mechanization to address significant labor shortages, (iv) Adoption of conservation agriculture and rainwater-harvesting techniques, (v) Recycling of organic nutrient flow, (vi) Embracing innovative technological advancements, and (vii) Implementing essential interventions (Javaria & Khan, 2010; Wu & Ma, 2015).

Author contributions

All authors contributed to the study's conception and design. The study was created and the protocol was written by author Esha Arshad. Material preparation, data collection, and analysis were performed by Muhammad Shahid and Esha Arshad. The first draft of the manuscript was written by Esha Arshad and Tajamul Abbas commented on previous versions of the manuscript. Author Iram shehzadi, Javeria Akram, Zunaira Arif the literature searches and contributed a lot in Strategies Portion. The final part of the manuscript is Hinder Hunger written by Rameesha Ali and Javaria Mushtaq. References and citations were managed by Esha Arshad. All authors read and approved the final manuscript.

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