Review Article

Role of Integrated Nutrient Management for Sustainable Maize Production

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Boosting crop productivity can be attained through the application of inorganic fertilizer; however, safeguarding the environment for future generations is overbearing especially for continuous increase in the world population. Sustainable crop productivity might be attained through the judicious use of both organic and inorganic fertilizers. The substitution of parts of inorganic fertilizers with organic fertilizer could maintain and sustain soil productivity and improve crop productivity. This paper has reviewed the past research work carried out by various scientists. A comprehensive literature review revealed that integrated nutrient management enhances maize yield, nutrient uptake, and economic return compared with the sole application of organic and inorganic fertilizers.

1. Introduction

Maize (*Zea mays* L.) is one of the most significant cereal crops which served as a staple food for greater than 900 million peoples in developing countries. It provided as a source of raw material for the production of food sweeteners, alcoholic beverages, protein, oil, and starch, as well as a fuel source. Due to its wider adaptability, the crop is growing across a wide range of climatic conditions of the world [1, 2]. Ethiopia is the fifth leading producer of maize in the continent and smallholder farmers accounted for 94% of its production. It ranks 1st in total production and 2nd in area coverage after tef [3]. Maize offers 16.7% of per capita calorie intake nationwide since maize is the inexpensive source of caloric intake in Ethiopia.

Maize is commonly called the queen of cereals thanks to high genetic yield potentials compared to the other cereals [4]. Considering its genetic potentials of yield and fast growth habits, maize is an extremely nutrient exhaustive crop. Maize requires more N and P than other essential elements for the development of all growth stages. To produce high yield and sustain soil fertility, essential nutrient elements ought to be

provided in an appropriate amount. Balanced application of plant nutrients through the integration of organic and inorganic fertilizers has been proved to enhance maize yield and soil fertility [5]. Integrated nutrient management resulted in synergistic effects and improved synchronization of nutrient uptake and release by crops [6] resulted in higher yields, especially when the rates of chemical fertilizers used are relatively low as is the case of most smallholder farmers in a developing country [7]. Integrated application of inorganic fertilizers with different sources of organic manures in different amounts has significant benefits to enhance maize productivity, improve nutrient uptake by plants, and maintain soil nutrient status in maize-based cropping systems [5]. Therefore, this review article aims to discuss the different components of integrated nutrient management and their effect on sustainable maize crop production.

2. Concepts of Integrated Nutrient Management

Integrated nutrient management (INM) is a method that helps to sustain agricultural production and protect the environment for future generations. It may be defined as the

application of soil fertility management practices that maximize fertilizer and organic resource use efficiency to enhance crop production [8]. This practice includes the judicious use of appropriate types of chemical fertilizers and organic resources [9]. It combines both organic and inorganic nutrient sources to achieve higher crop productivity, prevents soil degradation, and improves soil-water infiltration, thus helping to meet future food supply [10]. Sustainable food security needs a balance between increasing crop productivity and environmental sustainability. Neither nutrient deficiency nor surpluses can threaten this balance.

The three main components of INM as defined by FAO [11] are as follows:

- (i) Maintaining or improving the productivity of soil through balanced fertilizers, or by combining organic and inorganic fertilizers
- (ii) Improving stocks of plant nutrients in the soils
- (iii) Increasing the efficiency of plant nutrients, hence, limiting losses to the environment

Therefore, INM aims to maintain or adjust soil fertility and supply plant nutrient to an optimal level for sustaining crop productivity through the integration of the benefit of all possible sources of plant nutrients [12]. Integrated nutrient management is currently considered as an approach that helps smallholder farmers to alleviate many issues such as poverty and food insecurity through enhancing the amount and quality of food and improving soil fertility.

3. Effect of Chemical Fertilizer on Maize Production

Chemical fertilizer is a material that is applied to the soil to provide one or more essential elements for plant growth and productivity. Nitrogen, potassium, and phosphorus are the three major elements and magnesium, calcium, sulfur, and other elements such as boron, manganese, iron, zinc, copper, and molybdenum are the secondary elements. Fertilizers improve soil fertility or substitute the mineral elements taken from the soil by harvesting, erosion, grazing, or leaching. Chemical fertilizers are the most effective way to improve soil nutrient depletion, giving high N and P contents that are readily available to the crop, and thus improving livelihoods of the farmers [13, 14]. This is because the nutrients in chemical fertilizers are available immediately for plant uptake [15]. The application of adequate fertilizers improved nutrient concentrations in plant tissue and increased crop yield [16]. Obidiebube et al. [17] reported that the application of chemical fertilizer significantly increased the growth, physiological traits, and yield component of maize. Dubey et al. [18] also reported that the application of recommended 100% NPK fertilizers significantly increased crop yield and improved the available P, K, and total N as compared to the initial value thereby indicating a significant contribution towards sustaining the soil health.

Although higher crop yields can be achieved through the judicious use of chemical fertilizers, the adoption has been

poor in Africa [19]. Efforts to introduce chemical fertilizer technology to African smallholder farmers have been met with limited success, even with input subsidies and credit systems [20]. According to Stoorvogel et al. [21] estimation in sub-Saharan Africa (SSA) from about 200 million hectares of cultivated land, an average of 660 kg of N/ha, 450 kg of K/ha, and 75 kg of P/ha have been lost since the 1960s. However, chemical fertilizer use is estimated at 8 kg-ha⁻¹, which is only 10% of the world average due to high cost [22].

On the other hand, the intensive use of chemical fertilizer (especially N fertilizer) can result in detrimental changes in foods and negative effects on atmospheric and aquatic environments [23]. Mahajan et al. [24] and Satyanarayana et al. [25] reported that the nutrients provided through inorganic sources enhanced yield initially but led to unsustainable productivity over the years. Bokhtiar and Sakurai [26] stated that the use of imbalanced nutrients through chemical fertilizer in continuous cropping leads to an imbalance of nutrients in the soil, leaching of N, contamination of water resources, decimation of microorganisms and friendly insects, crop vulnerability to disease outbreak, soil acidification or alkalization, or decreased soil fertility thus bringing permanent loss to the whole system. This is due to their susceptibility to losses in gaseous forms or by leaching when applied at a wrong time or in an excess amount beyond the plant demand [15]. The negative effects of inorganic fertilizer coupled with their high costs have incited the interest for the utilization of organic fertilizer as a source of nutrients [27].

4. Effect of Organic Fertilizer on Maize Production

Organic fertilizers also referred to as organic sources are defined as those organic resources that are used in agriculture as a recycled or external input to produce crops for both subsistence and commercial purposes [28]. Animal manure, crop residues, compost, green manure, relay or intercropping of legumes (dual-purpose legumes), and biomass resulting from short- to long-term fallows are among the most promising organic sources [28]. These sources have been recognized as alternative nutrient sources for the smallholder farmers to fertilize their soils as their socioeconomic limitations prevent them from using chemical fertilizers correctly [29].

Organic manures affect the availability of nutrients by adding nutrients, through the mineralization-immobilization process, as a source of energy for microbial activities or as precursors to soil organic matter, and by lessening P fixation in the soil [30]. Organic manure improves the overall physical characteristics of the soil and soil organic matter together with the major and minor organic nutrients and prevents physical compaction of soil, improves soil aeration, and prevents leaching losses. According to Verma J. P. and Verma R. [31], the collective interaction of the nutrient components in organic fertilizer incorporates the soil with the complete range of nutrients within a comparatively short time, and their effects last longer for the current crop to benefit directly. Agriculture lacking organic

manures/crop residues has resulted in a lessening of biological and physicochemical properties of the soil [31].

Jolokhava et al. [32] reported that the grain yield of maize from two different types of organic fertilizers reached 70% of the yields attained with chemical fertilizers. This result is promising for future improvement of organic cereal crop production in the area. Similarly, the study conducted by Soro et al. [33] showed a positive influence of manure on the growth and development of maize crops and emphasized the opportunity of improving maize productivity and production in Daloa region by using poultry manure (PM). The result further revealed that grain yield is significantly boosted by the addition of manure and the highest grain yield was obtained at the rate of $7 \text{ t} \cdot \text{ha}^{-1}$ when PM was wind stored for six days. Similarly, Dikinya and Mufwanzala [34] reported that the application of poultry manure increased crop production and soil fertility.

Jjagwe et al. [35] reported that maize growth parameters and yields were all significantly increased ($p < 0.05$) with an application of both organic and inorganic fertilizers when compared with the control. The authors further confirmed that vermicomposting was the most economically feasible manure treatment method due to low operational costs and higher returns on investment that are complemented with the production of chicken fodder (earthworm biomass) and they recommended farmers to produce a fertilizer that increases maize yields with a guarantee of economic returns.

5. Effect of Integrated Nutrient Management on Maize Production

High and stable yield could be attained through reasonable and balanced fertilization of organic and inorganic fertilizers [36]. Several studies showed INM significantly improved yield and yield traits of maize [37]. The combined use of poultry manure and chemical fertilizer was more effective in increasing nutrient availability and maize performance than the sole application of any of the fertilizers [38]. Similarly, Ayoola and Adeniyi [39] reported higher yields in the combined application of poultry manure and chemical fertilizer than the sole application of poultry manure and control; however, the yield in a combination of organic and inorganic was not significantly different from sole inorganic fertilizer. Khan et al. [40] also found higher plant height, 1000 grain weight, LAI, and yield of maize in the combined application of 20 tons ha^{-1} FYM with $60 \text{ kg} \cdot \text{N} \cdot \text{ha}^{-1}$ inorganic fertilizer than the sole application of each fertilizer. The same authors recommended the combined application of organic manure with the reduced amount of inorganic fertilizer for sustainable crop production.

Thavaprakash et al. [41] found that a combined application of 50% NPK with poultry manure and biofertilizers (Azospirillum + phosphor bacteria) gave taller plants (183.1 and 158.4 cm) and higher LAI (3.47 and 2.75). The more rapid growth observed in the application of poultry manure and goat manure was due to the faster release of nutrients from the goat and poultry manures as compared to FYM. The same authors indicated the positive effect of INM practices on yield attributes of baby corn and conclude that

INM practices (50% NPK + poultry/goat manure + Azospirillum + phosphobacteria) could produce the maximum yield of baby corn.

The application of poultry manure with recommended NPK fertilizer gave higher grain ($5.8 \text{ t} \cdot \text{ha}^{-1}$) and green matter ($7.44 \text{ t} \cdot \text{ha}^{-1}$) yields than vermicompost with recommended NPK fertilizer and control treatments, and the grain yield with poultry manure, vermicompost, and farmyard manure increased by 33, 16, and 14% over control, respectively [42]. Negassa et al. [43] demonstrated that the integrated use of farmyard manure (FYM), compost, and bone meal with a low level of NP fertilizers gave a comparable maize grain yield as the yield obtained under the recommended rate of NP fertilizers ($110/20 \text{ kg} \cdot \text{ha}^{-1}$) in Western Ethiopia. Zerihun et al. [44] also reported that the combined use of organic and inorganic fertilizers increased the yield of maize and soybean in the intercropping system. The integrated use of NP fertilizer ($55:23 \text{ kg/ha}$) and FYM ($8 \text{ t} \cdot \text{ha}^{-1}$) was more profitable with some additional soybean yield than the sole application of either fertilizer in maize/soybean intercropping system.

Khaliq et al. [45] revealed that the combination of poultry manure + N fertilizer significantly increased biomass yield, grain yield, and chemical properties of soil followed by high N fertilizer treatment in two maize hybrids. Shivakumar and Ahlawat [46] also found that the combined application of crop residues and FYM along with 5 kg zinc/ha and 100% recommended dose of fertilizer gave significantly higher growth and yield of soybean. The combined application of 75% NPK with phosphocompost or poultry manure or farmyard manure in sorghum and soybean crops and application of 75% NPK fertilizer in wheat crop gave significantly greater grain yields compared to organic and control and saved 25% NPK fertilizer [47]. The same author reported that the number of grains per spike, dry matter accumulation, straw yield, grain yield, and NPK uptake of wheat were higher in a combination of organic and inorganic fertilizers than inorganic fertilizer alone. A field experiment conducted by Panwar [48] also showed that the growth, yield attributes, and economics of maize were optimum when 50% of the recommended dose of NPK was substituted by farmyard manure. Baes on Tatarwal et al. [49] recommended dose of fertilizer ($40\text{--}15 \text{ kg} \cdot \text{N-P/ha}$) + FYM 10 t/ha produced higher plant height, dry matter, number of cobs/plant, number of grains/cob, grain, and biological yields of maize.

Ravi et al. [50] study showed that higher plant height (187.8 cm), leaf area index (4.7), total dry matter production (309.4 g/plant), weight per cob (122.2 g), cob length (15.8 cm), cob girth (11.52 cm), and seed index (29.1 g) in maize were associated with the application of FYM 10 t/ha + 100 percent recommended dose of fertilizer ($150:75:37.5 \text{ kg NPK/ha} + 25 \text{ kg ZnSO}_4/\text{ha}$). Similarly, Samsul et al. [51] reported that application of 75% recommended dose of fertilizer ($90:45:45 \text{ NPK kg/ha}$) + vermicompost @ 2 t/ha gave the tallest plant (240 and 219 cm), higher leaf area index, dry matter production, tasseling and silking, and effective number of cobs per plant at Tarai region of West Bengal.

6. Effect of Integrated Nutrient Management on Nutrient Uptake of Maize

A combined application of organic and inorganic appears to be an ideal method to meet nutrient requirements of crops rather than a sole application of either source. The combined application of fertilizers and manures increased the nutrient uptake of the plants [9]. Prasad et al. [52] found higher NPK uptake of maize crop in a combination of organic and inorganic fertilizers compared to treatment where a full dose of NPK was applied as urea, single superphosphate, and muriate of potash. Ghosh et al. [53] also reported that combined use of organic manure and NPK fertilizers was significantly increased in NPK uptake of wheat.

Makinde and Ayoola [54] reported that nutrient uptake in the sole application of inorganic fertilizer was better than the sole use of organic fertilizer, which gave similar values with unfertilized plants due to the slow release of nutrients. Conversely, combined use of organic and inorganic fertilizers gave higher N and K values compared to the sole application of either fertilizer. Since organic manures supply all essential nutrients which play an important role in crop growth and hence finally increase the yield with balanced nutrition, higher nutrient uptake by the crops can result in higher yield. Quansah [55] also reported higher NPK uptake in the combined application of poultry manure (60 kg/ha N) with NPK (60-40-40 kg/ha) fertilizer than the sole application of either fertilizer.

Vidyavathi et al. [56] found significantly higher uptake of N, P, and K under a combination of organic and inorganic fertilizers compared to the sole application of either fertilizer. The response of crops to the combined application of both fertilizers is due to the higher availability of N, P, and K in the soil reservoir besides the additional amount of nutrients provided by FYM and NPK fertilizers. This was attributed to a steady supply of N, P, and K throughout the growing season. Similarly, Prajapat et al. [57] reported a significantly maximum total uptake of N and P of soybean at 25% recommended inorganic fertilizer + 50% recommended FYM + biofertilizers over sole application of inorganic fertilizer and FYM.

Tetarwal et al. [49] reported that significant buildup of organic carbon (0.74%), available N (316.0 kg/ha), available P (10.8 kg/ha), and Zn uptake were observed with the application of the recommended dose of fertilizer (40–15 kg N-P/ha) + FYM 10 t/ha. Similarly, Almaz et al. [58] reported that integrated application of 50% NPK + 50% poultry manure increased nutrient (N, P, and K) uptake of maize over sole poultry manure and sole inorganic fertilizer.

7. Economic Importance of Integrated Nutrient Management

Maintenance of soil fertility at the economic optimum level with an appropriate cropping system and affordable fertilizer rate is essential for sustainable crop production. Integrated nutrient management systems ensure inbuilt capacity to maintain and improve soil health and fertility leading to sustained crop production and lower variability of crop

yield. This resulted in stable yield, increased income, and sustainable agriculture. The economic importance of integrated nutrient management has been reported by previous researchers [59–61].

The economic analysis done by Jinwei and Lianren [62] showed that an integrated application of organic and chemical fertilizers reduced the cost of fertilizer compared with the sole application of either fertilizer. Saleem et al. [63] also reported the highest net benefit (Rs. 78,419.66 ha⁻¹) of monocropped maize with the combined use of 50% poultry manure + 50% PK + inoculation compared to the sole application of either fertilizer. Singh and Agarwal [64] noted that the combined application of 10 t/ha FYM and 180 kg N/ha gave higher net returns of Rs. 12,519 ha⁻¹ with the highest B:C ratio of 2.13, respectively. The combined application of 5 t/ha crop residues and FYM along with 5 kg/ha zinc gave higher yield and net returns from soybean-wheat cropping system than the sole use of either organic or inorganic fertilizers [64]. Similarly, Ali et al. [65] indicated that treatments that received a combined application of organic manure and inorganic fertilizer produced benefit: a cost of greater than 3.0, indicating the profitability of the system. Pathan and Kamble [66] also reported highest gross returns, net returns, and benefit: cost ratio (Rs. 191,981, Rs. 101,815 ha⁻¹ and of 2.13, respectively) of sorghum + cowpea-lucerne forage cropping system in the combination of FYM (25% N) + 50% NPK fertilizer + biofertilizers. Similarly, Subbarayappa et al. [67] revealed that integrated application of 100% NPK + FYM led to significantly higher net returns (Rs. 22,372/ha), higher benefit: cost (B:C) ratio (4.22), and gross returns (Rs. 29,306 ha⁻¹) in cowpea.

Panwar [48] found that the maize equivalent yield, net return, and B:C ratio for maize-mustard cropping system was higher under 50% NPK + 50% farmyard manure than under 25% of NPK substitution through farmyard manure + 75% NPK through inorganic fertilizer. Similarly, Lingaraju et al. [68] reported that the treatment of 7.5 t/ha FYM and 100 percent RDF (100:50:25 N, P₂O₅ and K₂O kg/ha) resulted in significantly higher gross return (Rs. 69059/ha) and net return (Rs. 51659/ha) which were on par with vermicompost @2.5 t/ha + 100 percent RDF concerning gross returns (66513). The benefit: cost ratio was markedly higher with poultry manure @1.0 t/ha + 100 percent RDF (4.48).

8. Conclusion

Soil fertility depletion is the fundamental biophysical cause of low crop production in developing countries. To maintain soil fertility, the use of inorganic fertilizers is important. Nevertheless, high cost of inorganic fertilizers combined with the low income of resource-poor farmers in developing countries is the main challenge using inorganic fertilizer. The use of organic manures can maintain soil organic matter and provide balanced nutrients to the present crop and leave an extensive residual nutrient on the subsequent crops in a cropping system. Retention of crop residue on the cropland has also a positive effect on soil organic matter and crop

production. However, the amount of organic sources required is huge as their nutrient content is low. The integration of different sources of nutrients has been proven to be documented success in a different part of the world than the sole use of either inorganic fertilizers or organic manures. The system is not only boosting crop productivity but also maintains and sustains soil productivity and also a cost-effective practice for developing countries.

Data Availability

No data were used to support this study.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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