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Review Article

Role of Integrated Nutrient Management on Maize (Zea Mays L.) Productivity, Nutrient Uptake and Soil Nutrient Status: Implications for Crop Productivity and Utilization of Natural Resources

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Abstract

Intensive cultivation, growing of exhaustive crops, use of unbalanced and inadequate fertilizers, over applications of inorganic fertilizers accompanied by restricted use of organic manures leads to nutrient imbalances, inefficiency and environmental contamination while insufficient application of nutrients causes soil fertility depletion and deteriorated the soil health. Over applications of inorganic fertilizers lead nutrient imbalances, inefficiency and environmental contamination while insufficient application of nutrients causes soil fertility depletion. This problem drives the use of organic manures, which supply balanced micro and macro nutrients to the current crop and also leave a substantial residual effect on the succeeding crops in different cropping systems. But it is required in bulk as it contains nutrients in small proportion. Hence its availability is scarce for large farms. Therefore, to eliminate both excessive and inadequate applications, judicious use of integrated nutrient management is best alternative for sustainable crop productivity while maintaining soil fertility status in maize and other cereal based cropping systems. Such integrated applications have complementary and synergistic effects. Various research results have confirmed that integrated nutrient management improves sustainable crop productivity and soil fertility status rather than organic or mineral fertilizers alone. Most of research findings reviewed in this paper indicated that among the alternative integrated nutrient management combinations, application of chemical fertilizers integrated with organic manures significantly improved sustainable crop productivity, nutrient uptake and soil nutrient status in maize crop. In general, combined application of inorganic fertilizers with different sources of organic manures in different proportions has significant role to boost crop productivity, improve nutrient uptake by plants and maintain soil nutrient status in maize production.

Keywords: Integrated nutrient management, Sustainable productivity, Nutrient uptake, Soil nutrient status and Maize.

INTRODUCTION

Maize (Zea mays L.) has a critical nutritional role to play in human as it is the third important cereal crop globally after wheat and rice with regards to cultivation area, total production and consumption (FAO, 2011). Data from the United Nations (UN) Food and Agriculture Organization (FAO) showed that in 2010 world maize production was over 840 million metric ton, with the United States and China as the leading producers. Over 70% of maize in Africa is produced by resource poor small-scale farmers and the average maize yield in Africa stood at 1.3 t ha-1 compared to 3.0 t ha-1 at developed countries (FAO, 2013).The low average yield per unit area is the main reason why Africa's share of global maize production is so small (Pingali and Pandey, 2001).

Maize has high genetic yield potential than other cereal crops. Hence it is called as 'miracle crop' and also as 'queen of cereals'. Being a C4 plant, it is very efficient in converting solar energy in to dry matter. As heavy feeder of nutrients, maize productivity is largely dependent on nutrient management. Therefore, it needs fertile soil to express its yield potential. Low soil fertility is one of the bottlenecks to sustain agricultural production and productivity. Intensive cultivation, growing of exhaustive crops, use of unbalanced and inadequate fertilizers accompanied by restricted use of organic manures have made the soils not only deficient in the nutrients, but also deteriorated the soil health resulting in decline in crop response to recommended dose of N–fertilizer. Anthropogenic factors such as inappropriate land use systems, mono-cropping, nutrient mining and inadequate supply of nutrients are aggravated the situation. To alleviate the problem, integrated nutrient management (INM) is an option as it utilizes available organic and inorganic nutrients to build ecologically sound and economically viable farming system. INM is the combined use of mineral fertilizers with organic resources such as cattle manures, crop residues, urban/rural wastes, composts, green manures and bio-fertilizers (Antil, 2012). The use of organics plays a major role in maintaining soil health due to buildup of soil organic matter, beneficial microbes. Boosting yield, reducing production cost and improving soil health are three inter -linked components of the sustainable triangle. Therefore suitable combination of chemical fertilizer and organic nutrients need to be developed for particular cropping system and soil.

Primarily INM refers to combining old and modern methods of nutrient management into ecologically sound and economically optimal farming system that uses the benefits from all possible sources of organic, inorganic and biological components-substances in a judicious, efficient and integrated manner (Jenssen, 1993). It optimizes all aspects of nutrient cycling, including macro- and micronutrient inputs and outputs, with the aims of synchronizing nutrient demand by the crop and its release into the environment. Under INM practices, the losses through leaching, runoff, volatilization, emissions and immobilization are minimized, while high nutrient-use efficiency is achieved (Zhang et al., 2012).

To replenish the soil nutrient depletion, application of chemical fertilizers is essential. However, high cost of chemical fertilizers coupled with the low affordability of small holder farmers is the biggest obstacle for chemical fertilizer use. Moreover, the current energy crisis prevailing higher prices and lack of proper supply system of inorganic fertilizers calls for more efficient use of organic manure, green manure, crop residues and other organic sources along with the inorganic fertilizers to sustain the yield levels (Sathish et al., 2011). Organic manures supply nutrients to the current crop and also leave a substantial residual effect on the succeeding crops in different sequential cropping systems. The efficiency of applied chemical fertilizers is also increased when applied along with organic manures. Therefore, better management of soil nutrients is required that delivers sustainable agriculture and maintains the necessary increases in food production while minimizing waste, economic loss and environmental impacts (Goulding et al., 2008). Various long term research results have shown that neither organic nor mineral fertilizers alone can achieve sustainability in crop production. Rather, integrated use of organic and mineral fertilizers has become more effective in maintaining higher productivity and stability through correction of deficiencies of primary, secondary and micronutrients (Milkha et al., 2010). Hence, judicious use of integrated nutrient management is best alternative to supply nutrient to crop needs and improve soil conditions (Naresh et al., 2013). Therefore, the objective of this paper is to assess the role of integrated nutrient management practices on sustainable crop productivity, nutrient uptake and soil nutrient status in maize.

LITERATURE REVIEW

Role of INM on Production and Productivity of Maize

Various studies revealed that sustainable yield and yield related parameters of maize are significantly improved by INM practices. Balanced application of NPK fertilizers with FYM and lime improved sustainable crop productivity and growth of maize (Vidyavathi et al., 2012, Dutta et al., 2013). Twenty years of experimental study, at Kathalagere, India, revealed that higher maize yields were observed with application of 50%N through FYM and 50% NPK through inorganic fertilizers (Sathish et al., 2011). Study in Islamabad revealed that substitution of 25 or 50% N with FYM + 4 kg Zn ha-1 performed better grain and straw yield than 100% N (120kg ha-1) from chemical fertilizer alone. Maximum maize grain yield (5.18 t ha-1) was obtained with 75% chemical fertilizer (CF) + 25% Farm Yard Manure (FYM) and 4 kg Zn/ha, which was statistically at par with application of 50% CF + 50%FYM or 4 kg Zn ha-1 or 75% CF + 25% FYM and 8 kg Zn ha-1 (Sarwar et. al., 2012). The growth parameters (plant height and leaf area) were found to be highest under INM of poultry manure (PM), FYM and recommended dose of fertilizers (RDF) which are statistically on par but comparatively higher than (100% RDF). The yield parameters (number of grains per cob, cobs weight per plant, test weight and stover yield) were significantly higher under INM compared to (100% RDF) (Wailare and Kesarwani, 2017). Combined application of 75% recommended NP fertilizer and 4.6 ton ha-1 (50%) compost can sustain the maize production in the Jimma area and similar agro ecology of Ethiopia (Sisay and Adugnaw, 2020). Therefore, the integration of 50% RDF along with either 5 t ha-1 FYM or PM or both resulted in maximum maize productivity on par compared with sole used of 100% RDF (Wailare and Kesarwani, 2017).

Another study revealed that application of 50% organic manure (poultry and FYM) along with 50% nitrogen from urea resulted in higher yield and yield components compared to either organic or mineral nitrogen alone. Application of mineral N and 50% poultry manure produced higher ear length, grain per ear, grain and biological yields of maize (Ali et al., 2012). The study on maize at Jimma, Ethiopia indicated that the highest grain yield of 8443 kg ha-1 and above ground biomass of 21.52 t ha-1 was obtained from 100% compost + 100% recommended NP fertilizer (Sisay et al., 2021). The results of Ahmad et al., 2013 showed that combining FYM with 50% of recommended NPK fertilizers produced the highest grain and biological yields of maize over the 50% NPK treatment and were statistically at par with

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those receiving 100% NPK fertilizers. Moreover, the net return was greatest when organic sources were combined with 50% of recommended NPK fertilizers. According to (Mugwe et al., 2007), sole application of cattle manure at 60 kg N ha-1 and combined application of cattle manure (30 kg N ha-1) with inorganic fertilizer (30 kg N ha-1) gave significantly higher yields than the recommended rate of inorganic fertilizer.

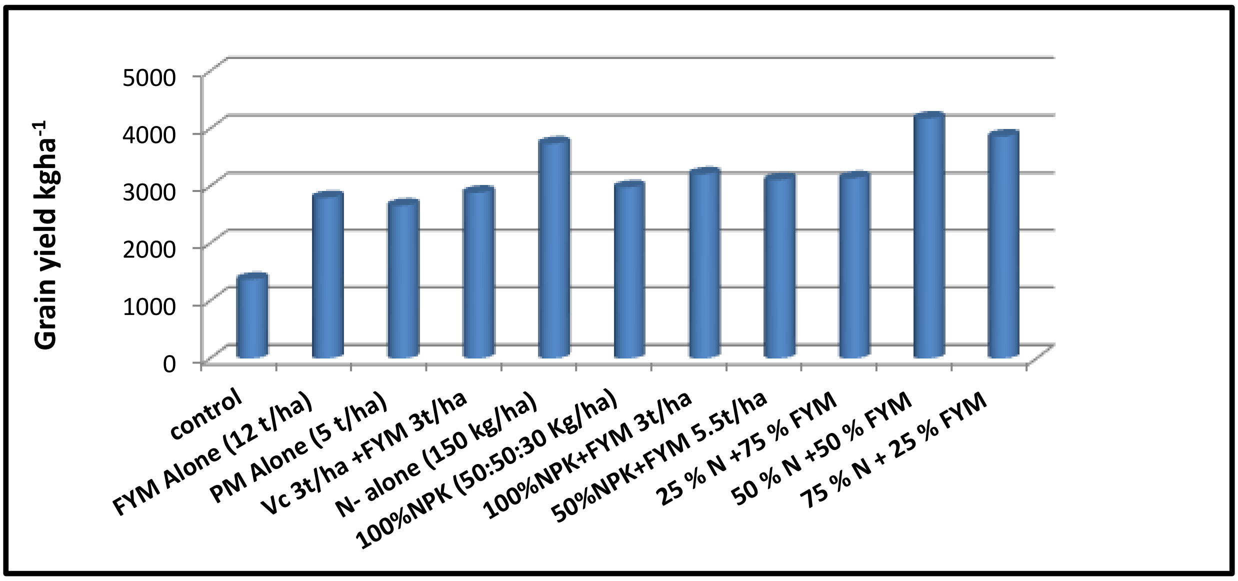

Figure-1: Grain yield of maize under different nutrient management
Key: FYM=Farm yard manure, VC=Vermi-compost, PM= Poultry manure

The highest grain and Stover yields (8.0 tons ha^{-1} and 8.9 tons ha^{-1} respectively) of maize were recorded by the combined applications of 60 kg N ha^{-1} from poultry manure and mineral fertilizer at 60-40-40 kg ha^{-1} NPK compared to the unfertilized treatment which recorded the lowest grain and Stover yields of 2.10 tons ha^{-1} and 4.30 tons ha^{-1} respectively (Quansah, 2010). The research result of (Ali *et al*., 2012) also showed that poultry and farm yard manure along with urea at equal proportion resulted in higher yield and yield components of maize than sole organic or mineral nitrogen. In other study, poultry manure alone or combination of 25% NPK from chemical fertilizer + 75% from poultry manure increased yield of maize by 579 %, while 50% NPK+ 50% poultry manure increased yield by 499 %, respectively over the unfertilized one. The author generally ranked the effects of INM on growth and yield of maize as poultry manure alone = 25% NPK+ 75% poultry manure > 50% NPK+ 50% poultry manure >75% NPK+ 25% Poultry manure > 25% NPK+ 75% Compost > Compost alone > 50% NPK+ 50% Compost > 75% NPK + 25% Compost > NPK alone > unfertilized plot (Hossain *et al*.,2012). Similarly, Cheema, *et al*.,2010 found that applying 50% N from poultry manure and remaining from urea fertilizer produced maximum grain yield of maize (5.6 t ha^{-1}), harvest index (24.91%) and grain weight per cob (68.98 g) compared to unfertilized treatment which gave the lowest harvest index (15.71%), grain yield (2.40 t ha^{-1}) and weight per cob (44.53 g).

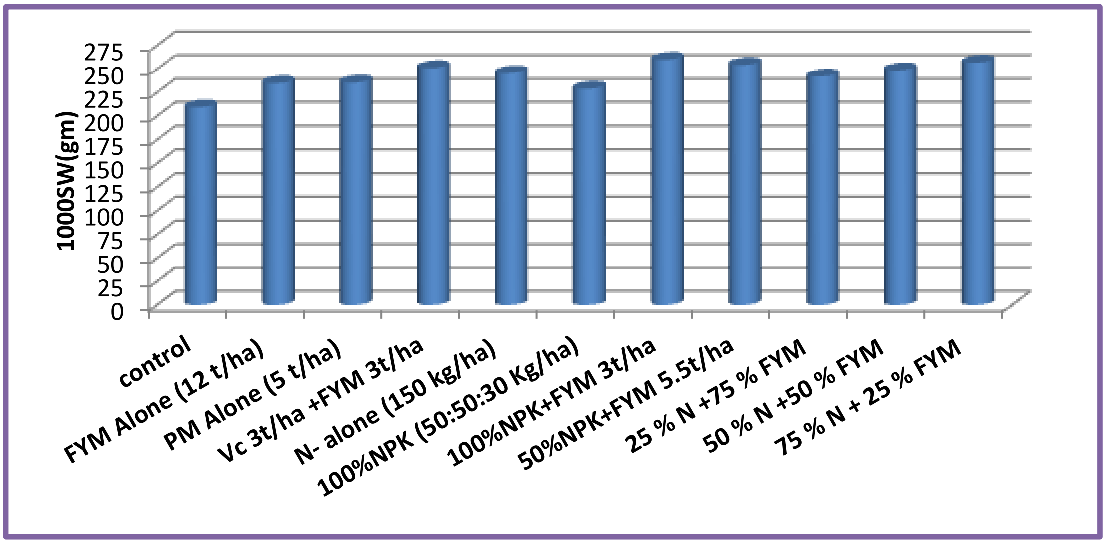

Figure-2: Effect of organic and inorganic sources of nutrients on 1000 seed weight of maize
Key: FYM=Farm yard manure, VC=Vermicompost, Poultry manure, SW=Seed weight

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Agricultural wastes alone or in combination with reduced rates of NPK fertilizer increased seed weight per plant, 100-seed weight, number of seeds per cob and grain yield of maize compared with un-amended treatment (Ogundare *et al*., 2012). Combination of industrial by-products in 2:1 P ratio produced 14 to 27% more dry matter yield of 40-days old maize plants compared to the chemical fertilizer alone (Manzar-ul-Alam *et al*., 2005). INM including vermicompost showed best results in yield parameters of maize like number of grains per cob, weight of the cob, 100 seed weight and yield (Kannan *et al*., 2013). Fanuel and Gifole, 2012 recommended to apply combination of compost at 5 ton ha-1 along with inorganic fertilizer (50 kg urea ha^{-1} + 100kg DAP ha^{-1}) to obtain better yield of maize.

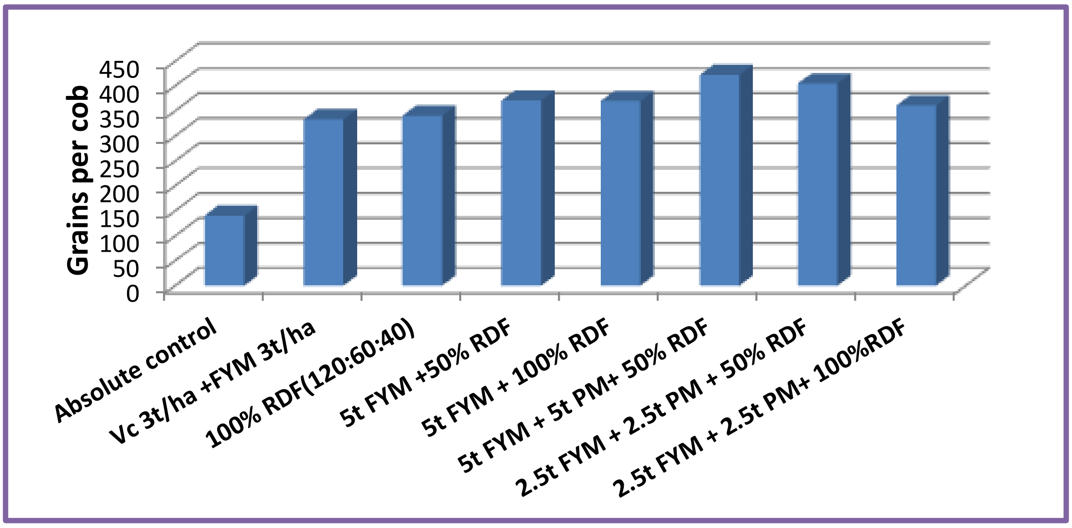

Figure-3: Grains per cob of maize as affected by INM
Key: FYM=Farm yard manure, VC=Vermi-compost, PM=Poultry manure, RDF=Recommended dose of fertilizer

Application of 25% recommended dose of fertilizers (20 kg N+ 60 kg P2O5+ 60 kg K2O ha-1) in combination with bio-fertilizers, green manuring and compost 10 t ha-1 /ha increased maize grain yield by 252.38% over control (no fertilizer application) and 147.62% over the application of 100% recommended dose of fertilizers alone (Kalhapure et al., 2013). A study in Ethiopia also revealed that integrated use of Mucuna green manure as fallow along with chemical NP fertilizers increased grain yield of maize (Wakene Negassa et al., 2007). Biomass transfer technologies involving Calliandra, Leucaenaand Tithoniaapplied solely or in combination with inorganic fertilizer at 60 kg N ha-1 can be used as nutrient sources to meet N requirement for maize in smallholder farming systems maintaining maize yields at 4 to 6 t ha-1. Though herbaceous legumes yielded the lowest maize yields, the increase in maize yield with application of herbaceous legumes compared with the control demonstrate that legumes make a significant contribution to maize crop production. Farmers can therefore be benefited by incorporating these legumes in the farming systems as an option to subsistence farming where farmers currently crop their farms without any inputs. Use of Tithonia combined with chemical fertilizer was most effective in increasing maize yields (Mugwe et al., 2007).

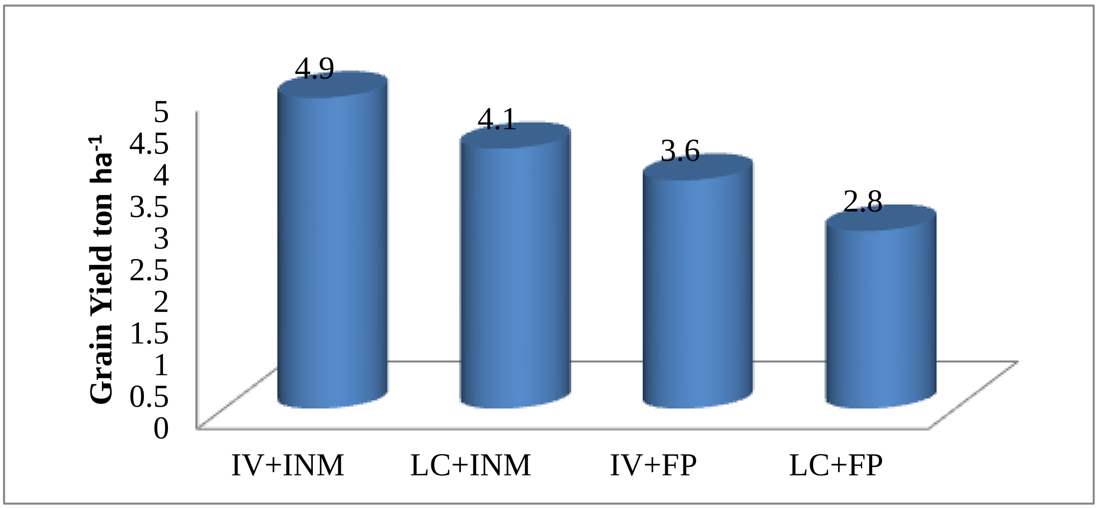

Figure-4: Productivity of maize under different nutrient management in North West India
Key: IV = improved Variety, LC = Local Cultivar, FP = Farmers' practice
Source: Naresh, *et al*., 2013.

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Role of INM on Nutrient Uptake of Maize

Improved application and targeting of inorganic and organic fertilizer not only conserves nutrients in the soil, but makes nutrient uptake more efficient. Study in Islamabad showed that substitution of 25 or 50% N with FYM + 4 kg Zn ha^{-1} performed better nutrient uptake than 100% N (120kg ha^{-1}) from chemical fertilizer alone. The highest N uptake (98.7 kg ha^{-1}) was observed with 50% CF + 50% FYM and 8 kg Zn ha^{-1} application, while maximum Zn uptake (250.7 g ha^{-1}) was observed with 75% CF + 25 % FYM and 4 kg Zn ha^{-1} application (Sarwar *et. al.*, 2012).

Combined application of NPK mineral fertilizer and poultry manure has significantly higher NPK uptake values of maize than the sole organic and inorganic fertilizers. Integrated applications of 60 kg ha^{-1} N as poultry manure and mineral fertilizer at 60-40-40 kg ha^{-1} NPK resulted in higher NPK uptake values than either organic or inorganic fertilizers alone (Quansah, 2010). Integrated use of P sources not only increased crop yield but also increased nutrient uptake, protein content and P recovery efficiency in maize. The P recovery efficiency and NP uptake by maize following the application of poultry manure with inorganic P source showed higher values than those recorded by applying inorganic P sources alone indicating that integrated use of poultry manure with chemical P sources can save 30 to 40 kg mineral P fertilizer (Zafar *et al*., 2011).

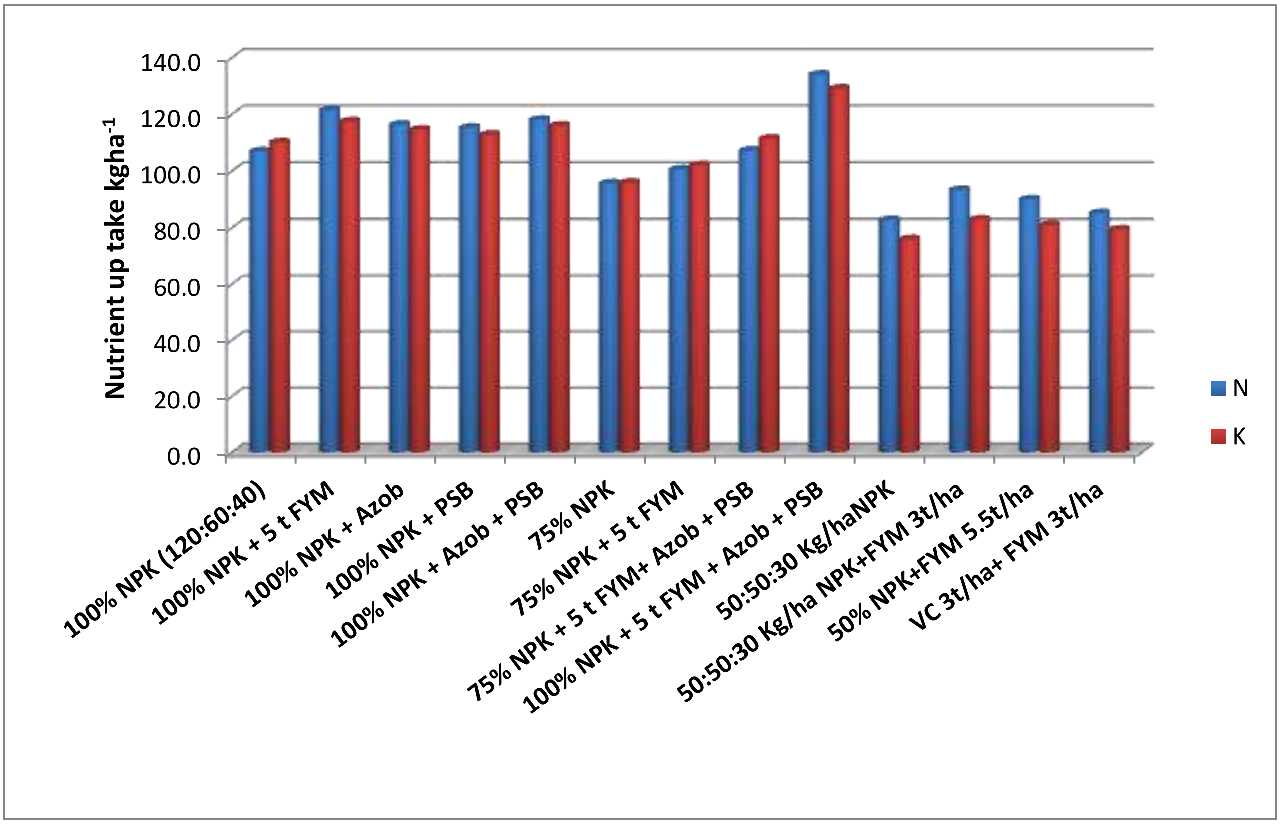

Figure-5: Effect of integrated nutrient management on uptake of N and K of maize
Key: FYM=Farm yard manure, VC=Vermicompost, PSB=Phosphorus solublizers bacteria, Azob= Azotobacter

Integration of poultry waste and di-calcium phosphate in 2:1 P ratio significantly increased total P-uptake and P fertilizer use efficiency of maize by 30 to 66% over single supper phosphate alone. It was also observed that integrated use of nutrients increased P-fertilizer use efficiency from 2.8 to 59.7% over chemical fertilizer alone (Manzar-ul-Alam *et al*., 2005). The results of Wakene Negassa, *et al*., 2007 showed that the uptake of N and P was significantly increased from Mucuna as improved fallow and supplemented with low dose of NP fertilizers and FYM. The uptake of K was significantly low only in treatment received the recommended NP fertilizers (Figure 5). Significantly higher removal of NPK were noticed under 100% NPK + 5 t FYM+ Azotobactor + PSB which was superior to rest of its counterparts, except P uptake in 100% NPK + 5 t FYM (Tomar et al., 2017) (Figure 5 and 6).

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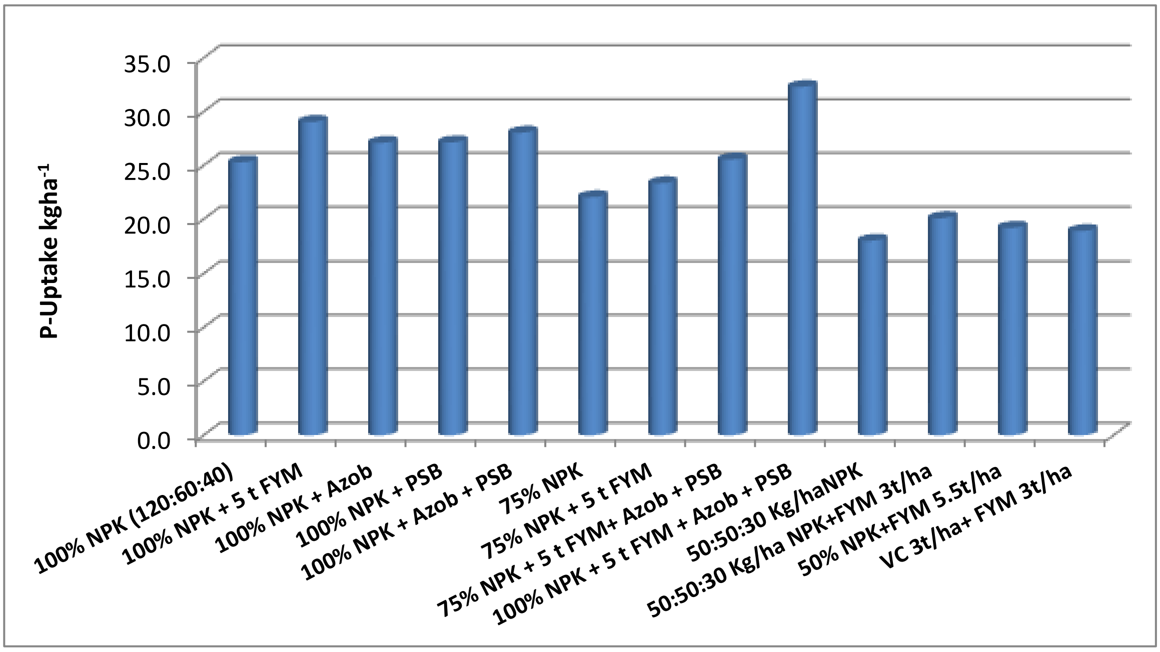

Figure 6 Effect of organic and inorganic sources of nutrients on P- uptake (kg ha^{-1}) of maize crop.
Key: FYM=Farm yard manure, VC=Vermicompost, PSB=Phosphorus solublizers bacteria, Azob= Azotobacter

Role of INM on Soil Nutrient Status in Maize Production

Different results reported that INM practices significantly improved macro and micronutrient status of soils in maize cropping system. Balanced application of NPK fertilizers with FYM or agricultural wastes improved the soil fertility status in addition to increase in maize yield (Dutta *et al.*, 2013, Ogundare *et al.*, 2012). As depicted in figure 10, organic matter content in INM superior than farmers' practice and initial soil organic matter content in maize (Naresh *et al.*, 2013). Substitution of 25 or 50% N with FYM + 4 kg Zn ha^{-1} increased soil organic matter content (Sarwar *et al.*, 2012). Application of compost at 5 ton ha^{-1} along with inorganic fertilizers (50 kg urea ha^{-1} + 100 kg DAP ha^{-1}) improved physico-chemical properties of the soil on sustainable basis rather than using inorganic fertilizer alone (Fanuel and G. Gifole 2012). Similarly, twenty years of experimental study showed that application of 50% N through FYM and 50% NPK through inorganic fertilizers improved soil fertility status (Sathish *et al.*, 2011). The soil analysis after maize crop harvest revealed that soil organic matter, total N, extractable P and K, were greatest from plots receiving organic sources with 50% of recommended NPK fertilizers, suggesting integrating organic sources with 50% of recommended NPK fertilizers are appropriate for sustainable crop production on a low fertility soil (Ahmad *et al.*, 2013).

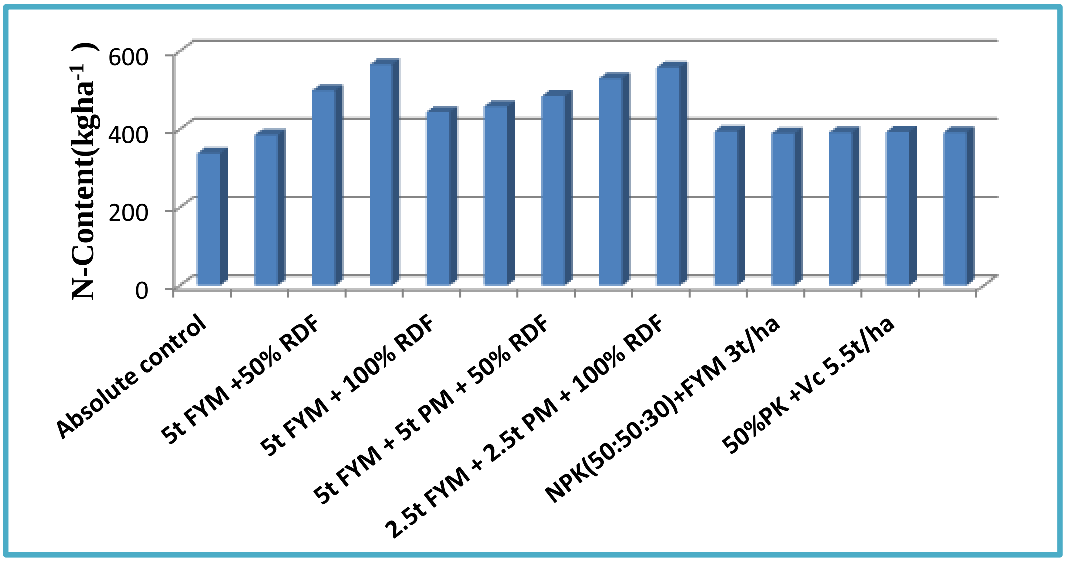

Figure-7: Effect of organic and inorganic sources of nutrients on N content of soil (kg ha^{-1}) at final harvest of maize crop
Key: FYM=Farm yard manure, VC=Vermi-compost, PM=Poultry manure, RDF=Recommended dose of fertilizer

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The availability of nutrients in soil were significantly high in organic and integrated nutrient management practices compared to chemical nutrient management practices at harvest of both in maize based cropping system. At the end of the fourth year in the study, there was increase in available N, P2O5, K2O and S by 19.0, 46.3, 9.6 and 54.1%, respectively due to integrated nutrient management over its initial values. There was also significant buildup of the micronutrient at the end of fourth year due to integrated nutrient management practices as compared to chemical nutrient management practices. Micronutrients such as Zn, Fe, Mn and Cu in the soil were increased by 18.5, 30.6, 36.5 and 30.0 % respectively due to integrated nutrient management practice over their initial values. On the other hand, in chemical nutrient management practices, there was depletion of micronutrient compared to its initial value (Vidyavathi et al., 2012).

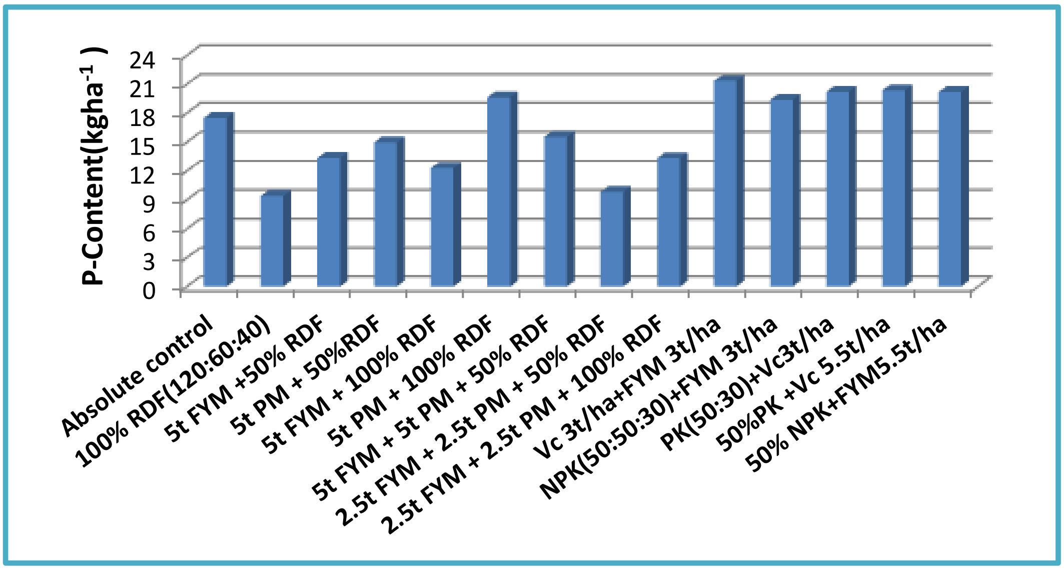

Figure-8: Effect of organic and inorganic sources of nutrients on P content of soil (kg ha^{-1}) at final harvest of maize crop.
Key: FYM=Farm yard manure, VC=Vermicompost, PM=Poultry manure, RDF=Recommended dose of fertilizer

Application of recommended dose of inorganic fertilizer along with vermicompost at 6t ha^{-1} to maize not only enhanced productivity of maize but also improved soil fertility in terms of higher available N, P, K and organic carbon content over the control and recommended N, P and K (Kannan *et al*., 2013). Furthermore, post-harvest soil physico-chemical properties (organic carbon and available nitrogen) were significantly improved under (5t PM + 50% RDF), whereas soil available phosphorus was recorded maximum under (5t PM + 100% RDF) compared to control and rest of the treatments combination (Wailare and Kesarwani, 2017).

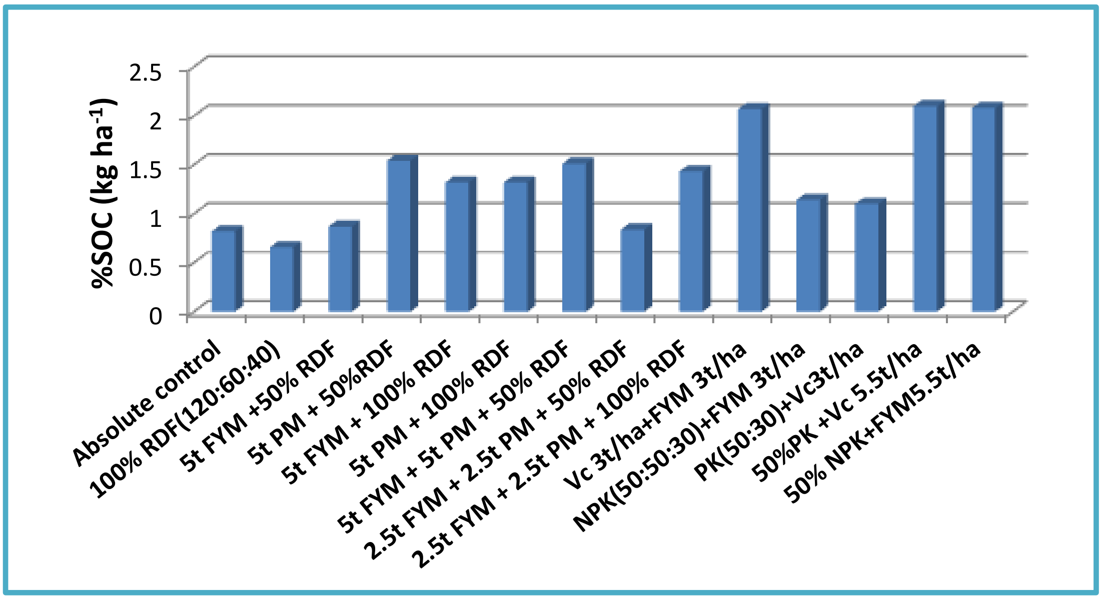

Figure-9: Effect of organic and inorganic sources of nutrients on soil organic carbon content of soil at final harvest of maize crop.
Key: FYM=Farm yard manure, VC=Vermicompost, PM=Poultry manure, RDF=Recommended dose of fertilizer

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Application of 25% chemical fertilizers (20 kg N + 60 kg P_2O_5+ 60 kg K_2O ha^{-1}) in combination with bio-fertilizers, green manuring and compost 10 t ha^{-1} increased organic carbon, available N and available P_2O_5 by 0.14%, 4.4 kg ha^{-1} and 11.7 kg ha^{-1}, respectively compared to the initial nutrient status of the soil (Kalhapure *et al*., 2013). Similarly, Wakene *et al*., 2007 reported that integrated use of mucuna green manure as fallow along with low dose of NP fertilizers increased soil nutrients status and related soil properties in addition to increasing maize yield, indicating INM improves both crop yield and soil fertility in sustainable way.

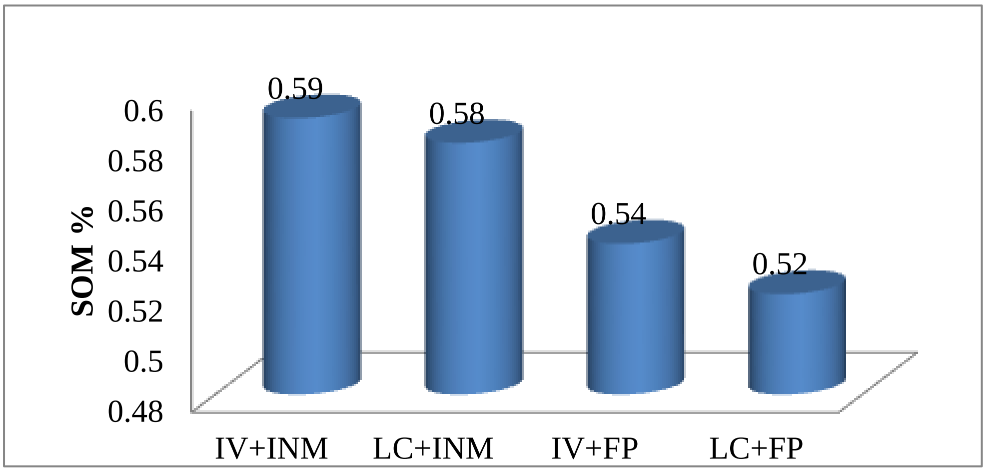

Figure-10**:** Soil OM content under different nutrient management of maize production in North West India
Key: IV = Improved Variety, LC = Local Cultivar, FP = Farmers' practice
Adapted from Naresh, et al., 2013

Summary and conclusions

The practice of INM includes all possible sources of plant nutrients to optimize nutrient inputs, spatial and temporal matching of the soil nutrient supply with crop demand and reducing N losses while improving crop yield. Interaction of agricultural inputs leads to increases in crop productivity while substantially reducing N losses and greenhouse gas emissions, judicious application of mineral and organic fertilization with higher resource-use efficiency, enhance the soil-plant-microbes-environmental sustainability. Balanced use of organic manures will be of fundamental importance for crop productivity and environmental concerns, which should be a priority for INM practices, provides a "win–win" opportunity to simultaneously increase crop productivity and agricultural sustainability.

The number of advantages that INM practices can bring to farmers and the environmental benefits are remarkable. By reviewing numerous research reports, here I have synthesized some strategies and recent opportunities that can be accessed and further enhanced by modification and adjustments in the adoption of site-specific INM practices. Future strategic development of INM under following points (i) combination of soil and plant analysis (ii) fine-tuned to the local environmental conditions (iii) mechanization due to serious labor shortage (iv)conservation tillage and rainwater-harvesting technologies (v) recycling of organic nutrient flows (vi) new technological innovations, and (vii) appropriate policy interventions.

At present, the environmental drawbacks of heavy fertilizer use are confined to some developed countries and a few regions in developing countries. Appropriate and responsible application of fertilizers will help to maintain yields and minimize pollution. By contrast, levels of fertilizer use in most developing countries are so low that there is little likelihood of major environmental problems from their application. In fact, greater application of organic and inorganic fertilizers in these areas could benefit the environment and increase yields.

The balanced and efficient use of plant nutrients from both organic and inorganic sources, at the farm and community levels, should be emphasized; the use of local sources of organic matter and other soil amendments should be promoted; and successful cases of integrated plant nutrient management should be analyzed, documented, and disseminated. Innovative approaches to support and pro-mote integrated plant nutrient management should be pursued. Special efforts are needed to overcome the serious problems of mining soils in many parts of Africa. The ongoing reduction of plant nutrients may well lead to irreversible degradation and soil infertility unless steps are taken to improve soil management. A comprehensive data base needs to be developed for all mineral and organic sources of nutrients, including their amount, composition, processing techniques, their economic value, and their availability. Support complementary measures to lower costs, recycle urban waste, secure land tenure, and increase production capacity. The recycling of

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pollutant-free organic urban waste into the wider peri-urban agricultural sector should be promoted, considering that such waste constitutes an increasingly significant and so far largely untapped source of plant nutrients.

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