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Integrated Nutrient Management: An Approach for Sustainable Crop Production and Food Security in Modern Agriculture

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ABSTRACT: Integrated Nutrient Management refers to the maintenance of soil fertility and of plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of organic, inorganic and biological components in an integrated manner.

KEYWORDS: integrated nutrient management, crop, food security, modern agriculture

I. INTRODUCTION

The aim of Integrated Nutrient Management (INM) is to integrate the use of natural and man-made soil nutrients to increase crop productivity and preserve soil productivity for future generations (FAO, 1995a). Rather than focusing nutrition management practices on one crop, INM aims at optimal use of nutrient sources on a cropping-system or crop-rotation basis. This encourages farmers to focus on long-term planning and make greater consideration for environmental impacts.

INM relies on a number of factors, including appropriate nutrient application and conservation and the transfer of knowledge about INM practices to farmers and researchers. Boosting plant nutrients can be achieved by a range of practices covered in this guide such as terracing, alley cropping, conservation tillage, intercropping, and crop rotation. Given that these technologies are covered elsewhere in this guidebook, this section will focus on INM as it relates to appropriate fertiliser use. In addition to the standard selection and application of fertilisers, INM practices include new techniques such as deep placement of fertilisers and the use of inhibitors or urea coatings (use of area coating agent helps to retart the activity and growth of the bacteria responsible for denitrification) that have been developed to improve nutrient uptake.[1,2,3]

Key components of the INM approach include:

1. Testing procedures to determine nutrient availability and deficiencies in plants and soils. These are:

• Plant symptom analysis – visual clues can provide indications of specific nutrient deficiencies. For example, nitrogen deficient plants appear stunted and pale compared to healthy plants

• Tissue analysis and soil testing – where symptoms are not visible, post-harvest tissue and soil samples can be analysed in a laboratory and compared with a reference sample from a healthy plant

2. Systematic appraisal of constraints and opportunities in the current soil fertility management practices and how these relate to the nutrient diagnosis, for example insufficient or excessive use of fertilisers.

3. Assessment of productivity and sustainability of farming systems. Different climates, soil types, crops, farming practices, and technologies dictate the correct balance of nutrients necessary. Once these factors are understood, appropriate INM technologies can be selected

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4. Participatory farmer-led INM technology experimentation and development. The need for locally appropriate technologies means that farmer involvement in the testing and analysis of any INM technology is essential

“An action research project carried out by CIAT (Centro Internacional de Agricultura Tropical) in three villages in Eastern Uganda implemented participatory on-farm testing of farmer-designed INM strategies during a two-year process. Twenty farmers representing three soil fertility management classes in the three villages were chosen by the farmer groups as test farmers for intensive monitoring of the on-farm[2,3,4] experimentation.

During the diagnostic phase of the PLAR process farmers analysed soil fertility management diversity and resource endowment resulting in the identification and prioritisation of 12 soil fertility and management constraints. Drought was the main constraint, followed by lack of knowledge and skills on soil fertility management, low inherent soil fertility, and soil-borne diseases and pests. The high cost of inorganic fertilisers was ranked number sixth, while soil erosion and poor tillage methods were ranked seventh. During the planning phase, farmers were taken on a farmer exchange visit to meet other farmer innovators who practise some of the proposed technologies.

Farmers designed 11 experiments and they proposed data collection procedures for monitoring and evaluation. Soil samples were collected for laboratory analysis and plant growth was monitored for germination percentage, crop performance, weed management, pests and disease incidence, time of harvesting, and crop yield Application of farmyard manure at 10 t/ha fresh weight tended to improve maize grain yield in the two years of the project. Although the grain yield increases were not significant, farmers were ready to adapt the technology at large-scale. However, the availability, quantity and quality of the manure in the area is a major constraint to wide-scale adoption of this technology. The farmers designed an experiment to evaluate various sources of phosphorous fertilisers. There were five treatments or different mixes, including a control with no fertilisers. There was significant response to the various sources of phosphate fertilisers on maize grain yield. However, capital constraints were identified as limiting factors affecting further adoption of this technology. Green manure application did not significantly improve maize yields however the mean annual dry matter (biomass) yields were significantly different. Farmers in the test area have been using green manure for more than five years. Therefore it was proposed that this technology be disseminated without any further on-farm testing.[3,4,5]

Farmer evaluation of on-farm experiments shows that simple, inexpensive technologies requiring little labour and locally available resources have a high potential for adoption. However, bio-economic modelling studies showed that a substantial improvement in the socio-economic environment is needed to give farmers sufficient incentives to adopt more sustainable land management practices. The results support the hypothesis that systematic learning with stakeholders, and farmers perceiving economic incentives, are necessary for changing farming practices. However, the capacity of different farmers to invest in improving soil fertility management depends on access to labour, livestock, land, capital and cash at the household level. The options available to poor farmers are much more constrained than those available to the well endowed farmers who are able to invest in large-scale use of organic and inorganic sources of nutrients.” (Source: Esilaba et al, 2004)

Harsh climatic conditions are a major cause of soil erosion and the depletion of nutrient stocks. By increasing soil fertility and improving plant health, INM can have positive effects on crops in the following ways:[4,5,6]

A good supply of phosphorous, nitrogen and potassium has been shown to exert a considerable influence on the susceptibility or resistance of plants towards many types of pests and diseases A crop receiving balanced nutrition is able to explore a larger volume of soil in order to access water and nutrients. In addition, improved root development enables the plant to access water from deeper soil layers. With a well-developed root system, crops are less susceptible to drought Under increasingly saline conditions, plants can be supplemented with potassium to maintain normal growth With appropriate potassium fertilisation, the freezing point of the cell sap is lowered, thus improving tolerance to colder conditions (ure 1)

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Effect of Potassium Application on Frost Injury to Potato Crop

Advantages of the technology

INM enables the adaptation of plant nutrition and soil fertility management in farming systems to site characteristics, taking advantage of the combined and harmonious use of organic and inorganic nutrient resources to serve the concurrent needs of food production and economic, environmental and social viability. INM empowers farmers by increasing their technical expertise and decision-making capacity. It also promotes changes in land use, crop rotations, and interactions between forestry, livestock and cropping systems as part of agricultural intensification and diversification.

Disadvantages of the technology

As well as facilitating adaptation to climate change in the agriculture sector, the INM approach is also sensitive to changes in climatic conditions and could produce negative effects if soil and crop nutrients are not monitored systematically and changes to fertiliser practices made accordingly. In Africa, high transport costs in land-locked countries contribute to prohibitively high fertiliser prices (FAO, 2008b). In the case of small-scale farmers these costs may represent too high a proportion of the total variable cost of production thus ruling out inorganic [5,6,7]fertiliser as a feasible option.

II. DISCUSSION

Institutional and organisational requirements

The success of INM will depend upon the combined efforts of farmers, researchers, extension agents, governments, and NGOs. Simply providing fertilisers is not enough to support INM implementation. Appropriate policy frameworks are essential, as are market structures, infrastructure development, credit facilities and the transfer of technology and knowledge.

INM requires knowledge of what is required by plants for optimum level of production ─ in what different forms and at what different timings and how these requirements can be integrated to obtain highest productivity levels within acceptable economic and environmental limits. Determining this information will require localised research but will also benefit from the cooperation of national and international agricultural research centres. Extension staff who are able to translate research data into practical recommendations will need to take account of both farmers' expertise and applicable research results. Available knowledge will need to be summarised and evaluated economically in order to provide practical guidelines for the adoption of INM by farmers that have a range of investment capacities.

Barriers to implementation

An insufficient availability of credit at an affordable price is frequently mentioned as a constraint on fertiliser use. Access to mineral fertiliser may be limited in rural or underdeveloped areas due to high import prices and high transport costs. A lack of adequate infrastructure for distribution and conservation can also present a barrier for access and use. In addition, fertilisers have a limited shelf-life and may be in high demand (leading to shortages) in peak seasons if appropriate planning is not put in place. Competition for organic resources may be high in areas where crop residues are used for fuel and animal feed.

Opportunities for implementation

A largely untapped source of potential fertiliser is urban waste. Although the quality or fertiliser produced from urban waste does not compare to commercially produced fertiliser, the sludge (Residual, semi-solid material[6,7,8] left from industrial wastewater, or sewage treatment processes) contains nitrogen, phosphorous, potassium and other micro-nutrients. Utilising urban waste for agricultural lands near urban centres puts to good use a material that otherwise would be disposed via costly means (Gruhn et al, 2000). Farmers associations and extension services provide an opportunity for production and dissemination of information on the most cost-effective and appropriate technologies.

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III. RESULTS

While the concept of sustainability as a goal has become widely accepted, the dominant agricultural paradigm still considers high yield and reduced environmental impact being in conflict with one another. During the past 49 years (1961–2009), the 3.4-fold increase in agricultural food production can be partly attributed to a 37-fold increase in N fertilization and a 91-fold increase in P fertilization, but the environment costs have been very high. New advances for sustainability of agriculture and ecosystem services will be needed during the coming 50 years to improve nutrient use efficiency (NUE) while increasing crop productivity and reducing environmental risk. Here, we advocate and develop integrated nutrient management (INM) based on more than 20 years of studies. In this INM approach, the key components comprise (1) optimizing nutrient inputs by taking all possible nutrient sources into consideration, (2) matching nutrient supply in root zone with crop requirements spatially and temporally, (3) reducing N losses in intensively managed cropping systems, and (4) taking all possible yield-increasing measures into consideration. Recent large-scale application of INM for cereal, vegetable, and fruit cropping systems has shed light on how INM can lead to significantly improved NUE, while increasing crop yields and reducing environmental risk. The INM has already influenced agricultural policy and national actions, and resulted in increasing food production with decreased climb of chemical fertilizer consumption at a national scale over recent years. The INM can thus be considered an effective agricultural paradigm to ensure food security and[7,8] improve environmental quality worldwide, especially in countries with rapidly developing economies.

The Green Revolution helped to create the world's "Miracle" with 9% of the world's arable land feeding 22% of the world population. In the past 49 years (1961–2009), cereal grain yields have increased 3.5-fold from 1.2 to 5.4 t ha− 1, while total grain production has increased 3.4-fold from 110 to 483 million ton (MT) (FAO, 2011). In 1998, grain, meat, and egg production per capita exceeded the world average. The increased demand in grain production has affected the global food supply and the natural resource bases required for nutrient production (fossil fuels, mineral sources of P and K) and has attained world recognition.

However, this 3.4-fold increase in agricultural food production during the past 49 years can be partly attributed to a 48-fold increase in chemical fertilizers from 1 to 49 MT, including a 37-fold increase in N fertilizer application and a 91-fold increase in P fertilizer use, and a 442-fold increase in the area of irrigated croplands (. 1). Total consumption of chemical fertilizers worldwide increased by 3.9-fold from 32 to 164 MT, indicating that 36% of the global increase (~ 132 MT) came during the past 49 years. In the past 10 years (2000–2009), 54% of the global increase in chemical fertilizer consumption (~ 27 MT) was contributed including 11 MT fertilizer N (54% of the global increase), 2.5 MT fertilizer P (52% of the global increase), and 1.1 MT fertilizer K (58% of the global increase) (ure 1, ure 2A,B).

Cereal yields in the past 10 years have continued to increase with no proportional increases in fertilizer use in many developed countries or regions such as Western Europe (rainfed cereal systems), North America (rainfed and irrigated corn), and Japan and South Korea (irrigated rice) (Dobermann and Cassman, 2005). For example, in the past 10 years, chemical fertilizer consumption in the United States increased by only 0.04 MT with 0.23% of total fertilizer consumption in 2009 and decreased by 0.32 MT in Western Europe (. 2A). By contrast, the application rate of chemical fertilizers was continually increasing and reached 448 kg ha− 1 in 2009, which is 2.8, 2.9, and 1.4 times the world average and rates in the United States and Western Europe, respectively (. 2B).

On the other hand, cereal crop production has stagnated at approximately 450 MT since 1998. From 1998 to 2009, grain yields increased by only 10%, while the consumption of chemical fertilizers increased by nearly 49%, 19%, and 33% for N, P, and K, respectively (. 1). That means that the large increase in fertilizer nutrient inputs did not result in a corresponding yield increase in the past decade . For example, the REN (the percentage of N fertilizer recovered in the aboveground plant parts at maturity) in cereal grain production decreased from about 35% in the 1980s (Zhu, 1998) to 28% in the 2000s (Zhang et al., 2008a), lower than the world average of 33% (Raun and Johnson, 1999). Often twice as much fertilizer N or P is applied compared with the removed nutrients by crops, and this nutrient imbalance in turn drives severe environmental problems, such as eutrophication of surface waters (Le et al., 2010), soil acidification (Guo et al., 2010), greenhouse gas emissions (Zheng et al., 2004), and other forms of air pollution (Liu et al., 2011). For example, about 60% of inland lakes in show eutrophication, and 57% of N inputs and 67% of P inputs are derived from agriculture (Ministry of Environmental Protection, 2010). Soil pH declined significantly ($P < 0.001$) from the 1980s to the 2000s in the major crop lands due to overuse of N fertilizer (Guo et al., 2010). On the total wet and dry deposition

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of N averaged 80–90 kg N ha− 1 yr− 1 in the 2000s (Liu et al., 2006b, Shen et al., 2009, Zhang et al., 2008b), a value nearly 10 times that at Rothamsted, Harpenden, UK (Goulding et al., 1998) or in central New York in the USA (Fahey et al., 1999). These problems are meaningful on a global scale[8].

To meet the demand for grain and to feed a growing population on the remaining arable land by 2030, crop production must reach 5.8 MT (an increase of > 40%) and yields have to increase by 2% annually (Zhang et al., 2011). Due to environmental and economic (e.g., rising cost of fossil fuels) constraints, further increases in food supplies projected for the coming 50 years must be attained through improved resource use efficiency rather than more agricultural inputs, especially N and P fertilizer applications (Cassman, 1999, Matson et al., 1997, Tilman et al., 2002). Toward this end, sound agronomic and environmentally acceptable integrated nutrient management (INM) is an essential approach for the achievement of a reduction in fertilizer-derived environmental risk while also increasing crop productivity and NUE.

In most intensive agricultural areas, however, current nutrient management strategies are focused on delivering soluble inorganic N and P from fertilizers directly to crops and have uncoupled soil and environmental N and P cycles spatially and temporally. As a result, agricultural ecosystems are maintained in a state of N saturation and are inherently leaky because chronic surplus additions of N and P are required to meet the goal of maximum yields (Drinkwater and Snapp, 2007). For example, the N and P surpluses in intensive wheat–maize systems on the NCP were recently estimated to be as high as 227 and 53 kg ha− 1 yr− 1 (Vitousek et al., 2009). Therefore, all these approaches have been successful in terms of maintaining grain yields; however, attempts to reduce nutrient losses and improve NUE have met with limited success in intensive agricultural areas (Cassman et al., 2002, Drinkwater and Snapp, 2007).

In INM, crop yields can be increased while minimizing nutrient losses to the environment by managing nutrient supply in the root zone within a reasonable range, which realizes the biological potential of crops, matches high-yielding crop N requirement, and controls minimal nutrient losses. Nutrient supply and nutrient requirements in high-yielding cropping systems must be matched in quantity and synchronized in time and space (Chen et al., 2010, Cui et al., 2010a).

IV. CONCLUSION

To realize this goal, some improvements must be made: using a variety of N sources from fertilizers, the environment, and the soil to meet crop demand; calculating the nutrient balance between the inputs and outputs to manage a variety of intrinsic ecosystem processes at multiple scales to recouple elemental cycles; and considering the biological potential of the root system and matching crop requirements by supplying sufficient N only when plant demand exists (Cui et al., 2010a; . 3). In this review, we discuss the principles of INM and the development of INM technology on a large scale with dissemination of INM in different cropping systems up to national scale.[8]

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