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Agriculture Technology Notes

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Integrated Nutrient Management

Smallholders Generally Lack Adequate Nutrients for their Crops

Nutrients are essential for plant growth, but on smallholders' farms, an inadequate supply is a key impediment to sustainable food production. Integrated nutrient management (INM) utilizes available organic and inorganic nutrients to build ecologically sound and economically viable farming systems.

INM optimizes all aspects of nutrient cycling — supply, uptake, and loss to the environment — to improve food production. This Note describes interventions that may be applied to a range of agroecological zones, cropping systems, and soil types. The interventions address a few key aspects of nutrient management, including improving organic matter in the soil, increasing plant-available nitrogen, and supplying both organic and inorganic fertilizers. These interventions have the potential to increase and sustain production levels, increase the economic potential of a production system, and counteract and minimize environmental pollution (Box 1).


CIMMYT

Maize intercropped with a legume.

Interventions

Crop residues increase soil organic matter. 'Crop residue management' means returning crop residues to the soil either by incorporation or as surface mulch. The main purpose is to conserve nutrients and energy embodied in the residues. No matter what the environment, the accumulation of soil organic matter is dependent on the quantity and quality of crop residues and other organic materials added to the field.

Crop residues can be left on the soil surface as mulch or incorporated into the soil. Mulch enhances biological activity, modifies soil temperature, improves soil water conservation, reduces soil sealing and crusting, reduces soil erosion, and may impede the growth of weeds. Crop residues can also be incorporated into the soil when animal traction is available, which usually accelerates decomposition. Residues should only be incorporated into the soil on less erosive, well-structured and humus-rich soils because tillage may increase erosion

As with most INM systems, crop residue management may have some drawbacks. High rates of residue application may be uneconomical, especially when corresponding yield increases are not substantial. Mulching with crop residues could lead to a build up of plant disease pathogens that may infest the next crop. Finally, there may be opportunity costs associated with use of crop residues for nutrient management. In sub-Saharan Africa and South Asia, crop residues are often used for fuel or fodder, thus farmers may be reluctant to use them as a nutrient source or mulch unless alternative sources of fuel and fodder are available.

Box 1. Nutrient Basics

Sources. This Note describes INM interventions to manage three plant nutrient sources — organic and inorganic fertilizers, as well as nitrogen fixed from the atmosphere. In addition to these sources, plants also derive nutrients from soil reserves (determined by soil composition and stage of weathering), aerial deposition (sulfur in acid rain, calcium in the form of dust, for example), and surface and groundwater (through treated irrigated water, or natural water sources that contain nutrients originating elsewhere in the watershed).

Types. *Micronutrients* reside in the soil, and although used by plants in very small amounts, they are essential. These include zinc, manganese, iron, copper, and boron. *Secondary nutrients* are taken up in larger quantities, and include calcium, magnesium, and sulfur. *Macronutrients* are the most critical, and are used by plants in relatively larger amounts. Key macronutrients are nitrogen (N), phosphorous (P), and potassium (K).

Inorganic vs. organic. Inorganic nutrients are fertilizers that are either single elements or compounds that do not include carbon. These fertilizers are usually manufactured, are in liquid or solid form, and can contain any of the nutrients described above. The most common inorganic fertilizers are N, P, and K. Organic nutrients are carbon compounds (excluding CO, CO_2, and carbonates), which may also contain micro, secondary, and/or macronutrients. Organic nutrient sources include plant residues, leguminous cover crops, mulches, green manure, animal manure, compost, and household wastes, all of which contribute to the formation and maintenance of organic matter. Finally, nutrients in their organic form cannot be used by plants. For example, for a plant to be able to use the nitrogen in organic matter, the carbon-nitrogen bonds must be broken by micro-organisms in the soil. Inorganic nutrients are already in a plant-available form.

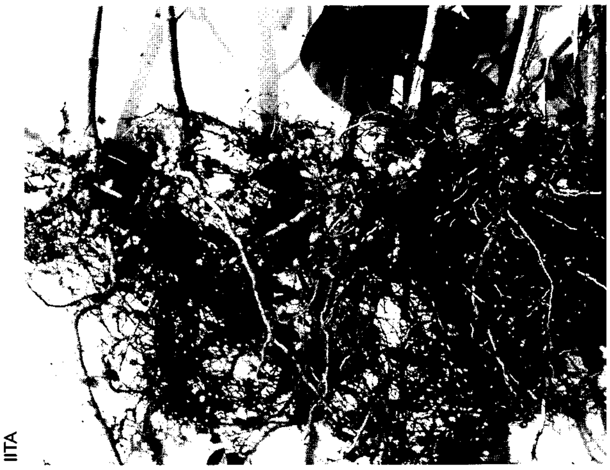
Cycle and recycle. The nutrient cycle comprises the supply, uptake, and the loss of nutrients to the environment. Nutrient recycling returns nutrients to the agroecosystems that would otherwise be lost to the environment. Intercropping and application of crop residues and farmyard manure are nutrient recycling techniques.

Organic matter. Plants in any form — live, dead, composted, residues, decaying, crops, weeds — are all organic matter. Theses materials contain many nutrients for future plant growth, including the carbon that is the most basic food source for the soil and (indirectly) for the plants themselves.

Increasing the organic matter content improves water penetration and retention, soil structure, microbial biomass, nutrient availability, heat stress resistance, resistance to compaction, and much more. Increasing soil organic matter content is perhaps the most important improvement a farmer can make. Soils that are below 2 percent organic matter in the upper horizon are low in organic matter. They do not have enough essential food (carbon) to feed the micro- and macro-organisms that regulate nutrient and water supply to plants.

Raw organic matter decomposes under proper conditions into humus. Humus has been 'digested' by soil microbes and earthworms, creating a soil-like material. Humus is full of soil microbial life and acts in much the same way as a yogurt culture or sourdough starter, but in this case, it stimulates soil life. As a product of the soil digestion process, humus is a highly concentrated source of nutrients available to plants.

Sources: FAO (1998) and (Cantisano, 1997).



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Nodules on soybean roots are a valuable source of nitrogen fertilizer.

Increasing plant-available nitrogen. Sowing legumes as an intercrop, in a rotation, or as a fallow crop all benefit nutrient management. Groundnuts, soybeans, cowpeas, and other legumes make nitrogen from the atmosphere available to plant roots through a process called nitrogen fixation. Bacteria on leguminous plant roots 'fix' nitrogen from the atmosphere, which is then available to plants. Nitrogen in legume root nodules is available to the subsequent crop (usually a non-legume) after senescence of the legume and decomposition of its organic residues.

In cropping systems where legumes are commonly used as intercrops with maize, sorghum, or millet, soil nitrogen can be improved by using cultivars that actively fix atmospheric nitrogen. Millet/cowpea and millet/groundnut rotations, for example, have performed much better than a sole millet crop receiving inorganic fertilizer applications. Statistics from trials in savanna soils low in organic matter and nitrogen show that maize yields about doubled when sown after five different nitrogen-fixing soybean varieties.

In areas where there is an urgent need to stabilize and improve the productivity of slash-and-burn systems, managing the fallow by planting a legume benefits both the soil and the economy. Although allowing the natural vegetation to grow is the most efficient labor-saving type of fallow for nutrient recycling and biomass accumulation, a carefully chosen legume has the ability to establish and grow more rapidly than bush fallow, as well as the ability to fix nitrogen.

A range of fallow strategies is available to farmers. A viney dry-season legume can integrate a legume component into the cropping sequence and provide livestock feed, or widely planted trees can return as much as six times more nitrogen to the soil than natural bush fallow. To date, however, use of leguminous cover crops as a managed fallow on small farms in sub-Saharan Africa is not very common.

Use of legumes for nutrient management, however, may require additional technical considerations. Where certain legumes are not indigenous, compatible nitrogen-fixing bacteria may not be present, and inoculation with an appropriate Rhizobium strain may be required. And for soybean, it is important to return the above-ground residue to the soil because soybean transports a large amount of nitrogen (60-70 percent) to the seeds and pods that are harvested.

Improving the supply of multiple nutrients. Farmyard manure and inorganic fertilizers both have the potential to supply a range of nutrients.

Farmyard manure. Application of farmyard manure (FYM) to the soil supplies multiple nutrients and also maintains organic matter content of the soil. Studies in Tanzania have shown that increased yields following a single 17-ton application of farmyard manure or compost per hectare were maintained for as long as 13 years for cotton, and 9 years for bulrush millet. Other studies have shown that on the coarse-textured soils of West Africa, favorable results were obtained when inorganic fertilizers were used in conjunction with relatively lower rates of manure applications. Similarly, in northern Nigeria, combined use of FYM and inorganic fertilizers on kaolinitic soils maintained crop yields under continuous cropping.

The use of FYM as a nutrient source for food crop production depends largely on prevailing farming systems. A traditional system of manure use in West Africa is known as 'kraaling'. During the dry season, host farmers confine cattle from nomadic Fulani herders in a designated field throughout the night to ensure concentration of manure and urine, which dramatically increases the amounts of both nitrogen and phosphorus available to plants. Increasing the amount of time that animals are confined on crop land would improve soil fertility compared to hand-spreading manure.

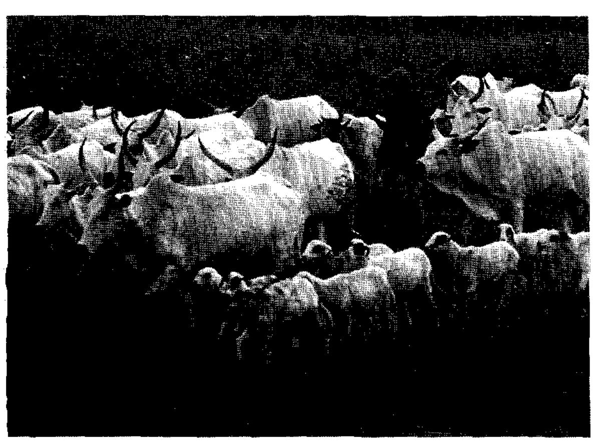
Inorganic fertilizers. Judicious use of inorganic fertilizers on the infertile arable soils in sub-Saharan Africa is needed to sustain high crop yields and maintain an optimum balance of nutrients. Judicious use means consideration of the rate, timing, and method of application.

Published results have shown that continuous use of relatively high rates of nitrogen fertilizers on arable soils in the sub-humid and semi-arid zones of sub-Saharan Africa, especially under cereal monoculture, can reduce soil pH (acidification) and seriously degrade soil fertility. Timing fertilizer applications across the planting and growing season has proven superior to a single-dose application at the time of planting in all three climatic zones of sub-Saharan Africa. Placement methods also affect fertilizer use efficiency. In the humid and sub-humid tropics, broadcast fertilizer performed significantly better than either band (in the furrows of row crops) or point placement. In the semi-arid tropics, point placement significantly decreased the performance of fertilizer, whereas broadcast and band applications behave similarly, except at high application rates. When inorganic fertilizer is needed to maintain soil productivity, however, it must always be in conjunction with management practices that help maintain soil organic matter, such as return of crop residues or use of FYM.

Farmers may also choose to plant crops that do not require high rates of inorganic fertilizer. Edible plant species with low nutrient demands, such as root crops, plantain, and starchy banana, are ecologically better suited to poor soils. Cassava and sweet potato are commonly grown on weathered acid soils with low nutrient reserves.

Selecting an option. In adopting these nutrient management options, it is important to note that at the farm level,

Nomadic herders in Nigeria drive cattle and sheep that are grazing on crop residues.



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Box 2. Farmers Balancing Their Systems

Integrated crop-livestock farms depend upon access to livestock and livestock feed, and the ability to store and apply manure.

In Nepal, farmers know livestock are essential for maintaining soil fertility and apply varying quantities, with irrigated fields receiving larger amounts. Six livestock units are needed to provide sufficient farmyard manure for one year to grow one hectare of rice-maize-wheat, but this quantity is presently not available, due to partial collection and inefficient storage.

In Indonesia, upland farmers apply manure to vegetables, rice, maize, and cassava. Inorganic fertilizer applications are low. Maize and cassava grown in valley bottoms show a negative N, P, and K balance.

In Kenya, a typical subsistence farm has a negative nitrogen balance of about 50 kg/ha and is close to self-sufficient in phosphorus. A move toward commercial dairy production would increase the outflow, but with the cash generated from the dairy cattle, a nutrient balance can be achieved through a combination of manure and commercial fertilizer. Nutrient balance studies demonstrate how farmers strategically use commercial fertilizer on coffee and manure on maizefields to achieve a nutrient-balanced system.

Sources: de Haan et al. (1997) and Ransom et al. (1993).

small-scale farmers with few resources are compelled to seek short-term gains when applying nutrients. Once all potential plant nutrient sources have been identified and the possible interventions selected, farmers will determine the correct mix of these interventions to optimize their resource use and meet their production targets and profitability objectives.

Further Considerations

Knowledge gaps. The technology options described in this Note are knowledge intensive because they require that resource inputs be replaced by knowledge of the complex interactions between soil and management technologies. Adoption of these technologies is predicated upon systematic information dissemination by building capacity and through training programs for farmers and extension staff.

There are still significant knowledge gaps related to the appropriate quantities of nutrients to be applied in these nutrient management interventions, thus most interventions are based on empirical results. In the absence of detailed information, extension workers and farmers need to understand the quantities of nutrients removed by crops.

Another area for further capacity building is the interactions between nutrient applications and other agricultural activities, and the likelihood of unforeseen problems such as environmental contamination, or deficiencies in secondary or micronutrients.

Policy. For low-income farmers, the pursuit of higher production must be balanced against the need to maintain soil fertility and minimize soil degradation. The profitability of adopting some of the nutrient management options described here should, however, be viewed over the long-term, since improved efficiency in crop nutrient use tends to become apparent only after several seasons. Because farmers access to resources is limited, they are compelled to look for short-term results when applying plant nutrients. If constraints to markets and production technologies were removed, then farmers would be able to use nutrients more economically and in ways that support sustainable crop production.

Some of the nutrient management interventions proposed in this Note depend to some extent on sources outside cropped areas, for example, manure, forest litter, or other organic materials physically transported from forests and pastures. Economic incentives for community-level participation in these practices have important policy implications. In traditional low input/output production systems, plant nutrient management is usually based on local nutrient resources collected in areas other than those farmed. An important component, and therefore an important policy issue, is improving transportation for these materials.

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Websites

The following websites carry useful information on a range of INM practices:

FAO — http://www.fao.org/ag/magazine/spot3.htm

International Fertilizer Development Center — http://www.ifdc.org/

Conservation Technology Information Center — http://www.ctic.purdue.edu/Core4/CropNutrient.html

Purdue University — http://www.hort.purdue.edu/newcrop/default.html

Tennessee Valley Authority — http://www.rural.org/Farmers_Guide/Agriculture/

Cornell University — http://www.sbg.ac.at/geo/idrisi/landeval/s494ch7p.htm

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