AGRICULTURE INVESTMENT NOTE

INTEGRATED NUTRIENT MANAGEMENT FOR SUSTAINING SOIL PRODUCTIVITY

Future food and fiber must be produced on existing agriculture land, with less negative impacts on natural resources and the environment than in the past. The timely supply, efficient use, and careful monitoring of nutrients in integrated crop, forage, and tree production systems offer the potential for significant improvement of efficiency in plant nutrient use. Farmers, researchers, and other stakeholders need to be more actively involved in the generation and use of the knowledge required for integrated nutrient management.

Although science-based agriculture has made major contributions to both the quantity and quality of the global food supply, the rate of yield increase for major food crops has begun to slow in recent years. In many parts of the world, agricultural production increases have been accompanied by significant degradation of natural resources including nutrient depletion on agricultural lands.

Integrated nutrient management (INM) is an approach that involves the management of both organic and inorganic plant nutrients for optimal production of cultivated crops, forage, and tree species, while conserving the natural resource base essential for long-term sustainability. Nutrient flows occur at different scales in any agroecosystem, and soil nutrient budgets for a given area and time can be calculated by the difference between the nutrient inputs and outputs (see figure 4.3). Large soil nutrient surpluses can lead to environmental pollution, whereas persistent soil nutrient deficits usually indicate nutrient mining.

Effective INM involves four interrelated strategies:

• Conservations and efficient use of native soil nutrients. Conservation practices help to reduce loss of nutrients from agroecosystems due to surface water flows and from erosion of soil by wind and water. Vegetative barriers minimize off-farm transport of dissolved nutrients, dust, and sediments, and deep-rooted plants act as nutrient safety nets, intercepting leached nutrients from the root zone and returning these to the soil surface via litter fall, mulch, or as green manure. In general, conserving existing nutrient resources is easier and cheaper than replenishing and rehabilitating degraded resources.

• Recycling of organic nutrient flows. Returning crop residues and/or animal manure to

![Diagram of Nutrient Flows in Agroecosystems](Diagram.png)

cropland is important for system
sustainability. Composting crop residues
and animal manures enhances the utiliza-
tion efficiency of easily lost nutrients such
as nitrogen. Converting linear flows (lost
from the system) of organic nutrients to
cyclical flows (returned to the system) can
reduce the need for external nutrient
inputs. There are related potential price
benefits in organic product markets. Livestock
are important for processing crop residues, adding value to farm outputs,
improving labor efficiency, and providing
manure.

- **Enhancing biological nitrogen fixation and soil biological activity.** Nitrogen fixing crop, forage and tree/shrub species scavenge nitrogen from the soil and/or fix nitrogen from the atmosphere when soil levels are below plant requirements. Most nitrogen-fixing plant species also form symbiotic relationships with mycorrhizal fungi that improve soil aggregation, nutrient and water use efficiencies, and protect the plant roots from a variety of pathogens. This is one example of an INM practice that also contributes to IPM. Integration of nitrogen-fixing species into cropping systems diversifies inputs/outputs and reduces risk on both economic and ecological fronts.

- **Addition of plant nutrients.** The nutrient content of highly weathered soils is very low. In most cases, the export of nutrients in harvested products results in one or more plant nutrients becoming limiting. In the humid tropics, calcium and phosphorus are often limiting for crop growth and productivity. Appropriate amounts of lime and nutrients are essential to optimize plant root growth, enhance the efficiency of added nutrients, and avoid soil degradation (see box 4.36). Although inorganic fertilizers such as limestone and rock phosphate are consistent with organic agriculture, inorganic fertilizers are often the most efficient means of adding soil nutrients. In many places (such as in Africa) they are essential for improving productivity to levels that will then enable adoption of wider INM practices.

In the past, the cost of soil and crop sampling and nutrient analyses made site-specific fertilizer application recommendations prohibitively expensive for most agricultural programs. Blanket fertilizer recommendations were common, but blanket application of fertilizers is often uneconomic and can lead to pollution. Recent advances in plant nutrient decision support models, improved access to high-resolution satellite images, and the improved interpretation of crop and soil spectral signatures make site-specific recommendations possible.

**Box 4.36 Soil nutrient recapitalization**

Researchers estimate that the croplands of many smallholder farmers, especially in Africa, have become depleted of the nutrients that are removed by crop harvests. Published estimates from 40 African countries indicate a net negative annual balance of 22 kg of nitrogen, 2.5 kg of phosphorus, and 15 kg of potassium per hectare of cultivated land. To meet increasing demand for food, soil scientists have recommended a major capital investment to replenish soil nutrients in Africa. Social scientists, however, caution against blanket nutrient recapitalization as nutrient deficit statistics are based on limited datasets, and fail to account for nutrient variability and transfers at the farm and watershed level. Furthermore, many socioeconomic and institutional factors influence farm management decisions. For example, smallholder farmers in western Kenya are gradually but significantly improving both crop yields and soil fertility because of the availability of locally repackaged one to five kg bags of fertilizer that they can afford, transport, and use on selected crop fields. As crop yields and input-output markets improve, they invest further resources for more fertilizer nutrients and improved seed.

Source: Anderson et al. 2002.

**BENEFITS**

The reduced erosion and increased cycling of organic residues in INM can increase or at least maintain native soil organic matter levels, and thus improve both nutrient and water retention capacity of the soil. Soils with around three percent soil organic matter content and dynamic soil fauna populations generally have better soil structure, water infiltration, soil
aeration, and plant root growth than soils with lower organic matter. Improved soil water infiltration and retention significantly reduces surface flow of water, soil erosion, and nutrient removals, and also minimizes the risk of downstream flooding.

INM can reduce plant requirements for inorganic nitrogen fertilizer, and reduced use of purchased fertilizer nutrients can result in a significant saving of scarce cash resources for small farmers. INM practices can also significantly reduce the emissions of greenhouse gases (nitrous and nitric oxides). Excessive applications of nitrogen fertilizer can result in increased leaching of nitrates into ground water, increasing health risks to newborn infants and cancer risk in adults. Organic nutrient flows cycled through the return of organic residues as compost, manure, and/or mulch have significant implications for conserving soil fauna biodiversity.

POLICY AND IMPLEMENTATION ISSUES

Precision farming. For large-scale farming, there has been significant private sector investment in fertilizer-based nutrient delivery and tracking systems. This has resulted in precision farming that uses satellite-based global positioning systems on tractors and harvesters to monitor and manage soil, plant, and grain nutrients by location in the field. Most smallholder farmers in the tropics, however, will need public support for participatory, multidisciplinary R&E services to apply INM principles to the varied infrastructure, soil, and climatic conditions of their farms. This will require extensive local adaptive testing of technologies supported by comprehensive databases on soil characteristics, crop nutrient use and productivity, organic and inorganic fertilizer properties, and market prices.

Results take time. Benefits from INM are often seen only in the medium to long term, and in many cases the benefits are to populations living downstream of INM practitioners. Costs and benefits of INM practices should be monitored and quantified at farm and landscape levels so that appropriate premiums and taxes can be assessed to facilitate and promote the wide-spread adoption of INM practices. INM programs need to consider also the impacts on water and air pollution, siltation, salinization, biodiversity impacts, carbon sequestration and greenhouse gas mitigation in research programs.

Fertilizer, soil, and plant-testing laboratories. Accurate information on the nutrient composition of available fertilizers and site-specific application recommendations are important to INM, which relies on a good understanding of nutrient contents and flows. Consequently, there is a need for reliable soil, plant, and nutrient input testing facilities that can provide low-cost testing services to farmers in the initial stages of INM adoption. Opportunities exist for use of properly tested and treated urban waste and sludge, and these and local rock phosphates need to be tested to ensure that materials with high concentrations of heavy metals or toxins are not supplied to farmers. Public laboratories (especially for soil testing) are often inefficient, inaccurate and poorly managed, whereas private laboratories are relatively rare and costly. Country-specific strategies are needed to establish and maintain accurate analytical laboratory capacity.

Price, trade and tax policies. Fertilizer prices for many tropical smallholder farmers, especially in Africa, are more than double the prices paid by farmers in industrial countries. Crop prices are also too low or too unstable to allow farmers to profitably invest in nutrient replenishment of their depleted or degraded farmlands. Public policy needs to seek ways of reducing high fertilizer prices to farmers through more efficient marketing systems, but rarely should consider introducing subsidies.

Labor supply. Labor markets can be constraining as INM often requires more labor inputs than do systems relying solely on inorganic fertilizers. Labor supply is affected by the dynamics of labor markets and the impact of disease (HIV/AIDS, for example). Appropriate tools and machinery for small farmers, that can be locally produced, refined, and maintained, can significantly reduce the drudgery of field work and
facilitate the adoption of labor-intensive INM practices. Excellent examples of such tools can be found in the cover crop and conservation tillage systems of southern Brazil.

**LESSONS LEARNED**

**FARMER LEARNING.** Adding fertilizer nutrients will not be enough to improve and sustain crop productivity. It is essential to also engage farmers in the diagnosis and design of farm and watershed nutrient management and facilitate farmer learning. As farmers become familiar with INM principles, they begin to innovate with different strategies in their own environments (see box 4.37).

**INORGANIC FERTILIZERS.** In most tropical soils and integrated cropping systems, inorganic fertilizers must supplement organic nutrients. On degraded soils, inorganic nutrients are needed to prime the biological potential of native vegetation to produce the organic inputs prior to the adoption of INM strategies. The availability of appropriately formulated fertilizers at accessible prices is important for increasing the use of these nutrient sources by smallholder farmers.

**PROPERTY RIGHTS.** Land and resource tenure rights influence the relative values of land, labor, and capital. Secure tenure is important in providing incentives for investment in land resources, soil nutrient buildup, erosion control, perennial crops, and other critical elements of INM. Land tenure security helps in accessing financial services to improve farmers’ access to credit for these investments.

**INFRASTRUCTURE AND SERVICES.** INM strategies are adapted to many situations, but are most likely to thrive in an environment in which supporting infrastructure and services exist and agriculture can be profitable. Roads are needed to bring in appropriate inputs and take out marketable products. Farmers must also have access to market information and INM knowledge obtained from productive research systems and extension information services. Good information services and other means to help manage risk provide a basis for farmer innovation and adoption of INM.

**LEGUMES AND ADAPTED SPECIES.** Legumes are central to the INM strategy, and leguminous species that combine moderate seed yield with high root and leaf biomass (and thus have a low harvest index) can help farmers meet household food needs while improving soil fertility.

**SOIL MICROBES.** The selection and use of adapted soil microbes (rhizobia and mycorrhizal fungi), together with the active manipulation of soil macrofauna (“soil engineers”), organic residues, and modest levels of inorganic nutrients, can promote significant synergistic responses in plant growth and yield.

**RECOMMENDATIONS FOR PRACTITIONERS**

Investments designed to facilitate widespread adoption of sustainable INM practices will need to consider the (see box 4.38):

- **General environment for agricultural profitability.** INM investment planning must assess adequacy of infrastructure (roads, communications, markets), financial services, and technical support, and structure INM programs accordingly.

- **Policy and price environment.** Fertilizer pricing policies as well as regulations governing environmental impacts of agri-

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**Box 4.37 Nutrient budgeting tools: NUTMON**

A consortium of African and Dutch research institutes has worked with farmers in Sub-Saharan Africa to establish a program called NUTMON to monitor farm level nutrients. Participating farmers know that land productivity has been declining for years, and that continuous cropping, loss of nutrients in harvested products, and manure shortages are to blame. NUTMON increases farmer awareness of the role of soil nutrients, and gives them a tool to assess nutrient balance on the farm. Researchers have documented changes in crop management as a result of NUTMON.

cultural production (such as pollution from overuse of fertilizers) affect acceptability of INM innovations, and need to be assessed in program planning.

- **Knowledge base.** R&E information systems are central to INM. NGOs and farmer organizations can be allies in promoting INM technologies, but sound research and soil/plant/fertilizer testing laboratories are essential backups.

### SELECTED READINGS

Asterisk (*) at the end of a reference indicates that it is available on the Web. See Appendix 1 for a full list of Websites.


### REFERENCES CITED


This Note was prepared by Erick Fernandes with input from the Sourcebook team.

### Box 4.38 Potential investments

- Policy analysis and formulation and regulatory system development relevant to fertilizers and soil fertility management.
- Training and extension to facilitate farmer access to knowledge on integrated nutrient management (INM) and advocacy and information campaigns.
- Soil-plant, and fertilizer testing facilities and incentives for private investment in testing facilities.
- Participatory research on soil nutrient management, including site and crop-specific fertilizer use recommendations.
- Regional fertilizer purchasing, mixing, and local repackaging.
- Processing of urban waste and sludge for use as soil amendments.
- Transportation infrastructure.
- Systems for environmental services payment (including quantifying on-farm and off-farm costs and benefits of INM).

Source: Authors.