INTEGRATED PLANT NUTRITION SYSTEM – KEY TO SOIL PRODUCTIVITY ENHANCEMENT AND SUSTAINABLE AGRICULTURAL PRODUCTION

M. VELAYUTHAM*

SUMMARY

Integrated Plant Nutrition System (IPNS) as a concept and farm management strategy embraces and transcends from single season crop fertilization efforts to planning and management of plant nutrients in crop rotations and farming systems on a long-term basis for enhanced productivity, profitability and sustainability.

The implementation of IPNS involves three stages: 1) experimental phase; 2) validation phase; and 3) extension phase. The participatory diagnosis of constraints and opportunities (PDCO) at farm level and community/village level and Farmers’ Field School (FFS) approach form an integral part of the implementation strategy. An effective farmer-extension-research interface will be crucial for the propagation of the IPNS approach for sustainable food production and environmental protection. The FAO activities in promoting this strategy are outlined.

Nutrient Use Scenario

During the Green Revolution era, from 1965 to 1995, fertilizers have been responsible for 55% of the yield increase in developing countries (FAO, 1995). It is also estimated that about two-thirds of the needed increase in crop production in developing countries will have to come from yield increases from lands already under cultivation. Recent FAO Study (2000), Agriculture: Towards 2015/2030 indicates that the fertilizer consumption in the world is expected to increase from 134 million tons in 1995/97 to 182 million tons in 2030, at an annual growth rate of 0.9% (Table 1). Wheat, maize and rice will continue to be the dominant fertilizer consuming crops, with maize emerging to be the foremost user in 2030, closely followed by wheat and rice (Table 2). Since these three crops are the predominant crops in Asia, the Asian trend of fertilizer use will determine the trend of use in the developing countries as a whole. Asia is projected to consume 86 million tons of fertilizer nutrients by 2030, accounting for 47% of the world’s and 77% of the developing countries’ fertilizer consumption. As regards per hectare nutrients consumption for the world (Table 3), the amount had almost trebled between 1961/63 and 1995/97. In the developing countries the amount had increased 13 times, from 7 kg/ha to 90 kg/ha during this period. In South Asia the increase was still more dramatic, from 3 to 79 kg/ha and in the East Asia from 9 to 147 kg/ha (Singh, 2001).

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### Table 1. Fertilizer consumption, total nutrient: historical and projected

<table>
<thead>
<tr>
<th>Regions/Groupings</th>
<th>Nutrient (million tons)</th>
<th>Growth rate (% p.a.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Asia excl. India</td>
<td>0.6</td>
<td>18.1</td>
</tr>
<tr>
<td>East Asia excl. China</td>
<td>1.7</td>
<td>44.4</td>
</tr>
<tr>
<td>Developing countries</td>
<td>4.1</td>
<td>78.7</td>
</tr>
<tr>
<td>Industrial countries</td>
<td>24.6</td>
<td>46.3</td>
</tr>
<tr>
<td>World</td>
<td>34.3</td>
<td>133.9</td>
</tr>
</tbody>
</table>

Source: FAO (2000)

### Table 2. Fertilizer consumption (nutrient, million tons) by crops

<table>
<thead>
<tr>
<th>Crops</th>
<th>1995/97</th>
<th>2030</th>
<th>Growth 1995/97-2030 (% per annum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>24.6</td>
<td>29.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Maize</td>
<td>22.3</td>
<td>30.4</td>
<td>0.9</td>
</tr>
<tr>
<td>Rice</td>
<td>22.2</td>
<td>27.2</td>
<td>0.6</td>
</tr>
<tr>
<td>All cereals</td>
<td>78.2</td>
<td>98.8</td>
<td>0.7</td>
</tr>
<tr>
<td>All crops</td>
<td>134.0</td>
<td>182.0</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Source: FAO (2000)

### Table 3. Per hectare nutrient consumption: historical and projected

<table>
<thead>
<tr>
<th>Regions/Groupings</th>
<th>Per hectare nutrient use (kg/ha)</th>
<th>Growth rate (% p.a.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Asia excl. India</td>
<td>3</td>
<td>79</td>
</tr>
<tr>
<td>East Asia excl. China</td>
<td>9</td>
<td>147</td>
</tr>
<tr>
<td>Developing countries</td>
<td>7</td>
<td>90</td>
</tr>
<tr>
<td>Industrial countries</td>
<td>125</td>
<td>206</td>
</tr>
<tr>
<td>World</td>
<td>35</td>
<td>107</td>
</tr>
</tbody>
</table>

Source: FAO (2000)
Environmental and Sustainability Implications of Fertilizer Use Patterns:

*Integrated Plant Nutrition System (IPNS): A Paradigm Shift*

Population growth, urbanization and industrialization will compete for more lands from the agricultural lands. Hence, the projected yield increases have to be met with greater mobilization and efficient use of nutrients, of both inorganic and organic sources. Thus the development of Integrated Plant Nutrient System (IPNS) to suit different farming systems is a major challenge for all stakeholders in agriculture to ensure sustainable food security. IPNS as a concept and farm management strategy embraces and transcends from single season crop fertilization efforts to planning and management of plant nutrients in crop rotations and farming systems on a long-term basis for enhanced productivity, profitability and sustainability.

The IPNS approach aims to:

1. Enhance crop and soil productivity through a balanced use of mineral fertilizers combined with organic and biological sources of plant nutrients to ensure sustainability of the production systems.
2. Improve the capital stock of plant nutrients in the soil and
3. Improve the efficiency of plant nutrients use, limiting losses of N and P to the environment and promoting environmental security.

The necessity of promoting and adopting the wider concept of IPNS management arises from past mineral fertilization-biased practices and their lessons and thus results in paradigm shifts in several aspects of farming as given below (adapted from Finck, 1995):

- from individual crop nutrient requirements to optimum use of nutrient sources;
- from static nutrient balances to nutrient flows (fluxes) and nutrient cycles;
- from least concern for environmental impact to due attention to the unwanted side effects of fertilization (on soils, weed growth, crop diseases etc.; pollution of water and air);
- from first year’s nutrient effects to long-term effects (residual nutritive effects, fate of non-used nutrients, storage, carry-over);
- from the narrow concern for yield effects to resistance of crops against stress conditions (dry, cold, salty, alkaline, toxicity, pollution);
- from the assumption of ideal growth conditions to an awareness of not or hardly controllable growth limiting factors and production risks;
- from exploitation of soil fertility to its improvement or maintenance;
- from the neglect of protective restrictions to awareness against dangerous or even toxic elements;
- from productivity to productivity and sustainability;
- from quantitative nutrient use to both quantitative and qualitative aspects of economy and efficiency in nutrient use;
- from fertilizer use promotion to knowledge intensive nutrient management; and
- from emphasis on direct effect of fertilizers to emphasis on synergy, and interactive effects of crop-water-nutrient

**Key Concepts Of IPNS**

IPNS enhances soil productivity through a balanced use of soil nutrients, chemical fertilizers, combined with organic sources of plant nutrients, including bio-inoculants and nutrient transfer through agro-forestry systems and has adaptation to farming systems in both irrigated and rainfed agriculture.

IPNS incorporates the underlying relationships between use of plant nutrients, economic feasibility and maintenance of environmental quality. Operationally it focuses first on the seasonal or annual cropping system rather than on an individual crop, secondly on the management of
nutrients in the whole farming system and thirdly on the concept of village or community areas and watersheds rather than individual fields through use of nutrient budgeting approach, soil fertility maps and analysis of practices which may be contributing to nutrient losses or inefficient plant nutrient management and their remedy.

The following key concepts are fundamental to IPNS and should be built into the strategy and techniques recommended for promoting IPNS as one of the tenets of sustainable agricultural production.

1. Loss of soil productivity is of greater concern than loss of soil fertility.
2. Adoption of soil conservation practices and improved organic matter management practices are crucial for maintaining soil productivity.
3. Inclusion of legume species in the cropping system and rotations as grain, forage or green manure crop.
4. Nutrient management cannot be dealt with in isolation but should be managed as an integral part of a productive farming system.
5. The synergy between best water management practices (rainwater under rainfed dryland conditions and irrigation water under irrigated conditions) and best nutrient management practices must be optimized.
6. The full benefits from the supply of plant nutrients can be realized by farmers only after they have made improvements in the biological, physical and hydrological properties of the soils and removed soil related constraints.
7. It is necessary to identify the socio-economic constraints in the adoption of IPNS at community level and devise appropriate policy interventions and improvements.
8. Promotion of IPNS must be bottom-up rather than top-down in orientation, planning and implementation with the full involvement and participation of the farmers and local communities.

Veritable Nutrient Sources

Various combinations of the following nutrient sources (adapted from Finck, 1995) can be used based on recommendations arising out of field experimental results specific to different cropping systems from the National Research and Extension system.

A. Internal (farm) nutrient sources
   - soil (available and reserve nutrients in the rooting zone)
   - subsoil and parent material (nutrient reserves)
   - legume plants and microbes (N-fixation by crops, green manure, free-living micro-organisms, BG algae, azolla, VA mycorrhiza, P solubilizing microbes)
   - crop residues (nutrients in straw, leaves, roots, etc)
   - green manure (for nutrient storage and saving, etc)
   - animal manure (nutrients in stable manure or sludge)
   - compost, ashes, etc. (organic or mineral nutrients)

B. External nutrient sources (from farm surroundings)
   - weeds, silt and mud from tanks, rivers, lakes, swamps, seaweed
   - litter and bark from forest
   - organic top soil layer from forests (peat, humus)
   - animal manure collected: for burning (ash), biogas, composting
• fodder collected for livestock (nutrients utilized as manure)
• other nutrient-containing substances (ashes, etc)
• atmospheric sources (rain, etc)

C. Imported nutrient sources (usually bought)

• organic fertilizers from waste products or by-products of plant or animal processing factories
• communal waste products (town compost, sewage sludge)
• mineral fertilizers
• fodder

Table 4 brings out the effect of IPNS on rice yield over a 10 year long-term study, at Gazipur, Bangladesh. The application of \(\frac{2}{3}\)rd recommended fertilizer for rice along with 5t FYM and 2.5 t ash/ha for boro rice gave higher total rice yield in the sequence than the application of \(\frac{2}{3}\)rd or full recommendation of fertilizers alone and also showed positive soil nutrient balance for P and K as well.

Table 4. Effect of IPNS on rice yield at Gazipur, Bangladesh

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Rice Yield t/ha/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>T(_1) – Control</td>
<td>5.35</td>
</tr>
<tr>
<td>T(_2) – (\frac{2}{3})rd recommended fertilizers</td>
<td>8.07</td>
</tr>
<tr>
<td>T(_3) – Full recommended dose</td>
<td>8.87</td>
</tr>
<tr>
<td>T(_4) – T(_2) + 5t FYM + 2.5 t ash/ha for boro rice</td>
<td>9.06</td>
</tr>
</tbody>
</table>


**Implementation of IPNS**

The implementation methodology involves 3 stages: 1) experimental phase; 2) validation phase; 3) extension phase. The details of the experimentation phase can be defined through Participatory Diagnosis of Constraints and Opportunities (PDCO process) with farmers, extension agents and research workers in the area and a rapid survey of the area. The extent of experimentation will take into account the already available research results of recommendation value in this area. The results of these researcher-managed trials will be used to identify promising treatments for validation in farmers' fields conducted by farmers themselves under the supervision of extension and research workers. The analysis of the data of the validation phase provides IPNS technologies for recommendation and large scale propagation.

The approach of participatory diagnosis of constraints and opportunities (PDCO) is the starting point, in any area-based sustainable soil productivity improvement programme. In promoting IPNS as a concept and strategy, FAO emphasizes this approach as an integral part of the implementation strategy.

The following steps and activities in this approach, enable the selection of appropriate experimentation and validation phase of the programme (Roy and Nabhan, 2001):

i. Prioritization of intervention areas based on Agro-Ecological Zone/Sub-zones;
ii. In each identified agro-ecology, identification of villages/communities representative of different cropping/farming systems, socio-economic conditions, dominant soil/nutrient management practices through Rapid Rural Appraisal (RRA) and analysis of basic information;
iii. In each identified community, participatory diagnosis of constraints and opportunities related to soil and plant nutrient management. This provides
identification of distinct farm categories/groups and of their constraints, resources and opportunities related to crop/soil productivity improvement.

iv. An in-depth assessment for one or two representative farms within each identified category.

These steps are further elaborated in Table 5 and figure 1. All these should lead to devising IPNS programme including testing technologies and adaptive trials and group demonstration to be conducted jointly by farmers and research and extension workers. There is scope for extending the farmers’ field school approach (FFS), as successfully developed and adopted for integrated pest management, for testing and promoting the IPNS management strategy.

| Table 5. The four basic steps of participatory diagnosis of constraints and opportunities for soil and plant nutrient management |
|---|---|---|---|
| STEPS | 1 | 2 | 3 |
| ACTIVITIES | Exploration of the production systems to identify recommendation domains | Diagnosis of constraints and opportunities | Classification and analysis of constraints and opportunities | Preliminary identification of strategies |
| Secondary data collection | Interviews with household and/or household-groups belonging to the same category or recommendation domain | Brainstorming within the multidisciplinary team and discussions with relevant specialists outside the team, as well as with key informants | Assessment and validation of the strategies proposed and identification of alternatives, together with the community |
| Discussions with key information both within and outside the community | Discussions with focus-groups within the community | Preliminary identification of solutions and strategies, conducted by the team |
| Group discussions at the community level | Discussions with focus-groups within the community | Assessment and validation of the strategies proposed and identification of alternatives, together with the community |
| Recording and consolidating information | Recording and consolidating information | Recording and consolidating information, and validating the results with the respective household groups |
| EXPECTED OUTPUTS | General understanding of the community’s production base and farming systems | Understanding of the farming systems of households belonging to various recommendation domains | Constraints classified and prioritized of cause-effect established, relationships, leading to analysis of constraints and identification of opportunities to overcome them |
| Understanding of differences within the community in terms of factors that may have implications for soil and plant nutrition | Preliminary diagnosis of the constraints and opportunities specific to each category of domain | Results validated by the respective household groups |
| TOOLS | Semi-structured interviews | Semi-structured interviews | Problem analyses |
| Transect walks | Seasonal calendars | - Problem analyses |
| Land-use and resource maps | Farming-system diagrams | - Worksheets |
| Community social maps | Appraisals of knowledge, attitudes and practices | Source: Roy and Nabhan (2001) |
Figure 1: IPNS Implementation Methodology

Source: FAO, 1998
**Research Backup**

IPNS is a dynamic concept and to be of continued relevance should be backed up by the national research system through on-station research by both short term and long term field experiments covering themes, which are constituent components of IPNS management strategy. These themes are nutrient removal by crops and crop sequences, soil test calibration and balanced fertilizer recommendation for specific yield targets of crops, best fertilizer management practices and suitable combinations of manures and fertilizers for different soil-climate-cropping systems, quantity of N fixed by biological sources, direct and residual effects of fertilizers and manures, nutrient losses and their prevention, soil fertility maps and extent of nutrient deficiencies, emerging secondary and micronutrient deficiencies, use of soil amendments and environmental contamination through improper fertilizer use and recycling methods of organic wastes. The national research system may bestow priority for taking up experimentation in these themes for major cropping systems.

**FAO Activities**

The Asian Network on Bio and Organic Fertilizers was established in 1988 by FAO Regional Office for Asia and the Pacific (FAO/RAP), Bangkok. The network expanded to 19 governments and para-statal focal institutions concerned with bio and organic fertilizer research and development from 13 Asian countries. Over a period of 10 years, this network, through the following 7 activities, greatly promoted this component of IPNS in the Region (RAP Publications 1995/12 and 1997/2):

1. Periodic compilation and dissemination of country-wise information regarding progress and problems of bio and organic fertilizer research, development and use
2. Documentation of methodologies and innovative techniques in regard to the introduction of bio and organic fertilizers in integrated plant nutrition systems with a view to technology transfer
3. Facilitating inter-country visits and training necessary to implement promising research and development technologies and application techniques to promote technical cooperation among developing countries
4. Organizing periodic network meetings to facilitate the exchange of experience between subject matter specialists on an inter-country basis
5. Maintenance of a directory of institutions and resource persons by country and field(s) of interest
6. Serving as a reference framework for inter-country exchange in matters relating to bio and organic fertilizer research, development and use
7. Assisting in the formulation and implementation of programmes to create national awareness in the pro's and con's of bio and organic fertilizer use

**Indian Farmers Fertilizers Cooperative Limited (IFFCO)** made significant efforts in promoting the IPNS strategy during 1994-98, with FAO assistance in the later phase. In total 146 farmers were associated from 55 locations, with the following objectives:

- to integrate the various sources of plant nutrients available at farmers' command
- to promote nutrient application based on soil testing
- to incorporate pulse/oilseed/green manure/vegetable crop as a 2nd or 3rd crop in the cropping system to maintain soil fertility and generate additional income to the farmer.

The farmers' practice was compared with IPNS practice in the cropping system. Yield data from 1647 entries, on the IPNS and farmer's practice were analyzed for 24 crops. The range of
yield increase from IPNS practice compared to the farmers’ practice in various crops varied from: 3.2-22.8% for rice, 1.9-136.6% for wheat, 38.3-210.9% for maize, 24.1-84.7% for rapeseed, 25.9-34.3% for groundnut, 33.1% for cotton and 23.9% for chickpea. The overdosing of nutrients in the farmer’s practice for potato production was not beneficial (Kumar et.al. 2001). The joint efforts and experiences from this study helped to bring out “A Guide to Field Implementation of Integrated Plant Nutrition System” by (FAO-IFFCO, 1997).

FAO assisted “Thana cereal technology transfer and identification” project in Bangladesh has promoted the IPNS strategy in compact blocks of five acres each involving 9-12 farmer families.

The Special Programme for Food Security (SPFS) was launched by FAO, after the World Food Summit, 1996 targeting low income – food deficit countries. The programme has focus on four components, water resource development and management, intensification, diversification and constraints analysis in production systems. The programme is currently operational in 14 countries of Asia. The intensification and diversification components provide opportunities for focussing integrated soil and plant nutrients management technology demonstration and extension.

The Soil Fertility Initiative (SFI) was launched by a consortium of agencies including FAO in 1996, with focus on Sub-Saharan Africa. Twenty SSA countries, with World Bank and FAO collaborative support, are engaged in a process to prepare national strategies and action plans for the restoration and enhancement of soil fertility.

Policy Support

The longterm planning, promotion and adoption of IPNS by the farming community demands periodic review of policy options and improvements that may be necessary from time to time at country level. Nutrient requirement assessment, organic wastes disposal and recycling systems, fertilizer related issues such as pricing, packaging, transport, storage, marketing, quality control, credit, training and support for research and extension efforts by both government and the private sector should constitute important elements of national policies on fertilizer use. Each country should have explicit policy on IPNS and make provisions for appropriate mechanisms, including human resource development (training), for implementing the approach. As effective farmer-extension-research interface will be crucial for the implementation of the IPNS approach for sustainable food security and environmental protection. FAO, International Fertilizer Association, FADINAP (ESCAP), and other related international organizations should work closely with concerned national organizations in formulating need-based policies and programmes on IPNS.

Acknowledgement

I am thankful to Dr. R.B. Singh, Assistant Director-General and Regional Representative for Asia and the Pacific, FAO - Bangkok for helpful discussion in writing this paper.
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