Managing Soil Fertility Problems of Marginal Agricultural Lands through Integrated Plant Nutrient Management Systems: Experiences from the Hills of Nepal

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Abstract

Hill farmers generally have to subsist on marginal land, partly because fertile topsoil tends to be washed away from sloping land, which then becomes marginal. The causes of decline in soil fertility in the Nepalese hills are diverse. One way of approaching it is by employing an integrated plant nutrient system (IPNS), a holistic approach which integrates all components of soil, plant, and nutrient management to achieve higher crop yields and better soil health. The farmers' field school (FFS) approach was adopted to disseminate the concept of plant nutrition management. Soil analysis was carried out to understand the status of plant nutrients in the soils, and a nutrient balance sheet was prepared by means of discussions with farmers. A total of 54 FFS were implemented throughout the mid-hills. Farmers learned about acidic soil management through organic matter management, more than 60% of the farmers adopted improved organic matter (OM) management practices, and realised the value of splitting doses of nitrogen fertilisers. Farmers' groups were empowered through regular meetings and close observation of plant growth stages and soil agro-ecosystems. Farmers became capable of handling soil analysis, particularly for nitrate, nitrogen, pH, and soil microbes using tools. An improvement in pH indicated a significant positive impact of IPNS in ameliorating the poor soil fertility status. Improved soil fertility resulted in an increase in crop yields by 26%. Soil analysis reports also showed an increase in soil fertility status, in particular increases in OM, nitrogen (N), phosphorous (P), and potassium (K) when compared to the base year even within a one to three-year time span. Micronutrients, particularly boron (B) and molybdenum (Mo) were found to be crucial for cauliflower yields, and adding 20 kg/ha borax increased yield by 45%. Application of urine to cauliflower crops also corrected B deficiency symptoms; however research is needed to find out the effect of liquid manure on micronutrient levels. IPNS was found to be an appropriate technology to mitigate soil fertility problems in marginal agricultural land and FFS was proved to be a good tool for disseminating the technology to the grass roots level in farming communities.

Introduction

The Sustainable Soil Management Programme (SSM-P), introduced at the beginning of 1999, is a technical cooperation programme between His Majesty's Government of Nepal (HMGN) and the Government of Switzerland. The overall goal of SSM-P is to reduce the decline in soil productivity. Its objective is to promote improved, sustainable soil management practices through government organisations (GOs) and non-government organisations (NGOs) and partners: viz., male and female farmers. The major guiding principles of the programme are participation and empowerment of the key actors, explicit gender orientation, institutional linkages between research and development organisations, combinations of 'pull' (technology) and 'push' (market forces) in line with the Agricultural Perspective Plan's (APP) priorities, a look at 'win-win' situations (short-term economic gains coupled with long-term ecological sustainability), and a judicious mix of indigenous and new technologies.

The objective of this brief paper is to highlight the approaches, major activities, and experiences gained during the implementation of the programme on integrated plant nutrient systems (IPNS) using farmer field schools (FFS). Based on the experience of the programme, suggestions are also given for research and extension for improvement of the soil fertility situation in hill farming systems.

Status of Soil Fertility in the Hills of Nepal

It is a well established that soil fertility in Nepal is declining (Sthapit et.al. 1988; Subedi et al. 1989; Tamang 1992; Joshi, et. al. 1995). Various workers have identified more and less common causes of declining soil fertility. Their findings show that soil erosion, nutrient mining with increased cropping intensity and use of high-yielding varieties (HYVs), reduced quantity of farm-yard manure (FYM), and imbalanced used of chemical fertilisers are the major factors leading to overall soil fertility decline. Table 1 summarises the current soil fertility status in Nepal.

Table1: **Summary of the current soil fertility status in Nepal (%)**

Soil fertility parameters	Samples analysed	Low	Medium	High
Total nitrogen	9872	48	41	11
Available phosphorous	8942	35	24	41
Available potassium	9522	27	33	40
Organic matter	7520	62	33	5

Source: Jaishy 2000

The issue of soil fertility is complex involving different technical and socioeconomic factors and can only be addressed by developing a holistic soil management approach. SSM-P is trying to address this issue by promoting different sustainable soil management (SSM) practices through training and demonstration with farmers.

Concepts and Need for IPNS in Nepal

In recent years, increased use of high-yielding crop varieties in intensive cropping systems have led to an increased demand for nutrients. The locally available sources of nutrients, mainly farm-yard manure (FYM), compost, and biologically fixed nitrogen are not sufficient to meet the needs. Depletion of organic matter content has been at the centre of the overall soil fertility decline and has led to an increasing reduction in nutrient balance in the soil. Farmers in accessible areas have started to use chemical fertilisers as a means of coping with the reduced nutrient availability. However, imbalanced use, and inappropriate timing and methods, of fertiliser application have resulted in adverse effects on soil productivity, on sustainability, and on environmental quality. A more efficient, economical, and integrated nutrient management system is needed.

'Integrated plant nutrient system' (IPNS) describes the concept of integrating all available means of soil, nutrient, and crop management in order to achieve optimum land productivity and sustainability. It includes the complementary and efficient use of external inputs where locally available sources of plant nutrients are not sufficient to achieve an optimum yield. It emphasises the principle that fertiliser and manure should be applied on the basis of soil fertility status, crop demand, and available resources. IPNS is, therefore, an approach that seeks to both increase agricultural production and safeguard the environment for the future. Not only does IPNS rely on balanced nutrient application, it also emphasises their conservation and improved efficiency.

The appropriate design for IPNS depends on local conditions and farmers' knowledge. This concept is now widely seen as an opportunity and challenge for promoting better soil management at the farm level. Since the concept had not been widely tested in field conditions in Nepal, SSM-P with the Directorate of Soil Management of the Department of Agriculture (DoSM/DOA) took the initiative of developing and testing the approach together with farmers in the middle hills of Nepal; and this brought together local and new knowledge and contributed to the design of productive and sustainable land management systems. So far, the following progress has been made.

- A workshop on IPNS was organised jointly by the Soil Testing and Service Section (STSS); Soil Science Division (NARC); Fertiliser Unit, Ministry of Agriculture and Cooperatives (MoAC); and SSM-P in February 2000 which synthesised and documented the available information on different components of IPNS in Nepal.
- A farmer field school (FFS) on IPNS was tested in the field with a maize/finger millet system in the mid-hills with a collaborating institution (CI) of SSM-P in Sindupalanchowk district. The programme was successful and farmers learned about integrated nutrient management of maize and finger millet crops. This has enabled farmers to produce maize with a two-thirds' reduction in fertiliser use, indicating improved efficiency of fertiliser use. More FFS were planned by different CIs in the season after 2000.
- A national level Working Group was established of representatives from the Nepal Agricultural Research Council (NARC); the STSS of the Department of Agriculture and Co-operatives; Fertiliser Unit of the MoAC; RARS Lumle; District Agricultural Development Office (DADO) Kavre; Institute for Sustainable Agriculture Nepal (INSAN); and the Programme Management Unit (PMU) of SSM-P. The meeting discussed and agreed upon a model of IPNS to support a common concept for the extension of IPNS in Nepal. Three main elements of IPNS were defined: the domains, the topics, and the approach. Revision of the national working group took place in 2003 when the Institute of Agriculture and Animal Science (IAAS) was included, hence linking this concept to an academic institution as well.

Domains for IPNS

IPNS is location and cropping-system specific. Thus, recommendations for IPNS need to be targeted to macro-domains with similar locational conditions and cropping systems. Within these macro-level domains, there remains a wide variability in micro-level conditions between locations and in crop management between farmers.

It was agreed, that the macro-level domains need to be targeted through the development of specific IPNS for each of these domains. The micro-level differences need to be covered through the formation of community clusters and the organisation of farmer-field schools (FFS) in which location-specific management can be discussed with farmers.

The Field Implementation Approach of IPNS

The most difficult aspect of handling FFS for IPNS is the design of the best location-specific nutrient management. The following key steps need to be considered while designing and implementing location-specific nutrient management for a given domain or system.

System selection: A system and domain for field implementation of IPNS is selected in a broader sense; for example, a maize/millet system.

Site or location selection: For a given system, one or more representative sites are selected for field implementation. As far as possible, representative, homogenous, and one cluster of farmers should be selected.

Assess soil status: Information on soil parameters, such as soil organic matter content, pH, nutrient availability, texture, extent of nutrient leaching, and erosion of the selected site should to be gathered through site visits and laboratory analysis.

Fixing of yield target: Expected yield levels should be targeted based on the availability of farm resources.

Calculation of nutrient balance: A nutrient balance can be calculated indicating how much and which nutrients are to be added based on the two estimates above. Emphasis should be given to organic matter balance.

Listing available nutrient sources: All available internal (farm level) and external (purchased) nutrient sources should be listed.

Integration : All available nutrient sources should be integrated.

Determine the amount, time, and methods of application suitable for a given crop, cropping system, and land type.

Different land, crop, and nutrient management options to increase the efficiency of farm resources are suggested in the following.

- *Increase organic matter incorporation* – Organic matter (OM) is the storehouse of plant nutrients or, in other words, the life of the soil. Its balance should always be considered in IPNS. The measures for increased OM can be improving the quality of FYM, increasing fodder production, stall feeding of animals, use of green manure/biomass, and efficient recycling of organic residues.
- *Improve the quality of FYM* – The quality of manure that Nepalese farmers use is very poor. There is ample room to increase the nutrient content, primarily nitrogen, through quality fodder production, proper collection or conservation of urine, and proper decomposition and application methods.
- *Reduce soil erosion* – Erosion of surface soil, particularly during the pre-monsoon rains, causes significant loss of nutrients from the soil. Reducing this erosion through different means, such as reducing bare land, mulching, cover crops, proper terracing, and so on, helps substantially.
- *Legume integration* – Integrating legumes into farming systems contributes significantly to nutrient supply through symbiotically fixed nitrogen.
- *Growing more crops that need manure in the rotation* – If crops like vegetables and potatoes are grown at least once a year, it helps to build up the organic matter balance and is believed to improve the physical and chemical properties of the soil.

- *Selection of less nutrient demanding crops* – There are certain crops/varieties that demand relatively lower amounts of nutrients. Selection of such crops helps nutrient management.
- *Balanced soil reaction* – Alkalinity or acidity of soil reduce the availability of many plant nutrients. Timely correction of soil pH through the application of organic manure and amendment helps nutrient availability.
- *Avoid excessive use of chemical fertilisers* – There are many instances in which farmers apply excessive or imbalanced amounts of chemical fertilisers. Improper timing and excess application of chemical fertilisers also cause wastage of resources as well as creating soil problems. So, only needs-based application is strictly recommended in an IPNS.
- *Minimise pesticide use* – Many pesticides persist in the soil for a long time and are harmful to soil lifeforms, e.g., earthworms and other beneficial organisms. Use of pesticides should be restricted for better soil productivity.

Results from an IPNS Farmers' Field School

Farmers expect higher productivity from IPNS. In areas with market access, they are interested in higher crop yields with optimum use of local or external inputs. Farmers in remote areas are interested in increasing their crop yields from locally available inputs and in minimising the need for external inputs. A total of 51 IPNS-FFS were carried out in different cropping systems in the working areas of SSM-P (Table 2).

Table 2: **IPNS FFS implemented in 2003/04**

District	Systems	Total integrated plant nutrient system farmers' field schools (IPNS-FFS)
Dolakha	maize - cauliflower; maize - wheat	2
Sindhupalchok	maize - millet; maize - cauliflower	6
Kavre	maize - wheat; maize - cauliflower	3
Syangja	maize - cauliflower	5
Parbat	maize - millet; maize - cauliflower	11
Baglung	maize - cauliflower; maize - millet	11
Surkhet	maize - wheat; maize - cauliflower	5
Baitadi	maize - wheat	5
Tanahun	maize - wheat	1
Palpa	maize - wheat	1
Ilam	maize - wheat	1

Source: SSMP 2003

A large amount of information on soil conditions, crop yields, inputs used, and other crop or field observations were generated through the FFS in 2002. Some groups and facilitators carefully recorded all the observations, while others provided rough estimates. The information is still being summarised. Table 3 shows an example of nutrient management treatment under IPNS and the farmer plots in different FFS. Other observations like varietal comparisons, weed management, and intercropping tests are not included.

Nutrient management in 2003 focused on nitrogen management. Analysis of soil nitrogen indicated that at most sites there was no need for basal application of N-fertilisers in addition to manure application, especially in the rainy season. There is a substantial amount of free N in the soil at the beginning of the season which rapidly declines once the monsoon rains set in. Field observations by farmers also confirmed the leaching of N into deeper soil layers (Figure1).

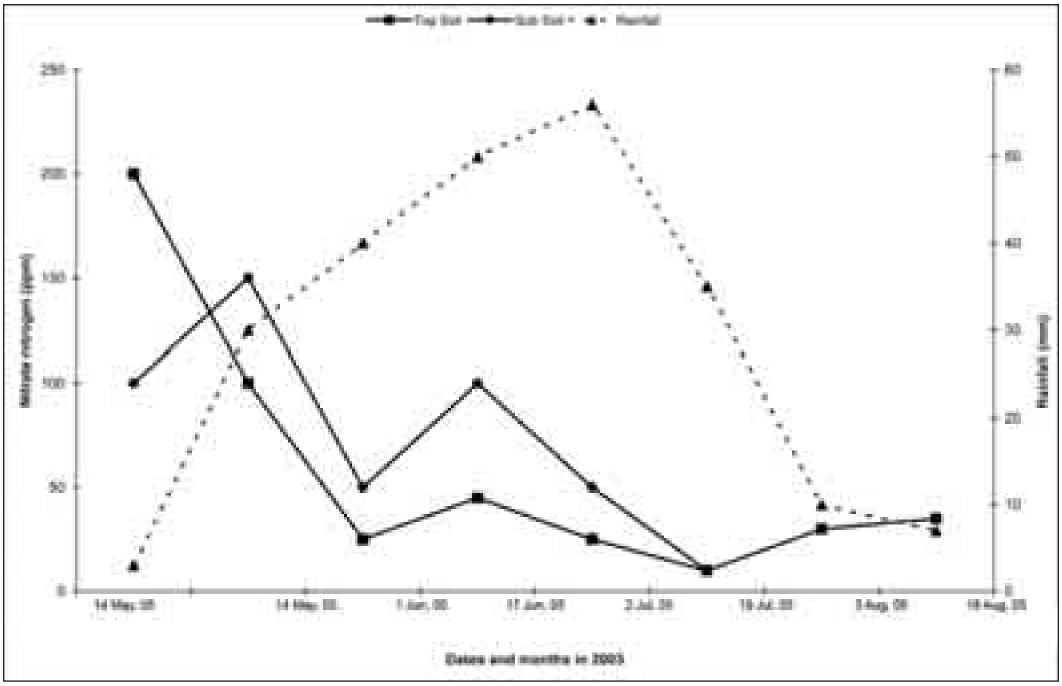

Figure 1: **Nitrate nitrogen levels in the soil as measured during a FFS**

Results are summarised in Tables 3, 4, and 5 for selected IPNS-FFS in areas identified as micronutrient deficit in boron (B), zinc (Zn), and molybdenum (Mo). The results show the positive impact of application of micronutrients. Cauliflowers were found to be very critical in many areas for B and Mo, whereas maize was found to be Zn deficit. Wheat was also found to be very sensitive to B application.

The results showed that efficient nutrient management has a significant impact on crop yield as well as on soil health. Soil pH, OM, nitrogen (N), phosphorous (P), and potassium (K) contents were often changed positively (SSMP 2003).

Micronutrients play a crucial role in crop productivity. Table 5 shows the results from different sub plots of IPNS-FFS in micronutrient trials. These results give a clear message that without considering micronutrients, optimum crop yield is impossible. Application of micronutrients increased crop yields from 15 to 45%, and overall by 20%, in IPNS sub trials (micronutrient treatments) in which all management practices were kept the same except for micronutrient application.

Micronutrient treatments were carried out in different places across the sites selected using farmers' observations and reports on likely deficiency symptoms of those micronutrients.

Table 3: **Results related to nutrient management of selected IPNS -FFS on maize -cauliflower based cropping systems**

Input/output		IPNS plots		Farmers' plots	
		Maize	Cauliflower	Maize	Cauliflower
Site 1	Urea (kg/ha)	58	100	80	155
	DAP (kg/ha)	39	100	30	112
	FYM (kg/ha)	19,650	23,580	19,650	23,580
	Urine (L/plant)		0.20		
	Yield (kg/ha)	**3.34**	**33.00**	**2.61**	**27.74**
Site 2	Urea (kg/ha)		100	80	155
	DAP (kg/ha)	30	100	30	112
	FYM (kg/ha)	19,650	23,580	19,650	23,580
	Urine (L/plant)	0.05	Borax 10 kg/ha		
	Yield (t/ha)	**2.96**	**30.20**	**2.61**	**26.74**

Source: DCRDC 2003

Key: DAP= Diammonium phosphate, FYM = farmyard manure

Table 4: **Results related to nutrient management of selected IPNS -FFS on maize -wheat based cropping systems**

Input/output		IPNS plots		Farmers' plots	
		Maize	Wheat	Maize	Wheat
Site 1	Urea (kg/ha)	58	100	80	155
	DAP (kg/ha)	39	100	30	112
	FYM (kg/ha)	19,650	20,580	19,650	20,580
	Yield (kg/ha)	**3.44**	**3.10**	**2.51**	**2.21**
Site 2	Urea (kg/ha)	30	30	80	50
	DAP (kg/ha)	30	10	40	50
	FYM (kg/ha)	19,650	21,580	19,650	21,580
			Borax 20 kg/ha		
	Yield (t/ha)	**2.56**	**3.20**	**2.41**	**2.14**

Source: BJJS 2004

Key: DAP= Diammonium p hosphate, FYM = farmyard manure

Table 5: **Micronutrient treatments in sub plots of IPNS -FFS in different crops at different sites**

Organisation and districts	Crops	Treatments (micronutrients)	Yield (t/ha)	
			IPNS plots	Farmers' plots
CDECF, Sindhupalchok (n=4)	Maize	Zinc sulphate (10 kg/ha)	4.31	3.63
DCRDC, Baglung (n=3)	Cauli	Borax (20 kg/ha)	35.41	27.31
DCRDC, Baglung (n=3)	Cauli	Mo (333 ppm)	33.21	30.25
DADO, Baglung (n=1)	Cauli	Borax (20 kg/ha)	29.31	27.33
BJJS, Baitadi (n=3)	Wheat	Borax (20 kg/ha)	2.95	2.32
CDRC, Syangja (n=2)	Cauli	Borax (20 kg/ha)	29.85	17.33

CDECF = Community Development and Environmental Conservation Forum; DCRDC = Dhaulagiri Community Resource Development Center; District Agriculture Development Office; BJJS = Basuling Janajagriti Samaj; CDRC = Community Development Resources Centre; n = number of replications; cauli = cauliflower

Research needs for IPNS

Observations from FFS on IPNS indicate that the development of models and recommendations for IPNS for specific sites can be improved. The predominant soil, topography, climate, land use, and socioeconomic conditions determine, to a certain extent, the problems of the individual farm system. More discussion and concrete information about these aspects can enrich the FFS. They need to be included in the curriculum for FFS.

Data on the relationships between nutrient status, soil management, and crop yield are limited. At the same time, the calculation of nutrient balances relies on such relationships. Thus, longer-term data on IPNS from a wide range of sites need to be developed. The implementation of IPNS over several years on a number of selected sites may contribute such data. The further development of IPNS will be a continuous process of identifying innovations, experimentation with farmers, and feedback to research. Table 6 lists some major research issues identified so far from FFS on IPNS.

General learning about IPNS and FFS

- *Location-specific IPNS* – IPNS addresses location-specific soil problems and thereby helps to sustain soil fertility.
- *Cropping system focus* – IPNS addresses the problems facing the entire cropping system for the whole year, and thus helps sustain soil fertility and crop productivity.

Table 6: **Topics for future research to address problems encountered in extension of IPNS**

Topic	Opportunities for research / research need
Simple assessment methods for nutrients	• Simple tools are available for assessment of pH, N, and soil microbial acti vity; however, no simple tools are available for the assessment of the status of OM, P, K or other micronutrients. • Can simple tools be developed for these?
Micronutrient management	• Field observations in FFS for IPNS indicate micronutrient deficiencies in many localities; this confirms surveys done by research • Micronutrient fertilisers are often not available, too expensive, or difficult to use for farmers; exploration of local resources for micronutrients (e.g., plant species, ashes, urine, local sediments , ….) may provide alternatives.
Local liquid fertilisers	• Farmers have confirmed the utility of urine and urine teas as valuable liquid fertilisers and organic pesticides; preliminary data show a 2 to 3-fold increase of P and K in urine teas if fermented w ith some plant leaves. • Research on urine tea preparation and on the factors that determine tea quality is needed; farmers will use local resources, therefore we need to know which plants can greatly increase the value of urine teas.
Soil acidity and acidification management	• Some areas have inherently low soil pH; in other areas the use of fertilisers contributes to soil acidification because the buffer capacity of the soils is low; application of large amounts of lime is not feasible in many areas. • Research on acidity-tolerant crop varieties, on the buffering capacity of local resources, and on the careful mobilisation of P or the careful use of P -fertilisers in these soils is needed.

Source: SSMP 2003

- *Learning by doing and seeing* helps to address the problems immediately – by testing and adding and growing and seeing improvement in the field; thereby it helps to form a basis for sustainable agriculture.
- *Frequent interactions* between technicians and farmers create a bond and confidence.
- *Multiplier effect* – Transferred technologies are disseminated quickly from farmer to farmer giving multiplier effects through community efforts.
- *Empowers farmers* – Builds capacity and enhances community efforts. It guides and supports the decision-making skills at micro-level and enhances the analytical and decision-making process of the farmer.
- *Information feed-back* – IPNS FFS can provide information about dominant soils, topography, and land-use patterns in each district. This can be used for the IPNS base maps, soil fertility maps, and GIS which are being developed by STSS and NARC.
- *Local nutrient balance calculations* – Local staff and farmers are able to use simple methods to calculate nutrient balance sheets for different crops for certain levels of production.

Specific technical learning related to nutrient management

- *Timing of nitrogen (N) application* – It was a key learning experience for farmers that N levels may be high in the soil. The timing of N-application depends on the N-level in the soil.
- *Improved FYM* – Farmers conducted trials on improved FYM against normal FYM and found that the yield response from improved FYM was better.
- *Urine use* – It was confirmed that urine can replace urea. Testing of urine in cauliflower showed reduced B deficiency. Farmers agreed that this needs to be verified.
- *FYM top dressing* – Improved FYM (well decomposed) can be top-dressed. The idea was tested by one group in a field with a poorly performing crop. They found that the crop recovered quickly.
- *DAP top dressing* – Farmers tested diammonium phosphate (DAP) as a top-dressing on maize at 40 days after sowing and found a good response in soils with P-deficiency. DAP is usually recommended for application only before planting.
- *Micronutrients may be crucial* – Some experienced farmers observed boron (B) deficiency in cauliflower before the extension staff and applied B to their plots. They got a better crop, and this created awareness among all participants.
- *IPNS is a systems' approach* – Performance of different varieties, new crops in the cropping pattern, mulching, and other factors need to be included. One farmers' group learned that off-season cauliflower can be planted in millet-based systems.
- *Nutrient balance* – Nutrient use by farmers is often unbalanced. In particular, farmers can reduce application rates and production costs by using organic fertiliser on cash crops.
- *Urine application on vegetables* – Application of urine on cauliflowers, cabbage, and radishes has led to recovery from B deficiency in some areas. However, further systematic research is essential to verify this outcome.

Key methodological learning

- *FFS as a regular process* – Regular meetings are needed; farmers recommended holding meetings about twice a month.
- *Farmer-led experimentation (FLE) as a part of FFS* – Learning can be improved if farmers conduct experiments and discuss the outputs with the group.
- *Farmers manage an IPNS plot on their own farms* – Some organisations promoted this and found it very stimulating for group members.
- *Training of facilitators* – A week-long training course for the local facilitators is not sufficient. Intensive follow-up, monthly experience exchange meetings, and strong technical backstopping are essential.
- *Curriculum for FFS* – The curriculum for IPNS should be more practical and location-specific.

Conclusions

The integrated plant nutrient system is an appropriate technology for addressing declining soil fertility; and farmers' field schools are an equally appropriate tool for taking this technology to the grass roots. The trials started with various cropping system models, but the IPNS models are still not sufficient for needs. For technology diffusion in an effective and practical way, it is important to develop human resources. The decline in soil fertility presents a challenge, and improvement in quality of FYM/compost is seen to be an important aspect in improving soil productivity. The timing and method of fertiliser application are crucial for efficient and effective use of fertiliser inputs.

Micronutrient deficiency is being reported by farming communities, particularly in cole crops, wheat, and rice. Therefore, ecologically-based, detailed research on micronutrient sources and recommendations from such research are highly relevant and essential in order to increase the productivity of soils and crops.

Building capacity at the institutional level is essential in order to implement FFS efficiently. Quality training for local facilitators with sufficient time for conceptualising the basics of the technical aspects of IPNS and FFS process are essential, as is reaching many farmers and people involved in this sector. Information sheets and simple guidelines need to be developed and distributed, and should be location-specific.

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