IMPROVING THE MANAGEMENT OF INFERTILE ACID SOILS IN SOUTHEAST ASIA: THE APPROACH OF THE IBSRAM ACID-SOILS NETWORK

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Abstract

The IBSRAM *ASIALAND* Management of Acid Soils network aims to improve the understanding of the broad range of biophysical and socio-economic production limitations on infertile acid soils of Southeast Asia, and to lead to development and implementation of sustainable land-management strategies for these important marginal areas. The main activities of the network are in Indonesia, Myanmar, Philippines, and Vietnam, with associated activity in Thailand, and minor involvement in Brunei, Cambodia, Laos, and Malaysia. The main experimental focus is through researcher-managed on-farm trials, to improve the management of phosphorus nutrition with inorganic and organic amendments. A generic design is used across the eight well characterised sites that form the core of the network. The results will be analysed across time and across sites. Improved methods for laboratory analyses, experimental management, socio-economic data collection, and data analysis and interpretation are critical components. Three important initiatives are associated with the core activities. These aim to establish a broader network on maintenance of quality laboratory analyses, to assess the potential for implementation of improved strategies through farmer-managed on-farm trials, and to improve our understanding of, and ways of estimating, nutrient budgets for diverse farming systems.

1. INTRODUCTION

There is no doubting that significant pressures exist on agricultural systems of the world, and therefore on land resources, to increase production, particularly in developing countries. These pressures arise from a combination of population growth [1], the need to improve the living standards of the poor, particularly their nutritional standards [2], and dwindling reserves of quality arable land [3]. It is vital that highly productive agricultural systems are maintained, but, increasingly, improved management of marginal lands is critical to increased and sustainable agricultural production. Marginal areas are underused where better are available and, in consequence, significant areas of quality agricultural land have been degraded through poor management practices [4]. Although the driving forces behind the need for increased agricultural production and the factors that limit production on marginal lands differ among regions, the need for improved management of marginal lands exists in many parts of the world, particularly in developing countries and certainly in Southeast Asia.

The development of sustainable land management systems for marginal soils requires an understanding of the particular production limitations, of methods for overcoming these limitations, and policies to implement changes. A network approach to solving these problems can yield a wider set of biophysical and socio-economic conditions, and thus a better understanding of the underlying processes, improved intra- and inter-regional (South-South and North-South) transfer of knowledge and experience, and greater institutional capacity building. Understanding the operations of the IBSRAM acid-soils network in Southeast Asia may prove useful in establishing a new IAEA/FAO Co-ordinated Research Project for acid soils.

2. THE CONSTRAINTS OF INFERTILE ACID SOILS

The low fertility of marginal soils can be due to inherent infertility or can result from mismanagement. As such, the need to improve the fertility of inherently infertile soils or to restore the fertility of degraded soils can be considered as the capitalisation or recapitalisation of the natural resources.

Most of the marginal soils of Southeast Asia, and of the tropics and sub-tropics in general, are marginal because of inherently low fertility or poor water supply, or both. The majority of these infertile marginal soils are acidic, particularly in upland areas. The acid upland soils of the tropics and sub-tropics are inherently infertile as a result of nutrient deficiencies, especially of P, Ca, Mg, and Mo, or toxicities, especially of Al and Mn. Correction of these disorders is often difficult, but failing to address them exacerbates the problem through further nutrient depletion and acidification. In contrast, correction of these constraints and proper management can yield productive and sustainable farming systems.

Although there can be many problems in acid soils, in most cases deficiencies of P and N limit agricultural production; overcoming these problems generates the greatest improvements. Sustainable N-replenishment strategies, particularly for low- to medium-input systems on marginal soils, can rely on biological N_2-fixing processes, with limited need for chemical fertilisers. A similar approach is not possible for P. It is likely that improved P-management strategies will continue to rely on fertilisers, albeit with as much biological supplementation and recycling as is feasible [5, 6].

Deficiency of P is widespread in soils of the tropics and sub-tropics. Most estimates suggest that more than 2 Gha are affected [6, 7, 8]. Such deficiency may be due to low-P-status parent material, weathering, loss by erosion and surface run-off, and long-term mismanagement, i.e. imbalance between nutrient input and removal in the harvested crop.

It is clear that improved management of these soils must involve adaptation of farming systems, with greater reliance on organic sources of nutrients combined with judicious use of inorganic fertilisers, particularly P. Although there is a large body of research work on P, knowledge gaps exist. There is reasonably good understanding of management of P with inorganic amendments, less detailed information exists on management with organic forms, and data on the interactions of organic and inorganic forms are limited. Even where the processes are understood, methods for efficiently matching management strategies to particular farming systems are limited. Practical recommendations are required that improve the synchrony of P supply and plant demand, through management of organic and inorganic amendments. A major aim of the IBSRAM acid-soils network is to reduce these knowledge gaps through high-quality applied research.

Clearly, P and N are not the only problems. When management strategies have been established to improve the P and N fertility of soils, the deficiencies of other nutrients may, or, in time, will, limit production. Consequently, the initial focus on P and N management must be expanded to an integrated plant-nutrient management approach.

3. THE IBSRAM NETWORK

Critical to developing and assessing the issues of improved management is the use of multidisciplinary and interdisciplinary approaches within the biophysical and socio-economic contexts. An expected outcome of this approach is a significant improvement in the capacity of all the collaborators, as individuals, as institutions, and as groups of institutions, to undertake quality collaborative research, development, and implementation, towards sustainable land management.

The objective of the IBSRAM *ASIALAND* Management of Acid Soils network is to contribute to the process of improving management of infertile marginal soils, with a particular focus on improved management of P in the acid upland soils of Southeast Asia. This is undertaken through collaboration with partners in the national agricultural research and extension systems (NARESs) of Vietnam, Philippines, Indonesia, Myanmar and Thailand, with advanced research institutes (ARIs) in Australia and New Zealand, and with other research and development agencies in the region.

A systematic approach is needed to tackle the complex of problems that can cause low productivity in these marginal infertile acid upland soils. Such an approach has been taken in the IBSRAM acid-soils network. The modus operandi of the network is to operate with a core set of institutions on a core set of initiatives, with a number of important related initiatives undertaken by a subset of these and other institutions.

Prior to 1996, the focus of the network was on ameliorating the toxic effects of Al and low pH, however, since then, the focus of the core of the network has been on establishing researcher-managed on-farm trials – concentrating on P management – designed within the biophysical and socio-economic constraints of the particular agroecosystems.

A significant part of these core activities is being undertaken in association with a project through the University of Queensland (UQ), under the leadership of Dr. Pax Blamey, and funded by the Australian Centre for International Agricultural Research (ACIAR). This project, entitled "Management of phosphorus for sustainable food crop production on acid upland soils in Australia, Philippines and Vietnam," operates with collaborators at the National Institute for Soils and Fertilisers (NISF) in Vietnam, the Bureau of Soil and Water Management (BSWM) and the Central Mindanao University (CMU) in the Philippines, and the Queensland Departments of Natural Resources (QDNR) and Primary Industry (QDPI) in Australia. The core set of collaborators extends beyond those associated with the UQ-ACIAR project to include the Centre for Soils and Agroclimate Research (CSAR) and the University of Gadjah Mada (UGM) in Indonesia, and, in Southern Shan State of Myanmar through a PhD student based at Massey University (MU), New Zealand, the Land Use Division of the Myanmar Agriculture Service (LUD-MAS).

The core of the network operates with three separate but integrated sub-projects: establishment of quality analytical and experimental methodologies, the development and implementation of appropriate field experimentation concentrating on inorganic and organic-P management, and the thorough assessment of socio-economic characteristics of the farming systems and of the particular treatments being used. In this approach, it is recognised that sound scientific methods and principles must be used in the interpretation of any improved crop growth that might be achieved. In addition, the results of field experiments will be implemented and extended successfully to other sites only if the results take full consideration of the socio-economic context.

3.1. Core field experiments

A generic experimental design was developed for adaptation and implementation by all collaborators in the core of the acid-soils network. The field experiment was designed to assess responsiveness to P, including combinations of inorganic organic amendments, and, in some cases, to assess response to lime. Having a reasonably standard design facilitates comparison of results across sites, with sufficient flexibility in treatments to maintain local relevance. Each collaborator selected particular treatments on the bases of biophysical constraints at the site and market conditions, and other economic and social limitations. The responsiveness to P is established with sources that are readily available in both the chemical and market senses. These include triple superphosphate (TSP), single superphosphate (SSP), and SP 36 – a phosphate fertiliser produced in Indonesia that contains 36% P_2O_5, or 16% P (Table I, I1). The inorganic/organic combinations included these same sources plus forms of inorganic P that are less available in the chemical sense, such as fused magnesium phosphate (FMP) and phosphate rocks from North Carolina (NCRP), Christmas Island (CIRP), and the Peoples Republic of China (CRP) (Table I, I2). These sources of inorganic P were chosen on the basis of what was available to farmers, or likely to become available. The organic sources were chosen on the basis of what was available, or may become available, for transfer within or importation from outside the farming system (Table I, O1, O2). The treatments were chosen after detailed discussions with researchers and surveys of farmers, farm suppliers, and local agro-industries.

The majority of the trials are located on farmers' fields previously assessed as representative of a major soil type and agroecosystem in the area. The experiments in Myanmar and Australia are located on research stations for reasons of access and management.

TABLE I. INSTITUTIONS COLLABORATING IN THE CORE OF THE ACID-SOILS NETWORK, AND THE TREATMENTS USED

Country	Province/State	Institution	Inorganic amendments		Organic amendments	
			I1	I2	O1	O2
Vietnam	Hoa Binh	NISF	SSP	FMP	Corn[a]	FYM[b]
Vietnam	Nghe An	NISF[c]	SSP	FMP	Corn	FYM
Philippines	Isabela	BSWM	TSP	NCRP	Chicken[d]	Tricho[e]
Philippines	Bukidnon	CMU	SP	NCRP	Chicken	Stylo[f]
Indonesia	Jambi	CSAR	SP-36	CIRP	FYM	Stylo
Indonesia	S. Kalimantan	UGM	SP-36	CIRP	Chicken	Stylo
Myanmar	S. Shan State	MU/MAS	TSP	CRP	FYM	Titho[g]
Myanmar	S. Shan State	LUD-MAS	TSP	CRP	Corn	Compost
Australia	Queensland	QDNR/QDPI[h]	TSP	NCRP	Lablab[i]	Rhodes[j]

[a]Corn residue. [b]Farmyard manure. [c]Includes *Tithonia diversifolia* as a third organic amendment. [d]Chicken manure. [e]Compost produced with the fungal agent *Trichoderma harzianum*. [f]*Stylosanthes guianensis*. [g]*Tithonia diversifolia*. [h]Includes a number of other organic amendments. [i]*Lablab pupureus*. [j]Rhodes grass (*Chloris gayana*).

3.2. Site characterisation

An essential component of running good field experiments, particularly multi-location experiments, is careful characterisation of the sites. Firstly, this is an essential part of treatment design. Secondly, it is done to ensure that the site is homogeneous, or that any heterogeneity can be used during analysis of results. Thirdly, site characterisation is essential for interpretation of data, to enable comparison of results from different sites, and for the development of relatively site-specific management recommendations. As the number and diversity of sites increases, the importance of characterisation for full interpretation of results becomes more evident. A range of techniques was used to characterise the sites.

Several techniques are available for analysis of soils and determination of P status in particular, therefore, the standard extraction methods regularly used, and with which the greatest amount of data have been generated, are recommended for each laboratory. The main soil-P methods used in the network are the Olsen, Bray II, or Bray I methods. For comparisons across sites, however, it is desirable that the same methods are used. For this reason, all collaborators are encouraged to use their customary method and a common technique or set of techniques. For the purposes of these field trials, all collaborators were encouraged to use the modified bicarbonate technique [9]. The longer extraction time (16 h) and wider soil:solution ratio (1:100) may be more useful for relatively low-P soils and where organic P may be more important.

As low availability of P in soils may be due to low P content and/or severe P-fixation, it is unlikely that a single extraction method will suit all soils or all farming systems to provide sufficient information for accurate interpretation of results. As such, a more universal approach to understanding P response requires measurement of both intensity and quantity factors – the ability of soil to supply P in the short term and medium- to long-term P-supply capacity. To support the standard extraction methods, P-sorption characteristics are assessed to better understand the quantity factor. In addition, since there is particular interest in the cycling of P in various organic and inorganic pools as affected by treatment, a limited set of soil samples has been collected for measurements of P fractions using a modification of the technique of Hedley et al. [10].

Representative surface and sub-surface soil samples were collected and analysed and used in pot experiments. Decisions on rates of P fertiliser used to assess the P responsiveness of the soils at each site were made from analyses of available P and P sorption, and the growth of corn seedlings in pots supplied with different rates of P. The available P and sorption capacities of the soils at the experimental sites differed markedly. For instance, in the Philippines are the fairly low-sorbing Isabela, with an estimated 67 mg P sorbed per kg of soil, at a soil solution concentration of 0.1 mg P L^{-1}, and the higher-sorbing Bukidnon, with 188 mg P kg^{-1}.

A broad set of analyses of the bulked soil samples from each site and measurement of the growth of corn seedlings in element-omission trials were used to assess the status of major nutrients and indicate likely basal applications. For most sites, the trials indicated deficiencies mainly of N and P, with less critical insufficiencies of other nutrients. Together, these analyses and pot experiments improved the capacity to select treatment P rates and basal, non-treatment, fertiliser application levels.

Although variability in soils is the reality with which farmers must cope, minimising heterogeneity, or at least understanding the variability, is important in the experimental context. Site uniformity was assessed, particularly where greater heterogeneity was observed or expected. For instance, at Bukidnon, Philippines, a maize crop was grown on the area in which the experiment was to be located and used to assess heterogeneity. Top-soil samples (0-15 cm) were collected from 4 x 4 m grids, and sub-soil samples (15-30 cm) collected from one-quarter of these. Soil samples were analysed for pH and available P. The height of the corn crop was measured at 33 days after germination as were grain yields, for each grid at maturity. A topographical map was developed to determine the best layout for the experiment. The resultant selection was fairly homogeneous and any major variability was documented for possible use in co-variate analyses. Similar approaches were used at other sites, as deemed necessary.

3.3. Quality of amendments

In order that results can be interpreted accurately, it is essential that there are sufficient data to characterise all amendments. To this end, samples of all fertilisers must be analysed, using appropriate methodologies, to determine total and available nutrient contents. For phosphate rocks, this can involve total and citrate-soluble P, as well as more-detailed analyses of the degree of chemical substitution, etc. At least initially, analyses of phosphate-rock samples used in the network have been limited to total and citrate-soluble P.

The analyses of organic amendments present far greater problems. Firstly, moisture content of the material as added must be measured. Secondly, the total content of inorganic elements must be determined, and thirdly, the content of particular organic compounds can be measured [11, 12]. All of these factors influence rate of breakdown of, and thus nutrient release from, residue. An alternative to estimating breakdown by thorough chemical analyses is to measure breakdown in litter bags or in-vitro systems [13]. To date, analyses have been limited to inorganic nutrients. However, as with fertilisers, samples of organic amendments are stored for subsequent analyses.

3.4. Field-experiment results

At all sites, as expected, there were significant responses in corn yields to applications of available P sources, although extent of the responses and yields differed. As an example, there was a five-fold increase in maize yield in response to application of P as SP-36 (up to 95 kg P ha^{-1}) in the first corn crop at Jambi, Indonesia. It was noted that the maximum yield was low; growth was limited by low rainfall, and acquisition of nutrients other than P from the infertile soil may have been restricted due to reduced root exploration under the dry conditions.

Combinations of inorganic and organic sources produced large differences between treatments. Response to the more available forms of P fertiliser (TSP, SSP and SP-36) were greater than to the less-available forms (FMP and the various phosphate rocks). With subsequent crops, differences between the treatments were less marked. Greater residual value appeared to compensate for lower initial availability.

Highly available organic sources, such as chicken manure, resulted in greater yields than lower quality farmyard manure and other organic treatments, such as corn residues. The initial responses to under-sowing corn with *Stylosanthes guianensis* were poor as the stylo offered too much competition, especially when drought conditions increased the sensitivity of corn to competition for water. Even then, however, leaf colour suggested that the stylo treatment improved N nutrition. This treatment was included as a result of evidence for improved corn growth when planted into a well managed stand of stylo, combined with farmer interest in quality forage for livestock. Management of the stylo is critical so as to maintain ground cover and limit competition during crop growth, particularly the earliest stages, and still produce enough legume biomass to improve soil fertility and, if required, forage for livestock. With improved management of the stylo, in terms of frequency and severity of cutting, decreased competition resulted in increased benefits to the corn. There is scope for further improvements in management.

More data are required from subsequent crops to more accurately assess responses to P, to determine the relative effectiveness of inorganic and organic sources, to appraise the combined effects of organic and inorganic sources, and the residual values of various sources. Careful characterisation of the soils, the fertilisers, and the organic sources is essential to allow more complete understanding of the dynamics of responses across sites and years.

3.5. Improvement of laboratories

Good site characterisation, accurate interpretation of experimental results, and appropriate matching of recommendations to particular farming systems, require good-quality laboratory analyses. Many of the laboratories in the region, and within the network, have severe limitations in undertaking basic soil and plant analyses, with limited capacity to monitor the quality of analyses. A significant component of network activities aims to improve laboratory facilities and their use. To varying degrees in the different institutions, equipment has been provided, facilities upgraded, staff trained and quality-assurance programmes initiated. In many cases, an important component of improving laboratory facilities has been in terms of upgrading layout, management, and maintenance of current resources. Improving laboratory facilities and monitoring the quality of analyses are an on-going activity within and beyond the network.

The importance of high-quality laboratory analyses is recognised in one of the related initiatives outside the core activities. The aim of this initiative, undertaken in collaboration with a

Bangkok-based scientist from the Institut de Recherche pour le Developpment (IRD) and the Thai Department of Land Development, is to establish a network for the improvement and maintenance of laboratory analyses throughout the region; the Southeast Asian Laboratory Network (SEALNET). The aim of SEALNET is to foster improved analyes of soil, plant, water, and fertiliser in Southeast Asia. Laboratories in Brunei, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, Philippines, Thailand, and Vietnam, and from ARIs and IARCs that collaborate with NARESs in agricultural research and development in this and other regions, have been involved. After a survey of laboratory practices and indications of significant support for the establishment of such a network, a workshop was held in December 1998 to develop a standard set of methods (neither too restrictive nor too comprehensive), to work towards the preparation of a detailed cookbook-style laboratory manual, and to further development the network. It is planned that the laboratory manual will form the basis of a series of training courses for laboratory technicians and managers, with follow-up visits to help participating laboratories implement changes in methods and to establish improved quality-assurance programmes with effective intra- and inter-laboratory comparisons to maintain standards.

3.6. Socio-economic analyses

Socio-economic information is essential during the identification of appropriate treatments and to assess their potential impact. Crop yields, soil characteristics and plant-nutrient uptake need to be assessed to evaluate the treatments. However, the development of appropriate strategies for sustainable land management by farmers requires additional economic analyses, and evaluation of social acceptability of proposed strategies and likelihood of broad implementation.

Analyses of field experiments revealed large differences in the relative economic benefits of different treatments at different sites. The recent economic crisis resulted in significant devaluation of many of the currencies in the region, affecting the absolute and relative costs of inputs and farmers' incomes. This emphasises the need to include sensitivity factors in such economic analyses, at least to the point of worst- and best-case scenarios, if not more complex stochastic analyses.

Another problem in such economic analyses is presented when the market for particular inputs or products has not developed, thus supply, pricing, and market-access factors have to be speculated upon. Economic analyses are a critical step in developing sustainable land-management practices, however, they must be implemented with due care.

3.7. On-farm farmer-managed evaluations

Direct comparison of a limited number of management strategies in farmer-managed trials is an important step in assessing biophysical and socio-economic impacts of these strategies and their acceptability to farming communities. In addition, such farmer-managed trials are very useful as extension exercises and to identify problems in, or potentials for, implementation and the requirement for policy intervention.

Another initiative outside the core activities of the network is underway in five provinces of Indonesia: a series of on-farm, farmer-managed evaluations. These form the *SebarFos* Upland Agriculture Improvement Project. They are being conducted by a number of agencies within the Indonesian Agency for Agricultural Research and Development (AARD) in partnership with the Potash and Phosphate Institute (PPI) – East and Southeast Asian Program, based in Singapore, and the collaboration of the acid-soils network and two upland farming projects supported by GTZ, with some financial support from Christmas Island Phosphates. Two of the detailed researcher-managed, on-farm experiments of the core of the acid-soils network, in Jambi and South Kalimantan provinces, are located in the same villages as two of these *SebarFos* studies; the other sites for farmer trials in the *SebarFos* initiative are in the provinces of Lampung, West Sumatra, and West Kalimantan.

In each of the five provinces, at least ten farmers are involved. The hypothesis is that the application of a large amount of reactive phosphate (approximately 150 kg P ha^{-1}, or 1 t ha^{-1} of phosphate rock), in combination with improved and locally adapted germplasm for whichever crop is used, and appropriate soil-conservation measures, is a strategic intervention for the development of improved farming systems. As most of the soils have some P-sorption capacity, most applied P remains within the zone of application. Except on very sandy soils with little or no sorption capacity, P-leaching losses are small, but, without protective soil-conservation measures, P contained in enriched surface horizons is susceptible to loss by surface run-off and erosion. It may be argued that a large initial input of P is not the most efficient practice on an agronomic basis or even at the level of farm economics; however, part of the reason this approach is being assessed is as a strategic intervention in terms of policy implementation. It may be that the only way farmers can achieve a level of productivity from which they can manage their farming systems in a sustainable manner is to get a significant improvement in soil fertility through nutrient capitalisation of the soil resource with a one-off injection of support from government or non-government agencies. It is likely that such a one-off intervention will be more acceptable to such agencies than a longer-term management of intervention.

The *SebarFos* trials involve direct comparisons on large areas of farmers' fields between current practice and the improved strategy. Comparable monitor "windows" are located in each treatment for the collection of more-detailed soil and crop information, and samples to aid interpretation. During the first year in Pauh Menang village, in Jambi, the *SebarFos* strategy increased peanut pod yields by between 25 and 400%, with large increases in net income, even when the costs of all inputs were met in the first year. With significant residual value from the phosphate rock, there should be even stronger justification for this strategy when costs are spread over a number of years. Linking the core field experiments, designed with a sound scientific base, to these more-applied trials that are oriented towards implementation and policy issues, adds strength to both initiatives. Improving the connection between agronomic, economic, implementation and policy issues increases the prospects for research, development, and implementation to operate as a continuum rather than as discrete and unrelated activities.

3.8. Nutrient-balance studies

An important component of degradation of land resources is nutrient removal and loss. Although water and wind are major causes of degradation of agricultural soil, it is estimated that as much as 40% of cropland degradation has resulted from chemical losses, of which nutrients are the most important [4]. Nutrient-balance studies in sub-Saharan Africa [14] and Central America [15] indicate some alarming annual losses of nutrients at the regional, farm and field levels.

Another related initiative, outside the core of the acid-soils network, is a project on nutrient-balance studies in northeast Thailand (NBS-NET). Initial estimates of crude nutrient budgets, using simple balance of fertiliser inputs and product removals, largely based on secondary statistics, indicated some major losses of nutrients for various crops, albeit with large variations between farms [16]. Through a series of surveys and measurements, and with the possibility of limited field experimentation, NBS-NET is developing improved databases on nutrient balances in rain-fed rice-based cropping systems in northeast Thailand. Better measurements and estimates of all input and loss pathways are required to understand nutrient dynamics at a number of spatial domains. At the field and farm levels, the result will be improved fertility-management recommendations to farmers. At the provincial and country levels, they will improve the efficiency of fertiliser importation, production, and distribution. These nutrient budgets vary with crop, soil type, and farm diversity, but, in addition, they vary with non-farm income and other socio-economic factors, which are important part of the surveys. When the methodologies have been developed for surveying the cropping systems in northeast Thailand, they will be used in other areas in the acid-soils network.

3.9. Implementation of improved land-management strategies

The IBSRAM Management of Acid Soils network is using a broad range of approaches to improve the management of infertile acid soils, as outlined above. These approaches include researcher-managed field experiments that have a sound scientific basis, a range of biophysical and socio-economic surveys of primary and secondary data to better understand the characteristics of the resource-management domains, and farmer-managed field trials to help evaluate the possibilities for implementation and aid in the extension process. A major focus is to increase the capacity of individual collaborators and their institutions to undertake high-quality, relevant research in a broad range of biophysical and socio-economic disciplines. In many instances, this involves the adoption, adaptation, and/or development of improved methodologies.

Although the network does not focus on large-scale implementation of improved land-management strategies, we must be cognisant of the need for, and problems of, implementation. The detailed assessments of the biophysical and socio-economic characteristics of systems in these studies cannot be replicated during the implementation phase. More-easily measured surrogate indicators must be identified so that important characteristics that define the likelihood of success with particular land-management strategies can be identified without time-consuming and expensive measurements [5]. Improved understanding of the underlying processes of critical land-management issues must be used to develop surrogate indicators, and the results of the network must be prepared in a form that can be used by extension workers, as well as in a more scientifically oriented format.

4. USE OF ISOTOPE TECHNIQUES IN COLLABORATIVE NETWORKS

Isotope techniques are not being used in the current phase of the IBSRAM network, and it is unlikely that they should ever play a predominant role in such an applied research effort. However, there are a number of areas in which radio- and stable-isotope techniques could be of significant use in improving understanding of underlying processes. Many of these techniques have been used in the region and by research groups associated with, or part of, the network, however, relatively few of the NARESs have well established isotope facilities. Since it can be argued that these techniques should not be the major focus of such research networks, it is logical that the research skills of collaborators should be matched with well equipped isotope laboratories, rather than undertaking the expensive and largely unjustifiable task of improving isotope facilities in the NARESs. The section that follows includes a brief outline of possibilities for using these techniques in such applied research networks.

4.1. Characterization of soils and fertilisers

Implementation of improved land-management strategies requires characterisation of the agroecosystems. Effective fertility recapitalisation needs good understanding of the soils and of the amendments. Simple methods will have to be developed for broad-scale use by extension workers and farmers, but these surrogate indicators will be developed only through detailed correlation studies. Isotope techniques can assist in more fully understanding P-sorption and -desorption characteristics of soils and P-release rates of different sources, particularly phosphate rocks. Such studies will be restricted largely to laboratory and glasshouse experiments.

4.2. Nutrient availability

The availability and uptake of nutrients, from organic and inorganic sources, can be assessed using direct and reverse-labelling techniques, and with multiple-isotope techniques, for the same and different elements. Likely isotopes include ^{15}N, ^{32}P, ^{33}P, ^{35}S, and ^{34}S. Such studies can be used to assess overall and temporal differences in the nutrient-supply capacity of different sources, and temporal and spatial differences in nutrient acquisition by plants. As the cost of buying and analysing stable isotopes decreases, so multi-element studies under realistic field conditions will become more common [17].

4.3. Soil organic matter dynamics

There is great need to increase our understanding of organic-residue and soil organic matter dynamics. The use of C-isotope techniques can aid in this quest. Studies using natural variations in ^{13}C and ^{12}C between plants with different photosynthetic pathways have revealed useful information on C-pool dynamics that cannot be appreciated by simple measurement of total C or other pool-fractionation techniques. Carbon inputs labelled with ^{14}C or ^{13}C have been used to follow the breakdown of specific organic amendments. Whilst the use of ^{14}C-labelled material must be restricted to a limited range of situations, primarily in the laboratory or glasshouse, the development of efficient and cost-effective methods for labelling material with ^{13}C may increase field studies on residue and soil organic matter breakdown, particularly where natural-abundance techniques are not applicable. In addition, these isotope methods should be combined with more appropriate measurements of active soil C [18].

4.4. Residue breakdown

Increasingly, the management of residue quality is seen as a critical part of achieving synchrony of nutrient release and increasing amounts of soil organic matter. There is scope to label residues with isotopes of C and important plant nutrients so as to monitor accurately release rates and improve our understanding of the chemical and physical factors that control the breakdown of residues and how they interact with soil and environmental factors.

4.5. Nutrient inputs and losses

Nutrient budgets are a useful tool for assessing an important component of the sustainability of land-management systems. Although some parts of the nutrient budgets, such as inputs of fertiliser and residues, are easily measured or estimated, other parts are more difficult to determine. There several areas in which the use of isotope techniques may play an important role in improving the accuracy of nutrient budgets, in particular: (i) ^{15}N natural-abundance techniques to estimate N inputs from BNF, (ii) ^{15}N techniques, mainly with enriched sources, to estimate denitrification, (iii) radio- and stable-isotope techniques for measuring nutrient (^{15}N, ^{34}S, ^{35}S, ^{33}P, ^{32}P, etc.) and C (^{13}C) movement down the soil profile and in solution samples, and (iv) isotope (e.g. ^{137}Cs) techniques for measuring erosion losses and sediment transport.

4.6. Soil and plant moisture

Lack of moisture can be a major constraint in many marginal soils of the tropics and sub-tropics, even if only for relatively restricted periods. Soil-moisture measurements based on isotope technology in neutron moisture meters (NMMs) can provide invaluable information on the distribution of water in a soil profile. The increased use of time domain reflectometry (TDR), with advantages in accuracy of measurement in surface layers, and multiple-site and time measurements with multiplexing, is proving to be an attractive alternative to isotope-based techniques.

In addition to ascertaining limitations for plant growth, dynamic measurement of fluxes of water in the soil profile, whether by NMM or TDR, is important for understanding leaching processes, especially when coupled with measurements of nutrients in soil and solution samples from the profile.

In certain rather specialised situations, ^{18}O and ^{2}H can be used to identify particular sources of water being used, most frequently in drier climates in which plants can get access to very different sources of groundwater.

Major variations in C isotopes in plant tissues result from different photosynthetic pathways, and smaller differences arise from other biochemical and physiologic processes, including N metabolism and water use. $\delta^{13}C$ data can be used to identify differences in water-use efficiency, although this is probably of greatest use in plant breeding and selection programmes, rather than in more-applied studies of moisture limitations in marginal soils.

5. CONCLUSION

The suite of activities within, or associated with, the IBSRAM acid-soils network constitutes a wide range of strategic and applied research, involving biophysical and socio-economic analyses. The modus operandi of the network is such that there is significant benefit to each of the collaborators and their institutions, through enhanced research and development capacity, and greater use of the research and development output by interpretation across the different agroecosystems being studied. The result of this collaboration should be soundly based strategies for improved management of the less fertile lands of the region, with a clear understanding of the potential for implementation, the process of implementation and extension, and the likely impact on the sustainability of farming communities.

Although isotope techniques are not used in the network, it is clear that they can play an important role in increasing the understanding of processes. Equally, it is clear that such techniques cannot dominate these applied research networks, but must form part of the important link that allows research output to be used for development and implementation of sustainable land-management strategies.

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