Accounting for environmental and socioeconomic sustainability in Northeast Thailand: Towards decision support for farmers and extension workers **

J.D. Wijnhoud [1], Yothin Konboon [2], and Rod D.B. Lefroy [3]

[1] *Netherlands Development Organization (SNV), PO Box 4468, Maputo, Mozambique, E-mail address: famwijnhoud@hotmail.com*

[2] *Ubon Rice Research Center (URRC), P.O. Box 65, Ubon Ratchathani, 34000 Thailand*

[3] *Present address: Centro Internacional de Agricultura Tropical (CIAT), PO Box 783, Vientiane, Lao PDR*

** Paper summarizing two Power Point presentations presented by Dr. Yothin Konboon and J.D. Wijnhoud, both in collaboration with Dr. Rod Lefroy.

Abstract

In Northeast Thailand, the sustainability of rainfed lowland rice-based systems is of concern, with regards the welfare of the population in this relatively poor area of Thailand. Poor soil fertility and low inputs are seen as major causes of sustainability problems. Appropriate decision support tools for sustainable agricultural production, natural resource management and livelihood development are required. However, the implementation of appropriate tools, and, management and development options is challenged by the complexity of these systems. The complexity arises, in part, from high spatio-temporal variation, as a result of large microtopographic and related biophysical variability, combined with erratic rainfall and various socio-economic factors. Many of the existing bottlenecks that constrain rural research and development can only be addressed through more innovative approaches; particularly participatory and interdisciplinary activities within the context of Dynamic Resource Management Domains (DRMD).

Partial Nutrient Balances (PNBs) can be utilized as indicators of critical components affecting agricultural sustainability and are important tools on which to base recommendations for soil fertility management. Consideration must be given, however, to the additional factors required for a Full Nutrient Balance (FNB). In addition, PNBs can serve as a template for economic accounting and the financial assessment of nutrient depletion. In combination with socioeconomic data, PNBs can assist in the identification of factors important for the sustainable management of land and can be used to develop improved recommendations aimed at both biophysical and socioeconomic aspects of sustainability.

Following a pilot survey conducted on 10 farms, Biophysical, socioeconomic and management-related data on the farming systems investigated were collected for 90 farms in two sub-districts of Ubon Ratchathani Province, Northeast Thailand. In addition to results from the pilot survey, this paper discusses the results of a well-verified sub-set of 30 farms (58 fields and 78 Land Utilization Types) in the two sub-districts. A Relational Database System (RDBS) was developed to manage and analyse the data. A two-scale approach was followed with outcomes of analyses and insights at the district level, as based on the complete data set, serving the analyses at the farm and field levels, and vice versa. Mean partial N, P and K farm balances for the rice-based systems of the 30 farms are 12, 8 and 7 kg ha^{-1} yr^{-1}, respectively.

Large variations in partial N, P, and K balances exist among and within farms, especially at the Land Utilization Type (LUT) level. Although the mean values were positive, many negative PNBs were observed, especially at the LUT level. The relatively high lower-scale variability in PNBs was similar for the two sub-districts of the main survey and for the district of the pilot-study. The results confirm the high inter-farm and intra-farm variability for partial N, P and K balances of preliminary studies. As such, similar tendencies appear to exist in large parts of Ubon Ratchathani Province and in major parts of Northeast Thailand, with similar Land Use Systems (LUS).

Diversification of income sources, through off-farm employment, non-agricultural on-farm income, such as weaving, and diversification of the agricultural system, beyond rice, has a large impact on household wealth. In turn, this can affect the capacity of the household to manage the natural resources of the farm. Off-farm employment has the greatest impact on household income ($P < 0.001$), with a very strong influence imposed by higher income households. Rice provides the main income at the lower income-end but in absolute terms provides a more significant to income at the higher income-end for the range. No significant correlation was found between total income and/or non-rice income and nutrient inputs, however, this does not mean that they are unrelated. Information obtained from farmers indicates strong, but opposing, relationships for different households. Where some households improved management of rice production with increased access to capital from non-rice activities, others do not or even decrease their efforts. No factors were identified to separate these groups.

Based on fertilizer use and price, mean elemental N, P and K retail prices were calculated as 12.4, 60.0 and 13.1 THB kg^{-1}, respectively. These values were used for integrated environmental and economic accounting, based on the mean partial N, P, and K balances to calculate partial N, P and K balances in monetary terms. For the 30 farms investigated the results follow the average positive PNBs for rice-based systems with large variability among different farms and, even more so, among different LUTs and cropping system-management combinations. At the district level, PNBs are most extreme for N and K balances. On the contrary, in monetary terms this is true for P. These analyses suggest there is too much invested in P, which is generally non-limiting and rather expensive, because of the customary use of N-P or N-P-K compound fertilizers. Although information on mean district balances can be useful, improved nutrient application must rely on additional farm-level data. Outcomes at the farm level may be used for correction of on-farm fertilizer allocation, from both agronomic and economic points of view.

Significant challenges remain to transform and integrate PNBs into a practical Decision Support Tool (DST) for site-specific decision-making of nutrient, land and farm management by farmers and extension workers.

1. Introduction

1.1. Background and rationale

Northeast Thailand is an important area for the production of rice, and a major source of high quality rice for export. Average rice yields in Thailand are low (2.2 t ha^{-1}), and those of the low input systems in Northeast Thailand are the lowest in the country (1.8 t ha^{-1}). Infertile sandy soils and declining soil fertility are widespread in many agroecosystems in Northeast Thailand, including the dominant rainfed lowland rice-based systems. In addition, agricultural management and planning is further complicated by a combination of erratic rainfall and significant microtopographic variability. The region has a Tropical Savannah climate with two distinct seasons, a dry season from November to April and a rainy season from May to October, with an average annual rainfall between 1300 and 1500 mm with a slightly bimodal character (peaks in May-June and August-September). Increased demand for agricultural produce has led to continuous deforestation and expansion of agriculture, including rainfed rice systems, into more marginal areas. Inappropriate management of these areas has resulted in their rapid degradation. Some of the lower parts of the areas under rainfed lowland rice-based systems are affected by salinization, partly caused by human-induced hydrological changes (Yuvaniyama, 2001).

The socio-economic structure of the small, but steadily growing non-farming sector in the region is relatively weak, as evidenced by the lowest socio-economic development indicators in the country, including lowest average income (OAE, 1999). It is likely that the Southeast-Asian economic crisis has increased the rate of interrelated social and environmental decline (Miyagawa et al., 1998; ADB, 1999).

Within a context of intertwined socio-economic and biophysical constraints, current practices in rainfed lowland rice-based systems, raise concerns with respect to sustained production (Poltanee et al., 1998) and sustainability in its broadest sense (Smyth and Dumanski, 1993; Lefroy and Konboon, 1998; Lefroy et al., 2000). In their framework for evaluation of Sustainable Land Management (SLM), Smyth and Dumanski (1993) distinguish five 'pillars of sustainability' that need to be satisfied simultaneously: productivity, stability or risk avoidance, economic viability, socio-cultural acceptability, and maintenance of the resource base, or protection. Konboon et al., (2001) suggest that, because of the complexity of the issue, bottlenecks that constrain rural research and development (R&D) can only be addressed efficiently through innovative approaches, particularly participatory and interdisciplinary activities within the context of Resource Management Domains (RMDs) (Syers and Bouma, 1998). This involves considering the overall biophysical, economic, socio-cultural and political setting of the activities, so that development strategies can be implemented effectively in the particular location and their performance assessed with the purpose of deriving general rules for extrapolation and scaling-up of R&D activities to more or less identical RMDs (Syers and Bouma, 1998). Both, the spatial dimensions of an RMD and its non-spatial level of complexity are purpose- and information-driven (Kam and Oberthür, 1998). In addition to the broader disciplinary and spatial context, the temporal context is important for the success of R&D activities (Wijnhoud et al., 2003). The broader concept of Dynamic Resource Management Domains (DRMD) therefore is a valuable addition to the RMD concept as it explicitly emphasises the relevance of temporal variability, change and development.

Nutrient Balance Analyses (NBA) are considered useful for interdisciplinary and participatory R&D activities in Northeast Thailand, especially those primarily aimed at designing improved and sustainable nutrient and land management systems (Konboon et al., 2001). This also holds for Partial Nutrient Balance Analyses (PNBA), if consideration is given to additional factors required for Full Nutrient Balance Analyses (FNBA; Wijnhoud et al., 2003). Both PNBA and FNBA are an important components of biophysical sustainability assessments and may serve as component indicators in broad scale sustainability assessments (Smyth and Dumanski, 1993; Lefroy et al., 2000; Coughlan et al., 2001). Because of the relatively simple logic utilized, NBAs are useful for training farmers and extension workers in appropriate nutrient management (Defoer et al., 1998; 2000). In addition, NBAs can serve as a template for economic accounting and financial assessment of nutrient depletion and surpluses (UNSD, 1993; De Jager et al., 1998a and 1998b; Drechsel and Gyiele, 1999; Moukoko Ndoumbe, *this proceedings*). Further, in combination with socioeconomic data, NBAs can support the identification of factors important for the sustainable management of land and the development of improved recommendations aimed at both biophysical and socioeconomic aspects of sustainability. Hence, NBAs are expected to be useful as core elements in integrated Decision Support Systems (DSS) and related Decision Support Tools (DSTs) aimed at improved and sustainable land management. However, problems remain in measurement and interpretation of NBAs and, at best they represent only a component of sustainability. Added analyses, for example of livelihood patterns and development, form part of a broader framework for DSTs based on pathways towards sustainable and improved land management and improved livelihoods in a DRMD-context.

The case reported here, started as Nutrient Balance Studies in Northeast Thailand (NBS-NET), a collaborative research activity centered around NBA in Ubon Ratchathani Province of Northeast Thailand (Figure 1), initiated in 1998 (Konboon et al., 2001; Wijnhoud et al., 2000 and 2003). It focuses primarily on the assessment of PNBA at farm and sub-farm levels, supplemented by socio-economic analyses and discussions of farmer perceptions. A major consideration was the potential for implementation and extrapolation of the methodology. The study focussed on farms characterized by land-use systems (LUS) based on rainfed lowland rice, the dominant LUS in the province and in much of this region of Thailand. Predominantly, these LUS are mono-crop rice systems in a seasonal lowland environment. However, where irrigation water or sufficient residual soil moisture is available, pre- and/or post-rice crops, such as peanuts, vegetables or dry-season rice, may be included.

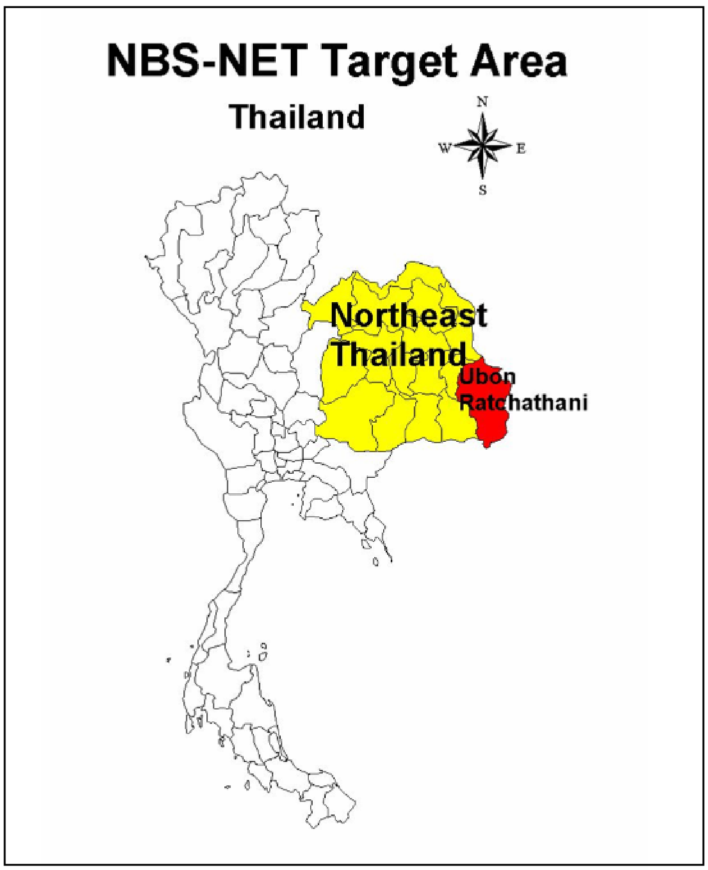


Figure 1. Map of Thailand indicating the target area of NBS-NET in Northeast Thailand, Ubon Ratchathani Province.

1.2. Goal and objectives

One main aim of NBS-NET was sustainability assessment of rainfed lowland rice-based LUS systems.. Initially, emphasis was on protection or maintenance of the resource base, as a condition for continued or sustainable production as centered around, NBA. A multiple-scale nutrient balance study served as the basis for a more extensive analysis aimed at highlighting and discussing some of the potential applications of NBAs within integrated R&D approaches aimed at Sustainable Land Management (SLM) and improved and sustainable livelihoods. The ultimate goal was to emphasise the usefulness of and need for more holistic and interdisciplinary approaches, and the possible contribution of NBAs, in order to generate information relevant to addressing the daunting twin challenges of SLM and improved and sustainable livelihoods. Methodologically, in was envisaged that the study would serve as a new paradigm.

Within the study, a first objective was DRMD characterization, both with respect to general aspects and developments and with respect to bottlenecks and challenges for R&D aimed at SLM, emphasizing soil fertility management, and improved livelihoods.

A second objective was assessment of some biophysical aspects of sustainability through multiple-scale assessment and interpretation of PNBAs. These PNBAs were assessed at four levels, increasing in scale from the Land Utilization Type (LUT), via the field and farm to the sub-district. A LUT is a unique cropping system-management combination implemented at the field level or sub-field level. Theoretically, a LUT could cover more than one field, but in the present study the (sub-) plot level was taken as the smallest and unique data collection unit. Hence, several different LUTs may occur in the same field, if the field is managed differentially in terms of inputs, cropping systems/varieties, or other distinct management factors.

A third set of objectives dealt with the relationship between agricultural production, biophysical sustainability and socio-economic characteristics. This was investigated by studying the relationships between farm performance and various biophysical and socio-economic factors. The fourth main objective of the study was to investigate the possibilities for integrated socio-economic and environmental accounting, starting from nutrient management, PNBAs and the valuation or costing of nutrients and PNBAs. The fifth and final objective was to identify and develop some of the basic elements of a DST based on PNBAs, aimed at dynamic and site-specific decision support for improved soil fertility, SLM and improved and sustainable livelihoods.

2. Methodology

Keeping in mind the study goal, objectives, priorities and available capacity, NBS-NET started with a general DRMD characterization. Konboon et al., (2001) provide a state-of-the-art overview on nutrient management in rainfed lowland rice-based systems in Northeast Thailand also touching on impact of R&D efforts, land-use and agricultural change over the past decades and some of the most recent developments, including the effects of the economic crisis of the late 1990s. More focused analyses were provided by the introductory explorative desk study on nutrient balances for land-use systems in Northeast Thailand (Lefroy and Konboon, 1998).

2.1 General survey method and issues of scale

During the 1998 growing season, a pilot study was undertaken on 10 farms in Muang District of Ubon Ratchathani Province (Figure 2) characterized by the dominant rainfed lowland rice-based LUS (Wijnhoud et al., 2000).

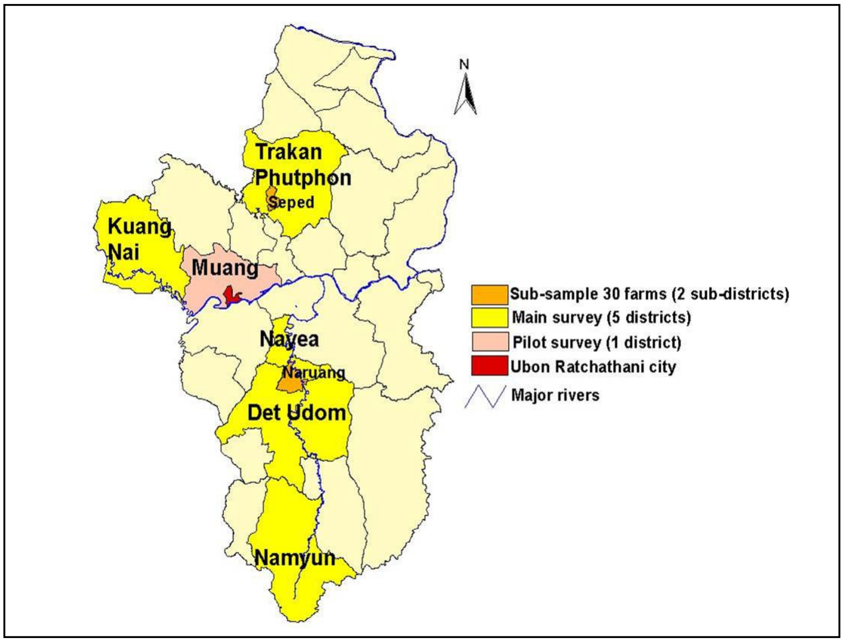


Figure 2. Map of Ubon Ratchathani Province indicating the (sub-) districts where primary data were collected for NBS-NET.

During the 1999 growing season, a more comprehensive survey of 90 farms with similar LUS, was undertaken in five other districts of Ubon Ratchathani Province (Figure 2). In addition to the data for the 10 farms surveyed during the pilot study the results presented in this paper evaluate a well-verified sub-set of 30 farms from two sub-districts namely Seped, in Trakan Phutphon District, and Naruang, in Nayea District (Figure 2). The 30 farms included a total of 58 fields containing 78 LUTs (Wijnhoud et al., 2003). Biophysical, socio-economic and farming systems data were collected during the survey, through a combination of semi-structured interviews and direct field observations.

Primary data collection focused at the farm level, included the collection of data for sub-farm units namely fields and LUTs. A multiple-scale approach was followed, from lower to higher spatial scale, i.e. from LUT to field, farm, (sub-) district and provincial level. As the overall dimension of the survey exceeded the sub-district level, it is further referred to as a district level survey. For the bulk of the analyses a two-scale or sometimes multiple-scale approaches involving more than two levels has been followed, with analyses at district, farm, field and LUT levels. In this approach the district level is represented by the multivariate data set of the 40 representative farms with some distinct analyses based on the pilot survey data (10 farms) and main survey data (30 farms) and at the farm level by evaluating each set of farm data. In addition to the pilot survey for the 1998 growing season (Wijnhoud et al., 2000), the main survey data collection took place during the period March 1999-February 2000, including the 1999 growing season (Wijnhoud et al., 2003). As no perennials are included in the LUS, climatic conditions have been rather average and major emphasis is on methodological issues rather than on temporally accurate analyses, the use of an annual "snapshot" rather than multi-annual monitoring seems justified.

2.2 Data collection, storage and management

Most of the quantitative data, such as crop yields, nutrient inputs, and data on residue management, were provided by the farmers during a single, rather extensive interview with in some cases, follow-up interviews.

Every effort was taken to check these estimates with secondary, follow-up questionnaires and through field observations. Units were standardized, which involved conversions such as volumes to weights, and fresh weights to dry-weights, and these conversions were checked carefully in the field. Nutrient contents in fertilizers, products, stubble, organic amendments, etc. were collated from a mixture of available data from within the region and laboratory analyses. Although the errors in the data could not be quantified, it was clear that there was variation in the accuracy with which different parameters were measured. Indications were that accuracy declined approximately in the following order: nutrient inputs in fertilizer, yields, nutrients removed in products, residue yields, nutrients in residues, and nutrient inputs in organic amendments. Fortunately, the first three parameters are, in most cases, the most significant factors in the PNBA calculations.

From the additional wide range of socio-economic and farming systems data, major efforts were made with respect to income from different activities and prices and cost data for fertilisers and rice. For on-farm data collection, hardcopy Farm Inventory Forms (FIF) were used. Collected data were subsequently entered into a compatible Relational Database System (RDBS) that was designed for storage, management and analyses of data, and includes a user-interface (front-end) developed in Visual Basic® that is compatible with the FIF (Figure 3). The database back-end is in Microsoft Access® and comprises two main components, a primary data component, including farm-specific data and a secondary or 'default' data component, including secondary and analytical data for samples that have been collected and that may serve as defaults for analyses. The RDBS may serve a wide-range of farm, farm household and farming system analyses.

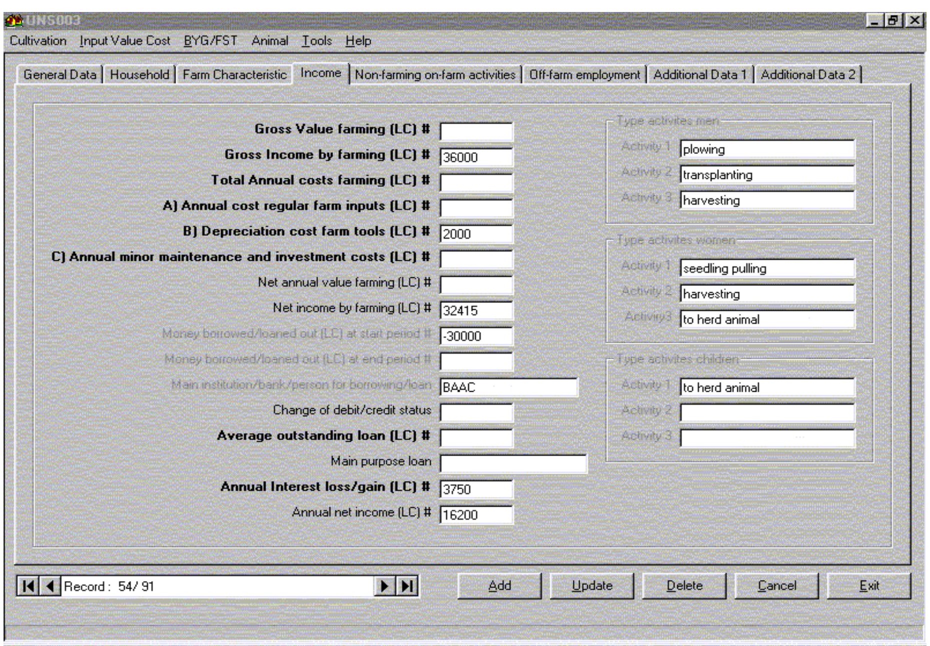


Figure 3. An example of one of the user-interfaces (front-end) developed in Visual Basic® that is compatible with the Farm Inventory Forms used for data collection.

Especially relevant for this study, the RDBS includes utilities to generate semi-automatically PNBs for N, P, and K at the LUT, field, and farm level (Figure 4) and cost-benefit analysis (CBA) for rice cultivation at the farm level.

In addition, some of its components may be of value for incorporation in a DST for dynamic and site-specific decision support, based on NBA and CBA in the form of a "ready reckoner".

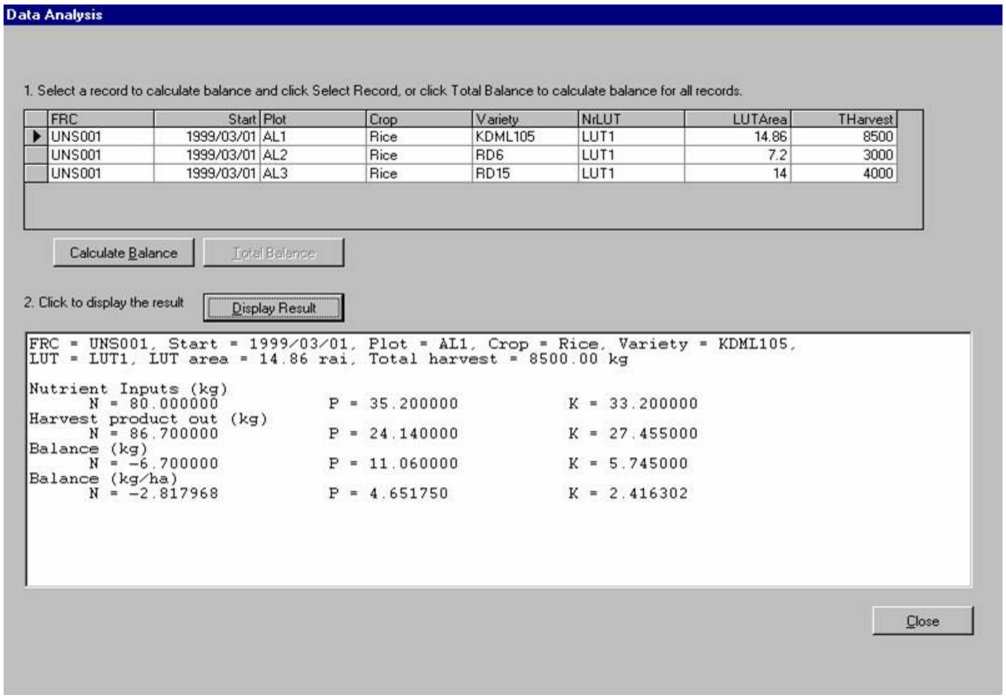


Figure 4. Example of data analysis utility for generating partial nutrient balances semi-automatically within the RDBS.

2.3 Data analyses

The conceptual nutrient balance model, used in the often cited nutrient balance study of Stoorvogel and Smaling (1990), includes five nutrient input components and five output components:

Inputs:
1: Mineral fertilizers
2: Manure and other organic inputs
3: Deposition by rain and dust
4: N-fixation
5: Sedimentation

Outputs:
1: Harvested product
2: Removed crop residues
3: Leaching
4: Gaseous losses
5: Erosion

Starting from this conceptual model, annual PNBAs (also referred to as 'farm gate balances') for N, P and K were calculated as Input – Output where;

Inputs = fertilizers + organics from outside the field/farm
Outputs = removal from field/farm in products and crop residues

These estimates exclude inputs through (biological) nitrogen fixation, wet and dry deposition, sedimentation, run-on, and nutrient recovery or exploration from sub-soil layers by deep roots and outputs by leaching, erosion, run-off, and gaseous losses.

While it is acknowledged that PNBAs must be interpreted with caution, the relatively accurate, rapid, and simple assessment of PNBAs can be of great value, especially if consideration is given to the plausible magnitude of the full balance factors that are not included. Such considerations require a combination of local and expert knowledge on relevant site characteristics. Moreover, PNBA fits in with an overall approach aimed at creating 'high' impact with finite/limited resources. This means that instead of the resource-intensive accurate assessment of small-scale FNBAs, PNBAs allow for somewhat less accurate, flexible larger-scale assessment.

The nutrient balance study of the 30 farms (main survey) served as basis for further, more integrated biophysical and socio-economic analyses. Analyses of organic and inorganic nutrient inputs, PNBAs and relationships between on- and off-farm income, were followed by integrated environmental and socio-economic accounting at district, farm, field and LUT levels, based on introductory analyses of average prices/values of elemental N, P and K, which is in turn, based on fertilizer use and price data derived from a fertilizer survey. In addition, based on the fertilizer survey, average district N, P and K prices/values were estimated and used for additional integrated environmental and socio-economic accounting at district, farm, field and LUT level. These integrated analyses provided additional insights and contributed to conclusions that could not have been made by mere mono-disciplinary analyses.

3. DRMD Characterization Summary of bottlenecks and challenges for R&D in Northeast Thailand

Major challenges exist to achieve the twin objectives of improved and SLM and improved and sustainable livelihoods in Northeast Thailand. A wide range of bottlenecks need to be overcome in the fight against the daunting associated problems of land degradation and poverty

Table 1. Bottlenecks and challenges for R&D in Northeast Thailand: Biophysical constraints and challenges

A) Bio-physical constraints and challenges

Constraints

- Dominance of inherently marginal soils
  - Coarse textures, limited nutrient pools, low Effective Cation Exchange Capacity (ECEC), low Base Saturation (BS), low Soil Organic Matter content (SOM), etc.; large areas of saline soils
- Erratic rainfall and lack of irrigation water
- Micro-topographic variability
- I, II and III result in high spatio-temporal variability along micro-topographic catenae.

Possible solutions

- Design and adoption of innovative dynamic and site-specific water and nutrient management strategies/land-use systems
  - Combinations of organic and inorganic inputs and cropping system approaches; inputs synchronised with crop requirements and weather conditions; slow-release inputs; leaching and erosion control; improved G*E interaction; site-specific (topographic position) land use systems and nutrient management.
- Integrated farming, focus on farm (and off-farm) activities not merely relying on the quality of natural resources` (e.g. zero-grazing, fish farming etc.)
- Small scale irrigation (ponds, pumps); larger irrigation works and biophysical improvement (e.g. land levelling), but only if and where biophysically and socio-economically appropriate and feasible

B) Socio-economic constraints and challenges

Constraints

- Generally low education level (partly because of brain drain to urban centres)
- Limited capacity of private sector; lack of capital
- Limited economic diversification; vulnerability
- Relatively weakly developed markets
- Insecure land rights and lack of quality land (partly a biophysical constraint) for resource-poor farmers
- Increasing rural population and increasing demand for agricultural products (partly related to economic crisis and international market situation)

Possible solutions

- Main focus on quality education, equity and empowerment of rural poor, gender equity.
- Create enabling conditions and opportunities in rural areas
- On and off-farm (livelihood) diversification (agriculture not only focus).
- Start-up initiatives, partnership building, creation of interest groups (institutional development at community level).
- Improved land policy based on multiple stakeholder involvement and insights
- Emphasis on environmental protection; reduce pressure on marginal lands
- VII) Reduced dependence on, or influence of fluctuations on international markets

C) Inherent (including institutional and policy related) R&D constraints and challenges

Constraints

- Sometimes technically inappropriate
- Inappropriate in broader (holistic) context: biophysical, socio-economic, cultural and/or political constraints may be overlooked.
- III Too static (focussed on current state instead of taking into account possible development trends; subject may become outdated before results appear)
- Too much site-specific/too little orientation on site-specificity; how to scale-up or account for site-specificity/diversity?
- Disregard for (second agenda) or lack of time to fulfil ultimate objectives/implementation/impact
- Lack of capacity (time, human, financial, organizational, institutional)
- Lack of coordination and priority setting (lost time and double, isolated or irrelevant efforts partly due to competition for financial and human resources and ideas)
- Inappropriate extension

Possible solutions

- Participatory and interdisciplinary approaches
  - Identification of constraints for proper implementation
  - Strengthen institutionalization for the use of participatory approaches
- More sharing, collaboration and partnerships both vertically and horizontally.
  - Strengthen partnerships between research and extension systems on one hand, and farmers and their organizations on the other hand.
  - Strengthen partnerships among national and international R&D institutions, among different farmer and community based organizations and among donor organizations and between these different stakeholder groups.
- Improved research planning, including priority setting
  - Consistent focus on objectives, final goals, sustainability (exit strategies) and impact
  - Reduction or elimination of non-constructive secondary agendas
- Education
- Changes in attitudes

Major bottlenecks may be categorised as biophysical, socio-economic and R&D-related (Table 1). It should be emphasised that, although categorised separately they are, interrelated. Moreover, not every bottleneck exists everywhere at any time, and critical notes placed with regard to R&D failures do not withstand the fact that some excellent and highly successful R&D efforts were made and are still ongoing. Rather it emphasises that in general, as related to different aspects, there is much scope for improvement regarding the efficiency and effectiveness of R&D efforts. R&D efforts in the past, including those in Northeast Thailand, too often have failed because of their narrow focus in space and time and/or a too narrow focus on technical aspects (Wijnhoud et al., 2003). For example, it would be inappropriate for R&D in Northeast Thailand to focus on improving rice systems without considering alternative agricultural and rural development options. The ultimate aim is to arrive at improved and sustainable livelihoods for the whole rural population, in combination with protection of the natural resource base. In this process, a proportion of the population may move to specialized non-agricultural livelihoods, at the household and/or in urban centres, or remain on appropriately managed sustainable low risk farm enterprises, possibly with reduced reliance on rainfed rice. At the organizational level, this could be achieved through improved priority setting, improved coordination and continuity in efforts as well as sincere collaboration among R&D stakeholders. As such, investment in capacity development aimed at institutional innovations should be top of the development agenda (Fukuda-Parr et al., 2002).

A wide range of remedies and approaches could be suggested to overcome or reduce, as much as possible, the bottlenecks affecting SLM and sustainable livelihoods development in Northeast Thailand (Table 1).

4. Results: Multiple-scale Nutrient Balance Analyses (NBA)

The production systems of the 30 farms investigated during the main survey were similar to those for the 10 farms in the pilot study (Wijnhoud et al., 2000), although there is a wide range in rice productivity, nutrient use, and other farm characteristics (Wijnhoud et al., 2003).

Within the main survey, rice was grown as a single crop on 73 out of the total of 78 rice-based LUTs. In the remaining 5 LUTs, covering only 1.8 % of the overall area, post-rice crops, mainly vegetables, were grown during the dry season. Although post-harvest management and crops were considered in the assessment of partial balances, due to their diversity and limited area, unlike the pilot survey (Wijnhoud et al., 2000) no significant comparative data could be given with respect to the mono-cropped areas (Wijnhoud et al., *2003),*. The mean yield of rice was 2.5 t ha^{-1}, which is higher than the average for Northeast Thailand of 1.8 t ha^{-1}. Nutrient inputs at the farm level, in the form of inorganic fertilizer and organic materials, averaged 39, 16 and 16 kg ha^{-1} y^{-1} for N, P and K, respectively. All farms used fertilizers and all but two applied organic materials. However, this was not the situation at the field and LUT level. No fertilizers or organics were used on one LUT and only two-thirds of the LUTs received organics (Wijnhoud et al., 2003). There was a large variation in the yields and nutrient input rates among farms and, even more so, among LUTs. Although there were significant positive correlations ($P \leq 0.05$) between yield and the rates of application, it is not surprising that yield could not be predicted from the application rates. This may in part be due to initial soil fertility, be that as a result of previous fertility management or of inherent soil characteristics. Multiple regression techniques could be used to predict yields from application rates and a range of additional factors, but this would require a much larger and biophysically more diverse data set (Wijnhoud et al., 2003).

Mean partial N, P, and K balances for rice production at the farm level on the 30 farms were respectively 12, 8 and 7 kg ha^{-1} (Wijnhoud et al., 2003; Figure 12). However large variations were observed particularly for N, among different farms and, even more so, for different LUTs, with many negative partial balances (Wijnhoud et al., 2003; Figures 13 and 14).

Farmers manage nutrients for different parcels of land used for rice cultivation in very different ways. This results in large variations in PNBs, even for the same type of land-use within the same farm (Wijnhoud et al., 2003; Figure 14). These results confirm the high inter-farm and intra-farm variability for partial N, P, and K balances observed in the earlier pilot study in this province. Figures 5a, 5b and 5c illustrate the variability in partial N, P and K balances among 18 fields of the 10 farms with farms ranked according to mean farm balances meaning that identical farm numbers in the different figures may not necessarily refer to the same farm.

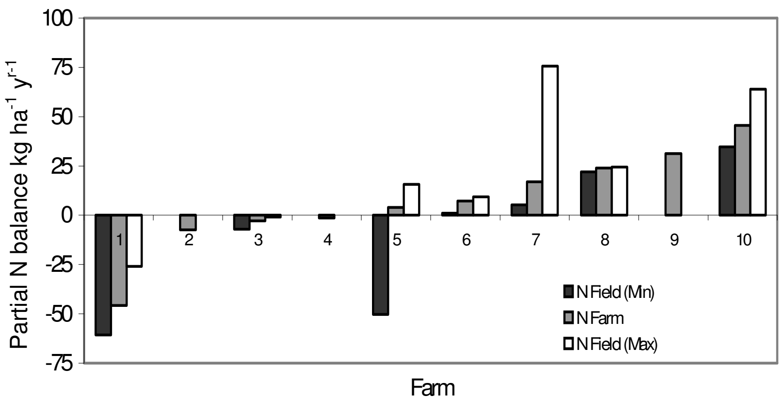


Figure 5a. The variation in partial N balances among different fields of 10 farms in Muang District, Ubon Ratchathani Province (adapted from Wijnhoud et al., 2000)

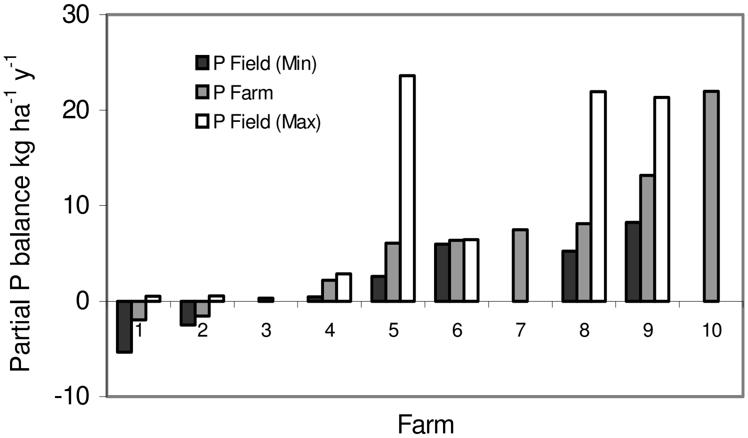


Figure 5b. The variation in partial P balances among different fields of 10 farms in Muang District, Ubon Ratchathani Province (adapted from Wijnhoud et al., 2000)

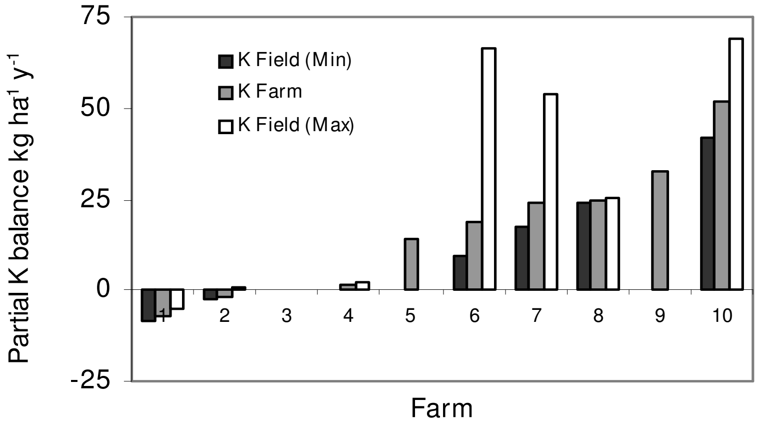


Figure 5c. The variation in partial K balances among different fields of 10 farms in Muang District, Ubon Ratchathani Province (adapted from Wijnhoud et al., 2000).

Similar observations were made in a preliminary nutrient balance study in the region (Lefroy and Konboon, 1998). The results of the main 30 farm survey indicate that the mean partial N balance at the LUT level for the main survey is higher than the mean partial P and K balances (Wijnhoud et al., 2003; Figure 13). However, the number of LUTs with negative partial P and K balances is much lower than the number of LUTs with negative partial N balances. This is similar to the results of the pilot study (Figures 5a, b and c).

Within the main survey, yield did not correlate significantly with either the N or P partial balances ($P > 0.05$), although there was a significant positive correlation between yield and partial K balance ($P = 0.03$) (*Wijnhoud* et al., 2003). Six rice varieties were grown on the 78 LUTs surveyed, but two varieties, the non-glutinous KDML105, which is grown primarily for sale, and the glutinous RD6, which is grown primarily for home and local consumption, were grown on 70 of the sites. There were no differences between the rates of fertilizer applied to these two varieties, although the partial N balances were significantly higher for KDML105, largely as a result of the slightly lower average yield.

Results from the pilot study (Wijnhoud et al., 2000) revealed that for rice-peanut cropping systems surveyed the range of partial N and K balances is much less favourable than that for the rice only systems (Figure 6). Even if inputs of N from Biological Nitrogen Fixation and N and K from other sources would be considered, the differences in the ranges of balances between these systems would persist. This indicates that supplementary inputs for the rotation crop are insufficient to attain a similar nutrient balance as under mono-cropping of rice (Wijnhoud et al., 2000). Sufficient availability or input of P and K is essential in order to take advantage of the N-fixing characteristics of leguminous crops within sustainable cropping systems (Konboon et al., 2001). Moreover, the amount of N fixed by a leguminous crop will be less than the overall N-requirements of that crop.

Partial N-balances have been presented at different scales, i.e. aggregation levels (Figure 7). Apart from incorrect insights due to interpretation of averages only, too much data integration may result in blurred outcomes, even if the analysis is performed at a lower scale level, i.e. the farm. Especially, the existence of a significant number (10 percent) of LUTs with rather negative partial N-balances of below 14 kg ha^{-1} y^{-1} would not have been revealed if analysis would have been limited to the farm level (Figure 7).

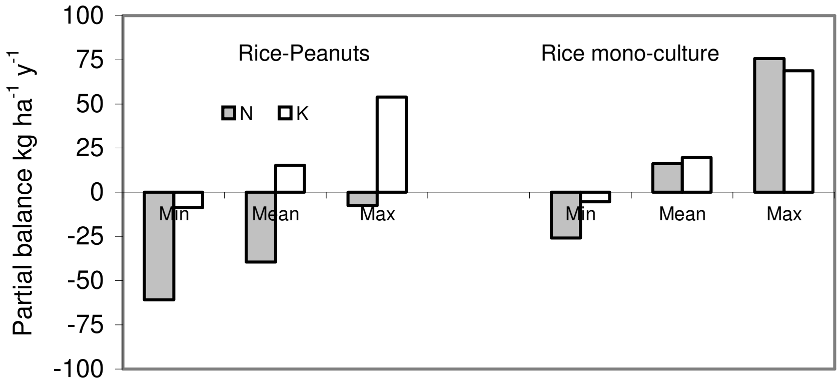


Figure 6. Partial N and K balances for rice-peanut systems and mono-crop rice systems on 18 fields in Muang District, Ubon Ratchathani Province (adapted from Wijnhoud et al., 2000).

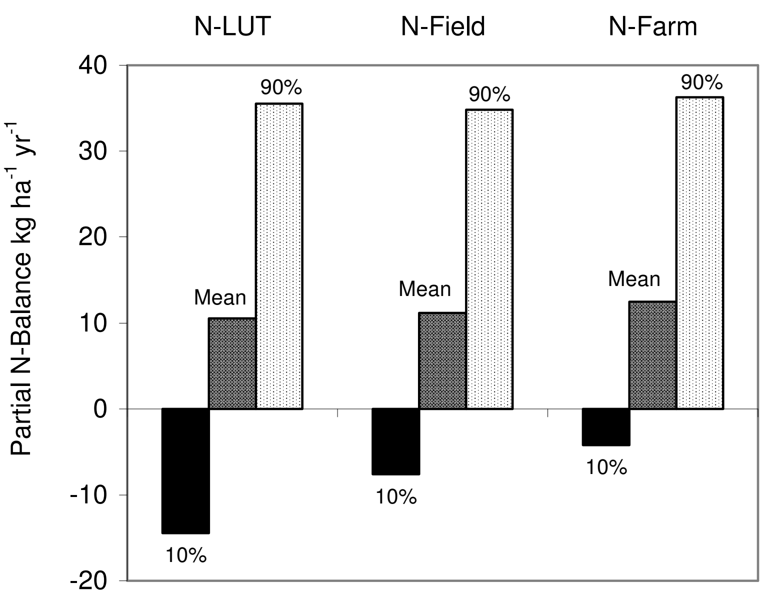


Figure 7. Partial N balances at the LUT (n=78), field (n=59) and farm (n=30) level (including 10 and 90 percentiles) for 30 farms in two sub-districts in Ubon Ratchathani Province.

A general look at the results for Trakan Phutphon District (20 farms, 1999 growing season), Nayea District (10 farms, 1999 growing season), and the pilot study for Muang District (10 farms, 1998 growing season), shows only minor variations in the values of partial N, P and K balances. The lowest values for the median partial N and P-balances are recorded in Muang District and the lowest median partial K-balance in Trakan Phutpon District (Figure 8). The higher number of fields with negative partial N and K balances in Muang District, may be due to the presence of a larger number of rice-peanut cropping systems (Wijnhoud et al., 2000). In addition, lower rainfall in 1998, resulted in farmers applying less fertilisers in the higher parts of the toposequence (Konboon et al., 2001).

However, the results clearly indicate that in all three districts the PNBs, especially for N and K, are highly variable (Wijnhoud et al., 2000). This was not identifiable from the lumped mean partial balances in the two sub-districts (Wijnhoud et al., 2003; see also Figure 13).

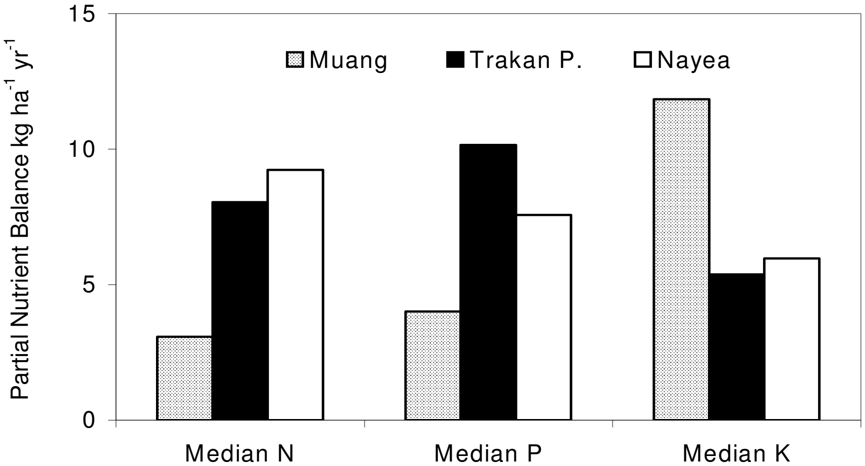


Figure 8. Median N, P and K partial LUT balances for 3 Districts in Ubon Ratchathani Province.

The semi-interactive interviews and field surveys indicated the impact of different biophysical and socio-economic factors on the inter- and intra-farm variability in partial nutrient budgets, although it was difficult to quantify these relationships (Wijnhoud et al., 2003).

4.1 Links between biophysical characteristics of land and nutrient budgets

In general, the 78 LUTs identified in the 30 farms evaluated in this study were characterized by relatively sandy soils and were situated on the old alluvial middle and upper parts of the toposequence within the gently undulating landscape. Few LUTs were located in the lowest micro- and meso-topographical positions. It is likely, therefore, that losses that were not included in the PNBAs, such as leaching, run-off (mainly N and K), and gaseous losses of N, will exceed the additional inputs that are not included in the PNBAs, such as surface and subsurface inflow, biological nitrogen fixation, wet and dry deposition, and gains from the subsoil by deep rooting plant species. The additional inputs and outputs not included in the PNBAs were estimated to be minor components. With well-managed bunds between the paddy fields, sedimentation, unlike subsurface flow, appears to be irrelevant (Wijnhoud et al., 2003). Considering these factors, particularly in the upper and middle topographical positions FNBAs can be expected to be more negative than the PNBAs estimated in this study. The magnitude of the difference may in part vary as a result of site characteristics such as the exact topographical position, soil texture, and for NPK, variations in input and output pathways (Wijnhoud et al., 2003).

In addition to the effect of bunds around the paddy fields, drainage characteristics are dominated by the combination of topographical position and soil texture. Other factors, however, do affect drainage rates and thus the estimated PNBs. For instance, the presence of shallow compacted, or impermeable layers, resulting from tillage practices or shallow iron pans and lateritic layers, can impede drainage. In general, the presence of such layers has positive effects on nutrient balances, by reducing leaching losses, as well as the important positive affect of maintaining water supply towards the end of the rice-growing season (Wijnhoud et al., 2003).

In most situations, there was little evidence of NPK inputs via water inflow into paddies except for two fields on two different farms in this survey, where inflow of nutrient-rich water added significantly to nutrient inputs, resulting in relatively high yields on fields with sandy soils and low fertilizer inputs. Farmers explained that the high yields were due to wastewater inflow from the households located directly above the fields.

In addition, for a limited number of fields investigated in this study animal wastes may constitute a significant on-farm source of NPK in inflow. While PNBAs will be underestimated where such sources are present, they can only be quantified accurately through very intensive monitoring and analysis. However, qualitative adjustments can be made to the interpretation of PNBAs where relevant. Many farmers appear aware of the inflow of nutrients in lower topographical positions and through wastewater inflow and some farmers adjusted their nutrient management accordingly (Wijnhoud et al., 2003).

The importance of site-specific conditions in the interpretation of PNBAs further emphasizes the risk of blanket nutrient or other management recommendations. Oberthür et al*.,* (1999) also demonstrated the micro-topographical and related spatial variability in the natural resource base characteristics of the region, on the basis of soil samples and mapping. Oberthür et al*.,* (1999) suggest that these short-range variations may create problems in the scaling up of data. Therefore, indigenous knowledge and/or careful observations on spatial variability of biophysical and non-biophysical factors can and should provide additional information for interpretation, particularly in data-sparse environments (Wijnhoud et al., 2003).

4.2 Problems and shortcomings of nutrient balance analyses (NBA)

The development and use of PNBAs has logical appeal to many farmers, extension officers, and researchers. However, there are problems in calculating PNBs and limitations in their application. Many of the weaknesses in PNBAs arise from the complexity of nutrient flows, interactions between nutrient pools, and measurement technique (Wijnhoud et al., 2000). Firstly, the fairly simple model used in accounting for nutrient flows does not take into account temporal or spatial variations in nutrient supply capacity or critical factors affecting the short to long term availability of nutrients as influenced by total nutrient contents, their release and crop uptake potentials. Secondly, the calculation of PNBs and FNBs relies on the accurate quantification of inputs and outputs, either for the particular case being studied or from appropriate default values and estimates. In the former situation, the results of PNBAs must be judged with caution, in the latter, quality data must be collected and research undertaken to develop easy methods of assessments, most appropriately incorporating the indigenous knowledge system and/or appropriate default values. As the method is data-intensive, strict priority setting, relying partly on expert knowledge, is needed to identify the most relevant factors within the nutrient balance and to determine the level of accuracy required. Optimal priority setting will depend on objectives, capacity and scale, both spatial and temporal, and, as such, will be site-specific and dynamic (Wijnhoud et al*.,* 2000).

In many nutrient balance studies the nutrient balance model as specified by Stoorvogel and Smaling, (1990) has been used implicitly considering it to be a FNB model. The model of Stoorvogel and Smaling, (1990) however, does not account for factors such as the redistribution of nutrients from the subsoil by deep rooting plant *sp*., inputs by weathering and losses due to immobilization in stable compounds or in above surface biomass. In addition, the model does not directly include the impact of subsurface inflow, including nutrient inputs by capillary rise, although this may be included if estimates of subsurface flows, including leaching, refer to net flows (Wijnhoud et al*.,* 2000).

Simultaneous application of methods from social and economic sciences could strengthen the nutrient balance approach and could provide the broader context within which the use of NBAs for wider practical implementation and for policy making need to be set (Scoones and Toulmin, 1998).

4.3 Shortcomings and advantages of partial nutrient balance analyses (PNBA)

The determination of PNBs instead of FNBs has several shortcomings. Partial balances provide quantitative data from which conclusions with respect to aspects of the sustainability of land use can be drawn, but only with caution. The essence of appraising omitted factors within PNBs has been emphasised already. This needs to be done in site- and on a nutrient-specific basis, especially in spatio-temporally highly variable environments, such as the micro-topographic catenae superimposed with erratic rainfall, encountered in the study area. It is difficult, time consuming and expensive to obtain accurate information regarding nutrient inputs via dry and wet deposition, biological nitrogen fixation, and subsurface inflow and outputs via gaseous losses, leaching and other subsurface outflows and erosion. However, a conceptual and qualitative understanding of the magnitude and variability of these inputs and outputs is essential. Their spatial variability is associated with sets of environmental conditions that vary per input and output term. In this study, appraisal of drainage patterns and hydrological flows will be most relevant for estimation of full N and K balances, while appraisal of gaseous losses, through denitrification and volatilisation, and biological nitrogen fixation may be relevant for the estimation of full N balances. Similarly to leaching, gaseous losses are site- and case-specific, depending on the type of N-inputs applied, timing and method of application and a wide range of spatio-temporally varying environmental conditions. Biological nitrogen fixation is only relevant when leguminous species have been included within cropping systems, like peanuts for some LUTs in the pilot study (Wijnhoud et al., 2000). Paradoxically, a major strength of PNBA derives from the omission of difficult-to-assess factors. The option of flexible, dynamic, site-specific appraisal of the omitted factors may be preferable to the use of transfer functions or investing disproportionately in their accurate measurement. In addition, the determination of PNBs fits much better than FNBAs with the participatory decision support efforts and the elaboration of a decision support tool for nutrient management to be applied by farmers and extension workers. The use of complex data intensive sensitive transfer functions might easily result in major mistakes or inaccuracies, especially if recklessly extrapolated and applied without sufficient calibration and validation.

4.4 Accuracy of measurement and estimation

The weakest points with respect to the accuracy of PNBs in this, and most other studies are likely to be the estimated and/or default values that are used (Wijnhoud et al., 2000). Estimates of the nutrient contents of fertilizers and the amounts applied can be determined to a high level of accuracy. Estimates of the product off-take in terms of yield may introduce errors depending on the method adopted. Estimates of the amounts and nutrient contents of crop residues and that removed in the yield component is highly dependent on Quality Assured sample collection, preparation and analyses. In addition, large inaccuracies in PNBAs are likely to occur in the estimates of amounts and, more particularly, nutrient contents of organic manures applied. In the pilot survey (Wijnhoud et al., 2000), two different combinations of estimates of N content in organic manure were used for the assessment of partial N balances for the 10 farms. These different combinations resulted in considerable differences in partial N balances (Figure 9), with balances decreasing for farms using cattle manure and increasing for those using large amounts of poultry manure, compared to the original default (default 1). Nutrient contents in manure vary considerably and better scientifically based estimates must be obtained to increase the accuracy of nutrient balances.

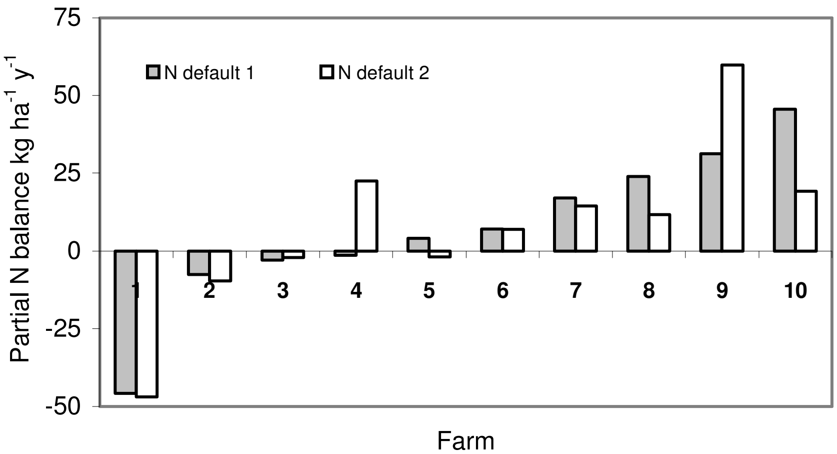


Figure 9. The effect of using different default values of N contents in manures on the range of partial N balances for the 10 farms (adapted from Wijnhoud et al., 2000). NB: Default 1: cattle manure N (%) = 1.58 (Dhanyadee, 1984), poultry manure N (%) =1.23 (average for chicken and duck manure according to Dhanyadee, 1984); Default 2: cattle manure N (%) = 0.9 (Naklang et al., 1988), poultry manure N (%) = 3.52, (Ariyathaj et al., 1988).

Another inaccuracy is associated with nutrient losses during burning of rice stubble, which in the pilot study occurred prior to land preparation for the cultivation of peanuts (Wijnhoud et al., 2000). The estimate for N-loss on burning (65%) was based on a relatively reliable experimental measurement (Chaitep, 1990). However, the estimates for losses of P (25%) and K (25%) are less accurate. Although nutrient balance calculations would be improved by better estimates of nutrient loss on burning and how losses relate to characteristics such as the degree of burning and the micro-climatic and environmental conditions, this may not be that critical as burning is decreasing in Northeast Thailand (Wijnhoud et al., 2000). Again, strict priority setting is needed in maximising accuracy, considering the limited capacity available.

The process will be facilitated where easy access exists to relevant secondary data sets. There is a great need to collect and collate existing data for particular climates, cropping systems, crops and soils, and to augment these data with new sampling programs and analyses where required. In this perspective, the secondary or 'default' data component of e.g. the NBS-NET RDBS could serve as a NBA-sustaining secondary data set for other studies and applications, such as decision support tools (Wijnhoud et al., 2003).

5. Integrated analyses

In combination with socio-economic data, PNBs can indicate factors that are important for the sustainable management of soils and that can be used to develop improved recommendations, aimed at both biophysical and socio-economic aspects of sustainability (Ref. Section 1). NBA can serve as a template for socio-economic accounting and financial assessment of nutrient depletion and surpluses (UNSD, 1993; De Jager et al., 1998a and 1998b; Drechsel and Gyiele, 1999; Moukoko Ndoumbe, *this proceedings*).

5.1 Links between socioeconomic factors, rice production, and natural resource management
Diversification of household activities, through off-farm employment, non-agricultural on-farm income, such as weaving, and diversification of the agricultural system, beyond the rice base, has a large impact on household wealth. As such, the various forms of diversification can affect the capacity of the household to manage the natural resources of the farm (Wijnhoud et al*., 2000* and 2003).

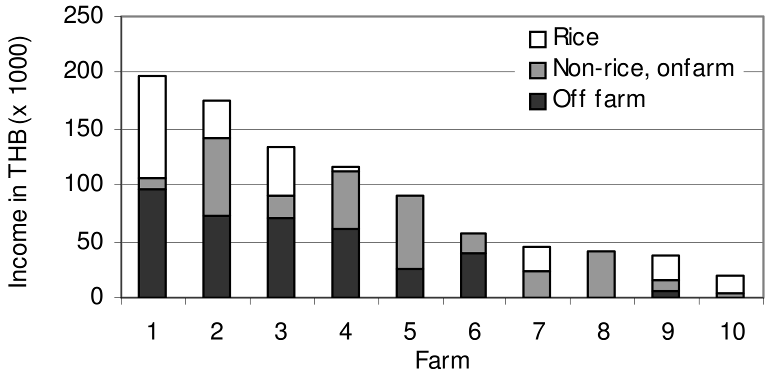


Figure 10. Components of annual farm income for 10 farms surveyed in Muang District, Ubon Ratchathani Province, Northeast Thailand.

Results of the pilot survey reveal that off-farm employment has the greatest impact on household income (Figure 10). The total gross household income for the 10 farms in the survey, and the proportion of income from the sale of rice, from other farm income, and from off-farm income vary markedly between farms. Diversification of income sources, particularly off-farm employment, appears to have a larger impact on household income than rice production.

A similar tendency was found for the main survey of 30 farms (Wijnhoud et al., 2003). Across the 30 farms, there was a strong and highly significant positive relationship between net off-farm income and the total of net off-farm income and gross farm income ($P < 0.001$). However, it should be noted that this relationship is strongly affected by a small number of higher income households with more than THB100,000 annual income from off-farm employment (Wijnhoud et al*.,* 2003*).* Despite the fact that non-rice income sources, particularly off-farm income, were the most important income sources for many of the better-off households, rice production provided a significant contribution to their income, which placed them among the households with the highest gross values of rice production (Wijnhoud et al., 2003). For the main survey cost-benefit analyses for rice production at farms surveyed revealed benefit/cost ratios between 2.5 and 3.5, meaning production costs amounted to between 25 and 35 percent of the gross rice value. Calculated benefit-cost ratios of non-rice farm activities were highly variable, but in general, exceeded 2.0.

The importance of rice is indicated by the fact that even the households with large off-farm income identified themselves as rice farmers. The gross value of household rice production, which, on average, is equivalent to approximately 40 percent of the total of gross farm and net off-farm income (Wijnhoud et al., 2003), plus the correlation between rice income and total income, show that this is more than a perceived social typology. For many less well-off households, rice was the most important source of income and, as such, was essential for their livelihoods (Wijnhoud et al*.,* 2003).

As revealed by Wijnhoud et al., (2003) there was no correlation between fertilizer use and the financial situation of the farm household ($P >> 0.05$). Despite this lack of correlation, interviews indicated that income was a factor in decisions on fertilizer use. Some of the better-off farmers chose to invest in fertilizers, whilst others appeared to ignore nutrient management, because of their focus on off-farm activities. With a sample of only 30 households, there was little possibility of statistically identifying the wide range of socio-economic or biophysical factors that might distinguish these two groups (Wijnhoud et al., 2003).

As long as the socio-economic situation does not permit an increase in off-farm income, solutions have to be sought on farm. Solutions might include farm diversification and increased use of alternative organic and inorganic inputs, and may require greater access to capital and credit (Wijnhoud et al., 2003). The fact that most of the farms in the survey raise fish on a commercial basis and some raise poultry and cultivate vegetables commercially, indicates this tendency for farm diversification.

5.2 Integrated environmental and socio-economic accounting

Within NBS-NET multiple-scale NBA was performed and used for more integrated environmental and socio-economic analyses, based on the main survey of 30 farms, which involved livelihood and correlation analyses, as well as integrated environmental and socio-economic accounting.

Conventional Economic Accounting (CEA) for agricultural and farming systems largely ignores costs associated with the degradation and/or depletion of natural resources and pollution and other negative environmental impacts (Moukoko Ndoumbe, *this proceedings*). Conversely, during the last two decades, both agricultural and environmental scientists have worked on methods to assess deficits and surpluses of nutrients through NBA. These were largely driven by biophysical research interests and aimed at the improvement and biophysical sustainability of agricultural production systems (Penning de Vries and Djitèye, 1982; Stoorvogel and Smaling, 1990). Partly induced by ‘Agenda 21’, the Plan of Action of the United Nations Conference on Environment and Development in Rio de Janeiro in 1992 (UNCED, 1992), the discipline of environmental economics has rapidly gained in importance. Various steps have been made towards methodological improvement in integrated socio-economic and environmental accounting (UNSD, 1993; Drechsel and Gyiele, 1999; Moukoko Ndoumbe, *this proceedings*).

5.3 Fertilizer survey and calculation of N, P and K retail prices

Average retail prices, i.e. the values of elemental N, P and K have been determined based on a fertiliser consumption and price survey. For all 78 LUTs, and distinguishable cropping system-management combinations on the 30 farms evaluated in the main survey, data on type and consumption of mineral fertiliser for the 1999 growing season was collected. The price ratio of N, P and K was derived from the prices of their raw materials (Table 2).

Table 2. Calculation of price ratio between elemental N, P and K.

US$ t^{-1}*	Ammonia	H_3PO_4	KCl
	140	276.8	94.7
Unit	N	P	K
Unit (%)	80	23	49.8
US$ kg^{-1}	0.18	0.87	0.19
Price ratio	1	4.8	1.1

* International prices in June 1998 (Fertecon, 1998)

Table 3. Cost (Thai Baht) per N, P and K unit expressed in N price equivalents per fertilizer; fertilizer price survey and N equivalent prices.

Price-ratio*	1.0 1.0	4.8 0.44	1.1 0.83	Sum (THB)	Price (kg)	
	N	P	K		100 kg	**N-eq.
Fertilizer						
15-15-15	15	32	13	60	862	14.3
16-16-8	16	34	7	57	712	12.5
16-20-0	16	43	0	59	692	11.8
$(NH4)_2SO_4$	21	0	0	21	400	19.0
Urea	46	0	0	46	531	11.5
					Mean	13.8

* Conversion ratio oxide → elemental form
** (N equivalents)

Table 4. Calculation of weighted mean N-equivalent price based on NPK-source (input) consumption.

	Input NPK (kg)	Weight Factor	Prices N-eq. (THB kg^{-1})	Weighted N-eq. (THB kg^{-1})
Fertilizer				
15-15-15	254	0.05	14.3	0.7
16-16-8	3732	0.70	12.5	8.8
16-20-0	1002	0.19	11.8	2.2
$(NH4)_2SO_4$	12	0.00	19.0*	0.0
Urea	302	0.06	11.5*	0.7
Sum	5302	1	13.8	12.4**

* $(NH4)_2SO_4$ is the most expensive and urea the cheapest N-source
** The weighted mean equivalent price amounts to 12.4 THB kg^{-1}

Subsequently, the cost per unit nutrient (N, P and K), based on their price ratio and the conversion rates from oxides into elemental form, has been expressed in N-price equivalents (N-eq.) for each macro-nutrient (N, P or K) and the total of all macro-nutrients per fertiliser (Table 3). A fertiliser price survey for the 30 farms yielded data on average farm gate prices per 100 kg of the 5 types of mineral fertiliser consumed in the area (Table 3). For each type of fertiliser the N-equivalent price (per kg) is obtained by dividing the average price of 100 kg of fertiliser by the percentage N-equivalents within the fertiliser (Table 3). By averaging the values of the 5 fertilisers, an average N-equivalent price is derived (Table 3). This value, however, has not been corrected for the market share of each of the consumed mineral fertilisers. A weighted N-equivalent price (N-eq.), based on the consumption of each of the fertilisers, will provide a more realistic outcome (Table 4). The weighted average N-equivalent price amounts to 12.4 Thai Baht per kg (THB kg^{-1}) (Table 5). Based on the existing price ratio of elemental N, P and K, their mean elemental retail prices, as corrected for the relative purchase of mineral NPK-sources, were calculated (Figure 11). They amount to 12.4, 60 and 13.2 THB kg^{-1} N, P and K, respectively. This directly shows the relatively high price of P as compared with that of N and K.

5.4 Monetary assessment of inputs and monetary partial balances

The calculated mean prices of elemental N, P and K were used to assess the input costs per nutrient in mineral fertilizer (Table 5). The real costs for mineral fertilizer application will be somewhat higher than the costs of elemental nutrients, as transport and labour costs have not been accounted for. The ratios indicate that the proportions in which macro-nutrients are applied to the system are imbalanced, even more so if crop requirements would be considered. Remarkably, farmers tend to invest about twice as much in P as compared with either N or K, even though there is evidence that N and K are limiting crop growth in rainfed lowland rice-based systems of Northeast Thailand (Konboon et al., 2001).

Table 5. Mean nutrient inputs and their monetary costs/values for 78 LUTs on 30 farms.

	N	Mean	*SD*	Mean	*SD*
		(kg ha^{-1} y^{-1})		*(THB ha^{-1} y^{-1})*	
Mineral					
N	77	35	22	434	273
P	77	14	7	840	420
K	64	14	9	183	118
Organic					
N	52	6	10	74	124
P	52	2	5	120	300
K	52	8	16	105	211
Total					
N	77	39	25	484	310
P	77	16	9	960	540
K	73	18	17	236	224

* N (number of non-zero values), Mean and SD (standard deviation) refer to non-zero values. One LUT did not receive inputs.

Macro-nutrtients in organic inputs were valued on the basis of the calculated 'equivalent' retail prices of N, P and K in mineral fertilizers (Table 5). The monetary value of macro-nutrients in organic inputs comprises a small, yet significant share of the overall value of nutrients added to the system.

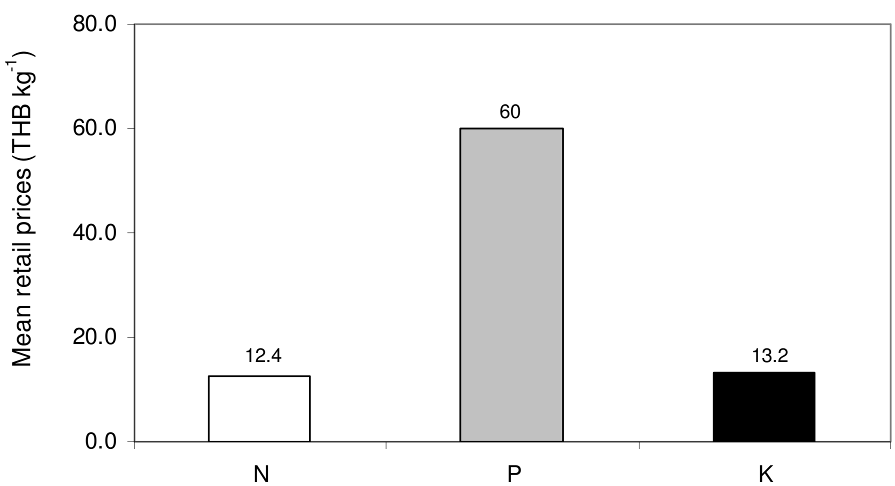


Figure 11. Mean retail prices of elemental N, P and K as based on prices of raw materials and mineral fertilizers and their relative consumption. Price ratio of N:P:K = 1:4.83:1.06

The word 'value' instead of 'costs' is used, as not all organic inputs may have been purchased. Even if all organic inputs would have been purchased, it would be hard to estimate the costs of their nutrients, depending on farmer's motives for purchase of organic materials. Organic inputs may or may not have been purchased. If purchased, additional transport and labour cost may be involved in their application.

In contrast to mineral fertilizers, valuation of organic inputs should not be based on their nutrient contents only (Drechsel and Gyiele, 1999). Hence, it is hard, or even impossible, to estimate the relative value of nutrients in these multi-functional materials. Functions of organic inputs may vary, but in general they improve soil structure and increase water and nutrient retention capacity and thus usually will result in increased nutrient recovery from mineral fertilizers. The monetary NPK-ratio in organic inputs is much more balanced as compared with mineral fertilizers, while in physical terms it appears to better match the NPK-ratio required by crops. Even though organic amendments appear to contribute only marginally to crop nutrient requirements, they appear to be especially relevant for adding K to the system (Konboon et al., 2001).

This is particularly relevant in a nutrient management situation where applied mineral fertilizers appear to contain disproportionally low quantities of K (Table 5). It should be emphasized that the type of nutrient input significantly affects nutrient availability and recovery efficiency which is both input type- and LUS-specific. However, in valuing the nutrients in organic and inorganic sources, differences in nutrient release and recovery under different circumstances have not been taken into account (Konboon et al., 2001). In general, nutrient release will be much slower from organic than from inorganic inputs. Overall recovery efficiencies in the long term, taking into account more than one growing season, will generally be higher for organic than for inorganics, if recovery efficiency includes storage, whereas short-term recovery efficiency by crops in general is much higher for inorganic inputs.

Using the weighted average retail prices determined for elemental N, P and K (Figure 11), costing and valuation may be performed in a similar way for (partial) N, P and K balances. Physical N, P and K balances can be expressed in monetary terms, further referred to here as partial monetary N, P and K balances. Partial monetary balances, unlike physical balances, provide direct insights into the monetary aspects of nutrient management practices. Monetary balances are mirror images of the PNBs, and are either amplified or dampened, depending on prices and price ratios. As already indicated PNBs may be very useful, provided due consideration is given to the likely magnitude of the FNB terms that are not included. The same holds for the partial monetary balances.

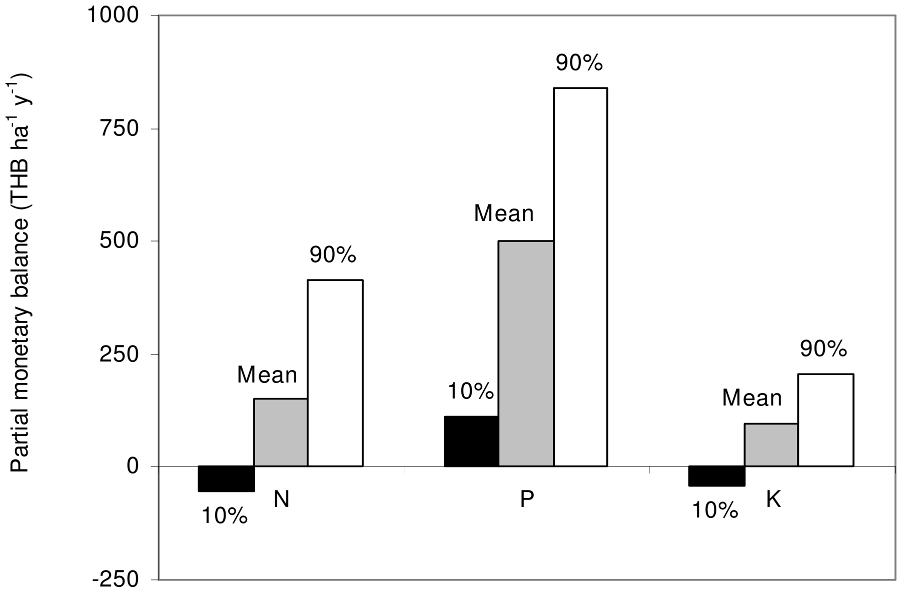


Figure 12. Partial monetary N, P and K farm balances for 30 farms (including 10 and 90 percentiles) based on average market prices of nutrients.

The graphical overview of monetary partial N, P, K balances of the 30 farms (Figure 12), reveals positive values at the farm level. For P, the average is even strongly positive with a positive 10-percentile value. Comparison between physical partial N, P and K balances and their corresponding monetary values at the LUT level reveals that absolute values of PNBs are most extreme and variable for N and K, while monetary partial balances are most extreme and variable for P (Figure 13). This is in part due to the prevailing prices and price ratios. On an individual farm basis, similar trends are observed at the LUT-level (Figure 5). Comparison of trends at the farm and LUT level indicate that results of the monetary partial balances are similar to those for PNBs as dependent on the scale of analysis. The negative 10 percentile partial monetary balance for P identified at LUT level (Figure 13) does not appear at the farm level (Figure 12)

At a district level, represented by complete data sets of farm and LUT data for the 30 farms (Figures 12 and 13), outcomes may be useful to assess nutrient management in biophysical and economic terms. Such district level analyses may be useful for policy makers, fertilizer retailers and industry, but also for farmer groups/associations and extension workers. The results reveal high investment in P and insufficient investment in N and K. This may be explained by the common use of compound N-P-K and N-P fertilizers (Table 4), in which the relative price of P is high. The average investment in mineral P of 840 THB ha^{-1} yr^{-1} is more than half of the average overall investment in mineral fertilizers (Table 5). The observed high investment in mineral P is even stronger if the nutrient requirements for the rice crop within these systems are considered (Konboon et al., 2001). N and K, rather than P, are generally considered most limiting to crop growth, where P only becomes critical in nutrient management strategies based on cropping systems that include leguminous crops, such as peanuts (Konboon et al., 2001; Wijnhoud et al., 2000).

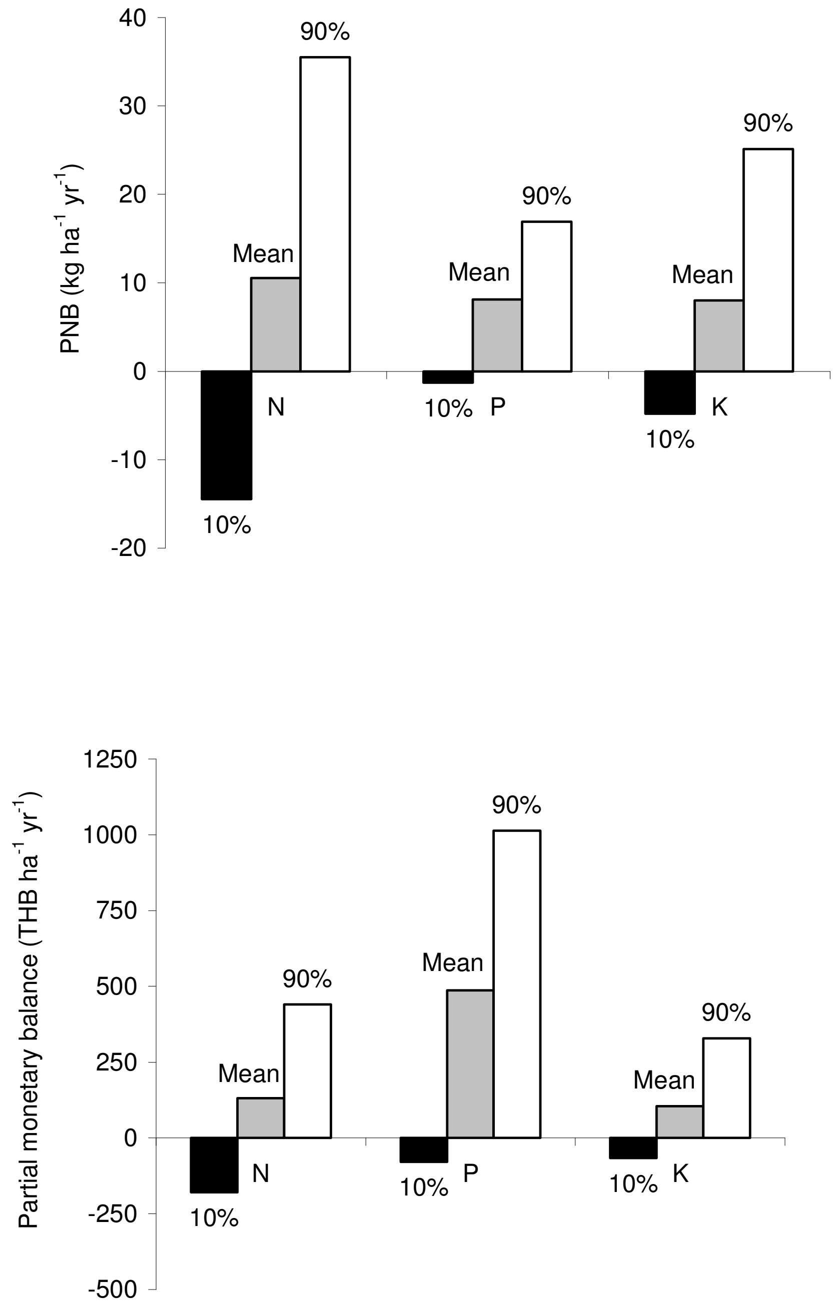
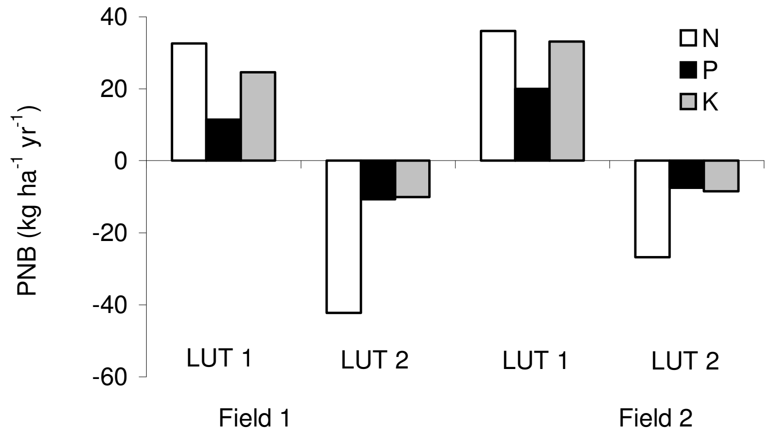


Figure 13. Comparison of biophysical PNBs and their monetary values/costs, based on average market prices of nutrients for 78 LUTs on 30 farms (including 10 and 90 percentiles) (PNB graph adapted from Wijnhoud et al., 2003).



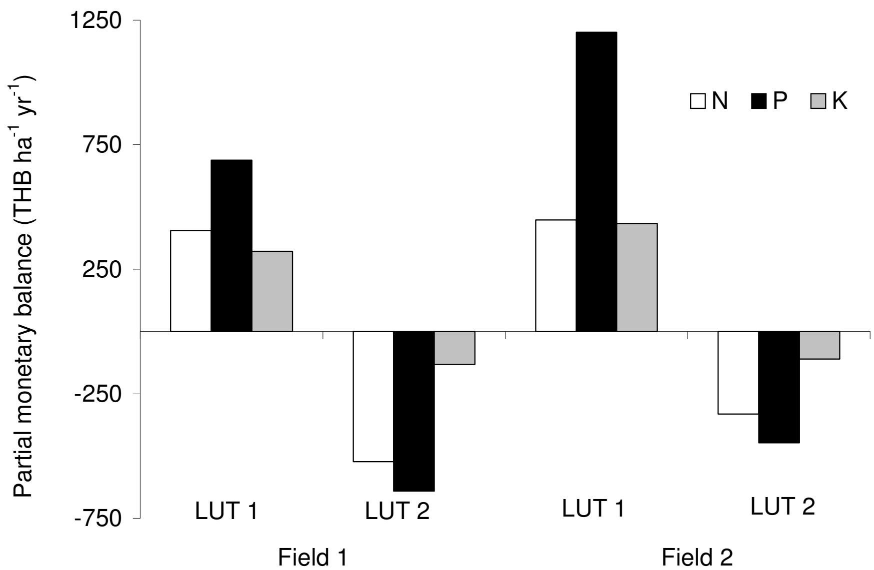


Figure 14. Comparison of biophysical partial balances and their monetary values/costs, based on average market prices of nutrients for 4 LUTs, 2 each on one field, of one farm (PNB graph adapted from Wijnhoud et al., 2003).

At the farm level, integrated socio-economic and environmental accounting could provide a very useful method to assess biophysical and socio-economic performance and sustainability. In addition, the results of such analyses may be useful for decision support aimed at promoting biophysically and socio-economically more sustainable land use systems. This may be further emphasized by evaluating the relationship between the partial physical and monetary N, P and K balances from one farm in Seped sub-District which is characterized by a high degree of intra-farm variability in both nutrient and monetary partial balances (Figure 14) (Wijnhoud et al*.,* 2003).

A first technical conclusion could be that inputs may not have been distributed homogeneously over the farm. Hence, possibilities might be examined to modify allocation of nutrients between the LUTs within one field, or if needed for a more optimal allocation, between fields. This means one could look into the possibilities of filling shortages of one nutrient in one LUT with a surplus of the same nutrient in another LUT. For monetary balances, unlike physical balances, negative values for one nutrient may be compensated by positive values for any other nutrient, so that re-arrangement of investments would be a possibility. In this way integrated economic and environmental accounting, based on nutrient and monetary balance analyses may serve as a decision support system with respect to nutrient management.

Surely, this reasoning would be too simple for formulation of recommendations and decision support, without considering additional information required for full nutrient and monetary balances and the broader context. Evaluating the results in a broader context for example, might reveal that negative partial balances may be associated with high off-take in harvested products, rather than with insufficient use of inputs. This might be the case where relatively high yields are obtained on inherently fertile soils (Wijnhoud et al*.,* 2003). Such situations may occur in lower sections of toposequences, where sufficiently large nutrient pools are sustained by continuous nutrient inflows of N and K from upper sections of the toposequence (Poltanee et al., 1998) which are not accounted for in the PNBs. Such systems, characterized by negative PNBs may be sustainable and the result of well-considered farmer management.

In this perspective, one should be aware that farmers may have their reasons for heterogeneous distribution of inputs, aiming for optimising production and sustainability. Integrated physical and monetary partial nutrient balance assessment will only be useful in practice, if combined with simple field monitoring for site-specific aspects, preferably led by the farmers.

6. Discussion and Conclusions

This study has clearly shown that diversification of income sources, through off-farm employment, non-agricultural on-farm income, such as weaving, and diversification of the agricultural system, has a large impact on household wealth. This, in turn, can affect the capacity of the household to manage the natural resources of the farm. Off-farm employment has, on average, the largest impact on household income, with a very strong influence from higher-income households. Therefore, at a regional level the aim of perpetuating a predominantly agricultural society, even through introduction of innovative agricultural developments, would be an inappropriate starting point for general R&D policy (Wijnhoud et al., 2003).

Decisions regarding land management made by farmers are based on their integrated analysis of a wide range of biophysical, socio-economic, cultural and political factors. Therefore, sustainability analyses and R&D must be interdisciplinary and participatory. Farmers indicated that constraints in financial and labour resources are significant socio-economic factors that, in combination with appreciation of biophysical variability, result in heterogeneous resource allocation, and thus management, between and within farms. Because of the large number of factors that influence decision making, the difficulties in accurately measuring these factors and the relatively small number of farms and fields sampled in this survey, it is not surprising that significant relations could not be established between the multitude of individual farm-specific factors and management. Moreover, farm managerial behaviour is not only determined by biophysical and socio-economic factors, but also by difficult-to-assess intangible factors related to private constraints and opportunities, as well as by personal skills, capacity and character, involving purely subjective behaviour (Wijnhoud et al., 2003).

By investigating small scale variability in management, adapted to variability in biophysical characteristics and variations in the socio-economic setting, improvements may be possible in the decisions made by farmers who are constrained by resource limitations. Interesting research topics, related to socio-economic factors include the impact of non-rice agricultural income and non-agricultural income, both on- and off-farm, on land management; the impact of off-farm labour on farming practices through changes in the availability, gender, and education of farm labour; and the impact and opportunities for farm diversification and reduced reliance on rainfed rice (Wijnhoud et al., 2000). Identification of at least some relevant socio-economic and biophysical factors that affect nutrient budgets, e.g. through correlation and/or regression analyses, and that encompass major heterogeneities at different scales, will increase the possibility of developing effective decision support tools.

Expressing physical N, P and K balances in monetary terms may increase awareness an be used as a basis for improved biophysical and socio-economic nutrient management and sustainable land management. Monetary balances, unlike physical balances, may provide direct financial insights into nutrient management practices. If such integrated environmental and socio-economic accounting is based on multiple-scale NBA, scale-synergy may add to the inherent synergistic advantages of interdisciplinary analysis. It needs to be emphasised that where PNBs are assessed, this "partiality" also affects the results of the monetary balances. Monetary balances are, in general disproportionate, mirror images of physical PNBs, amplified or weakened depending on prices and price ratios. It is clear that integrated environmental and socio-economic accounting is a promising tool for the design of improved farm and land management regimes, as well as for policy and marketing purposes. The results of this study revealed and emphasized aspects of inappropriate fertilizer use, especially the high P-content in compound fertilizers and thus unnecessary high investments in relatively expensive P. At the farm level, the methods adopted in this study provide useful insights for biophysically more balanced and economically more viable nutrient management packages. In addition to the relevance of these case-study outcomes themselves, the study may have a paradigmatic value and includes some innovations that could be followed in future efforts, including those aimed at decision support at the policy level and for the fertilizer sector (producers and retailers) and the development of a Decision Support Tools (DST) for dynamic and site-specific decision support for farmers and extension workers.

References

ADB (1999). ADB Online News Release No.28/99. Asian Development Bank. Manila, Philippines.

Andriesse, W., Fresco, L.O., Van Duivenbooden, N. and Windmeijer, P.N. (1994). Multi-scale characterization of inland valley agro-ecosystems in West Africa. *Netherlands Journal of Agricultural Science 42:* 159-179.

Ariyathaj, C., Prapanpong, S., Soravitsutra, Y., Deemark, R. (1988). Rapid composting by nitrogen activator from various sources. In: *Soil Science Annual Report for 1987/1988*. Soil Science Division, Department of Agriculture, Bangkok, Thailand. pp. 144-156.

Chaitep, W. (1990). The use of fertilisers and crop residues as sources of sulfur in flooded and unflooded rice-cropping systems. Ph.D.-thesis, University of New England, Armidale, New South Wales, Australia. 120 pp.

Coughlan, K.J., Lefroy, R.D.B. (2001). Assessment of Sustainable Land Management using the Framework for the Evaluation of Sustainable Land Management: The IBSRAM experience. Issues in Sustainable Land Management no.8. International Board for Soil Research and Management. Bangkok, Thailand.

De Jager, A., Nandwa, S.M., Okoth, P.F. (1998a). Monitoring nutrient flows and economic performance in African farming systems (NUTMON). I: Concepts and methodologies. *Agriculture, Ecosystems and Environment* 71: 37-48.

De Jager, A., Kariuku, I., Matiri, F.M., Odendo, M., Wanyama, J.M. (1998b). Monitoring nutrient flows and economic performance in African farming systems (NUTMON). IV: Linking nutrient balances and economic performance in three districts in Kenya. *Agriculture, Ecosystems and Environment* 71: 81-92.

Defoer, T., De Groote, H., Hilhorst, T., Kante, S., Budelman, A. (1998). Participatory action research and quantitative analysis for nutrient management in Southern Mali: A fruitful marriage? *Agriculture Ecosystems and Environment* 71: 215-228.

Defoer, T., Budelman A., Toulmin, C., Carter, S.E. (2000). Building common knowledge. Participatory learning and action research (Part I). In: Defoer, T., Budelman A. (eds.) Managing Soil Fertility in the tropics. A resource guide for participatory learning and action research. Royal Tropical Institute (KIT), Amsterdam, The Netherlands. 207 pp.

Dhanyadee, P. (1984). Organic recycling in Thailand. *Paper presented at the Technical Workshop on the problem of land with declining and stagnating productivity.* November 6-9, 1984, Pattaya. Thailand.

Drechsel, P., Gyiele, L.A. (1999). The economic assessment of soil nutrient depletion. Analytical issues for framework development. *Issues in Sustainable Land Management no.*7. IBSRAM / SWNM, Bangkok, Thailand. 80 pp.

Fertecon (1998), http://www.fertecon.com: fertilizers, economic market analysis and consultancy.

Fukuda-Parr, S., Lopes, C., Malik, K. (2002), Capacity for Development: New solutions to old problems. United Nations Development Programme. Earthscan Ltd. London, UK. 284 pp.

Kam, S.P., Oberthür, T. (1998). Delineating resource management domains in highly variable and data-sparse environments. In: Syers, J.K., Bouma, J. (eds.). *Proceedings of the Conference on Resource Management Domains; International Workshop on Resource Management Domains.* IBSRAM Proceedings no.16. IBSRAM, Bangkok, Thailand. pp. 225-244.

Konboon, Y., Wijnhoud, J.D., Lefroy, R.D.B. (2001). Nutrient management in rainfed lowland rice-based systems in Northeast Thailand. In: Kam, S.P., Hoanh, C.T., Trebuil, G., Hardy, B. (eds.). *Natural resource management issues in the Korat*

Basin of Northeast Thailand: An overview. IRRI Limited Proceedings No.7. IRRI, Manila, Philippines. pp. 137-146.

Lefroy, R.D.B., Bechstedt, H.D., Rais, M. (2000). Indicators for sustainable land management based on farmer surveys in Vietnam, Indonesia and Thailand. *Agriculture, Ecosystems and Environment* 81: 137-146

Lefroy, R.D.B., Konboon, Y. (1998). Studying nutrient flows to assess sustainability and identify areas of depletion and imbalance: an example for rainfed rice systems in Northeast Thailand. In: Ladha, J.K., Wade, L.J., Dobermann, A., Reichardt, W., Kirk, G.J.D. and Piggin, C. (eds.), *Rainfed lowland rice: Advances in Nutrient Management Research*. Proceedings of the International Workshop on Nutrient Research in Rainfed Lowlands, 12-15 Oct. 1998, Ubon Ratchathani, Thailand. IRRI, Philippines. pp. 77-93.

Miyagawa, S., Kono, Y., Nagata, Y., Nawata, E. (1998) Technical changes in rainfed rice cultivation in Northeast Thailand. Japanese Journal of Crop Science 67, pp. 264-265.

Moukoko-Ndoumbe, F. (*this proceedings*), Integrated economic and environmental accounting (Background/Discussion Paper). Paper presented at International Workshop on Nutrient Balances for Sustainable Agricultural Production and Natural Resource Management in Southeast Asia, 20-23 February 2001, Bangkok, Thailand.

Naklang, K., Loudhapasitiporn, L., Seetanun, W., Rochanakusol, S., Sunthornpitak, S., Podisuk, V. (1988). Rice fertilizer trials on sandy soils in Roi-Et Province. In: *Soil Science Annual Report for 1987/1988*. Soil Science Division, Department of Agriculture, Bangkok, Thailand. pp. 51-61.

OAE (1999). Agricultural Statistics of Thailand Crop Year 1997/98. Center for Agricultural Information, Office of Agricultural Economics. Ministry of Agriculture and Co-operatives, Bangkok, Thailand. Agricultural Statistics No. 31/1999.

Oberthür, T., Goovaerts, P., Dobermann, A. (1999). Mapping soil texture classes using field texturing, particle size distribution and local knowledge by both conventional and geostatistical methods. *European Journal of Soil Science* 50: 457-479.

Penning de Vries, F.W.T., Djitèye, A.M. (1982) *La productivité des pâturages sahéliens. Une étude des sols, des végétations et de l'exploitation de cette ressource naturelle*. Agricultural Research Report 918. Pudoc, Wageningen. 525 pp.

Poltanee, A., Treeloges, V., Rouaysoongnern, S., Patanothai, A. (1998). Sustainability analysis of existing land-use systems in Northeast Thailand. In: Patanothai, A. (ed.) *Land degradation and agricultural sustainability: Case studies from Southeast and East Asia*. Regional Secretariat of the Southeast Asian Universities Agroecosystem Network (SUAN), Khon Kaen University, Khon Kaen, Thailand. pp. 117-132.

Scoones, I., Toulmin, C. (1998). Soil nutrient balances: what use for policy? *Agriculture, Ecosystems & Environment*. 71 (1-3): 255-267.

Smyth, A.J., Dumanski, J. (1993). FESLM: An international framework for evaluating sustainable land management. FAO World Soil Resources Reports No. 73. FAO, Rome, 74 pp.

Stoorvogel J.J., Smaling, E.M.A. (1990) Assessment of soil nutrient depletion in Sub-Saharan Africa: 1983-2000. Report 28, Winand Staring Centre, Wageningen, the Netherlands. 137 pp.

Syers, J.K., Bouma, J. (eds.) (1998). International Workshop on Resource Management Domains. Proceedings of the Conference on Resource Management Domains. IBSRAM Proceedings no.16. IBSRAM, Bangkok, Thailand. 322 pp.

UNCED (1992). Agenda 21. United Nations Conference on Environment and Development. Rio de Janeiro, Brazil.

UNSD (1993), Handbook of National Accounting - Integrated Environment and Economic Accounting. United Nations Statistics Division, Document F, No.61, New York, USA.

Wijnhoud, J.D., Konboon, Y., Lefroy, R.D.B. (2000). Towards greater sustainability in rainfed lowland rice-based systems in Northeast Thailand. Paper presented at the IUSS-BSWM International Conference on Paddy Soil Fertility, Manila, April 24-27, 2000. Manila. 12p.

Wijnhoud, J.D., Konboon, Y., Lefroy, R.D.B. (2003). Nutrient budgets: Sustainability assessment of rainfed lowland rice-based systems in Northeast Thailand. *Agriculture, Ecosystems & Environment 100: 119-127.*

Yuvaniyama, A. (2001). Managing problem soils in Northeast Thailand. In: Kam, S.P., Hoanh, C.T., Trebuil, G., Hardy, B. (eds.). *Natural resource management issues in the Korat Basin of Northeast Thailand: An overview*. IRRI Limited Proceedings No.7. IRRI, Manila, Philippines. pp. 147-156.

Sustainability Analysis of Existing Land-use Systems in Northeast Thailand

Viriya Limpinuntana[1], Vidhaya Trelo-ges[2], Patma Vityakon[2] and Aran Patanothai[1]

[1] *Department of Agronomy*
[2] *Department of Land Resources and Environment, Faculty of Agriculture, Khon Kaen University, Khon Kaen, Thailand.*

ABSTRACT

Agricultural systems in Northeast Thailand have been developed on marginal sandy soils within an undulating landscape. Agricultural productivity has declined considerably under the currently adopted land use systems as indicated by declining crop yields and an increasing dependency on chemical fertilizers. This has resulted in skepticism with regards the sustainability of the current the land-use systems of the region.

From 1999-2001 researchers at Khon Kaen University conducted research to evaluate the sustainability of currently adopted land-use systems using a nutrient balance model. The project was funded by the National Research Council of Thailand (NRCT) and the Thailand Research Fund (TRF). The specific objectives of the project were to investigate nutrient inputs and outputs from selected land-use systems in a micro-watershed area; investigate changes in land use and management as affected by socioeconomic and cultural factors; model the characteristics and dynamics of land degradation in a micro-watershed, and to identify factors affecting land degradation. It is envisaged that knowledge gained from this project will lead to the development of sustainable land use and management for Northeast Thailand.

A micro-watershed at Ban Khummuang village, Khao Suan Kwang District, Khon Kaen Province, was selected as the study site. Nutrient balances were determined for the major land uses in the area, and for the entire micro-watershed under investigation. Specific studies relating to the different input and output parameters were also conducted. These include studies on (1) ground cover and placement of surface structures under current land uses in relation to soil erosion, (2) rainfall-runoff relationships, (3) sediment transport, (4) unconfined groundwater hydraulics, (5) subsurface flows of nutrients, (6) estimation of the water table in paddy systems, and (7) soil organic matter build up and dynamics under the selected land-use systems. A summary of the nutrient balance studies is presented in this paper. It should be noted that the nutrient balance analysis did not include nutrient loss from leaching; nutrient gain and loss from accumulated moisture and runoff or wind erosion; and nutrient gains from capillary water in the soil, and weathering of parent materials, N fixation, and livestock manure. The results represented in this paper can therefore only be considered as an incomplete and estimated nutrient balance for the agricultural systems evaluated.

INTRODUCTION

From 1999-2001 researchers at Khon Kaen University conducted research to evaluate the sustainability of currently adopted land-use systems using a nutrient balance model. The specific objectives of the project were to investigate nutrient inputs and outputs from selected land-use systems in a micro-watershed area; investigate changes in land use and management as affected by socioeconomic and cultural factors; model the characteristics and dynamics of land degradation in a micro-watershed, and to identify factors affecting land degradation.

MATERIALS AND METHODS

A micro-watershed at Khummuang village, Khao Suan Kwang District, Khon Kaen Province, was selected as the study site. A rapid rural appraisal was conducted to obtain information on landuse, and land management practices. Nutrient balances were determined for the major land uses in the area, and for the entire micro-watershed under investigation.

Specific studies relating to the different input and output parameters were also conducted. These include studies on (1) ground cover and placement of surface structures under current land uses in relation to soil erosion, (2) rainfall-runoff relationships, (3) sediment transport, (4) unconfined groundwater hydraulics, (5) subsurface flows of nutrients, (6) estimation of the water table in paddy systems, and (7) soil organic matter build up and dynamics under the selectedt land-use systems.

The land-use patterns investigated comprise eight subsystems of sugarcane planted at the end of the rainy season; cassava planted at the end of the rainy season; and rainfed paddy rice. The sugarcane subsystems used a combination of different chemical fertilizer rates, burning or not burning of leaves before harvesting, and planting on the upper or lower parts of upland fields. Chemical fertilizer applications were the primary source of nutrient inputs to the sugarcane subsystems., Rainfall data including N, P and K concentrations were obtained from secondary sources. Information on nutrient losses via eroded soil particles was obtained from secondary data derived from erosion plots located under similar agro-systems in Khummuang village. Nutrient outputs were determined on removed crop products, burned leaves, and eroded soil particles.

RESULTS AND DISCUSSION

Nitrogen (N), phosphorous (P) and potassium (K) showed positive balances for all sugarcane subsystem investigated (Tables 1-8). This infers that the current rates of fertilizer application are excessive. Further, increasing the rate of fertilizer application resulted in increasingly positive nutrient balances. In the case of the burned stubble, a significant amount of N was lost through burning but the nutrient balance for this element was still highly positive (Tables 2, 4, 6 and 8). There were no significant differences in the macronutrient balances for sugarcane grown on upper and lower upland fields (Tables 1-8).

Table 1. Nutrient balance of a sugarcane subsystem: Upper field with high fertilizer rate (stubble, not burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	93.75	40.91	77.81
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Total input	98.51	42.11	83.34
Outputs			
Sugarcane stems	22.62	1.78	32.24
Eroded soil particles	1.14*	0.07	3.06
Total output	23.76	1.85	35.30
Balance	74.75	40.26	48.04

* Estimated from erosion plots located under similar agro-systems Khummuang village.

Table 2. Nutrient balance of a sugarcane subsystem: Upper field with high fertilizer rate (stubble, burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	93.75	40.91	77.81
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Total input	98.51	42.11	83.34
Outputs			
Sugarcane stems	20.84	1.64	29.70
Losses from burning	4.47	0.58	0.55
Eroded soil particles	1.14*	0.07	3.06
Total output	26.45	2.29	33.31
Balance	72.06	39.82	50.03

Table 3. Nutrient balance of a sugarcane subsystem: Upper field with low fertilizer rate (stubble, not burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	46.88	20.46	38.91
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Total input	51.64	21.66	44.44
Outputs			
Sugarcane stems	16.67	1.31	23.76
Eroded soil particles	1.14*	0.07	3.06
Total output	17.81	1.38	26.82
Balance	33.83	20.28	17.62

Table 4. Nutrient balance of a sugarcane subsystem: Upper field with low fertilizer rate (stubble, burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	46.88	20.46	38.91
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Total input	51.64	21.66	44.44
Outputs			
Sugarcane stems	14.49	1.14	20.65
Losses from burning	12.52	2.38	3.21
Eroded soil particles	1.14*	0.07	3.06
Total output	28.15	3.59	26.92
Balance	23.49	18.07	17.52

Table 5. Nutrient balance of a sugarcane subsystem: Lower field with high fertilizer rate (stubble, not burned)

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	93.75	40.91	77.81
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Eroded soil particles (from upper fields)	15.44*	0.07	3.06
Total input	113.95	42.18	86.40
Outputs			
Sugarcane stems	23.42	1.84	33.37
Eroded soil particles	0.81	0.07	3.06
Total output	24.23	1.91	36.43
Balance	89.72	40.27	49.97

Table 6. Nutrient balance of a sugarcane subsystem: Lower field with high fertilizer rate (stubble, burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	93.75	40.91	77.81
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Eroded soil particles (from upper fields)	15.44*	0.07	3.06
Total input	113.95	42.18	86.40
Outputs			
Sugarcane stems	22.42	1.77	31.96
Eroded soil particles	0.81	0.07	3.06
Losses from burning	19.40	3.69	4.98
Total output	42.63	5.53	40.00
Balance	71.32	36.65	46.40

Table 7. Nutrient balance of a sugarcane subsystem: Lower field with low fertilizer rate (stubble, not burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	46.88	20.46	38.91
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Eroded soil particles (from upper fields)	15.44*	0.07	3.06
Total input	67.08	21.73	47.50
Outputs			
Sugarcane stems	16.87	1.33	24.04
Eroded soil particles	0.81*	0.07	3.06
Total output	17.68	1.40	27.1
Balance	49.40	20.33	20.4

Table 8. Nutrient balance of a sugarcane subsystem: Lower field with low fertilizer rate (stubble, burned).

Nutrient balance components	**Nutrients (kg ha^{-1})**		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	46.88	20.46	38.91
Rainfall	1.78	0.97	1.29
Planting material	2.98	0.23	4.24
Eroded soil particles (from upper fields)	15.44*	0.07	3.06
Total input	67.08	21.73	47.50
Outputs			
Sugarcane stems	16.07	1.27	22.91
Eroded soil particles	0.81*	0.07	3.06
Losses from burning	13.80	2.63	3.54
Total output	30.68	3.97	29.51
Balance	36.40	17.76	17.99

For cassava production, N and K showed negative balances while the balance for P was slightly positive (Table 9). This indicates that the current rates of fertilizer application are inadequate and further research is required to determine optimum rates of fertilizer application in relation to maximizing crop production. For rice production, N and P had positive balances while the balance for K was highly negative as the farmers did not add K fertilizer (Table 10). Apparently, K input is insufficient to cover the losses incurred from plant removal in the cassava and rice production systems investigated. All macronutrient balances were higher for sugarcane when compared to cassava and rice as the sugarcane received a higher fertilizer rate.

Table 9. Nutrient balance of cassava crop planted at the end of the rainy season.

Nutrient balance components	Nutrients (kg ha^{-1})		
Inputs	*N*	*P*	*K*
15-15-15 (N: P_2O_5: K_2O) fertilizer	28.13	12.27	23.34
Rainfall	1.78	0.97	1.29
Planting material	1.47	0.20	2.67
Total input	31.38	13.44	27.30
Outputs			
Cassava roots	31.88	4.39	58.00
Cassava stems	15.69	1.33	12.63
Eroded soil particles	6.42*	0.07	3.06
Total output	53.99	5.79	73.69
Balance	-22.61	7.65	-46.39

Table 10. Nutrient balance for rainfed rice planted in a paddy field.

Nutrient balance components	Nutrients (kg ha^{-1})		
Inputs	*N*	*P*	*K*
16-20-0 (N: P_2O_5: K_2O) fertilizer	25.00	13.64	0.00
Rainfall	1.78	0.97	1.29
Planting material	0.31	0.07	0.49
Total input	27.09	14.68	1.78
Outputs			
Rice grain	15.00	1.68	41.81
Rice straw	12.28	0.50	19.44
Total output	27.28	2.18	61.25
Balance	-0.19	12.50	-59.47

However, it should be noted that the nutrient balance analysis did not include nutrient loss from leaching; nutrient gain and loss from accumulated moisture and runoff or wind erosion; and nutrient gains from capillary water in the soil, weathering of parent materials, N fixation, and livestock manure. The results represented in this paper can therefore only be considered as an incomplete and estimated nutrient balance for the agricultural systems evaluated.

It has been hypothesized that the total nutrient loss from the whole watershed might not be equal to the sum of the loss from individual farm plots. Observation of the surface structures within the agricultural systems investigated indicates that a proportion of the potential nutrient loss associated with surface runoff (soil particles and water) may be retained before reaching the next plot thus preventing complete loss from the system. Such surface structures include tillage generated furrows and small scale surface depressions caused by weeding, natural and/or man made levees/dikes, and grass strips.

Visual observation of the ground cover and amount of soil loss generated by erosion suggested that cassava planted in the middle of the rainy season lost more soil particles, implying more nutrient losses, as opposed to cassava or sugarcane planted at the end of the rainy season (observations not quantified by field derived data).

CONCLUSIONS

Discussions with farmers revealed that they were aware of the influence of nutrient inputs and outputs on soil fertility. To a certain extent, farmers address nutrient balance components to maintain soil fertility through the use of chemical fertilizers.. However, due to land-use pressure, farmland in Northeast Thailand is increasingly associated with declining soil fertility that is currently addressed by the excess application of chemical fertilizers. The maintenance of farmland soil fertility requires higher costs or an extended fallow period for the land to recover. The incomplete estimated nutrient balances presented in this paper indicated that further studies are required to determine optimum rates of fertilizer application in relation to maximizing crop production.

Nutrient Balance Studies: General use and perspectives for SE Asia

Rod D.B. Lefroy[1] and J.D. Wijnhoud[2]

[1] Present address: Centro Internacional de Agricultura Tropical (CIAT), PO Box 783, Vientiane, Lao PDR E- mail address: r.lefroy@cgiar.org
[2] Netherlands Development Organization (SNV), PO Box 4468, Maputo, Mozambique, E-mail address: famwijnhoud@hotmail.com

Abstract

The principles behind nutrient balance studies and the comparison of inputs and outputs from a system have been at the heart of the development of plant nutrition as a science and the development of world agriculture. Only in relatively recent times, however, has there been much interest in using nutrient balance approaches to assess the status of agroecosystems and ecosystems in general.

Nutrient balances can be used across a wide range of scales - from a farmer's field to global – and for a wide range of reasons – for recommendations to farmers through to national policy making. A primary objective of nutrient budgeting has been to develop appropriate recommendations for management, particularly for the use of fertilizers, with the aim of increasing productivity. However, there is increasing use of nutrient balances for assessing a component of the sustainability of agroecosystems, as well as for broad scale policy decision-making.

The methods of estimating nutrient balances vary significantly, depending on the scale of the study and its objectives. Many studies, particularly those at higher scales namely, national and supranational rely almost solely on the use of secondary data. Most studies use some secondary or published data, while only a few, particularly those aimed at better understanding of the underlying processes, rely solely on measurements. The quality of the data that are used has a significant impact on the accuracy and precision, and thus the usefulness, of the calculated balance

Many of the nutrient balances that are calculated are partial balances in that they do not include all component inputs and outputs of the system. These must be interpreted with great care, such that the impacts of the component nutrient flows that are not included are not ignored completely. Even those nutrient balances that do attempt to include all component pathways must be interpreted carefully as the assumptions involved in estimating different flows can have significant impact on the results. Despite these potential weaknesses, both complete and partial nutrient balances can provide very useful information for a wide range of end-users. In most cases, decisions on the completeness of the calculated balances involves a trade-off between a more accurate assessment of a full balance, which may be very specific or very time-consuming and/or expensive, and a partial balance, which may be quicker, cheaper, and less specific, albeit with more significant caveats. A number of nutrient balance exercises, from different scales, and with different complexities, are briefly outlined as examples.

Introduction

Nutrient budgets and early developments in agriculture

Principles of assessing nutrient balance or nutrient budgets, being the comparison of inputs and outputs, have been at the heart of the development of plant nutrition and of agriculture more broadly. Many important examples of the early use of such analyses are outlined in the introductory section of "Soil Conditions and Plant Growth" (Russell, 1961). One of the earlier studies into how plants grow was the experiment of Woodward in 1699, in which he grew spearmint in different quality water. By measuring the mass of plant growth with different amounts of contaminants (Table 1) he concluded that the plants were "not formed of water, but of a certain peculiar terrestrial matter" and that the plants were "more or less augmented in proportion as the water contains a greater or lesser quantity of that matter". Hence, although not appreciating the exact nature of the "terrestrial matter", Woodward did appreciate the relationship between plant growth and inputs.

Table 1. Comparison of relative growth rates (RGR) of spearmint grown in water of different quality from the experiment of John Woodward in 1699.

Water source	RGR relative to control
Rainwater (control)	1.0
River Thames	1.5
Hyde Park conduit	2.0
Hyde Park conduit + garden mould	5.0

Another major advance in the development of the science of agriculture, which used nutrient balance approaches, were the experiments of Jean Baptiste Boussingault in the 1830s, which were the first real agricultural field experiments undertaken. In these experiments, a balance sheet was drawn up for different nutrients and plant constituents for a range of crops grown in different rotations. The uptake by the crops was compared to the input in manure and those derived from other sources, with the recognition that the relative balance affected the enrichment or depletion of the soil. These studies led to those of Liebig in the 1840s and to his conclusion that "The crops on a field diminish or increase in exact proportion to the diminution or increase of the mineral substances conveyed to it in nature." and, subsequently, to his "Law of the Minimum" that "by the deficiency or absence of one necessary constituent, all the others being present, the soil is rendered barren for all those crops to the life of which that one constituent is indispensable".

Nutrients and agricultural expansion

Direct or indirect assessment of nutrient budgets continued at the heart of expansion in agricultural production, with movement from areas of low or reduced fertility to areas of greater fertility and, more recently, as fertilizer technologies allowed for previous limitations to be overcome. The development of early phosphorus fertilizers, based on the use of basic slag, enabled the intensification and expansion of agriculture. Subsequently, as phosphorus became non-limiting in agricultural systems in Europe and North America, the artificial N fertilizers were developed and adopted broadly. In contrast, the late 20th century intensification and expansion of food and fibre production, particularly in the developing world, was driven by the use of nitrogen fertilizers, with the subsequent mining of other nutrients, particularly K and P, to the point that their under-use has become a concern.

In between these changes in the use of fertilizers for macronutrients, improved understanding of other plant nutrients led to increased agricultural production on previously unused or under-utilized areas for which micronutrients such as copper, zinc, and molybdenum, were recognized as the primary limitations.

Increased interest in Nutrient Balance studies

The need for increased agricultural production

The rapid expansion of agricultural production in the last four decades of the 20th century managed to outpace the increase in population, with the net result that average per capita consumption of food increased. These gains resulted from a combination of factors, namely an increase in the area of land cultivated, the development of higher yielding varieties of the major staple foods, particularly wheat, rice, and maize, and increased use of irrigation, fertilizers, pesticides, and herbicides, which enabled at least some of the potential of the higher yielding varieties to be reached.

Despite these overall improvements, the average increase was insufficient and the gains were unevenly distributed throughout the developing world. The continued increase in population, particularly in the developing world and most particularly the cities of the developing world, the current number of poor, and the current level of malnourishment combine to pose a significant challenge for agricultural production in the early 21st century.

Population pressure: Using the example of the 10 ASEAN countries demonstrates easily the pressure of population growth on the demand for agricultural production. The total population approximately doubled, from 240 million to 500 million, during the 35 years from 1965 to 2000, and is expected to almost double to approximately 720 million in the 35 years to 2035 (Figure 1).

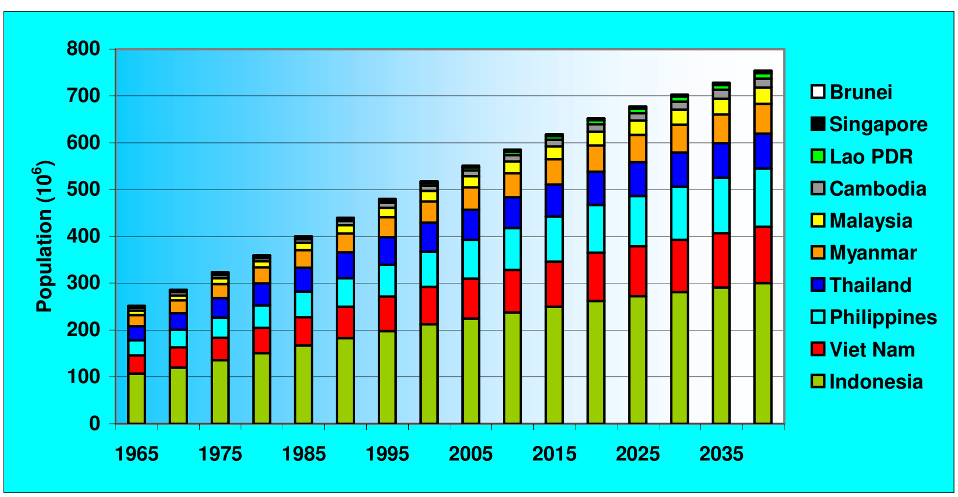


Figure 1. The change in population of 10 Southeast Asia nations for the period from 1960 to 2040 (Source: FAOSTAT)

Available land: The reserves of unutilized but potentially arable land are not distributed evenly throughout the world (Alexandratos, 1995). The majority of unused land is in just 10 countries, with the largest reserves in Brazil and the Congo. There are limited reserves in Asia, with Indonesia having the largest reserves in SE Asia. Even where agriculture can expand to unused areas, in general, the quality of the remaining land is much lower than the land in use at present. In addition, much of the current agricultural lands are being lost to degradation.

With production being the product of yield and land area, it is possible to estimate current production (current average yield x current land area) and current potential production (estimated maximum yield x estimated potential arable land) and compare these with projected production and projected potential production estimates (Penning de Vries, 2001). Average yields can be expected to increase with time, although land degradation is likely to cause a reduction in both the potential yields and the potential area of land for agriculture. Although such analyses must be interpreted with great care, such an analysis for East Asia and the Pacific, for 2000 and 2025, indicates significant potential for expansion of agricultural production, but with very limited potential for further increase, through expansion or increased yield, after 2025. These analyses differ for different regions of the world, with variations in land reserves and/or yields.

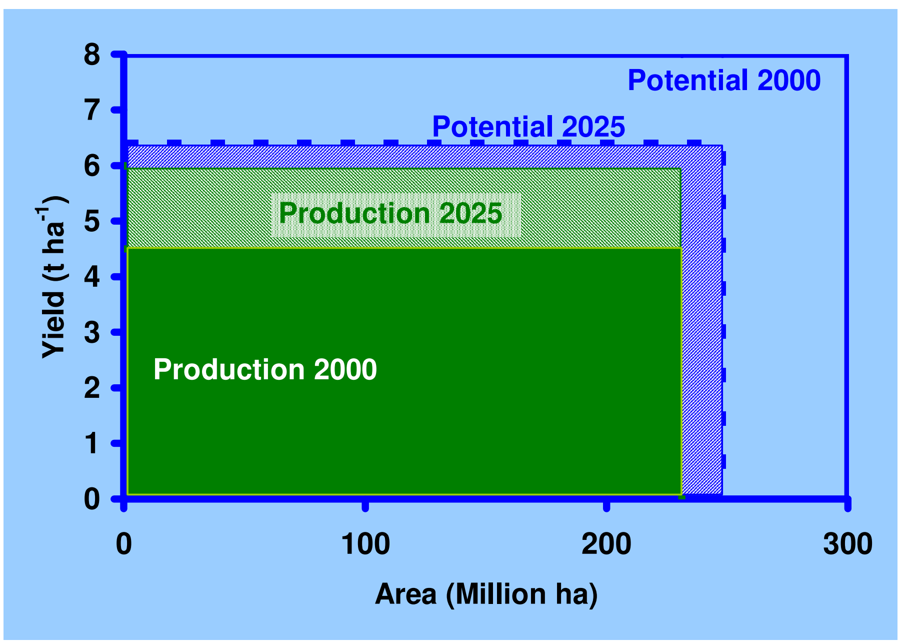


Figure 2. Agricultural production and potential production for East Asia and the Pacific in 2000 and 2025

Global fertilizer use: The recent expansion of agricultural production has been concomitant with a large increase in the use of fertilizers. In fact, the differential increase in agricultural production in different regions can be related fairly directly to the expansion in fertilizer use, which has been greatest in parts of Asia, especially China, and least in sub-Saharan Africa. Analysis of the changes in global fertilizer use shows that the vast majority of the increase has been as nitrogen fertilizer, with much lower increases, and some recent decline, in the use of potassium and phosphorus fertilizers (Figure 3).

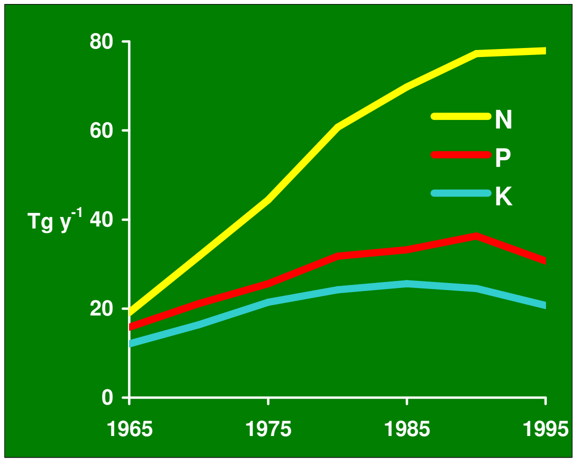


Figure 3. Global trends in the use of nitrogen, phosphorus, and potassium fertilizers (Tg y^{-1}) from 1965 to 1995

To meet the challenges of providing an adequate food supply to all regions of the world, it is clear that agricultural production must increase substantially and that land degradation must be reduced and eventually reversed. This will require much greater efficiency of resource utilization and the development of more sustainable production systems. While there are many aspects of production systems that will need to be addressed, the efficient use of nutrients is critical, which explains the greater interest in nutrient balance analysis in recent times.

Nutrient Balance Analyses

How and why

Nutrient balance analyses or nutrient budgeting can be undertaken at very different scales, with different aims, and using different methods. Clearly the scale of the analysis can vary enormously, depending on the use to which the results will be put. There are no fixed scale categories, but the main scale groups are analyses carried out at the field or farm level, at the district, province or country level, and at the regional or global level. These different scale classes are likely to have different uses in terms of the management of inputs, particularly fertilizers, and in terms of the use for management and the impact on sustainability. Such examples include the following:

Scale:	*field/farm*	*district/country*	*region/global*
Fertilizers/inputs:	*recommendations*	*distribution*	*production/trade*
Management tool:	*farm sustainability*	*infrastructure/policy*	*trade/aid*

A major interest in undertaking nutrient balance analyses is for management of fertilizers and other nutrient source inputs. At the local level, particularly at the field and farm level, such analyses can be part of the process of developing recommendations or decision support systems for the applications of inorganic and organic fertilizers. At a slightly higher level, the results of nutrient budgets can be useful in planning the geographic distribution of inputs, such as fertilizers, so that the temporal and absolute level of supply meets the likely demand. At an even higher level, such information is invaluable for developing strategies for the production and/or importation of fertilizers.

In a related, but slightly different way, nutrient balance analyses are management tools for different scales. At the field and farm level such analyses can be utilised to develop land use plans, including annual and multi-annual/perennial cropping patterns, the management of cultivation, irrigation, and fertilizers, and as part of economic analyses. At a higher level, they are a management tool for developing infrastructure (roads, storage, etc.) and government or government/private policies. At an even higher, supra-country level, they can be used for planning trade and aid policies.

Another important use for nutrient balance analyses, which follows the earlier examples of Woodward, Boussingault, and others, is the understanding of process. As such, nutrient budgeting is undertaken to increase our understanding of nutrient, carbon, and hydrologic cycles, again at different scales, with different levels of accuracy and precision, and with different aims.

The mechanics of nutrient balance analyses

Depending on scale, interest, and the capacity to make measurements or estimates, different parts of the nutrient cycles are included in different analyses. The main input and output factors that are included are listed in Tables 2 and 3, with a qualitative indication of the ease with which these characteristics can be monitored for the nutrient balance exercise and managed within the farming systems. For instance, the amount of nutrients applied in fertilizer can be both monitored accurately and managed easily. In contrast, the application of organics can be managed fairly easily, although the monitoring is slightly more difficult due to difficulties in estimating accurately the amount of material applied and the nutrient content. Other input and output factors, such as irrigation, erosion, and sedimentation can be affected by management, but are very difficult to monitor. Further, the quantity of rainfall can be measured relatively easily, but the nutrient content is measured less frequently, and there is no practical way to manage either of these characteristics.

Table 2. The main Inputs used in nutrient balance analyses and estimates of the ease with which they can be monitored and managed

Input	Characteristic	Monitor	Manage
Fertilizer	rate / source	✓✓	✓✓
Organics	residues / rate / quality	✓	✓✓
BNF	cropping system	✓	✓✓
Irrigation	quantity / concentration	?	✓
Rainfall	quantity / concentration	?	-
Sedimentation	quantity / concentration	?	✓
	Sum of inputs	?	?

✓✓ = can be monitored/managed easily; ✓= can be monitored/managed;
? = limited capacity to monitor/manage; - = cannot be monitored/ managed

Table 3. The main Outputs used in nutrient balance analyses and estimates of the ease with which they can be monitored and managed

Outputs	Characteristic	Monitor	Manage
Product	Harvest	✓	✓✓
Residues	residue recycling	✓	✓✓
Runoff	cropping system / tillage	?	✓
Erosion	mulch / groundcover	?	✓
Leaching	Irrigation	?	?
Gaseous	fertilizer/water management	?	✓
	Sum of outputs	?	?

✓✓ = can be monitored/managed easily; ✓= can be monitored/managed;
? = limited capacity to monitor/manage; - = cannot be monitored/ managed

Types of nutrient balance analyses
In addition to, and within the variations in the scale of the analyses (from field to global) and the objectives of the studies (from management, to policy, and to understanding process), there are a number of further variations in the types of analyses.

Complete or partial: The budgeting exercises can vary in their completeness both in terms of the number of nutrients included and, more importantly, in the number of input and output factors included. Considering the variation within which the various factors can be monitored and managed, as indicated in Tables 2 and 3, in some cases it is recognised that it may be more useful to undertake a more accurate partial analysis, including only the input and output factors that can be measured (and managed) with reasonable accuracy, than a less accurate estimate of all the factors. In the case of a partial budget, the interpretation needs to be done with care, in acknowledgement of the factors that have been excluded, whereas in a complete budget the interpretation needs to be done with care in acknowledgement of the different accuracies with which different factors have been measured. In many ways, a more accurate partial budget may be less at risk of misinterpretation than a complete budget in which the completeness implies an accuracy that does not exist.

Temporal aspects: Nutrient analyses can be conducted as a one-off analysis that provides a "snapshot" of the situation. In most cases, this is all that is required, however, where the aim is to understand the underlying processes a more continuous monitoring is required, so as to capture the dynamic nature of nutrient cycles.

Data sources: The information required for nutrient balance analyses can come from a mixture of sources. Clearly, the most accurate will involve direct measurements of the amounts of nutrients transferred in and out through each factor. Many of these factors can be estimated with reasonable accuracy by using a combination of observations, interviews, and secondary data. The accuracy with which such estimates can be made is closely related to the rankings in Tables 2 and 3. For instance, interviews can provided good estimates of the amounts of fertilizer applied and secondary data, rather than measurements, provide the amounts of nutrient or nutrients applied for a given weight of fertilizer. Nutrients applied in organic matter are less easy. While the amount, usually the volume, applied can be ascertained with reasonable accuracy the dry matter content and the nutrient content are less easily estimated and may require laboratory-based determination. Many farmers can provide reasonable estimates of crop yield and secondary data can be used with reasonable accuracy as default information on nutrient contents, especially if the secondary data is for similar growth conditions and varieties.

The same is not true for nutrient removal in residues as few farmers can provided good estimates of the amounts of crop residue, let alone the nutrient content, and although they are related to crop yield, the relationship is far from direct. Some of the other factors, such as inputs in biological nitrogen fixation, irrigation, rainfall, and sedimentation, and offtake or losses in runoff, erosion, leaching, and gaseous losses are both more difficult to measure and, to estimate.

Examples of nutrient balance analyses

Biogeochemical cycles

Detailed analyses of global nutrient cycles have been used in many instances to study environmental and ecological impacts of human activities. Particular examples have looked at the natural and anthropogenic cycles of nitrogen and sulphur, which have included studies at different scales, from the atmospheric, the continental, and the local, and for different ecosystems and agroecosystems (Galloway et al., 1985; Howarth et al., 1992). These and related studies on carbon cycles and emissions of greenhouse gases are central to the appreciation of global warming.

NUTMON in Sub-Saharan Africa

The NUTMON model developed in Wageningen (Smaling and Fresco, 1993) has been the basis for one of the better known series of studies on nutrient balances. In one of the earlier studies, N, P, and K balances were estimated on a country basis in Sub-Saharan African using secondary data sources (Stoorvogel and Smaling, 1990). Their analysis divided the 38 countries analysed into four main categories of annual nutrient depletion rates (Table 4).

Table 4. Categories of annual nutrient depletions (kg ha^{-1}) in Sub-Saharan Africa

	N	P	K
Average	22	2.5	15
Low	<10	<1.7	<8.3
Moderate	10 - 20	1.7 - 3.5	8.3 - 16.6
High	20 - 40	3.5 - 6.6	16.6 - 33.2
Very High	>40	>6.6	>33.2

Clearly, such national level assessments have little value for developing fertilizer recommendations, but they can assist in policy and management at the national level. Drechsel and Gyiele, (1999) re-expressed these country-level N, P, and K balances in economic terms by expressing the nutrient losses as a percentage of agricultural GDP, with an average cost in nutrient loss across the 38 countries of 7% of agricultural GDP. The NUTMON analyses have been continued for other regions, particularly Central America, and at different scales, such that within and between regional variations in nutrient balances have been compared (Stoorvogel and Smaling, 1998).

Partial Sulphur balances in Indonesia, Malaysia, and Thailand

In an analysis of the partial balance of sulphur (S) in Indonesia, Malaysia, and Thailand (Blair and Lefroy, 1987), which compared the S applied in fertilizer with that removed in crop products and residues, again based largely on secondary data sources, large differences were found in the extent of the national balances of S, from very negative in Indonesia to very positive in Thailand (Table 5).

Further analysis of the different agricultural sectors indicated that in Indonesia the industrial crops sector had a positive S balance, while the food crop sector had a very large negative balance between the S applied as fertilizer and the S removed in crop and residue (Table 6). This indicates one of the dangers of over-interpretation of country wide data.

Table 5. Partial S balances (Mg) for Indonesia, Thailand, and Malaysia in 1983

Country	Product	Residue	Fertilizer	Balance
Indonesia	79,574	53,295	85,806	-47,063
Thailand	46,761	35,350	255,000	+172,889
Malaysia	30,032	2,147	123,211	+91,032

Table 6. Partial S balances (Mg) for different agricultural sectors in Indonesia in 1983

Sector	Product	Residue	Fertilizer	Balance
Food crops	59,393	44,675	21,452	-82,616
Industrial crops	18,241	8,620	64,354	+37,493
Animals	1,940	0	0	- 1,940

While such partial analyses have to be assessed with care, because many important inputs and losses are ignored, they can only be utilized to contribute to policy developments. A workshop held in Indonesia in 1989 reviewed the status of fertilizer production, importation and use in the country, agricultural research work on sulphur nutrition, and the current fertilizer recommendations for different agricultural crops. An outcome of this workshop was the development of a relatively simple set of recommendations aimed at utilizing the same amount of sulphur fertilizer but with much greater efficiency in terms of addressing the sulphur requirements for different crops, soil types and climatic situations (Blair and Lefroy, 1990). Positive S partial balances at the district level indicated over-use of S fertilizer for major crops in much of Java, which were confirmed by soil S measurements. At the same time, there was a great deal of evidence for S deficiency on the outer islands of the Indonesian archipelago. The recommendations were to reduce the S applications in Java to the maintenance applications that were required to balance S off take and then distribute the remaining S to the outer islands. Thus, through a reasonably crude assessment of S balances without further refinement of S fertilizer recommendations to be highly site-specific, the majority of deficiencies could be overcome without increasing the importation of S.

Impact of S in rain on fertilizer requirement in Malaysia

While many of the major inputs and losses from systems are reasonably well understood, the impact of some parts of the various nutrient cycles are not so well understood. The input of S from rain is known to be important and even damaging in certain circumstances, particularly inputs from heavily industrialised areas. However, t in many agricultural systems there is relatively little appreciation of the importance of S inputs via rainfall. A relatively cheap and efficient ion-exchange collection system was developed and installed at 31 sites on peninsular Malaysia in an attempt to assess this part of the S cycle (Lefroy and Hussin, 1991). Cumulative accessions of S in rainfall in two-monthly periods were collected and an annual S accession map developed, with accessions ranging from approximately 1 to 30 kg S $ha^{-1}y^{-1}$ (Figure 4). The S accessions indicated that marine and anthropogenic inputs were the main sources and that they each exhibited different temporal and geographic variations.

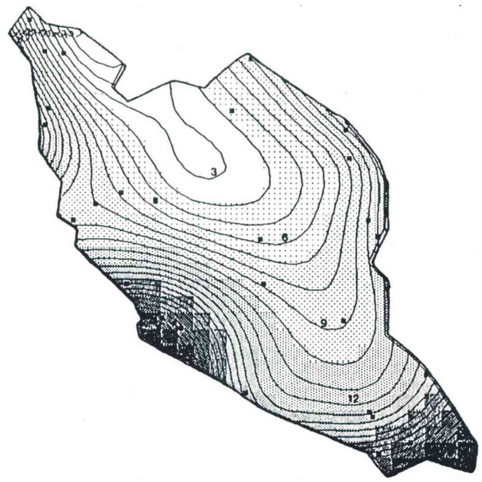


Figure 4. S accessions in rainfall for peninsular Malaysia (kg S $ha^{-1}y^{-1}$).

When S offtake for major crops (Table 7) were compared to inputs of S in rainfall, it was possible to develop basic S fertilizer recommendations that could be modified for local conditions, such as likely losses by leaching. As such, the low requirement of rubber would be met everywhere by the S in rainfall. The moderately high S requirement of coconut and tea would not be met everywhere, but would be met for coconuts in the coastal areas, but would not be met for tea in the central highlands, hence the need for S fertilizer applications for tea. The high S requirement of oil palm requires S applications in all areas, while those for cocoa, coffee, and rice are more complex, especially for rice, where the non-perennial nature and inputs from irrigation make a simple balance less easy to interpret.

Table 7 S removal (kg ha^{-1}) for different crops at average yields.

Crop	S content (kg t^{-1})	Yield (t ha^{-1})	S offtake (kg ha^{-1})
Rubber	0.15 - 0.4	1.5	0.2 - 0.6
Coffee	3.7	1	3.7
Cocoa	5.6	1	5.6
Rice	2.25	4	9
Coconut	4.5	2.5	11.25
Tea	4	3	12
Oil Palm	1.1	20	22

Complete nutrient balances as Decision Support Systems

The examples of S partial balance studies demonstrate how fertility management can benefit from improved understanding of specific parts of nutrient cycles, such as fertilizer applications, S in rainfall, etc., without attempting to measure or estimate the whole nutrient cycle. In other cases, studies of the specific components have been combined into complete balances to be used as nutrient management decision support systems. The study of Dobermann and White (1999), in which N, P, and K inputs and losses are estimated for a lowland rice system that yields between 4 and 6 t ha^{-1} of grain, is an example of such a combined study. This style of complete (or more complete) nutrient balance is the forerunner of the decision support systems that are being developed to enable more site-specific nutrient management that uses available knowledge and expert systems, rather than extensive on-site measurements.

Conclusions

The principles of nutrient budgeting have been used increasingly for a range of purposes and scales, from ecological to agricultural, from policy to research on underlying mechanisms, and from global to field level. In the agricultural realm, nutrient balances, even partial balances, can provide very useful insights and information on productivity and sustainability at different scales. Perhaps the two main areas of interest will remain at the field and farm level, for improved nutrient use, economic return and sustainability, and at the country level, for developing and monitoring policy on agricultural production and support services, such as fertilizers, principally importation, production, distribution and subsidies.

While precise and accurate measurement of all nutrient inputs and outputs can be undertaken and justified in studies of the mechanisms of nutrient dynamics, in the majority of cases the critical part of the budgeting process is to achieve an appropriate level of accuracy with minimal complexity in measurement or data gathering. Herein lie the greatest weaknesses of nutrient balance studies; either the inaccuracy of measurements or estimates of included component inputs or outputs, especially in complete balance studies, are too great, or accurate partial balances are invalidated because of the exclusion of critical parts of the nutrient cycles. The key is in the interpretation of the nutrient budgets. In some cases, a more accurate partial balance that is interpreted with appropriate caveats is more useful than a much less accurate complete balance that has relied on poor estimates of certain components. In other cases, a loss of overall accuracy in the balance, but with inclusion of all parts of the cycle, may be more useful. In the former case, the risk is that caveats will be ignored, in the latter case, the risk is that too much accuracy will be ascribed to the total balance figure. In general, it is important that nutrient balances should not be used in isolation, whether partial or complete, for policy or for farm-level fertility management recommendations.

References

Alexandratos, N., 1995. World Agriculture: Towards 2010. An FAO Study, Food and Agriculture Organization of the United Nations and John Wiley and Sons Ltd, England, 488pp.

Blair, G.J., and Lefroy, R.D.B. (1987) Sulphur cycling in tropical soils and the agronomic impact of increasing use of S free fertilizers, increased crop production and burning of crop residues. In “Proceedings of the Symposium on Fertilizer Sulphur Requirements and Sources in Developing Countries of Asia and the Pacific”, FADINAP-FAO-TSI-ACIAR, 12-17.

Blair, G. and Lefroy, R. (ed.) (1990) “Sulfur Fertilizer Policy for Lowland and Upland Rice Cropping Systems in Indonesia”. ACIAR Proceedings No. 29, ACIAR, Canberra, 142pp.

Dobermann, A. and White, P.F. (1999): Strategies for nutrient management in irrigated and rainfed lowland rice system *In* V. Balasubramanian, J.K. Ladha, and G.L. Denning (eds.), Resource Management in Rice Systems. Kluwer, Netherlands, 1-26.

Drechsel P. and Gyiele, L.A. (1999): The Economic Assessment of Soil Nutrient Depletion: Analytical Issues for Framework Development, Issues in Sustainable Land Management No. 7, IBSRAM, Bangkok.

FAOSTAT - FAO Statistical database. http://apps.fao.org/

Galloway, J.N., Charlson, R.J., Andreae, M.O., and Rodhe, H. (ed.) (1985) “The Biogeochemical Cycling of Sulfur and Nitrogen in the Remote Atmosphere”. Reidel, Boston, 249pp.

Howarth, R.W., Stewart, J.W.B., and Ivanov, M.V. (ed.) (1992) “Sulphur Cycling on the Continents: Wetlands, Terrestrial Ecosystems and Associated Water Bodies”. John Wiley and Sons Ltd., Chichester, 350pp.

Lefroy, R.D.B, and Hussin, A. (1991) S in rainfall and its relevance to Malaysian agriculture. In Y.M. Khanif, S.R. Syed Omar and J. Shamshuddin (Ed) "Developments in Soil Research in Malaysia" Proceedings of Soil Science Conference of Malaysia, Malacca, 20-21 March, 1990. pp. 14-22. Malaysian Society of Soil Science, Kuala Lumpur.

Penning de Vries, F.W.T. (2001) Food security - we are losing ground fast. In: Crop Science: Progress and Prospects. J. Noesberger, H.H. Geiger and P.C. Struik (Eds). CAB International, Wallingford, UK. pp 1-14.

Russell, E.W. (1961) “Soil Conditions and Plant Growth” (9^{th} Edition). Longmans, London, 688pp.

Smaling, E.M.A., and Fresco, L.O. (1993) A decision-support model for monitoring nutrient balances under agriculture land use (NUTMON). Geoderma 60, 235-256.

Stoorvogel, J.J., and Smaling, E.M.A., (1990) Assessment of soil nutrient depletion in Sub-Saharan Africa: 1983-2000. Volume I: Main Report (2^{nd} Edition), Report 28, Winand Staring Centre, Wageningen.

Stoorvogel, J.J., and Smaling, E.M.A., (1998) Research on soil fertility decline in tropical environments: integration of spatial scales. Nutrient Cycling in Agroecosystems 50, 151-158.

Accumulative Nutrient Balance on a Toposequence of Sloping Land Used for Upland Crop Production in Northeast Thailand

S. Ruaysoongnern[1] and A.D Noble[2]

[1] *Department of Land Resources and Environment, Faculty of Agriculture, Khon Kaen University, Khon Kaen 40002, Thailand.*
[2] *CSIRO, Davies Laboratory, PMB Aitkenvale, Townsville, Quaeensland 4814, Australia.*

ABSTRACT

Soil degradation issues are assuming increasing importance in Northeast Thailand and are challenging the sustainability of current land management systems. In this study, the impacts on soil chemical properties resulting from conversion of natural dipterocarp forest to agricultural production are compared. Soil samples were collected at 10 cm increments to a depth of 1 m from a dipterocarp forest and an adjacent agricultural (cultivated) production system along a transect. Since conversion to agricultural production, the cultivated site has undergone a significant decline in soil pH as a result of reduction in soil organic C leading to the loss of exchangeable basic cations, especially Ca, Mg, and K, and Al domination of the exchange complex. Consequently, the ability of the cultivated soil to retain basic cations has been compromised. A significant proportion of the extracted cations from the surface soil of the cultivated site was non-exchangeable and therefore subject to leaching at the onset of the wet season.

In this study, the assessment of soil degradation from a soil chemical perspective has demonstrated the fragility of these soils after continuous agricultural production. This is evidenced by the degree of degradation measured by an index that takes into account changes in the surface charge characteristics and the basic cation retention capacity of the soil. It is suggested that the degradation index may assist in quantification of what is commonly referred to as "soil health".

The long-term consequences of soil degradation are permanent and bring into question the sustainability of current production practices at this site. Soils that have a low buffering capacity (i.e. low clay and organic matter content) are prone to acidification and cation depletion, which has a dramatic effect on the productivity of these soils.

INTRODUCTION

Light-textured sandy soils are relatively widespread in the tropics and constitute an important economic resource for agricultural production despite their low inherent fertility (Panichapong, 1988). Such soils occupy a significant area of the Northeast Thailand plateau (Ragland and Boonpuckdee, 1987), and up until 40 years ago were dominated by climax dipterocarp forests. Subsequently, they were then extensively cleared for timber and agricultural production. Continuous agricultural production of crops such as rice, kenaf (rosella) cassava, and sugarcane has resulted in a rapid decline in soil fertility, with an associated loss of productivity. For the resource-poor farmers of Northeast Thailand, the soil is one of the major biophysical resources that they have at their disposal, but under the prevailing socioeconomic conditions, it is one of the most fragile. A study was conducted to understand soil degradation and some nutrient losses of these soils for appropriate land-use planning and potential soil improvement technologies.

MATERIALS AND METHODS

The soil was classified as belonging to the Yosothon series (LDD, 1993) or a fine loamy siliceous, Oxic Paleustults (Soil Survey Staff, 1994). The cultivated farmer's field—50 km due east of Khon Kaen (16° 56' N; 102° 50' E)—was cleared of climax dipterocarp forest in 1962 for the production of kenaf (or rosella) until 1969. Thereafter, cassava was planted in rotation with peanut until 1990. Since 1991, a sugarcane-cassava rotation has been practiced.

Soil Sampling and Analysis

A paired site approach was used to quantify differences between the dipterocarp forest (undeveloped) and agricultural (developed) sites. The selection of the sites was based on the following criteria: (i) the existence of an undisturbed dipterocarp forest in close proximity to an agricultural production field of known history with respect to the period under production; (ii) a well-defined boundary separating the two land-use systems; (iii) the same soil type in both areas; and (iv) few topographical differences (i.e. slope) between the two areas. Soil samples were collected during the dry season in March 2000 by hand auguring at five points at each of the sites on a toposequence along a transect at right angles to the boundary separating the two systems. Sampling points were 5 m apart and samples were collected at 10 cm increments to a depth of 1 m.

Samples were air-dried and sieved to pass a 2 mm mesh before the pH was measured in a 0.01 M $CaCl_2$ solution using a 1:5 soil:solution ratio. Basic exchangeable cations were determined by atomic absorption spectrometry after replacement with 0.1 M $BaCl_2/NH_4Cl$ as recommended by Gillman and Sumpter (1986). Acidic cations were extracted with 1 M KCl and the extractant was titrated to pH 8.0 as described by Rayment and Higginson (1992). The effective cation exchange capacity (ECEC) was calculated as the sum of basic and acidic cations (Ca+Mg+K+Na+Al+H). Soil organic carbon was determined by wet oxidation using the Walkley and Black method as modified by Rayment and Higginson (1992). Statistical analysis was performed for each of the site x depth combinations, thereby testing for any effect due to the contrast between the developed and undeveloped sites. The analysis of variance routine of the GENSTAT 5 (Anon, 1989) statistical package was used and least significant differences were calculated where appropriate.

RESULTS AND DISCUSSION

The mean soil pH, organic C, exchangeable basic and acidic cations, and ECEC to a 100 cm depth for forested and cultivated soils are presented in Tables 1-3. Significant differences in pH between the forest and adjacent cultivated sites were observed to a depth of 100 cm. Soil pH decreased by around 0.2 to 0.3 in the 0 to 100 cm depth (Tables 1-3). The decline in pH was accompanied by a significant increase in exchangeable acidity at the cultivated sites. Exchangeable K levels were significantly lower for the cultivated site at all depth intervals when compared to the forested site. In contrast, exchangeable Ca decreased significantly at the cultivated site in the surface 20 cm but increased thereafter, suggesting that there was leaching of Ca from the surface horizons.

Over the course of 37 years since conversion from forest to continuous agricultural production, soil organic carbon has declined significantly ($p<0.05$) in the upper soil layers (0–20 cm) (Tables 1-3). The loss in soil organic carbon from the cultivated site amounted to the equivalent of 19.9 mt C ha^{-1} over the 37-year period. Clearly such dramatic declines in soil organic C would have a significant impact on properties associated with cation retention and fertility.

A direct consequence of a decline in soil pH is an increase in exchangeable Al on the exchange complex with an associated decline in exchangeable bases (Ca, Mg, and K). This decrease in exchangeable cations and increase in exchangeable Al has a direct impact on the agronomic performance of the cultivated site. Since Ca is relatively immobile in the phloem of plants and therefore not subject to redistribution within the plant (Mengel and Kirkby, 1982), adequate supplies of this nutrient at the actively growing root tip are required for root elongation. With a decrease in exchange Ca on the exchange complex and the associated increase in Al, it is likely that crops grown on these soils would have restricted root growth due to Al phytotoxicity and Ca deficiency.

Furthermore, the results indicate that a large percentage of the already low amounts of basic cations extracted in the laboratory determination are not associated with the exchange complex in the semiarid environment, and are therefore vulnerable to leaching at the beginning of the wet season. In the humid subtropical region, extractable cations are dominantly exchangeable, and are therefore afforded some measure of protection from leaching.

Table 1. Mean and least significant differences for pH, exchangeable cations, exchangeable acidity, ECEC, and OC for each depth interval for soil collected from the forest and cultivated sites on the top slope.

Characteristics	**Site**	**Depth (cm)**									
		0–10	**10–20**	**20–30**	**30–40**	**40–50**	**50–60**	**60–70**	**70–80**	**80–90**	**90–100**
pH ($CaCl_2$)	Forest	6.33	6.51	6.57	6.69	6.74	6.70	6.49	6.35	6.23	6.20
	Cultivated	6.02	6.23	6.33	6.34	6.37	6.21	6.16	6.23	5.86	5.76
Ca $cmol_c$/kg	Forest	1.457	0.729	0.323	0.279	0.252	0.329	0.265	0.168	0.152	0.155
	Cultivated	0.137	0.127	0.131	0.182	0.284	0.381	0.325	0.271	0.363	0.306
Mg $cmol_c$/kg	Forest	0.789	0.477	0.303	0.248	0.258	0.459	0.693	0.700	0.743	0.768
	Cultivated	0.073	0.059	0.055	0.083	0.174	0.383	0.527	0.698	0.771	0.906
K $cmol_c$/kg	Forest	0.057	0.049	0.048	0.057	0.085	0.072	0.060	0.062	0.070	0.088
	Cultivated	0.088	0.066	0.052	0.077	0.043	0.040	0.041	0.041	0.043	0.049
OC%	Forest	0.90	0.53	0.22	-	-	-	-	-	-	-
	Cultivated	0.24	0.25	0.23	-	-	-	-	-	-	-
Al + H $cmol_c$/kg	Forest	0.112	0.127	0.167	0.340	0.462	0.679	0.921	1.186	1.318	1.411
	Cultivated	0.375	0.446	0.492	0.429	0.321	0.565	0.770	1.009	1.488	1.815
ECEC $cmol_c/kg^{-1}$	Forest	2.506	1.442	0.870	0.967	1.043	1.539	1.950	2.125	2.295	2.409
	Cultivated	0.657	0.699	0.746	0.768	0.870	1.415	1.705	2.065	2.712	3.127

Table 2. Mean and least significant differences for pH, exchangeable cations, exchangeable acidity, ECEC, and OC for each depth interval for soil collected from the forest and cultivated sites on the middle slope.

Characteristics	**Site**	**Depth (cm)**									
		0–10	**10–20**	**20–30**	**30–40**	**40–50**	**50–60**	**60–70**	**70–80**	**80–90**	**90–100**
pH ($CaCl_2$)	Forest	5.92	5.99	6.01	5.98	5.93	5.69	5.68	5.33	5.20	5.06
	Cultivated	5.71	5.80	5.83	5.71	5.73	5.57	5.13	5.11	5.05	4.97
Ca $cmol_c$/kg	Forest	1.891	0.752	0.420	0.302	0.216	0.255	0.180	0.173	0.237	0.517
	Cultivated	0.121	0.123	0.102	0.115	0.237	0.328	0.384	0.379	0.338	0.267
Mg $cmol_c$/kg	Forest	0.536	0.250	0.153	0.128	0.139	0.176	0.175	0.170	0.178	0.233
	Cultivated	0.571	0.492	0.513	0.611	0.342	0.372	0.293	0.374	0.347	0.456
K $cmol_c$/kg	Forest	0.096	0.077	0.058	0.064	0.061	0.078	0.090	0.077	0.081	0.091
	Cultivated	0.036	0.047	0.031	0.030	0.042	0.044	0.046	0.050	0.058	0.057
OC%	Forest	0.85	0.42	0.24	-	-	-	-	-	-	-
	Cultivated	0.21	0.20	0.16	-	-	-	-	-	-	-
Al + H $cmol_c$/kg	Forest	0.091	0.128	0.262	0.617	1.051	1.417	1.720	1.834	1.832	1.999
	Cultivated	0.397	0.397	0.511	0.570	0.940	1.092	1.197	1.624	1.788	2.015
ECEC $cmol_c$/kg	Forest	2.675	1.477	1.279	1.619	1.698	2.148	2.308	2.487	2.522	3.087
	Cultivated	0.663	0.669	0.721	0.806	1.417	1.851	2.229	2.656	2.830	2.882

Table 3. Mean and least significant differences for pH, exchangeable cations, exchangeable acidity, ECEC, and OC for each depth interval for soil collected from the forest and cultivated sites at the bottom of the slope.

Characteristics	**Site**	**Depth (cm)**									
		0–10	**10–20**	**20–30**	**30–40**	**40–50**	**50–60**	**60–70**	**70–80**	**80–90**	**90–100**
pH ($CaCl_2$)	Forest	5.78	6.00	6.17	6.20	5.83	5.47	5.43	4.91	4.75	4.60
	Cultivated	5.51	5.81	5.91	5.75	5.39	4.98	4.72	4.59	4.56	4.53
Ca $cmol_c$/kg	Forest	1.300	1.240	1.407	1.000	1.428	1.377	0.937	1.051	0.761	0.671
	Cultivated	0.156	0.143	0.109	0.120	0.288	0.450	0.236	0.146	0.133	0.167
Mg $cmol_c$/kg	Forest	0.533	0.302	0.271	0.341	0.523	0.773	0.731	0.591	0.548	0.634
	Cultivated	0.542	0.426	0.407	0.158	0.102	0.090	0.094	0.136	0.299	0.382
K $cmol_c$/kg	Forest	0.073	0.054	0.041	0.036	0.044	0.068	0.122	0.137	0.118	0.124
	Cultivated	0.052	0.046	0.046	0.036	0.041	0.039	0.045	0.045	0.149	0.052
OC%	Forest	0.49	0.24	0.13	-	-	-	-	-	-	-
	Cultivated	0.15	0.14	0.12	-	-	-	-	-	-	-
Al + H $cmol_c$/kg	Forest	0.072	0.091	0.114	0.206	0.436	0.747	0.994	1.280	1.466	1.517
	Cultivated	0.297	0.342	0.443	0.632	0.737	0.820	1.133	1.175	1.291	1.356
ECEC $cmol_c$/kg	Forest	1.993	1.705	1.849	1.600	2.448	2.984	2.800	3.078	2.911	2.964
	Cultivated	1.073	1.065	1.027	0.973	1.191	1.419	1.530	1.522	1.893	1.981

GENERAL DISCUSSION

The results from this study highlight the impacts of land clearing on a sloping terrain and continuous cultivation of light-textured soils in the semiarid tropics; this has particular relevance to important soil properties such as organic matter content, soil pH, and cation retention capability. A reduction in soil organic matter in the surface horizons of the cultivated Ultisol (by 30 to 50 percent of that found in the forested counterpart) reduced the cation exchange capacity severely, the major portion of which became Al dominant. The high percentage of Al on the cation exchange complex denotes a high *reserve* acidity, which in turn maintains a high *active* acidity in soil solution, expressed as low pH.

As an alternative to the more conventional approaches to soil fertility improvement, involving additions of organic material or attempts to increase soil organic matter content, inorganic amendments may have a useful role. Thus, the addition of clays to sandy-textured soils would result in an increase in permanent negative charge, which in turn could be supplied with well-balanced quantities of slowly released Ca, Mg, and K from basic and ultrabasic rock sources such as crushed basalt (Gillman, 1980).

CONCLUSION

This study has contrasted the almost irreversible degradation of a soil in the semiarid tropics under continuous crop production with a milder degradative management practice in the humid subtropics, which is easily reversible.

The long-term consequences of soil degradation are permanent and bring into question the sustainability of current agronomic production systems practiced in some regions. Soils that have a low buffering capacity (i.e. low clay and organic matter content) are prone to acidification and cation depletion, which has a dramatic effect on the productivity of these soils.

REFERENCES

Anon. 1989. Genstat 5 Reference Manual. Oxford University Press.

Land Development Department (LDD). 1993. Characterisation of soil series established in the northeastern region and their interpretation for uses. Bangkok, Thailand: Department of Land Development. Technical Report No. 314.

Gillman, G.P. 1980. The effect of crushed basalt scoria on the cation exchange properties of a highly weathered soil. *Soil Science Society of America Journal,* 44, 465–468.

Gillman, G.P.; and Sumpter, E.A. 1986. Modification of the compulsive exchange method for measuring exchange characteristics of soils. *Australian Journal of Soils Research* 24, 61–66.

Mengel, K.; and Kirkby, E.A. 1982. *Principles of plant nutrition*. Switzerland:
International Potash Institute.

Panichapong, S. 1988. Soil and water resources in Northeast Thailand. In: *Soil, water and crop management systems for rainfed agriculture in Northeast Thailand* –. Thailand: Khon Kaen University Press. pp 2–13.

Ragland, J.; and Boonpuckdee, L. 1987. Fertiliser responses in Northeast Thailand: 1. Literature review and rationale. *Thai Journal of Soils and Fertiliser* 9, 65–79.

Rayment, G.E.; and Higginson, F.R. 1992. *Australian laboratory handbook of soil and water chemical methods*. Melbourne: Inkata Press.

Soil Survey Staff. 1994. *Keys to soil taxonomy, sixth edition*. United States Department of Agriculture, Soil Conservation Service.

Nutrient Budget Considerations for Rice in Lao PDR

Pheng Sengxua[1] and Bruce Linquist[2]

[1]*National Agriculture and Forestry Research Institute, Vientiane, Lao PDR*
[2]*Lao-IRRI Project*

ABSTRACT

Developing efficient and balanced nutrient recommendations is important to ensure sustainable crop production systems. Rice, the primary crop grown in Lao PDR and the focus of this paper, is grown in three ecosystems: rainfed uplands, rainfed lowlands, and irrigated lowlands. Fertilizer consumption in LaoPDR is the lowest in Asia. Nitrogen and P account for 95 percent of the nutrients imported and K only 5 percent. Based on nutrient budgets (accounting for fertilizer and irrigation nutrient inputs and losses due to grain harvest and current residue management practices), the K balance is negative in all rice systems. In the irrigated environment, where higher amounts of N and P are applied and two crops of rice are grown each year, it is likely that K deficiency will become increasingly common. The N balance is positive only in the irrigated environment; however, if one accounts for losses due to denitrification, leaching, etc., it is most likely to be balanced or negative in these production systems. Phosphorus tends to be over applied in the lowland rice systems due to farmers' preference for 16-20-0 fertilizer. Since P is not readily lost in the lowland systems it is probable that P will build up in these soils under current management practices.

INTRODUCTION

With the increasing use of fertilizers in farming systems of Lao PDR it is important to develop sound policies with regard to fertilizer imports, use and balanced nutrient recommendations for various farming systems. Developing nutrient budgets for cropping systems helps us to understand where nutrient imbalances exist and can be instrumental in developing balanced recommendations.This paper focuses on the rice system, as this is the most important crop in Lao PDR. Further, this paper discusses the current trends in fertilizer consumption in Lao PDR and in which farming systems it is being applied. Rice farming systems are then discussed in detail by examining the potential nutrient inputs and losses in the system. Finally, based on the authors' assumptions, a nutrient budget is developed for each of the main rice systems.

FERTILIZER CONSUMPTION IN LAO PDR

Fertilizer consumption for Lao PDR is the lowest in Asia (IRRI, 1995) but it is increasing with approximately 10,000 tonnes being imported in 1998 (Figure 1). These figures are at best rough estimates as there is considerable unregulated cross-border trade between Lao PDR and its neighbors. There is no inorganic fertilizer production in Lao PDR so all such fertilizers are imported. Lao PDR imports primarily three fertilizers namely, urea, 16-20-0, and 15-15-15 (Table 1).

International Workshop on Nutrient Balances for Sustainable Agricultural Production and Natural Resource Management in Southeast Asia. Bangkok, Thailand, 20-22 February, 2001

In 1996 and 1999 these fertilizers comprised approximately 92 percent of total fertilizer imports. Of all the nutrients imported in fertilizers (the average of 1996 and 1999), N constituted 72 %, P 23 %, and K 5 % (Table 2).

Table 1. Fertilizer imports in 1996 and 1999 to Lao PDR.

% of total imports		
Fertilizer	1996	1999
Urea	31	11
16-20-0	56	62
15-15-15	10	13
Total	97	86

Source: Dept. of Agriculture, MAF.

Table 2. Nutrient imports in 1996 and 1999 to Lao PDR.

% of total imports		
Nutrient	1996	1999
N	77	67
P	19	27
K	4	6

Source: Dept. of Agriculture, MAF.

RICE

Rice accounts for 87 percent of the cultivated area and 60 percent of total agricultural production (UNDP, 1999); it provides 67 percent of total calorie intake (IRRI, 1995). Rice is grown in three ecosystems: rainfed uplands (using slash and burn), rainfed lowlands, and irrigated lowlands. During the 2000 wet season, the lowland rice area (irrigated and rainfed) accounted for 475,600 ha and 152,000 ha were cultivated in the uplands (Department of Agriculture, MAF). Most of the lowland rice (77 percent) was grown on the six main plains located in southern and central Laos. Lowland wet-season rice can be classified broadly into rainfed or irrigated rice. Wet-season irrigated rice can receive supplemental irrigation during the wet season. During the 2000 wet season, approximately 280,000 ha of the lowland rice area (almost 60 percent) had access to supplemental irrigation water.

One of the most striking features of rice production in Lao PDR during the latter half of the 1990s was the rapid expansion of the irrigated area. Through 1995 the irrigated area was approximately 13,000 ha. Between 1995 and 2000, the irrigated area increased by almost 600 percent to 91,800 ha.

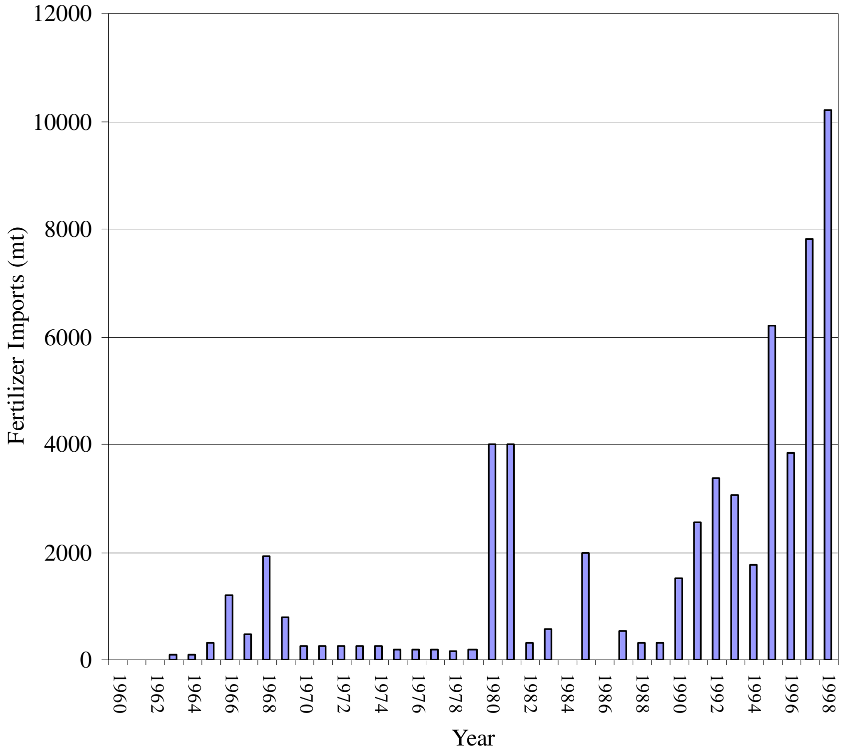


Figure 1. Fertilizer imports to Lao PDR between 1961 and 1998. (Source: FAO 1998: www.fao.org).

NUTRIENT INPUTS

Nutrient inputs include nutrients in rainfall, irrigation water, crop residues, and fertilizers. Nitrogen (N) and S inputs from rainfall were collected during a two-year period (1999 to 2000) from seven locations in Lao PDR. The rainwater contained very little N. In all cases less than 1 kg N ha^{-1} was deposited annually in rainfall (Table 3). Sulfur was supplied in the rainwater at a rate of 5 kg ha^{-1} yr^{-1}. This is slightly higher than the figure reported for Northeast Thailand which receives about 4 kg S ha^{-1} yr^{-1} via rainfall (Blair, 1990). Irrigation water can be a major source of plant nutrients. The amount of nutrients supplied by the water depends on the concentration of nutrients in the water and the amount of water used. The amount of irrigation water applied depends on the soil type, season and crop water requirement. Consequently, during the dry season, more irrigation water is applied than during the wet season. Soils with high hydraulic conductivity (usually sandy soils) require more water than soils with low hydraulic conductivity. Soils in southern and central Lao PDR, where most of the lowland rice is grown, are usually coarse-textured (Linquist et al., 1998). Irrigation water was sampled during the dry season from 12 irrigation schemes in Lao PDR. Table 4 presents the amount of nutrients added per hectare assuming a cumulative irrigation application depth of 1,000 mm of water. The quantity of N and P is either low or not detectable in most irrigation water. Potassium (K) and S are also generally low and highly variable. It is interesting to note that Sayaboury (Phiang District) where K deficiencies are most frequently observed, K concentrations in irrigation water are the lowest. Other nutrients such as Ca and Mg are relatively high.

Table 3. Annual nitrogen and sulfur inputs from rainfall water.*

	Nitrogen	**Sulfur**
	kg ha^{-1}	
Vientiane Municipality	0.18	5.27
Vientiane	0.23	5.58
Savannakhet	0.48	5.67
Champassak	0.17	6.58
Sayaboury	0.19	4.93
Luang Prabang	0.21	4.64
Luang Namtha	0.28	5.49
Mean	**0.25**	**5.45**

Data collected from March 1999 to February 2001.

Table 4. Nutrient inputs from irrigation water. (kg ha^{-1} assuming a cumulative irrigation application depth of 1,000 mm of water).

Province	**N**	**P**	**K**	**S**	**Ca**	**Mg**	**Mn**	**B**	**Fe**	**Cu**	**Zn**	**Na**	**Al**
Vientiane	0	0.06	14.2	0.0	53	9	0.57	0.07	0.41	0.02	0.13	5	0.00
Vientiane	0	0.22	14.6	0.3	87	20	0.33	0.10	0.74	0.07	0.05	15	0.01
Vientiane	0	0.20	12.8	0.5	90	17	0.17	0.07	0.46	0.01	0.03	8	0.00
Vientiane	0	0.47	11.1	12.7	168	32	0.02	0.18	0.11	0.00	0.02	65	0.09
Savannakhet	0	0.17	12.6	7.8	40	33	0.12	0.25	3.81	0.06	0.08	529	8.43
Saravane	0	2.05	25.1	3.9	88	63	0.14	0.12	0.55	0.03	0.13	67	0.57
Champassak	0	0.24	10.6	2.0	83	48	0.07	0.06	1.21	0.02	0.05	37	2.27
Champassak	0	0.29	18.0	58.9	349	60	0.02	0.27	0.23	0.04	0.01	110	0.21
Sekong	0	0.54	14.6	4.6	78	48	0.24	0.11	0.38	0.05	0.13	48	0.55
Sayabouli	0	0.11	5.3	9.2	337	31	0.03	0.07	0.47	0.02	0.01	38	0.98
Sayabouli	0	0.22	6.0	6.1	331	35	0.03	0.06	0.35	0.02	0.02	41	0.34
L. Prabang	0	0.34	20.5	11.4	583	63	0.04	0.31	0.28	0.04	0.03	76	0.27

Inputs from fertilizer vary between ecosystems, seasons, regions, and farmers. Little to no fertilizer is applied to upland rice systems. This is partially due to the high risk of crop production in this environment, the difficulty of carrying fertilizers to remote areas on small footpaths, and the limited availability of fertilizers in areas where upland rice is grown.

In the lowland systems, more fertilizer is applied to the irrigated dry season rice crop, although fertilizer use is increasing in the wet season in both the irrigated and rainfed lowland systems. A survey of rainfed lowland rice farmers conducted in Champassak and Saravane in 1996 suggested that the amount of fertilizer used is low (Pandey and Sanamongkhoun, 1998). Of those farmers using fertilizer on average only 27 kg of nutrients (N, P, and K) were applied per hectare. There are no data on fertilizer use in the irrigated environment, but based on informal interviews about four bags (each weighing 50 kg) are applied per hectare on average, or about 70 kg of nutrients per hectare.

Other potentially major inputs are those from on-farm residues such as straw, rice husks, and manure, which are by-products of the rice farming system. Residues are discussed separately below as these may be considered inputs or as a loss depending on how they are managed.

Nutrient Losses

Nutrient losses from the soil may be caused by crop removal, leaching, runoff, erosion, and/or losses to the atmosphere as ions are converted to gases. Runoff and erosion are important considerations for upland rice systems but are of less importance in the lowland rice systems. Roder et al., (1995) reported annual soil losses of 0.3 to 29 mt ha^{-1} from upland rice systems. This was accompanied by a loss of up to 71 kg N ha^{-1} and 30 kg P ha^{-1}. Soil losses vary considerably due to the effects of slope, soil physical properties, and above ground biomass.

In the lowlands where rice is grown under flooded conditions, N is highly susceptible to leaching and gaseous N losses (through denitrification and NH_3 volatilization) (Schnier, 1995). Nitrogen losses are difficult to quantify, however the efficiency of N fertilizer is generally low in flooded rice systems, with normally less than 40 % of applied N being taken up by the crop (Schnier, 1995). NH_3 volatilization is not expected to be a major problem in soils with a low pH such as those in much of Lao PDR. Denitrification is potentially a major problem especially in rainfed lowland rice systems where it is common for soils to cycle between flooded (anaerobic) and aerobic states (Wade et al., 1998). Leaching is a potential problem in sandy soils that have high water percolation rates and low nutrient retention capacity. Such soils are prevalent in the lowland rice systems of southern and central Lao PDR.

Phosphate and K are primarily lost via soil erosion and runoff, but leaching losses are possible, especially in sandy soils when high amounts of these nutrients are applied or when heaps of straw are burned leaving ash that is high in P and K. Linquist et al., (2000) reported that if soil P is not applied at excessive levels, residual P remains in the soil and is as available to rice in the following year as freshly applied P. However, they also reported that under conditions where high levels of P are applied, P may be susceptible to leaching in coarse-textured soils.

A major loss of nutrients results from the removal of rice grain and straw at harvest. Table 5 provides the approximate amount of various nutrients in the rice plant at harvest. Nitrogen and K are taken up in the largest quantities (13–15 kg per tonne of grain yield). Phosphorus is taken up in much smaller quantities, averaging about 2.5 kg per tonne of grain yield. At harvest, most of the N and P is in the grain with relatively little being found in the straw. Therefore harvested grain removes most of these nutrients. The straw contains 50 percent or more of the other nutrients, thus indicating the importance of straw management on soil fertility, which will be discussed in more detail in the following section.

Table 5. Macro- and micronutrients in the rice grain and straw at harvest.

	N	P	K	S	Ca	Mg	Mn	Zn	Cu
	Nutrient concentration								
	%	%	%	%	%	%	*u*g/g	*u*g/g	*u*g/g
Grain	0.79	0.19	0.28	0.10	0.04	0.10	103.12	22.81	38.75
Straw	0.32	0.04	0.79	0.10	0.39	0.17	883.90	25.24	24.62
	Nutrients per tonne of grain yield (kg mt^{-1})*								
Grain	7.9	1.9	2.8	0.9	0.4	1.0	0.1	0.02	0.04
Straw	4.8	0.6	11.8	1.4	5.9	2.6	1.3	0.04	0.04
Total	**12.6**	**2.4**	**14.7**	**2.4**	**6.3**	**3.6**	**1.4**	**0.06**	**0.08**
	Percent of nutrients in grain or straw at harvest								
Grain	62	76	19	41	7	28	7	38	51
Straw	38	24	81	59	93	72	93	62	49

* Assumes a harvest index of 0.4. Therefore, if rice grain yield is 1 mt/ha, the straw yield would be 1.5 mt/ha.

RESIDUE MANAGEMENT EFFECTS ON NUTRIENT BUDGETS

On-farm residue (straw, rice husks, and manure) management can have a significant impact on nutrient balance and soil fertility. Generally, current residue management practices for lowland rice systems in Lao PDR can be described as follows. At harvest, farmers cut off the panicle, leaving about half (depending on the variety and the farmer) of the rice straw in the field. Usually, this straw stubble is grazed by livestock during the dry season, but it may also be burned. The straw panicles, which are removed with the grain, are moved to a central location, which depends on how the rice will be threshed. Large mechanical threshers mounted on trucks are becoming more common and, in such cases, the straw will be moved near the road. Following threshing, the straw is usually burned in the ditch beside the road. If the panicles are to be hand-threshed, the straw is moved near the house, where it will be threshed. In this case, the straw panicles are often stored for livestock feed. There is a tradeoff between the amount of straw potentially available and the number of ruminant livestock. Although rice straw may be important for soil fertility, it is also an important livestock feed during the dry season when other forage is in scant supply. Livestock accounts for a significant portion of expendable cash income (50 percent in southern Lao PDR, Pandey and Sanamongkhoun, 1998). Therefore, the most valuable use of straw may be as livestock feed. Livestock graze freely and little effort is made to collect and use manure. Data from southern Lao PDR indicates that only 11 percent of farmers use manure, with application rates (mostly to nurseries) varying from 35 to 1,050 kg ha^{-1} (Lao–IRRI, 1995). Removing the rice husk and bran is usually done at a rice mill. The cost of milling is the bran removal from the rice. The mill owner retains the rice bran in loo of cash payment and sells the bran for animal feed. The rice husks are usually left at the mill, although some farmers return the husks to their fields.

In upland rice systems, some farmers strip the rice from the panicle without removing the panicle, thus leaving all the straw spread uniformly across the field. Most farmers, however, cut the panicle and move the panicles to a central area in the upland field for threshing. The panicle straw remains in a large heap following threshing. During the dry season animals are allowed to graze in these areas. Following a fallow period of several years, fallow vegetation is cut and burned in preparation for planting.

The amount of residue available annually can be estimated relatively accurately for straw and rice husks. Straw accounts for approximately 60 percent of aboveground biomass and is the most abundant on-farm residue. Rice husks account for about 20 percent of unmilled rice. Therefore, if farm grain yields average 3.5 mt ha^{-1}, there will be 5.3 mt ha^{-1} of straw (assuming a harvest index of 0.4) and about 0.7 mt ha^{-1} of rice husks. Accurate estimates of the amount of available manure are much more difficult to estimate. Lowland rice farmers have on average five cows or buffaloes (Lao–IRRI, 1995). Assuming that each animal produces 1.5 mt manure yr^{-1}, 7.5 mt of manure are produced per farm. In the uplands, there are fewer large animals and typically they are allowed to graze freely during the dry season.

Table 6 provides the nutrient concentrations of some residues. The nutrient concentration estimates for plant residues are relatively accurate, whereas nutrient concentrations of animal wastes can vary widely.

Table 6. Nutrient concentrations of some on-farm residues.

	N	**P**	**K**	**S**	**Ca**	**Mg**	**Mn**
Residue	**%**	**%**	**%**	**%**	**%**	**%**	**$\mu g\ g^{-1}$**
Rice straw	0.4	0.05	1.0	0.09	0.38	0.17	814
Rice husks*	0.43–0.55	0.03–0.08	0.17–0.87	0.05	0.07–0.15	0.03	116–337
FYM**	0.5–1.0	0.12–0.17	0.22–0.26	na	na	na	na
Cattle dung**	0.35	0.11	0.09	na	na	na	na
Cattle urine**	0.80	0.02	0.26	na	na	Na	na

* Juliano and Bechtel, (1985).
** Uexkull and Mutert, (1992).
na = not available.

Table 7. Nutrient balance for lowland irrigated and rainfed systems and upland rice systems in Laos (for assumptions used, see text).

Ecosystem	**Inputs kg ha^{-1}**			**Losses kg ha^{-1}**			**Balance kg ha^{-1}**		
	N	P	K	N	P	K	N	P	K
Upland	0	0	0	16.3	3.4	15	-16.3	-3.4	-15.2
Rainfed lowland	18.5	8.1	0.9	29.8	5.9	34.4	-11.3	2.2	-33.5
Irrigated lowland	78	8.6	0	44.5	7.7	30.5	33.6	0.9	-30.5

Straw management, in particular, has a major effect on the nutrient balance because many nutrients are present in larger quantities in the straw than in the grain. Table 5 shows the percentage of other nutrients that are in the straw compared with the grain. With the exception of N, P, and Cu, more than 50 percent of the nutrients are in the straw at harvest. Therefore, removing the grain removes most of the N and P, but straw management has a greater effect on the nutrient balance of the other nutrients. Potassium (K) is of critical concern because of the amount required by the crop. If straw is continually removed from the field, K deficiencies are likely to occur. This process is accelerated if farmers apply N and P without K, as N and P inputs will initially increase yields. However, this also results in greater K uptake, which will lead to K deficiencies in the long term. The process is further accelerated in the irrigated rice system, in which farmers apply more nutrients (N and P) and crop twice a year.

Nutrient Budgets

Nutrient budgets were developed for the each of the main rice systems in Lao PDR using the following assumptions. In the upland system, rice yields are 1.5 mt ha^{-1}, the harvest index is 0.35, there are no fertilizer inputs and all the grain and half of the straw is removed. In the rainfed lowlands, yields are 2.4 mt ha^{-1} and the harvest index is 0.4. Fertilizer inputs were based on data from Pandey and Sanmongkhoung, (1998), namely 18.5, 8.1, and 0.9 kg ha^{-1} for N, P, and K, respectively. In addition, all the grain and straw is removed. In the irrigated environment, yields are 3.5 mt ha^{-1}, the harvest index is 0.4 and the fertilizer inputs are 78, 8.6, and 0 kg ha^{-1} for N, P, and K, respectively. In addition, all the grain and half of the straw is removed and the remaining stubble is burned resulting in loss of all the N but the P and K remain in the ash. The grain and straw nutrient concentrations were in each case based on data in Table 5. There was no estimate of losses apart from those removed by the crop. As indicated above, N losses are usually quite high with up to 50 percent of the N being lost.

In the upland system, all nutrient balances are negative because only nutrient losses via crop removal are accounted for and no fertilizers are applied (Table 7). Despite the fact that they are negative, the negative balances are quite small due to the low yields in these systems. Small inputs during the fallow period from N fixation, rainwater, and leaf deposition from trees with deep root systems may be able to make up for these losses. However, due to rising populations that are leading to shorter fallow periods, rice yields are declining (Fujisaka, 1991; Roder et al., 1997). Furthermore, the nutrient balance did not account for losses due to erosion, which can be significant (Roder et al., 1995).

In the rainfed lowland system, N and K are both negative suggesting a non-sustainable system. Potassium is of special concern as almost 34 kg of K ha^{-1} are removed annually (Table 7). In coarse-textured soils, which are prevalent in Lao PDR, K deficiencies are likely to increase especially with the increased use of N and P fertilizers which have improved yields (and K uptake) in the short term. The P balance is positive, as farmers tend to over apply 16-20-0 because it is the cheapest fertilizer available. Research examining the fate of residual P in these soils, indicates that at the application rates typically applied by farmers, P remains in the soil and is available (Linquist et al., 2000). Under current management practices, it is likely that there will be a buildup of soil P. In the irrigated rice system, N and P are both positive (Table 7). If 50 percent of the N is accounted for by leaching, denitrification, etc, then the actual N balance is close to zero. The major concern for the irrigated environment is K. Assuming two crops of rice are grown annually, there will be a net removal of over 60 kg K ha^{-1}.

Table 4 indicates that an average of 14 kg K ha^{-1} is applied in the irrigation water during the dry season (assuming a cumulative irrigation application depth of 1,000 mm of water). Assuming half of this amount is applied during the wet season, a total of 21 kg K ha^{-1} is applied annually in irrigation water. This still represents a negative balance of about 40 kg K ha^{-1}.

Given the low nutrient reserves in these primarily coarse-textured soils, K deficiencies are likely to become a problem in the irrigated systems. Potassium deficiencies are not yet a major problem with about 30 percent of soils responding to K inputs (Linquist et al., 1998). However, given the current nutrient and residue management practices and the recent increase in irrigation area and fertilizer use, K deficiencies are likely to become a greater problem. In the irrigated environment this process is accelerated.

To evaluate the effect of not applying K in irrigated systems, an experiment was initiated at 17 sites during the 1999 dry season. There were three treatments with only one replication per site. The treatments were; a control with no fertilizer and 16-20-0 or 15-15-15 as a basal fertilizer. In the two treatments that received fertilizer, N was applied at a rate of 90 kg N ha^{-1} in both cases. The N was equally split between an application at transplanting and at 30 and 50 DAT. The compound fertilizer supplied all the N in the first application, while urea was the N source for the two topdressings. The total P and K for each treatment was 16 and 0 kg ha^{-1}, respectively for the 16-20-0 compound fertilizer; and 13 and 25 kg ha^{-1} for the 15-15-15 compound fertilizer. These plots (50 m^2 each) were maintained for four seasons to examine the long-term effects of each fertilizer management strategy.

Across all sites and seasons there was a significant response to both fertilizer treatments. Yields in the no fertilizer control averaged 1.9 mt ha^{-1} as compared to 3.5 mt ha^{-1} for the with fertilizer treatments. In the first season, the K containing fertilizer (15-15-15) produced higher yields than the 16-20-0 fertilizer at only 13 percent of the sites (Figure 2). However, after four seasons, this had increased to 40 percent of the sites. Examining the yield trends, yields remained relatively stable averaging 3.5 mt ha^{-1} across all four seasons when 15-15-15 was applied. However, in the 16-20-0 plots, yields during the first three seasons averaged 3.6 mt ha^{-1} but in the last season yields dropped to 3.1 mha^{-1}. In all cases where farmers were questioned on their straw management practices, the straw remaining after harvest was either burned or grazed by livestock. These data highlight that K deficiencies will become more prevalent if farmers apply only N and P containing fertilizers and remove straw, supporting similar reports by Doberman et al., (1998).

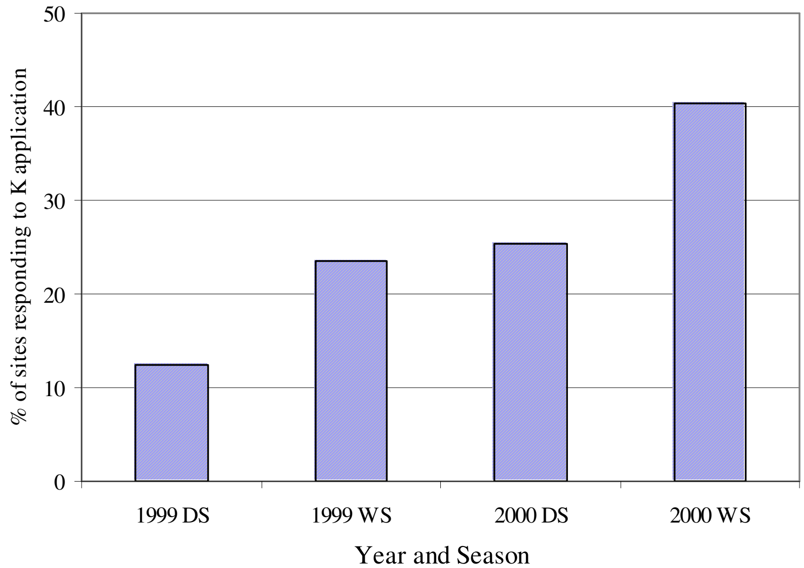


Figure 2. Results after 4 seasons comparing the use of 16-20-0 and 15-15-15 as a basal fertilizer for rice. Graph presents the percentage of sites in which the 15-15-15 fertilizer produced yields which were at least 0.4 mt ha^{-1} greater than those from 16-20-0 fertilizer. (DS = Dry Season; WS = Wet Season)

SUMMARY

National statistics on fertilizer imports suggest the probability of negative K balances in farming systems as the primary imported fertilizer nutrients are N and P. Furthermore, fertilizer and straw management practices by rice farmers indicate negative balances for K in all rice systems. With the increase in irrigation area (allowing for double cropping) and rising N and P inputs, the potential for negative K and other nutrient balances is exacerbated. Irrigation water can provide some of the required K but unless K is added or straw management practices are changed so that more of the straw K is returned to the field, K deficiencies are likely to increase especially on these coarse-textured soils.

REFERENCES

Blair, G.J. 1990. ACIAR's sulfur in rice research program in S.E. Asia. In Blair, G.J. and Lefroy, R. (Eds.), *Sulfur fertilization policy for lowland and upland rice cropping systems in Indonesia.* ACIAR Proc. No. 29. pp. 51–55.

Dobermann, A.; Cassman, K.G.; Mamaril, C.P.; and Sheehy, J.E. 1998. Management of phosphorus, potassium and sulfur in intensive, irrigated lowland rice. *Field Crops Research,* 56: 113–138.

Fujisaka, S. 1991. A diagnostic survey of shifting cultivation in northern Laos: targeting research to improve sustainability and productivity. *Agroforestry Systems,* 13: 95–109.

International Rice Research Institute (IRRI). 1995. *World rice statistics 1993–1994.* Los Baños, Philippines: IRRI.

Lao–IRRI. 1995. *Annual technical report*.

Linquist, B.A.; Sengxua, P.; Whitbread, A.; Schiller, J.; and Lathvilayvong, P. 1998. Evaluating nutrient deficiencies and management strategies for lowland rice in Lao PDR. In Ladha, J.K., Wade, L.J., Dobermann, A., Reichardt, W., Kirk, G.J.D. and Piggin, C. (Eds.), *Rainfed lowland rice: Advances in nutrient management research.* Proceedings of the International Workshop on Nutrient Research in Rainfed Lowlands, 12–15 Oct. 1998, Ubon Ratchatathani, Thailand.

Linquist, B.A.; Sengxua, P.; and Whitbread, A. 2000. Residual phosphate availability in lowland rice ecosystems of Laos. Abstracts from conference on Rice Research for Food Security and Poverty Alleviation. International Rice Research Institute. March 31 to April 3, 2000.

Pandy, S.; and Sanamongkhoun, M. 1998. Rainfed lowland rice in Laos: A socio-economic benchmark study. Los Baños, Philippines: IRRI.

Roder, W.; Phengchanh, S.; and Keobulapha, B. 1995. Relationships between soil, fallow period, weeds and rice yield in slash-and-burn rice systems of Laos. *Plant and Soil,* 176: 27–36.

Roder, W.; Phengchanh, S.; and Keobulapha, B. 1997. Weeds in slash-and-burn rice fields in northern Laos. *Weed Research,* 37: 111–119.

Schnier, H.F. 1995. Significance of timing and method of N fertilizer application for the N-use efficiency in flooded tropical rice. *Fert. Res.,* 42: 129–138.

UNDP (United Nations Development Programme). 1999. *Development cooperation report 1998, Lao People's Democratic Republic.* 153p.

Wade, L.J.; George, T.; Ladha, J.K.; Singh, U.; Bhuiyan, S.I.; and Pandey, S. 1998. Opportunities to manipulate nutrient-by-water interactions in rainfed lowland rice systems. *Field Crops Research,* 56: 93–112.

Water and Nutrient Flows under Different Farming Systems on Sloping Lands in Northern Vietnam

Nguyen Cong Vinh and Thai Phien[1]

[1]*National Institute for Soils and Fertilizers, Tu Liem, Hanoi, Vietnam.*
Tel: 84-8385635/838035. E-mail: ncvinh-nisf@vnn.vn; ncvinh_nisf2003@yahoo.com; tphien@netnam.org.vn

INTRODUCTION

Vietnam occupies an area of approximately 33 million ha, three-quarters of which is considered hilly and mountainous. Nguyen Tu Siem and Thai Phien, (1999) suggest that 24.9%, 11.8% and 63.3% of the hilly and mountainous area is associated with slopes of <15^o, 15-25^o and >25^o, respectively. The strongly weathered red-yellow soils of the mountainous zones are according to the FAO classification (FAO, 1988) predominately Acrisols. The climate of Vietnam is characterized by humid monsoons, with mean annual rainfall varying from 1,500 to 2,500 mm yr^{-1}, of which 80 percent is concentrated in the rainy season, from May to September. The traditional cultivation on uplands is a monoculture of upland rice, cassava, and corn without chemical fertilizer inputs. This has resulted in soil impoverishment and low nutrient pools.

OBJECTIVES

The main objectives of this study were, for upland the areas studied, to estimate the soil water and nutrient flows, evaluate a range of agroforestry systems and identify appropriate soil improvement technologies for dissemination to farmers.

MATERIAL AND METHODS

Site Description

The study was conducted from 1996-1999 in Rong Can village, Lam Son Commune, Luong Son District, Hoa Binh Province. The terrain is undulating with slopes of 8–25^o. On the experimental plots, the slopes ranged from 18–22^o. Plot size was 22.5m x 5m (112.5m$^{2)}$ For treatments with hedgerows (Table 1) hedge rows were 1.5 m wide with 6m intervals between rows.

Methods

The field experiment was set up in a completely randomized block design as indicated in Table 1. Rainfall was measured directly with rain gauges at the site and runoff and soil loss were collected in the collection tanks below each experimental plot. Soil and plant samples were collected and prepared following the methodological guidelines outlined by the International Bureau for Soil Research and Management (IBSRAM, 1991). Organic carbon was determined by wet oxidation using the Walkley and Black method as modified by Rayment and Higginson (1992) and total Nitrogen (T-N) by Kjeldahl steam distillation. Total soil P and K was digested by mixed concentrated HNO_3 + $HClO_4$. Available P was determined following the Bray II method. Available K was extracted as exchangeable K with

1M NH_4OC, pH 7, and measure by flame photometer. Soil pH was measured in 1M KCl at a soil:solution ratio of 1:5. Exchangeable calcium (Exch-Ca) and magnesium (Exch-Mg) were determined using 1M NH_4OAC buffered at pH 7.0 (Rayment and Higginson, 1992).All samples were analyzed in triplicate and a Standard Reference Material (Soil sample No. 1 supplied by ACIAR Project 9414) incorporated within the analytical batches. Soil texture was determined by pipette method.

Table 1. Experimental treatments.

Treatment	1996	1997	1998	1999
T1	R-M	R-M	R-M	R-M
T2	Fal.	Fal.	R-M	R-M
T3	R-H-Mch	R-H-Mch	R-H-Mch	R-H-Mch
T4	R-Mch	R-Mch	R-Mch	R-Mch
T5	Corn–peanut	Corn–peanut	Corn–peanut	Corn–peanut

R-M: Upland rice monocropping; Fal.: Fallow; R-H-Mch: Upland rice with hedgerow of Tephrosia candida and mulching; R-Mch: Upland rice monocropping and mulching with Tephrosia candida.

RESULTS AND DISCUSSION

Soil Characteristics

The chemical properties are given in Table 2 and show that the soil is inherently acidic and infertile as indicated by the low pH, low Org-C, and low T-N. In addition the soil is extremely low in total and available P and K. The inherently low buffering capacity of the soil is indicated by the low exchangeable Ca^{++}, Mg^{++} values (Table 2).

Table 2. Soil chemical properties (March 1996).

Soil depth (cm)	pH_{KCl} (1: 5)	Total content, (%)				Available forms		Exch. cations, meq $100g^{-1}$	
		Org-C	N	P	K	P (mg kg^{-1})	K (mg kg^{-1})	Ca^{++}	Mg^{++}
0–12	3.5	1.63	0.16	0.08	0.62	5.88	12.0	0.52	0.40
12–29	3.6	1.18	0.13	0.07	0.63	3.00	5.0	0.24	0.16
29–42	3.8	0.69	0.10	0.08	0.62	2.00	4.0	0.64	0.36
42–55	3.8	0.40	0.08	0.07	0.60	1.88	3.0	0.48	0.28

According to the USDA classification (Gee and Bauder, 1986) soil texture in the experimental plots ranged from silty clay loam to silty clay, (Table 3).

Table 3. Soil particle size distribution.

Soil dept (cm)	% dry weight			
	2–0.20 mm	0.20–0.02 mm	0.02–0.002 mm	< 0.002 mm
0–12	7.7	12.3	38.8	41.2
12–29	7.0	14.8	40.5	37.7
29–42	17.5	5.2	29.6	47.7
42–55	19.0	13.4	21.8	45.8

Water Flow and Runoff Budget

Rainfall

At the study site, rainfall is the only water source for cultivation. During the four-year study period, annual precipitation recorded at the study site was 1,664 mm in 1996, 1,441 mm in 1997, 720 mm in 1998, and 836 mm in 1999 (Figure 1).

The rainy season lasts from April to November. The mean cumulative rainfall from June to August was 736 mm, accounting for approximately 63 percent of the mean annual rainfall of 1,165mm. The heavy rainfall associated with June to August generated soil loss and runoff. In contrast, from November to March no rainfall was recorded.

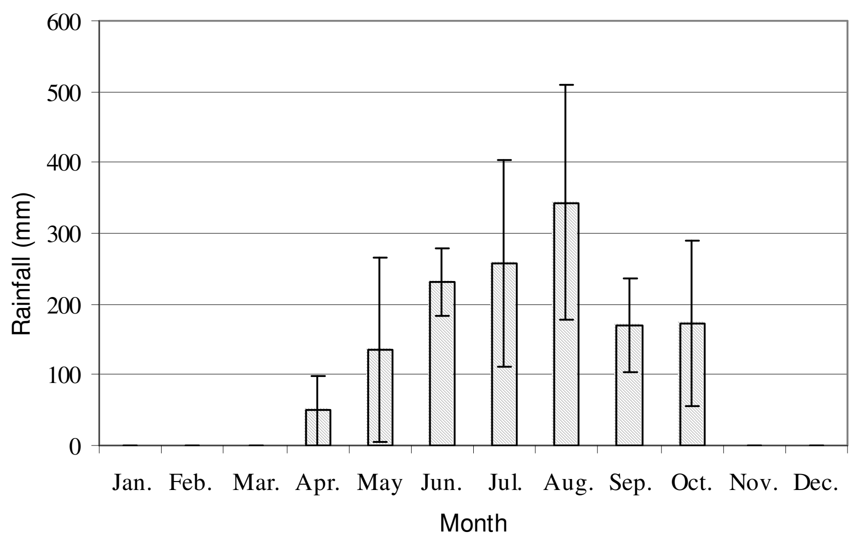


Figure 1. Mean monthly precipitation (mm) at Lam Son-Vinh during the 1996-1999 study period (error bars indicate ±1 STDEV)

Runoff under the treatments evaluated

During the June to August rainy season, rainfall exceeded the soil's water holding and infiltration capacity and runoff was generated. For the treatments evaluated, annual and total runoff is presented in Table 4.

Table 4. Effect of treatment on runoff (m^3 ha^{-1}) during the four year study period.

Treatment	**Year**				**Total**	
	1996	**1997**	**1998**	**1999**	**m^3 ha^{-1}**	**%**
1	1,424	1,941	388	504	4,275	100
2	808	379	89	239	1,515	35
3	1,065	351	60	69	1,545	36
4	1,359	1,240	168	368	3,135	73
5	536	252	67	73	928	22
LSD 0.05	113.2	109.2	27.8	37.4		

Data in Table 4 indicates that the highest rates of runoff occurred in the hill rice monoculture system (T1) and in Years 1 and 2 in the T4 mulching with *Tephrosia candida* treatment. In addition, fallowing (T2) significantly reduced runoff as compare to the control. Hedgerows of *Tephrosia candida* impeded water flow on the soil surface. Following initial establishment during year 1, *Tephrosia candida* hedgerows (T3) reduced runoff. The lowest 4-year runoff occurred in the corn–peanut system (T5). In this system, corn residue and peanut plant mulch covered the soil surface during the rainy season. In general, with improved technologies runoff decreased by 22–73 percent as compared to the control hill rice monoculture system.

Soil Loss under Agroforestry Systems

Soil loss from the treatment plots is presented in Table 5 and showed a similar trend to runoff. Upland rice monoculture had the highest amount of soil loss. The lowest soil loss occurred in the corn–peanut system (T5), which was mulched with crop residues. In addition, mulching with *Tephrosia candida* (T4) for upland rice decreased overland flow resulting in less soil loss than the non-mulched control (T1).

The results indicate that in the first year after clearing, the soil surface was disturbed, and excessive soil loss occurred in all treatments. However there were differences between treatments. The amount of soil loss in treatments T2, T4 and especially T5 was lower than T1 and T4. This was dependent on rainy season soil cover. From the second year (1997) the amount of soil loss decreased significantly in all treatments in comparison with the first year of the experiment (1996). Again, there were major differences between the improved technologies (T2, T3, T4, T5) as compared with the control (T1). Data for the total amount of soil loss in the four-year experiment showed that with improved technologies the amount of soil loss decreased remarkably, being only 19- 44 percent as compared to control (T1).

Table 5. The effect of the treatments evaluated on soil erosion during the four year study period (mt ha^{-1}).

Treatment	**Year**				**Total (1996-99)**	
	1996	**1999**	**1997**	**1998**	**mt ha^{-1}**	**%**
1	55.2	3.7	21.3	5.7	85.9	100
2	22.7	2.8	0	0	25.5	30
3	36.3	0.7	0.7	0	37.7	44
4	57.3	2.5	9.4	1.9	71.1	83
5	15.5	0.4	0	0	15.9	19
LSD 0.05	6.2	0.21	7.4	2.5		

Balance of soil N, P, and K under the Agroforestry Systems evaluated

Nutrient loss from the soil via runoff

The amounts of N, P, and K removed from the soil are presented in Table 6 with the highest losses associated with K followed by N.

Table 6. N, P, and K removed by runoff (kg ha^{-1}).

Treatment	Total 1996–97			Total 1998–99			Total 1996–99		
	N	P	K	N	P	K	N	P	K
1	28.3	2.0	67.3	7.5	0.5	17.8	35.8	2.6	85.1
2	6.6	0.2	35.6	1.8	0.1	9.8	8.5	0.3	45.5
3	11.9	0.6	53.8	1.1	0.1	4.9	13.0	0.6	58.7
4	29.1	1.8	83.2	6.0	0.4	17.2	35.1	2.2	100.3
5	6.6	0.3	25.2	1.2	0.1	4.5	7.8	0.4	29.7
LSD 0.05	4.5	0.5	27.1	0.6	0.1				

It was observed that the lowest amount of nutrient removal occurred in the corn–peanut system (T7), this was followed by upland rice with hedgerows of *Tephrosia candida* (T2). This demonstrated that covering the surface of the soil with biomass prevented nutrient losses via runoff (T2). In T3, *Tephrosia candida* decreased runoff. There was no significant difference between monoculture of upland rice (T1) and monoculture of upland rice with mulching (T4).This may in part have been due to inadequate surface mulching.

Table 7. N, P, K removed through soil loss (kg ha^{-1}).

Treatment	Total 1996–97			Total 1998–99			Total 1996–1999		
	N	P	K	N	P	K	N	P	K
1	82.2	30.6	198.9	10.1	3.8	24.4	184.7	68.7	446.7
2	23.8	9.1	61.3	2.9	1.1	7.6	53.6	20.4	137.7
3	38.9	13.9	120.3	0.7	0.3	2.3	79.2	28.3	245.1
4	68.4	26.7	220.1	4.5	1.8	14.5	145.8	56.9	469.3
5	36.4	11.6	95.3	0.9	0.3	2.5	37.4	11.9	97.8
LSD 0.05	11.5	5.2	57.6	1.2	0.6	4.9			

The amount of N, P, and K removed from the soil surface by soil erosion is reported in Table 7. Nutrient loss via soil erosion was much greater than loss via runoff. Crops absorb nutrients from the soil and accumulate them in tissues. Loss of N, P, and K associated with crop grains is presented in Table 8. Crop grain removed 20–85 kg ha^{-1} of N in the first two years and 31 kg ha^{-1} in the following two years of the four-year rotation. The highest amount of nutrient removal via grain occurred in theT5 (corn–peanut system).

Table 8. N, P, K removed via crop grains (kg ha^{-1}).

Treatment	Total 1996–97			Total 1998–99			Total 1996–99		
	N	P	K	N	P	K	N	P	K
1	22.5	2.7	4.5	19.5	2.7	3.9	42.0	5.7	8.5
2	0	0	0	35.8	4.7	8.4	35.8	4.7	8.4
3	20.4	2.9	4.0	19.1	2.9	3.7	39.5	6.1	7.7
4	31.2	4.7	4.8	32.1	4.7	4.9	63.3	9.4	9.6
5	85	3.9	6.5	30.7	3.9	2.3	115.7	14.8	8.8

Returning N, P, and K to the Soil

For the treatements evaluated, the return of N, P, and K to the soil via crop residues is detailed in Table 9. In treatments with fallow in the first two years (1996-97), where grasses were not cut, no plant residues were returned to the soil. In the second period of the study (1998-1999) in the fallow–upland rice cycle, N, P, and K were returned to the soil via crop residues. The highest amount of N, P, and K was returned into the soil under upland rice with *Tephrosia candida* hedgerows (T3). N, P, and K returned to the soil under the monoculture upland rice system with mulching (T4) was twice that associated with the monoculture upland rice system without mulching (T1).

Table 9. Return of N, P, and K to the soil from crop residues (kg ha^{-1}).

Treatment	Total 1996–97			Total 1998–99			Total 1996–99			
	N	P	K	N	P	K	N	P	K	NPK
T1	17.4	2.1	87.8	16.6	2.0	83.7	34.0	4.1	171.5	209.6
T2	0	0	0	24.0	3.0	133.0	24.0	3.0	133.0	159.6
T3	82.0	6.0	135.0	67.0	6.0	148.0	149.0	12.0	283.0	444.0
T4	80.0	6.0	135.0	61.0	5.0	130.0	141.0	11.0	266.0	417.6
T5	91.0	12.0	30.0	88.0	11.0	29.0	179.0	23.0	59.0	260.5

Soil nutrient balances under the farming systems evaluated

The N-nutrient balance was calculated as the difference between that returned by crop residues and the total amount of N removed via soil loss, runoff, and crop grain. Figure 2 illustrates the N balance in the soil under the different farming systems evaluated. During the first two years, the N balance was negative with the greatest negative balance associated with the upland rice monoculture. After a further two years, soils under the upland rice monoculture without mulching and natural fallow continued to exhibit a negative N balance. In contrast, the upland rice monoculture treatement with mulching via hedgerows of *Tephrosia candida* (T3) had a positive N balance. Dry cultivation with hedgerows of *Tephrosia candida* (T3 and T5) effectively prevented soil loss via erosion. Therefore, soil under these farming systems had the lowest imbalance of N.

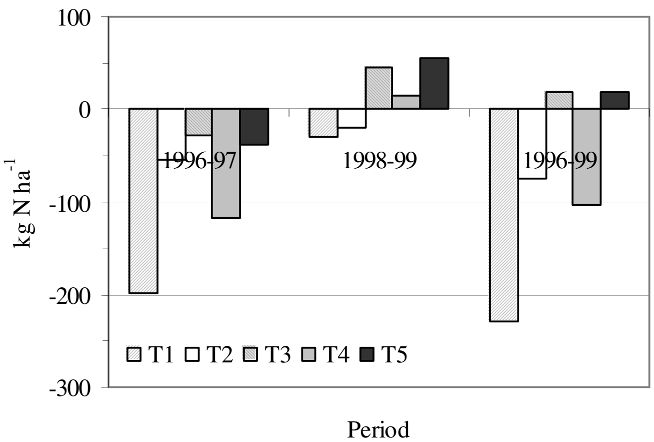


Figure 2. Soil N-balance (kg N ha^{-1}) for the cropping systems evaluated.

For treatments T1, T2 and T4 the net N-balance was negative (Figure 2). The loss of N from the soil was greatest in the natural fallow (T1). Soil N-loss was slightly reduced in treatments with mulching by *tephrosia candida* residue (T4). The T3 *Tephrosia candida* hedgerow and mulching treatment was associated with the lowest soil N-loss. In the first 2 year period (1996-1997) the N balance for the T3 treatment was negative with a value -28.1 kg N ha^{-1}. However, in the second 2 year period (1998-1999) and taken cumulatively over the 4 year study period, the T3 treatment was associated with a positive N-balance (Figure 2). The Corn-peanut system (T5) in association with the return of residues to cover the soil surface was also associated with a net cumulative N-balance. In summary, the farming systems with hedgerows namely T3 and T5 had the highest balance of N, as compared to control

In comparison, the soil P-balances for the treatments evaluated are shown in Figure 3. The results indicate that for all treatments, the net cumulative 4 year P-balance is negative. However, it is of note that during the second half of the study period (1998-1999) the beneficial role the *Tephrosia candida* hedgerows enabled a positive balance for the T3 and T5 treatments.

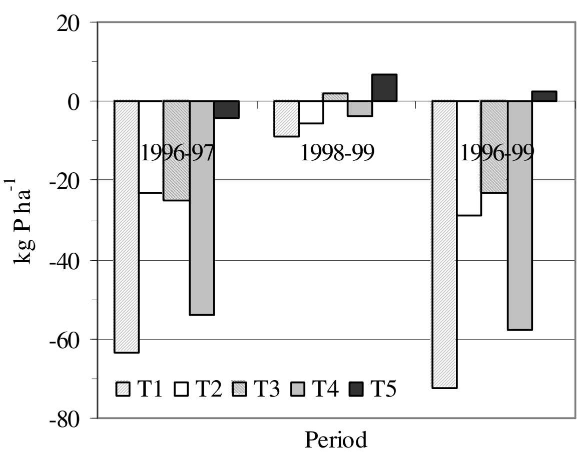


Figure 3. Soil P-balance (kg P ha^{-1}) for the cropping systems evaluated.

The balance of K in the soil is presented in Figure 4. The results indicate that the removal of K was much greater in the first two years of the study period (1996-1997). This may in part be due to the high rates of runoff and soil erosion associated with plot clearance and implementation (Tables 4 and 5). In contrast, for the period 1998-1999 more K was returned to the soil with crop residues than was removed resulting in net positive K-balances for all treatments (Figure 4). However, net cumulative K-balances for all treatments evaluated were negative.

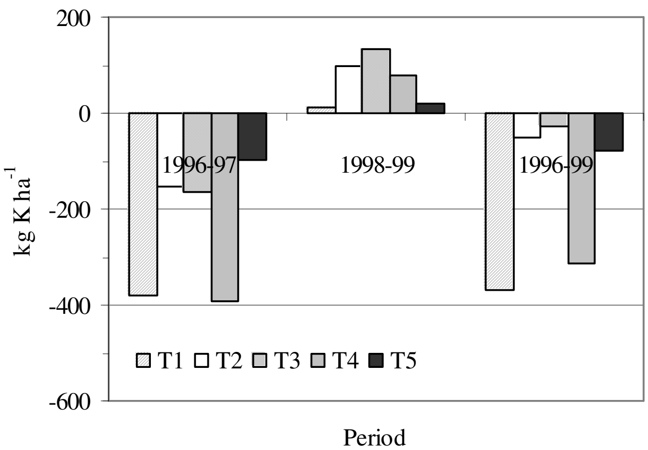


Figure 4. Soil K-balance (kg K ha^{-1}) for the cropping systems evaluated.

CONCLUSION

Water and nutrient flow on sloping land are strongly affected by rainfall and farming systems. Rainfall not only supplies water for plants, but also influences the nutrient balance in the soil. These flows vary very much from farming system to farming system, depending on the cropping systems. The results of this study indicate that for the soil type investigated the adoption of an upland rice monoculture and short fallow systems resulted in stronger negative balances of N, P, and K than the upland rice system with hedgerows of *Tephrosia candida.* Mulching with crop residues in combination with hedgerow technology reduces soil erosion and can effectively prevented nutrient loss.

REFERENCES

Bo, N.V.; and Nguyen Trong Thi. 1997. Mineral fertilizer's utilization-resolution for safety food in Vietnam. In *Proceedings of the workshop on ventilation and soil Environment,* Hanoi, 22–24 January. pp 43–51.

FAO. 1988. *Guidelines for soil profile description.* 3rd ed. Rome: FAO.

Gee, G.W.; and Bauder, J.W. 1986. Particle-size analysis. Methods of Soil Analysis Part 1, Physical and Mineral Methods. Second Edition, Madison. Wisconsin: SSSA.

IBSRAM, March,1991. Methodological guidelines for IBSRAM's soil management networks.

Mutert, E.; and Fairhurst, T. 1997. Nutrient management on sloping land in Southeast Asia: limitations, challenges and opportunities. In *Proceedings of the workshop on water and plant nutrition management on sloping land in Northern Vietnam.* pp 8—20.

Thai Phien; and Nguyen Cong Vinh. 1993. The management of acid upland soils for sustainable agriculture in Vietnam. Reports and papers on the management of acid soils, IBSRAM/*ASIALAND*. Network Document No. 6. pp 201–216.

Thai Phien; and Nguyen Cong Vinh. 1998. Nutrient management for cassava-based cropping systems in northern Vietnam. In *Cassava breeding, agronomy and farmer participatory research in Asia.* CATAS, CIAT, NIPON. pp 268–279. Bangkok, Thailand, April, 1998.

Nguyen Tu Siem; and Thai Phien. 1999. Upland soils in Vietnam - degradation and rehabilitation. Hanoi: Agricultural Publishing House.

Nutrient Balances in a Rice–Vegetable System: A Case Study of an Intensive Cropping System in Ilocos Norte, the Philippines

Raj K. Shrestha[1] and Jagdish K. Ladha[2]

[1]*Nepal Agricultural Research Council, Khumaltar, Lalitpur, Nepal*
[2]*International Rice Research Institute, P. O. Box 3127, MCPO, 1271 Makati City, Philippines*

ABSTRACT

Sustaining soil fertility for economically motivated intensive agriculture is a challenge in the rainfed lowlands of Ilocos Norte, the Philippines. Many residual nutrients are left in the soil after the harvest of dry season crops such as sweet pepper, garlic, tomato, and tobacco. Some of these nutrients are prone to loss through leaching, denitrification, and fixation. Conservation and recycling of nutrients are essential for maintaining soil fertility and the resource base. Partial nitrogen (N) balances have indicated that the integration of a nutrient 'retention' crop during dry to wet season (DTW) transition reduced N losses by 39 to 59 percent. However, the introduction of a cash crop alone was not able to reduce the high N losses in the rainfed lowland system investigated. A positive P balance was observed, which ranged from 63 to 123 kg ha^{-1} (0-25 cm soil depth). A higher balance was observed in plots where nutrient 'retention' crops were grown and residues were incorporated. Nutrient 'retention' crops, especially indigo, improved the K balance in the soil by 34 to 67 percent. The K balance was positively correlated with K input. The C balance indicated a loss of about 600 kg ha^{-1} of labile C from the top 0–25 cm of the soil profile in the farmers' practice (keeping the land fallow) and a gain of up to 3,000 kg ha^{-1} with nutrient 'retention' crops grown during the transition period with residue incorporation before rice transplanting.

INTRODUCTION

Maintaining soil fertility is essential to meeting the food requirements of a rising population. Rice is the staple food of 2.4 billion people worldwide. Further, it is estimated that by 2050, this figure will have increased to 4.6 billion people. This means that more than one billion tonnes of rice must be produced just to maintain current per capita consumption. Irrigated rice ecosystems are already under severe stress and are not likely to expand. To meet the rice needs of the future, we must look to the less favorable, high-risk ecosystems of the rainfed lowlands.

The loss of nutrients from the soil is both an agricultural and environmental concern. The long-term sustainability of agricultural systems depends on maintaining the level of soil Organic Matter (OM) and associated nutrients. Understanding how ecosystems are altered by intensive agriculture, and developing new strategies that take advantage of ecological interactions within agricultural systems are crucial to the continuance of high-production sustainable agriculture (Matson et al., 1997).

The rainfed lowlands of northern Luzon, the Philippines, which exemplify high cropping intensity and input use, serve as a model system for intensified agriculture. The wet season rice followed by one or two dry season non-rice crops including sweet pepper, tomato, garlic, mungbean, corn, and tobacco are among the most common cropping systems. Alternate soil drying (aerobic) during the dry season and wetting (anaerobic) during the wet season are the main features of this system. The cropping system is input intensive. Farmers apply 394–698 kg N ha^{-1}, 64–213 kg P ha^{-1} and 88–347 kg K ha^{-1} (Sta Cruz et al., 1995; Tripathi et al., 1997; Shrestha, 1997). Irrigation and pesticide applied for dry season rice-rotation crops are estimated to be 18 times (Lucas et al., 1999) and 22 times (Shrestha, 1997), higher respectively as compared to the wet season condition. This has revolutionized the crop production system. Previously, Tripathi et al., (1997) reported large N losses of up to 550 kg ha^{-1} across a range of cropping patterns, with the largest occurring in the rice–sweet pepper system, which is the predominant cropping sequence in northern Luzon, the Philippines. The major pathway of N loss is NO_3^- leaching to the groundwater (Shrestha and Ladha, 1998). Groundwater utilized as drinking water contains NO_3^--N at concentrations > 10 mg l^{-1} and is considered unsafe for human consumption (Fletcher, 1991; Viets and Hagemen, 1971). Due to excess use of N fertilizer by farmers, other problems such as decline in soil OM and imbalances of other nutrients are rapidly emerging.

The development of sustainable nutrient management systems that conserve and recycle nutrients is imperative for economic and environmental sustainability. A possible strategy is to grow a nutrient ‘retention’ crop during the transition period between the dry season and the wet season when the soil would otherwise have been left bare. It is envisaged that a nutrient ‘retention’ crop, apart from accumulating NO_3^--N, would preclude NO_3^- loss upon soil flooding and permit recycling of other macro- and micronutrients to the succeeding rice crop. Incorporation of the residue of the nutrient ‘retention’ crop grown during this dry to wet season transition period can also increase the quality and quantity of soil OM. Thereby, the use of a nutrient ‘retention’ may in large part reduce the demand for continued high fertilizer inputs. Residue mineralization can be expected to be high in the first year, but what is not mineralized will mineralize slowly over the succeeding year (Jensen, 1991; 1992). Residue recycling provides a greater buffering capacity for the soil with respect to nutrients and fertility attributes, namely C, N, P, and K.

Changes in the cropping system and residue utilization are likely to affect the quality and quantity of soil OM. The effect of a nutrient ‘retention’ crop on the soil OM status has not been studied in the context of an intensive system. The development of a sustainable agriculture system requires techniques that monitor changes in the amount of soil OM, especially the labile (active) pool, and accurately evaluate nutrient balances under different management systems. This paper describes the effect of selected nutrient ‘retention’ crops on partial nutrient (C, N, P, and K) balances in an intensive rice–vegetable system of Ilocos Norte, the Philippines.

NUTRIENT BUDGET MODEL

A partial nutrient budget model for C, N, P, and K was developed to assess nutrient stocks and flows. A partial C balance was obtained with the difference of initial and final labile C in the soil. Fertilizers added to the soil for all the crops were the sources of nutrient inputs; nutrients captured by all the crops grown in one year were sources of nutrient outputs. Input and output differences were used to calculate the apparent N, P, and K balance. The labile C balance was calculated for a 25 cm soil depth.

Nitrogen (N), Phosphorus (P), and Potassium (K) Balance

The mineral N balance was calculated to evaluate the effect of the nutrient 'retention' crop and wet season management on reducing N losses (Table 1). The N loss from the 100 cm soil profile ranged from 109 to 317 kg ha^{-1}. It was highest in the sweet pepper–fallow–rice system and lowest in the sweet pepper–corn–rice system where corn residue was incorporated in the rice field.

Table 1. System level partial N balance of a sweet pepper–rice cropping system at Magnuang, Philippines (average of 4 sites).

Treatments	Nitrogen (kg ha^{-1})		
	Input from fertilizer (A)	**Output from crop uptake** (B)	**Balance** (A-B)
Sweet pepper–fallow–rice (n=4?)	558	241	317
Sweet pepper–indigo–rice (n=4)	519	390	129
Sweet pepper–indigo + mungbean–rice (n=4)	519	358	161
Sweet pepper–corn–rice (n=4)	519	411	109

The efficiency of the nutrient 'retention' crop in decreasing N loss was in the order of corn > indigo > indigo + mungbean. Corn was more efficient in its ability to capture a soil N (177 kg ha^{-1}) as compared with indigo (151 kg ha^{-1}) and indigo + mungbean (118 kg ha^{-1}) (data not shown). The reduction in N loss due to the integration of a nutrient 'retention' crop during the DTW transition and incorporation of the residue prior to the rice cropping season ranged from 66 % (corn to 49 % (indigo + mungbean) of N losses associated with the traditional fallow. The inability of the nutrient 'retention' transition crops investigated to reduce N losses completely may in part be due to the high buildup of soil mineral N which for the treatments evaluated ranged from 227 to 626 kg ha^{-1}, 97 % of which is NO_3-N (data not shown). This indicates that the strategy of introducing a transitional nutrient 'retention' crop alone is not effective enough to create a closed system and prevent N loss. There is therefore an urgent need to explore other avenues, especially reducing the N fertilizer application rates to better match the N-requirement by dry season crops.

Table 2. System level partial phosphorus balance of a sweet pepper–rice cropping system at Magnuang, the Philippines.

Treatments	Phosphorous (kg ha^{-1})		
	Input from fertilizer (A)	Output from crop uptake (B)	Balance (A-B)
Sweet pepper–fallow–rice	114	27	87
Sweet pepper–indigo–rice	127	42	85
Sweet pepper–indigo + mungbean–rice	127	38	89
Sweet pepper–corn–rice	127	48	79

The P balance was positive, ranging from 79–89 kg P ha^{-1} (Table 2). Incorporation of the indigo + mungbean nutrient 'retention' crops in the sweet pepper–indigo + mungbean–rice system gave a higher P balance as compared to indigo alone or the corn nutrient 'retention' crop with residue incorporation. The corn nutrient 'retention' had the least positive balance due to higher plant P uptake and removal losses.

Table 3. System level partial potassium balance of a sweet pepper–rice cropping system at Magnuang, the Philippines.

Treatments	Potassium (kg ha^{-1})		
	Input from fertilizer (A)	Output from crop uptake (B)	Balance (A-B)
Sweet pepper–fallow–rice	332	203	129
Sweet pepper–indigo–rice	357	318	39
Sweet pepper–indigo + mungbean–rice	357	303	54
Sweet pepper–corn–rice	357	467	-110

The K balance was positive for both the indigo and the indigo + mungbean treatments with crop residue incorporation. In contrast, corn residue incorporation resulted in a negative balance of -110 kg K ha^{-1} due to the large biomass and K uptake (467 kg K ha^{-1} for the sweet pepper–corn–rice system) as compared to indigo + mungbean (303 kg K ha^{-1} for the sweet pepper–indigo + mungbean–corn system) and indigo alone (318 kg K ha^{-1} for the sweet pepper–indigo–rice system). The balance was negative for the sweet pepper–corn–rice system as only 96 to 143 kg K ha^{-1} of K was returned to the soil out of 271 kg K ha^{-1} captured by the corn (data not shown). The balance was highly positive for the traditional sweet pepper–fallow–rice system as compared to the nutrient 'retention' crop treatments due to the absence of crop uptake during the DWT.

Nitrogen, Phosphorus and Potassium Recycling and Soil N-Status

Sweet pepper residue was incorporated in the sweet pepper–fallow–rice treatment whereas both sweet pepper and the respective nutrient 'retention' crop residues were incorporated in the nutrient 'retention' crop treatments (Table 4). The high amounts of residual soil N after the sweet pepper harvest result from excessive (500 kg N ha^{-1}) N–fertilizer application in the dry season sweet pepper crop. After the wet season crop of rice, residual soil N was significantly reduced. However, the incorporation of indigo residue increased residual soil N after the rice harvest as compared to the indigo + mungbean and corn treatments. This may in part be due to its deep rooting system.

Table 4. Recycling of residue N and soil N status in a sweet pepper– rice cropping system at Magnuang, the Philippines.

Treatments	Soil residual N (kg ha^{-1})		
	Residual N recycled	Initial	Final
Sweet pepper–fallow–rice	62	459	55
Sweet pepper–indigo–rice	137	459	61
Sweet pepper–indigo + mungbean–rice	134	459	56
Sweet pepper–corn–rice	127	459	56

Although recycled residue P was small (3–10 kg P ha^{-1}), the amount and type of nutrient 'retention' crop residue had an effect on soil P (Table 5). Incorporation of nutrient 'retention' crop residue maintained higher soil P as compared to the traditional sweet pepper–fallow–rice system without residue incorporation. Corn residue maintained higher soil P as compared to the other cropping systems investigated (Table 5).

Table 5. Recycling of residue P and soil-P status in a sweet pepper–rice cropping system at Magnuang, the Philippines.

Treatments	Soil residual P (kg ha^{-1})		
	Residual P recycled	Initial	Final
Sweet pepper–fallow–rice	3	78	63
Sweet pepper–indigo–rice	9	78	69
Sweet pepper–indigo + mungbean–rice	10	78	79
Sweet pepper–corn–rice	10	78	81

Residue incorporation increased soil K in all residue-incorporated fields as compared to the traditional sweet pepper–fallow–rice system without residue incorporation (Table 6). The increase ranged from 42 kg K ha^{-1} for the indigo treatment to 140 kg K ha^{-1} for the corn treatment. The highest increase in recycled K was associated with the sweet pepper–corn–rice system due to the greater amount of K added in the form of corn residue.

Table 6. Recycling of residue K and soil-K status in a sweet pepper–rice cropping system at Magnuang, the Philippines.

Treatments	Soil residual K (kg ha^{-1})		
	Residual K recycled	Initial	Final
Sweet pepper–fallow–rice	41	699	679
Sweet pepper–indigo–rice	80	699	741
Sweet pepper–indigo + mungbean–rice	110	699	798
Sweet pepper–corn–rice	166	699	839

Labile Carbon Balance

A gain in the labile C (C_L) pool ranging from 1,901 to 2,853 kg C_L ha^{-1} in the sweet pepper–rice system was observed with as a result of the incorporation of nutrient ‘retention’ crop residue. In comparison, a loss of 249 kg C_L ha^{-1} was observed in the traditional fallow transition period and fields without the incorporation of residue (Table 7). Indigo either alone or mixed with mungbean had a higher C_L balance as compared to the sweet pepper–corn–rice and traditional sweet pepper–fallow–rice systems.

Table 7. Labile soil C (C_L) balance for 0–25 cm soil depth as a result of the treatments evaluated.

Treatments	soil C_L (kg ha^{-1})		
	Before nutrient 'retention' crop (A)	Residual soil C_L after rice harvest (B)	A-B
Sweet pepper–fallow–rice	6,071	6,075	4
Sweet pepper–indigo–rice	6,192	8,353	2,161
Sweet pepper–indigo + mungbean–rice	6,107	8,960	2,853
Sweet pepper–corn–rice	6,107	8,008	1,901

Irrespective of the nutrient 'retention' crop grown during the dry to wet season transition period incorporation of crop residue produced a significant gain in soil C_L. In comparison, the traditional sweet pepper–fallow–rice system was associated with a mean (n=4) soil C_L of 4 kg C_L ha^{-1}.

CONCLUSIONS

The prevention of further degradation of soil fertility and the rehabilitation of already degraded land are challenges that must be addressed if agricultural productivity is to be improved and sustainably maintained. Rice–vegetable cropping systems involving rice in the wet season and one or two rotation crops in the dry season are practiced under high-input (N, P, K fertilizer; irrigation; pesticide; increased tillage) conditions in many parts of the rainfed lowlands of the tropics. A high cropping intensity with high inputs, especially for vegetable crops, affects crop production economics, soil fertility, and environmental quality.

Lowland agriculture in Ilocos Norte, Philippines, exemplifies high cropping intensity and input use. Farmers' use of excessive amounts of inputs because of the high economic returns from these cash crops is leading towards an unsustainable system. Therefore there is an urgent need to identify the factors that contribute to poor input efficiency. The crop's water and nutrient requirements for a given yield potential should be examined and appropriate recommendations for timing, amount, and sources to match the demand and supply of nutrients should be developed. The strategies for growing nutrient 'retention' crops during the dry-to-wet transition period in cropping systems, in fields which would otherwise be left fallow, should be promoted to capture and recycle nutrients, and thereby decrease the need for excessive nutrient inputs.

REFERENCES

Fletcher, D.A. 1991. A national perspective. In *Managing nitrogen for groundwater quality and farm profitability.* Madison, Wisconsin: Soil Science Society of America, Inc. pp 9–17.

Jensen, E.S. 1991. Nitrogen accumulation and residual effects of nitrogen catch crops. *Acta agriculturae scandinanica,* 41: 333–344.

Jensen, E.S. 1992. The release and fate of nitrogen from catch crops materials decomposing under field conditions. *J. Soil Sci.,* 43: 335–345.

Lucas, M.L.; Pandey, S.; Agustin, E.O.; Villeno, R.; Marcos, T.F.; Culannay, D.R.; Sta Cruz, P.C.; and Obien, S.R. 1999. Characterization and economic analysis of intensive cropping systems in rainfed lowlands of Ilocos Norte, Philippines. *Exp. Agric.,* 35: 211–224.

Matson, P.A.; Parton, W.J.; Power, A.G.; and Swift, M.J. 1997. Agricultural intensification and ecosystem properties. *Science,* 277: 504–508.

Shrestha, R.K.; and Ladha, J.K. 1998. Nitrate in groundwater and integration of a N-catch crop in intensive rice-based cropping systems to reduce nitrate leaching. *Soil Sci. Soc. Am. J.,* 62 (6): 1610–1619.

Shrestha, R.K. 1997. Nitrogen conservation and recycling, and carbon management for the sustainability of intensive rice-based cropping system. Ph.D. Thesis submitted to the University of the Philippines, Los Baños, Laguna, Philippines.

Sta Cruz, P.C., Garcia, F.D.; Marcos, T.F.; Ingram, K.T.; Ladha, J.K.; and Zeigler, R.S. 1995. Sustainability of rainfed lowland rice and rice-based production systems. In K.T. Ingram (Ed.). *Rainfed lowland rice: Agricultural research for high-risk environments.* Manila, Philippines: IRRI.

Tripathi, B.P.; Ladha, J.K.; Timsina, J.; and Pascua, S.R.. 1997. Nitrogen dynamics and balance in intensified rainfed lowland rice-based cropping systems. *Soil Sci. Soc. Am. J.,* 61: 812–821.

Viets, F.G. Jr.; and Hageman, R.H. 1971. *Factors affecting the accumulation of nitrate in soil, water, and plants.* Agriculture Handbook No. 413 ARS-USDA, Washington, D.C.

The Influence of Soil Surface Management Practices on the Nutrient Status and Physical Properties of Calcareous Soils in Thailand

Ian Grange[1]

[1] *Faculty of Environment and Resource Studies, Mahidol University, Thailand.*

ABSTRACT

The high pH level of calcareous soils can result in reduced availability of micronutrients as well as phosphate. These problems are often compounded by soil physical constraints such as shallow soils, high stone contents, soil crust formation, and low plant available water. The use of appropriate soil surface management practices can help alleviate some of these soil problems. A field scale assessment was made of the partial nutrient balance in a time series of four different soil surface management techniques (bare soil, grass/mulch, Sunnhemp, and Sword bean) as applied to two soil series. In addition, soil physical properties were also assessed. For both soil series evaluated with the exception of the bare soil treatment, all treatments resulted in increased soil organic matter and total N, whilst the Sunnhemp, and Sword bean treatments were also associated with increased available P and exchangeable K. The bare soil treatment maintained soil organic matter and soil nutrients at constant levels throughout the trial period. Soil pH decreased significantly for all the management systems with this being particularly relevant to the soil series most susceptible to nutrient deficiency problems. The formation of surface crusts is common to both the soil series evaluated and was present prior to the initiation of field trials. However, the surface crust was disintegrated during soil preparation in all but the grass treatments, thus reducing the soil bulk density and penetration resistance, and increasing the soil water infiltration rate. The Sunnhemp treatment maintained these beneficial characteristics for a longer period as compared to the other treatments in which the crust tended to re-form. Despite the grass cover in the grass/mulch system, a soil surface crust remained before and throughout the trial, which maintained higher soil bulk density values and slower soil water infiltration rates. Soil temperatures were lowest for the uncut grass sward, whilst the bare soil had the highest temperatures for all depths measured.

INTRODUCTION

Frequently, calcareous soils are associated with plant nutritional problems such as micronutrient deficiencies and low phosphate availability (formation of unavailable calcium phosphate). These constraints to plant growth are often compounded by restrictive soil physical properties including the formation of surface crusts, shallow depth, high stone contents and, low plant available water, especially in dry regions or during extended dry seasons. Soil surface management practices that place emphasis on the input of organic residue, either from *in situ* or external sources, have the potential to reduce the impact of many of these constraints. This input has to be regular and of an adequate quantity/quality in order to sustainably maintain and/or improve crop yields and the soil resource.

Soil surface management techniques affect soil characteristics in different ways and for varying duration.. Further, studies conducted on crop residue management have indicated the temporal nature of some of these soil characteristics. Prasad and Power, (1991) in their review, reported that when organic residues are returned to the soil surface (5 cm depth), organic carbon, total nitrogen, available phosphorus, and exchangeable potassium generally increased, whilst soil pH and soil temperature decreased. However, in the same review, the effects on soil physical properties were less well defined and tended to show wide variations. Vangnai et al., (1986) reported similar physicochemical effects for the upland soils of Thailand. Lal, (1986) reviewed selected soil surface management techniques and reported a general improvement in plant nutrient status, together with increases in soil water infiltration rates and better soil moisture retention. The same review suggested that the management techniques used were not appropriate for all soils, which may in part explain some of the discrepancies in soil physical properties described by Prasad and Power, (1991).

It is useful to determine whether the effects of different soil surface management techniques are potentially beneficial or detrimental to the particular soil environment as the management techniques applied may have consequences for sustainable crop production. The main objective in this trial was to assess the nutrient balance and soil physical properties of existing and innovative soil surface management techniques, over a time period, and to use the information as an indication of sustainable soil fertility. Two soil series were investigated in order to evaluate the role of potential differences in soil characteristics, in the selection of appropriate management strategies.

MATERIALS AND METHODS

The trials were conducted on two sites, designated A and B, at Kanchanaburi Horticultural Experiment Station in western Thailand (13^{o} 58'N, 99^{o} 27'E, 58 m asl). Site A was associated with the Thap Kwahng soil series (Aquic Paleustalf) and Site B the Hin Son soil series (Lithic Paleustalf) which, represent 5,726 ha and 11,765 ha of Kanchanaburi Province, respectively (SSCD, 1994). The Thap Kwahng soil series is predominantly of clay texture whilst Hin Son soil series is a sandy clay loam with significant influence from limestone gravels (Table 1). The climate is tropical wet and dry, (Trewartha, 1968) with a mean annual temperature of 28^{o}C and mean annual rainfall of 1,148 mm. The rainy season is bimodal with peaks in May and September.

Soil Management Treatments

The soils at both sites were disc-plowed approximately one year prior to the commencement of the trial. Subsequently periodically harvested grass cover predominated both Sites (*Cyndon nlemfuensis* on Site A and *Brachiaria reptans* on Site B)., All plots, except for the grass treatment were cleared of weeds using hand-hoes, cutting to a depth of about 5 cm. The cut weeds were removed. The trial commenced in June 1998 (Sampling *Time 1 (T1)*), during the trough of the bimodal rainy season, and continued until the end of December 1998 (Sampling *Time 2 (T2)*), at the onset of the dry season. The four treatments evaluated were:

1) Bare soil: Hand-hoed and the weeds removed when the weed cover reached 50 percent. The plot received the same amount of irrigation water as the other treatments (56 mm every 10 days).
2) Grass/mulch: The grass cover was cut every time it reached a height >30 cm and clippings were returned to the soil surface as a mulch.
3) Sunnhemp (*Crotalaria juncea*): Seeds were broadcast and raked in (~200 seeds m^2 or 64 kg seeds ha^{-1}). A surface mulch of partially composted straw (2000 kg ha^{-1}) was applied to conserve moisture and enable better initial establishment. Sixty Days After Sowing (DAS), plants were cut, chopped, and returned to the surface. A second crop was not sown, as in August the days were too short for high vegetative production.
4) Sword beans (*Canavalia ensiformis*): Seeds were planted at two seeds per station (40 x 40 cm). A surface mulch of partially composted straw (2000 kg ha^{-1}) was given. At 60 DAS, the plants were cut, chopped and returned to the surface. A second crop was sown using the same method.

Soil Sampling, Analyses and Measurements

Composite soil samples (0–5 cm depth) were collected randomly from each plot, at *T1* and *T2*. For the green manure treatments, several weeks elapsed between cutting and soil sampling which allowed for some decomposition of the plant material and soil incorporation. Samples were air-dried and passed through a 2 mm sieve before analysis.

Total nitrogen (N) was determined using the semi-micro Kjeldahl digestion method (Bremner and Mulvancy, 1982). Available-phosphorus (Avail-P) was determined using the Bray 2 method (Murphy and Riley, 1962) and exchangeable-potassium (Exch-K) was determined by ammonium acetate extraction method following Knudsen et al., (1982). Organic matter content (OM) was determined using the Walkley–Black dichromate method (Nelson and Sommers, 1982) and Cation Exchange Capacity (CEC) measurements made using a 1 M ammonium acetate leaching solution buffered at pH 7. Soil pH and electrical conductivity (EC) measurements were made in water using a soil:solution ratio of 1:5 with a 15 minute standing time.

Table 1. Selected soil physical and chemical properties of Site A and Site B.

Soil texture	Soil depth (cm)	Soil particle size analysis (%)			CEC ($cmol_c$ kg^{-1})	pH
		Sand	Silt	Clay		
Clay	0-10 cm	29.7	15.8	54.5	25.2	7.53
(Site A)	30–40 cm	35.4	6.9	57.7	20.4	6.47
Sandy clay	0-10 cm	63.0	12.7	24.3	11.8	8.13
loam (Site B)	30–40 cm	55.5	13.1	31.4	15.4	8.04

Soil dry bulk density (BD) measurements were made using metal cylinders with duplicate samples being taken from each plot at *T1* and *T2*. Particle size distribution was determined using the pipette sampling technique of Avery and Bascomb (1974) and infiltration rate measured using the double ring infiltrometer as described by Landon (1991). Soil penetration resistance was measured using a hand-held penetrometer (Eijkelkamp Agrisearch Equipment). Soil temperature was measured at regular intervals at 1300 hours using the method of Taylor and Jackson (1965).

Experimental Design and Statistical Analyses

A split-split plot design was used with the soils of Sites A and B as the main plots, the management treatments as subplots and times of sampling as sub-subplots. The experiment was arranged in a randomized complete block design with four replications. Subplot sizes were 9 m^2 with a guard row of 0.5 m. Statistical analyses of field and laboratory data was performed using the MSTAT-C program (version 1.42). All tests were made at a significance level of 95%.

RESULTS AND DISCUSSION

The soil at Site A generally had a higher inherent soil OM content than the soil at Site B, before any of the treatments were applied (Figure 1). This is related to the higher inherent clay content at Site A (54.5 %) as compared to that of Site B (24.3 %) (Table1). The ability of clay to stabilize OM, particularly the older fraction of soil OM, by protecting it, both physically and chemically has long been recognized (Anderson and Paul, 1984). Soil CEC values were also higher at Site A than at Site B, which is again related to the higher clay content and soil OM found at Site A. For both soils highly significant increases in soil OM levels were observed between T1 and T2 for the grass, Sunnhemp, and Sword bean treatments (Figure 1). Sunnhemp grown at Site A had the highest overall mean OM value at 3.92 %. Whilst soil OM levels at Site B increased significantly for grass, Sunnhemp, and Sword bean between *T1 and T2*, these levels were lower than Site A. This was attributable to the greater initial biomass productivity found at Site A (results not shown).

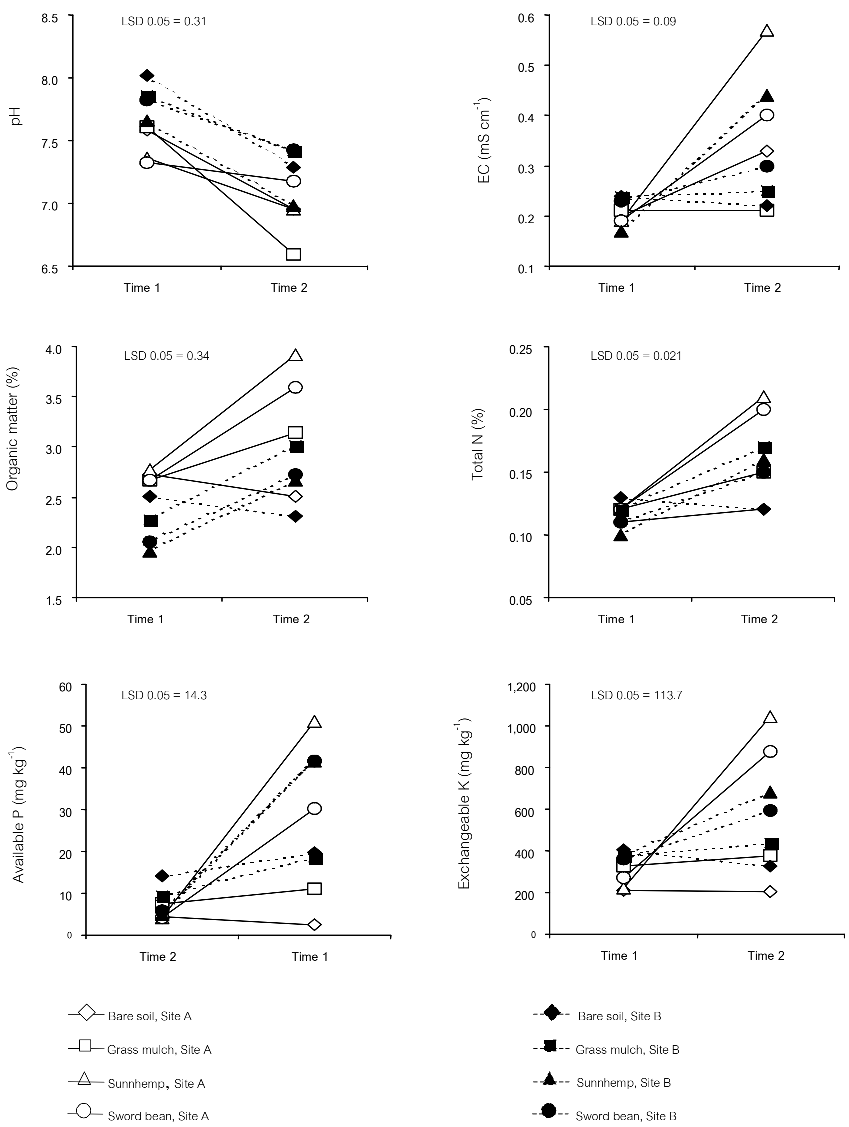


Figure 1. Changes in the surface soil (0-5cm) chemical properties as influenced by soil management techniques over time (six months between Time 1 and Time 2).

The total-N levels, at both sites, significantly increased for the Sunnhemp, Sword bean, and grass treatments, with the bare soil treatment remaining constant (Figure 1). Intuitively, total-N levels in the the Sunnhemp and Sword bean treatments should have been higher than those observed in the grass treatment due to the N-fixing microbes associated with the plant roots. There are two possible reasons why this was not so. Firstly, the plant roots may not have been inoculated effectively with N-fixing microbes as was demonstrated, in the same soils, by Grange and Phudphong, (1999). Secondly, there may have been effective inoculation, but the fixed N may have had a fast turnover rate in the system resulting in a rapid loss or use before the final analyses were conducted.

For the bare soil treatments, the soil OM and total-N levels between the two times of measurement remained almost constant (Figure 1). This indicated that under the current management system (periodic disc plowing/short-term trials/fallow), an equilibrium level of soil OM and total-N had been attained (Grange, 1999).

An indication of the long-term effect can be obtained when a comparison is made with analyses of soil samples taken from an area of secondary forest adjacent to Site A. The mean soil OM level at Site A of 2.47 %, which had been cultivated for 10 years, was significantly lower than that associated with the secondary forest soil (3.22 %). This represents a 23 % decrease in soil OM. Brown et al., (1994) reported that, in general, the soil OM of tropical soils under cultivation can fall to a minimum of 30 percent, but more usually 60 percent, of the corresponding values of soils under natural vegetation within 10 years or less. If this applies to the soil at Site A then a further decrease in soil OM levels might be expected. However, as the discussion above indicates equilibrium has already been achieved with the current management system. This, however, could change if a change in management system occurred and further analyses would be required over an extended time period to determine the longer-term equilibrium of the measured values.

A consideration of this trial was to increase the *in situ* organic material production in order to maintain or improve soil fertility via the ameliorative effects it has on other, direct constraints to plant growth. The clay soil at Site A gave the highest overall dry matter (DM) shoot production for all three crops when compared to the sandy clay loam at Site B. DM production was significantly greater for grass and sword bean. Sunnhemp, whilst giving low total shoot DM production, gave the highest values for any single harvest at 6.3 and 5.0 t DM ha^{-1} for Site A and B, respectively. For comparison, Beri et al., (1989) reported 5.4 mt DM/ha, whilst a range of 0.3 to 4.7 mt DM/ha was reported by Werasopon et al., (1998).

Soil pH levels, measured by water suspension, are subject to variations due to seasonal changes in soil moisture and the ionic concentration of the soil solution. The control these factors has on the hydrogen ion concentrations can affect soil pH by up to 0.6 of a pH unit in any one year (Slattery et al., 1999). Both soils and all treatments showed significant pH decreases over time (Figure 1). The high pH values of the sandy clay loam soils at Site B (Table 1), and to a lesser extent the clay soil at Site A (Table 1), are dependent upon the relative amounts and equilibrium between carbonate and calcium ions and carbon dioxide. An increase in the concentration of carbon dioxide causes a decrease in soil pH. Microbes that decompose organic material respire carbon dioxide (Brown et al., 1994) and this may in part explain the observed decreases in soil pH.

Electrical conductivity values (EC) remained constant for the bare soil and grass treatments, whilst there were significant increases for the Sunnhemp and Sword bean treatments, particularly at Site A (Figure 1). This has been attributed to the dissolved salts in the irrigation water (TDS = 0.2–0.5 g l^{-1}, Grange 1999) and crop related variations in evapotranspiration in combination with the leaching process. However all EC levels are considered to be low at <2 mS cm^{-1}, (Richards, 1954). For both available-P and exchangeable-K, all the levels follow a similar trend, with the highest values occurring after treatment with Sunnhemp and Sword bean (Figure 1).

The increases are due in part, to the Sunnhemp and Sword bean treatments with additions also derived from the partially decomposed straw surface mulch and follow similar trends to those reported by Werasopon et al., (1998) and Badanur et al., (1990). In addition, the significant decreases in pH may have enabled the increased dissolution of calcium phosphate, together with the greater mineralization of organic phosphorus.

The exchangeable-K values are, however particularly high and this is probably due to a combination of the inherent secondary illite derived from micas and alkaline feldspars present in the soils, together with additions from the Sunnhemp and Sword bean plant material and the straw surface mulch. There is however a large coefficient of variation (25.4 %) reflecting the wide range of values. Moody and Bolland, (1999) give critical values of available-P attained using the Bray II method of 33 to 64 mg kg^{-1} for a range of crops. The Sunnhemp and Sword bean treatments in both soils clearly bring available-P levels to within this given range (Figure 1). Similarly Gourley, (1999) gives, for a range of crops, moderate to high levels of exchangeable-K as being between 78 to 351 mg kg^{-1}. Both soils tested here were adequately supplied with exchangeable-K both before and after treatments.

The bulk density (BD) values of the sandy clay loam soils at Site B are inherently higher than the clay soil at Site A (1.45 and 1.25 kg m^3, respectively) and are related to the soil texture (Tables 1 and 2). The Sunnhemp and Sword bean treatments decreased soil BD at both sites, being highly significant for the soil at Site B. Soil BD, however, was not significantly changed for either the bare soil or grass treatments at both sites. An increase in BD might have been expected for the bare soil since exposure to raindrop and irrigation water impact, for long periods, leads to soil crusting, even in well-structured soils (Le Bissonnais and Arrouays, 1997).

This suggests that the surface soil had reached a minimum stable BD. This was shown when the soil profile was examined revealing a compact surface crust of 1-2 cm thickness at both sites. This was also demonstrated using a hand-held penetrometer which showed greater resistance to penetration in the surface 0–5 cm than in the subsurface 5–20 cm horizon at uniform moisture levels. This surface crust was also present in the soils of the grass treatments, which might also explain why there was no reduction in BD as might have been expected under grass (Lal, 1986).

A higher root penetration resistance would discourage root establishment from the runners of the dominant grasses (*Cyndon nlemfuensis* and *Brachiaria reptans*), hence tending to favor a soil surface cover of competitive leafy stems at the expense of roots, which on examination, appeared sparsely distributed, thus reducing the soil ameliorating effects of a full root cover.

Table 2. Dry bulk density of surface soil samples (0–5 cm) as influenced by management techniques for clay soil (Site A) and sandy clay loam soil (Site B).

	Bulk density (Mg m^{-3})[a]						
Management technique	**Clay soil (Site A)**			**Sandy clay loam (Site B)**			
	T1	***T2***	***difference***	***T1***	***T2***	***difference***	[b]**Average**
Bare soil	1.29	1.33	*-0.04 ns*	1.44	1.33	*0.11 ns*	1.35 a
Grass	1.27	1.37	*-0.11 ns*	1.48	1.36	*0.13 ns*	1.37 a
Sunnhemp	1.28	1.17	*0.11 ns*	1.45	1.14	*0.31* **	1.26 b
Sword bean	1.18	1.18	*0.00 ns*	1.42	1.18	*0.25* **	1.24 b
[b]Average	1.25 b	1.26 b		1.45 a	1.25 b		

[a]Average of four replications. ** = significant at 1% level, ns = not significant.
[b]In a column and row LSD (0.05) = 0.0553

For both Site A and Site B soil water infiltration rates (data not shown) and cumulative intake rates (Figure 2) are highest for the bare soil treatments at *T1*. This is probably due to the hand-hoeing action when clearing the weeds, which broke up the soil surface crust. The infiltration tests were conducted soon after this hoeing, before a new surface crust had time to develop.

This can be seen as a temporary improvement since infiltration and cumulative intake rates again decrease, to what might be regarded as a base level after the six months of treatments due to soil surface crust formation (Figure 2). The infiltration rates for the grass treatments at *T1* are low, particularly at Site B, and remain low at *T2*. This is due to the poor soil surface structure, this time compounded by the lower overall BD values, despite having a thick cover of grass. However, this grass has a poor soil structure ameliorating ability, as described above.

The Sunnhemp treatment at Site A (Site B value was not determined) improves the infiltration and cumulative intake rates. This may in part be due to high plant density, with the stems and taproots creating channels for water percolation during and after decomposition. This too was reflected in the penetrometer measurements with the soil surface maintaining a structure with least penetration resistance and lower BD. The Sword bean treatment, having a lower plant density and a larger area of exposed soil, is vulnerable to soil crust formation and therefore shows low infiltration and cumulative intake rates (Figure 2).

Soil temperature can influence rates of OM decomposition, N mineralization, and soil respiration with these rates increasing exponentially within a soil temperature range of 10 to 30^{o}C (Woomer and Swift, 1990). The optimum soil temperature for plant growth is species dependent, and a range of 20 to 30^{o}C has been reported by Marshall and Holmes (1994). High soil temperatures can have detrimental effects on crop growth with Harrison-Murray and Lal (1979) reporting corn plants ceasing to grow at soil temperatures exceeding 36 ^{o}C. In the present trial soil temperatures were measured at regular intervals. Temperatures were the lowest, at each depth, for soils with an uncut grass cover (range of 32–36 ^{o}C), whilst the highest occurred for the bare soil, with surface temperatures over 50 ^{o}C and a range of 40–43 ^{o}C at a 12 cm depth. The Sunnhemp treatment maintained relatively low temperatures, particularly at Site A, whilst the Sword bean treatment with a lower canopy shade area was higher (data not shown).

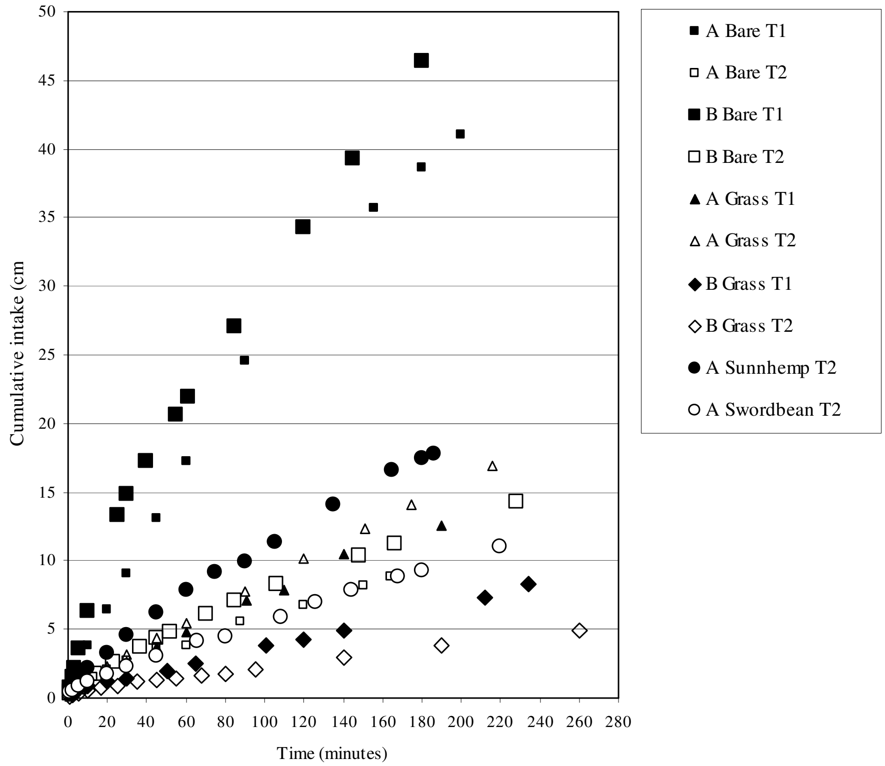


Figure 2. Comparison of cumulative soil water intake rates for the different soil management systems.

CONCLUSION AND RECOMMENDATIONS

The clay soil (Site A) was inherently more fertile with a greater nutrient balance than the calcareous sandy clay loam soil (Site B). Any increases to this balance that might occur due to the soil management technique would therefore be more significant for the sandy clay loam soil giving proportionally better benefits than for the clay soil. The significant decreases in soil pH is a good example, where plant nutrient deficiencies related to high pH are a major problem in the calcareous soils and where the same unit pH reduction would be expected to give proportionally better improvements to soil nutrient availability.

The Sunnhemp and Sword bean management systems are labor-intensive, but give the best soil nutrient returns. This labor cost therefore needs to be offset against the savings made in fertilizer applications that might otherwise be required. The Sunnhemp and Sword bean management systems also improve soil physical characteristics by breaking the soil surface crust and, in the case of Sunnhemp, prevent the re-formation of this crust for a longer period, improving root penetration and water infiltration. Sunnhemp and Sword bean produce the most soil OM, which will have ameliorative benefits, over time, on other soil characteristics that affect plant growth (Woomer and Swift, 1990).

The bare soil management system requires similar labor inputs to that of the Sunnhemp and Sword bean management systems but has little impact on the nutrient balance with levels remaining constant. Additional nutrient inputs, such as fertilizer might therefore have to be considered for adjacent fruit tree crops.

The periodic cutting of the grass/mulch sward requires a lower labor input and increases levels of organic matter and total-N, although phosphorus levels remained low and additional inputs would be required to optimize yields. A method might be developed for improving the rooting potential of the grass by breaking the soil surface crust under the grass. A chisel plow or tined cultivator could be used, or even completely re-establishing the sward with an improved grass–legume mix.

The results of this study apply to the two soil series over a relatively short, six month duration, Any conclusions drawn should be considered within this context. Further study over a longer time frame would help verify some of the initial conclusions made here and would also give a better indication of the temporal effects.

REFERENCES

Anderson, D.W.; and Paul, E.A. 1984. Organo-mineral complexes and their study by radiocarbon dating. *Soil Science Society of America Journal,* 48: 298–301.

Avery, B.W.; and Bascomb, C.L. 1974. *Soil survey laboratory methods*. Soil Survey Technical Monograph No. 6, Harpenden.

Badunar, V.P.; Poleshi, C.M; and Naik, B.K. 1990. Effect of organic matter on crop yield and physical and chemical properties of a vertisol. *Journal of Indian Society of Soil Science,* 38 (3): 426–429.

Beri, V.; Meelu, O.P.; and Khind, C.S. 1989. Biomass production, N accumulation, symbiotic effectiveness and mineralization of green manures in relation to yield of wetland rice. *Tropical Agriculture (Trinidad),* 66 (1): 11—16.

Bremner, J.M.; and Mulvaney, C.S. 1982. Total nitrogen. In Black, C.A. (Ed), Methods of soil analysis. Part 2. Chemical and microbiological properties.. Agronomy No. 9, Part 2. Madison, Wisconsin: Am. Soc. of Agron. pp. 595–623.

Brown, S.; Anderson, J.M.; Woomer, P.L.; Swift, M.J.; and Barrios, E. 1994. Soil biological processes in tropical ecosystems. In Woomer, P.L. and Swift, M.J. (Eds.), *The biological management of tropical soil fertility*. Chichester,UK: John Wiley and Sons Ltd. pp. 15–47.

Gourley, C.J.P. (1999). Potassium. In Peverill, K.I., Sparrow, L.A. and Reuter, D.J. (Eds), *Soil analysis: an interpretation manual*.. Australia: CSIRO Publishing.

Grange, I.; and Phudphong, N. 1999. Biofertilization by rhizobial inoculation in clay soils of Kanchanaburi, Western Thailand. *Thai Journal of Soils and Fertilizers,* 21 (4).

Grange, I.D. 1999. Soil Survey of Kanchanaburi Horticultural Experiment Research Station. DOA, Bangkok; Horticultural Research Institute..

Harrison-Murray, R.S.; and Lal, R. 1979. High soil temperature and the response of maize to mulching in the lowland humid tropics. In Lal, R. and Greenland, D.J. (Eds.), *Soil physical properties and crop Production in the tropics*. John Wiley and Sons. pp 285–304.

Knudson, D.M.; Peterson, G.A.; and Pratt, P.F. 1982. Lithium, sodium and potassium. In Black, C.A. (Ed.), Methods of soil analysis. Part 2. Chemical and microbiological properties. . Agronomy No. 9, Part 2. Madison, Wisconsin: , Am Soc of Agron. . pp 225–245.

Lal, R. 1986. Soil surface management in the tropics for intensive land use and high and sustained production. In Stewart, B.A., Ed., *Advances in soil science*. 5: 1–109.

Landon, J.R. (Ed). 1991. Booker tropical soil manual. UK: Longman Scientific and Technical.

Le Bissonnais Y.; and Arrouays, D. 1997. Aggregate stability and assessment of soil crustability and erodibility: II Applications to humic loamy soils with various organic carbon contents. *European Journal of Soil Science,* 48: 39–48.

Marshall, T.J.; and Holmes, J.W. 1994. *Soil physics* (2nd ed.). Cambridge University Press.

Moody, P.W.; and Bolland, M.D.A. 1999. Phosphorus. In *Soil analysis: an interpretation manual*. Australia: CSIRO Publishing..

Murphy, J.; and Riley, J.P. 1962. A modified single solution method for determination of phosphate in natural waters. *Anal. Chem Acta,* 27: 31–36.

Nelson, D.W.; and Sommers, L.E. 1982. Total carbon, organic carbon and organic matter. In Black, C.A. (Ed.), Methods of soil analysis. Part 2. Chemical and microbiological properties. . Agronomy No. 9, Part 2. Madison, Wisconsin: Am Soc of Agron.. pp 539–577.

Prasad, R.; and Power, J.F. 1991. Crop residue management. *Advances in Soil Science,* 15: 205–251.

Richards, L.A. (Ed.) 1954. Diagnosis and improvement of saline and alkaline soils. Handbook 60. Washington, D.C.: USDA.

Slattery, W.J.; Conyers, M.K.; and Aitken, R.L. 1999. Soil pH, aluminium, manganese and lime requirement. In *Soil analysis: an interpretation manual*.. Australia: CSIRO Publishing.

Soil Survey and Classification Division (SSCD). 1994. Soil Survey Report for Kanchanaburi Province. No. 570. Bangkok: Department of Land Development.

Taylor and Jackson. 1965. Soil temperature. In Methods of Soil Analysis Part 2. Chemical and microbiological properties. Agronomy No. 9, Part 2. Madison, Wisconsin: Am. Soc. of Agron. pp 936–939.

Trewartha, G.T. 1968. An introduction to climate. Fourth edition. New York, USA: McGraw-Hill.

Vagnai, S.; Kheoruenromme, I.; and Sukthumrong, A. 1986. Soil organic matter, crop residue and green manure management. In *Proceedings of the first regional seminar on soil management under humid conditions in Asia*. IBSRAM, *ASIALAND*, 13–20 Oct., 1986.

Werasopon, O.; Chairoj, P.; Leangsiroru, S.; and Wongubol, W. 1998. Green manuring effects of perennial, annual and cover legumes on upland rice yield and some properties of soils. *Thai Agricultural Research Journal,* 16(2): 178–184.

Woomer, P.; and Swift, M.J. 1990. Effect of declining soil organic matter on the soil constraints to crop growth. Conference: IITA Workshop on Soil Fertility Processes, Ibadan, Nigeria, 6–10 Nov. 1990.

Nutrient Inputs and Losses in Cassava-based Cropping Systems—Examples from Vietnam and Thailand

Reinhardt H. Howeler[1]

[1] *CIAT Regional Cassava Office, Dept. of Agriculture, Chatuchak, Bangkok 10900, Thailand*

ABSTRACT

Cassava (*Manihot esculenta* Crantz) can extract large amounts of nutrients from the soil and cause serious erosion when grown on slopes, resulting in degradation of the soil's physical and chemical properties. This paper examines in detail the nutrient losses resulting from the harvest of either cassava roots alone or together with stems and leaves, as practiced in some parts of Asia. It also reports on nutrient losses in eroded sediments and runoff.

It was found that in the root harvest of cassava, relatively large amounts of K and N are removed from the field, but removal of P is very low. Total nutrient removal per hectare is usually lower than for other crops, with the possible exception of K, while nutrient extraction t Dry Matter^{-1} in the harvested products is usually well below that of other crops. However, if stems and leaves are also removed from the field, the extraction of all nutrients increases, especially that of N and Ca. In this case nutrient losses may be greater than for other crops, and considerable nutrient inputs in the form of chemical fertilizers or manures are required to maintain a positive nutrient balance.

When grown on slopes cassava may cause more soil erosion than most other crops due to the wide plant spacing used and its slow initial growth. This can result in high nutrient losses in eroded sediments and runoff. Total nutrient losses in the eroded soil tend to be high in N and K, but relatively low in P. In comparison, nutrient losses in the runoff are smaller but tend to be relatively high in Ca and K, followed by N, Mg, and P. Thus, total nutrient losses due to cassava cultivation can be quite high, especially those of N and K, when cassava yields are high, or when the crop is grown on slopes. To maintain a positive nutrient balance it is important to apply enough fertilizers or manures that are high in N and K, and to use cultural practices that will reduce runoff and erosion.

In both Vietnam and Thailand farmers tend to apply too much P but not enough N and K. To maintain a positive balance of all three major nutrients it is recommended that farmers in Vietnam apply less P and farmyard manure (< 5–10 t ha^{-1}), but apply additional K in the form of chemical fertilizers. In Thailand, it is recommended that farmers shift from applying 15-15-15 to the use of a compound fertilizer high in K and N such as 15-7-18, applying at least 200 kg ha^{-1} to sustain an average cassava root yield of about 15 t ha^{-1}.

INTRODUCTION

In 1997 the global harvested area and production of cassava (*Manihot esculenta* Crantz) in Asia amounted to 3.48 million ha and 18.07 million metric tonnes (mt), respectively. Southeast Asia alone accounted for 2.97 million ha and 14.33 mt. In Southeast Asia cassava is the third most important crop in terms of area, and the fourth in terms of dry matter (DM) production, after rice, sugarcane, and corn (FAOSTAT, 1999).

In Asia, cassava is usually grown in upland areas, above the lowland rice paddies, but below the forested areas found on the upper and steeper parts of the mountains. In Thailand, Malaysia, and India cassava is mostly grown in monoculture. In Indonesia cassava is frequently intercropped with upland rice, corn, and grain legumes, while in Vietnam, China, and the Philippines both systems are practiced extensively.

Cassava in Asia is usually grown from sea level up to 500 m above sea level, indicating that, unlike Africa and Latin America, there is basically no highland cassava cultivation in this continent. In Asia the crop is grown mostly on Ultisols (55%), followed by Inceptisols (18%), Alfisols (11%), Entisols (9%), and other types of soils (7%) (Howeler, 1992). The soil texture ranges from sandy loams (Thailand), sandy clay loams (Thailand, Vietnam), clay loams (China, Vietnam) to clays (Indonesia, China, Vietnam, Philippines). Most of the light-textured soils are acid and very low in nutrients with the heavier soils tending to have better fertility.

Nutrient Balance

A nutrient balance is usually considered to be the difference between nutrient inputs and outflows (or losses). If the balance for a particular nutrient is positive, that nutrient will accumulate in the soil. In contrast, if the balance is negative depletion occurs, and the soil's fertility status may deteriorate. In this case the production practices are unsustainable and the soil may eventually not be able to maintain adequate levels of available nutrients required for crop production. During plant growth, nutrients are taken up from the solution phase of the soil, which is replenished through ion exchange, by dissolution from the solid mineral phase, or by mineralization of organic compounds. A portion of the nutrients will be returned to the soil in the form of crop residues. The remainder will be removed from the field in the form of harvested products. Nutrients can also leave the field via erosion, either in the form of water runoff or soil sediments. In addition, nutrients are lost through leaching (mainly N and K) and volatilization (mainly N). The loss of nutrients is partially countered by biological N-fixation, atmospheric deposition (mainly N and S) in rainfall, and by deposition of soil eroded from upper slopes. In addition, nutrient losses can be countered by the application of chemical fertilizers, animal manures, compost or mulch (collected elsewhere) and industrial by-products. Fallow rotation, green manuring, *in-situ* mulching, intercropping, and incorporation of crop residues may improve the N status of the soil through biological N fixation. Although these practices may also bring up P and K from the subsoil to the topsoil, this does not add nutrients to the system, but merely recycles those nutrients within the system. In this case there is no net gain.

NUTRIENT LOSSES IN CASSAVA PRODUCTION SYSTEMS

Nutrient Uptake and Removal by Cassava

Nutrient Uptake and Distribution in the Plant

Like any other plant, the growth and nutrient uptake of cassava depends on the climatic conditions and nutrient status of the soil. When these are favorable, growth, and consequently, nutrient uptake are enhanced. Figure 1 and Table 1 show that total dry matter (DM) production was markedly enhanced by irrigation as well as by fertilizer application of cassava grown in Carimagua, Colombia. At time of harvest, DM was found mainly in the roots, followed by stems, fallen leaves, leaf blades, and petioles.

Table 1. Dry matter and nutrient distribution in 12-month-old cassava cv. M Ven 77, grown with and without fertilizer in Carimagua, Colombia.

		Nutrient Status kg ha^{-1}										
	DM (mt ha^{-1})	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
Un-fertilized												
Top	5.11	69.1	7.4	33.6	37.4	16.2	8.2	0.07	0.03	0.45	0.33	0.26
Roots	10.75	30.3	7.5	54.9	5.4	6.5	3.3	0.08	0.02	0.38	0.02	0.10
Fallen leaves	1.55	23.7	1.5	4.0	24.7	4.0	2.5	0.04	0.01	-	0.37	0.18
Total	**17.41**	**123.1**	**16.4**	**92.5**	**67.5**	**26.7**	**14.0**	**0.19**	**0.06**	**-**	**0.72**	**0.54**
Fertilized												
Top	6.91	99.9	11.7	74.3	55.0	15.3	9.6	0.08	0.03	0.78	0.57	0.30
Roots	13.97	67.3	16.8	102.1	15.5	8.4	7.0	0.07	0.03	0.90	0.06	0.17
Fallen leaves	1.86	30.5	2.0	7.1	31.9	4.7	2.6	0.05	0.02	-	0.46	0.19
Total	**22.74**	**197.7**	**30.5**	**183.5**	**102.4**	**28.4**	**19.3**	**0.20**	**0.08**	**-**	**1.09**	**0.66**

Source: Howeler, 1985a.

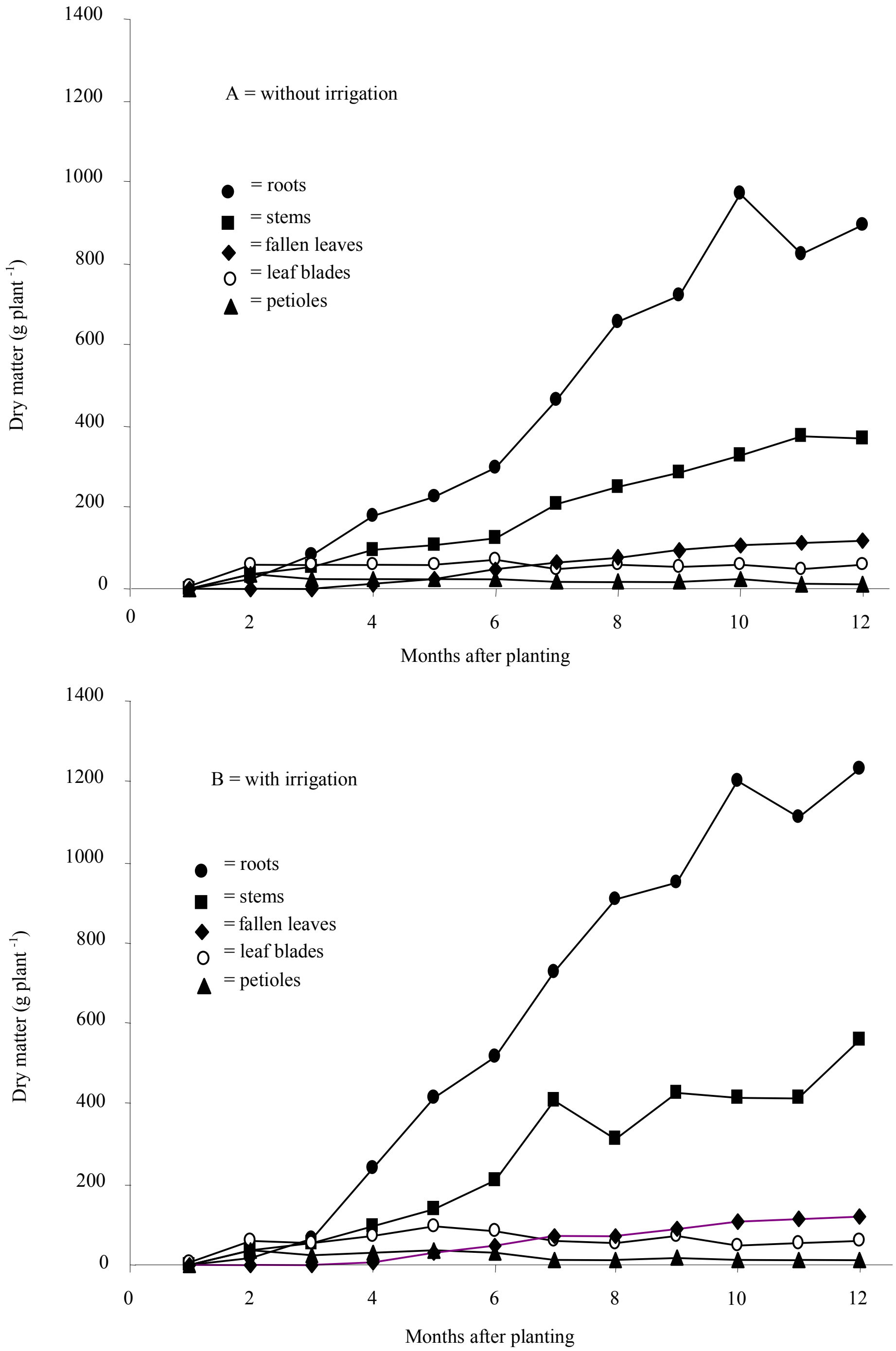


Figure 1. Dry matter distribution among roots, stems, leafblades, petioles, and fallen leaves of fertilized cassava during a 12-month growth cycle in Carimagua (Colombian Eastern Plains), without (A) or with (B) irrigation in 1983/84. Source: CIAT, 1985b

Nutrients Removed from and Returned to the Field

Table 1 shows that if only roots are harvested and removed from the field, as practiced in Thailand, only about 60 % of total DM produced, 25–30 % of total N, 45–55 % of total P, and 55—60 %t of total absorbed K are removed from the field. In contrast, in areas where leaves are also harvested for animal feed, the stems are used for firewood, and the fallen leaves for kindling, as in parts of north Vietnam practically all DM produced and all nutrients absorbed will be removed from the field. In the latter case, nutrient removal by the harvest of all of these cassava products will be substantial.

The amount of nutrients absorbed and removed also depends on the variety used and the yield levels obtained. Table 2 shows the yields obtained and the amount of nutrients in either the roots or the whole plant (without fallen leaves) at time of harvest for 19 experiments reported in the literature, with fresh root yields ranging from 6.0 to 64.7 mt ha^{-1}. Obviously, nutrient absorption and removal increase as yields increase. Based on the data in Table 2, Table 3 shows the average values for nutrients removed in the roots or in the whole plants in terms of kg ha^{-1}, as well as in terms of kg mt fresh or dry roots. According to these data, approximately 37 % 49 % and 56 % of absorbed N, P and K is found in the roots and will be removed if only roots are harvested, respectively. However, when the nutrients in the roots or whole plant are plotted against yield (Figures 2 and 3) it is clear that the nutrient removal is not proportional with yield as plants with a high root yield also tend to have higher nutrient concentrations in the roots as well as in the leaves and stems (Howeler, 1985). Thus, if we base our nutrient removal calculations for a particular situation on the average removal data shown in Table 3, we would overestimate nutrient removal if yields are low and underestimate removal if yields are high (Figures 2 and 3). For instance, assuming an average fresh root yield of 15 mt ha^{-1} (as obtained in Thailand) and that only roots are removed from the field, we would calculate a removal of about 34.8 kg N, 5.85 kg P, and 45.7 kg K ha^{-1} using the average values in Table 3, while Figure 2 shows that actual removal is likely to be about 30 kg N, 3.5 kg P, and only 20 kg K ha^{-1}.

Table 2. Fresh and dry yield, as well as nutrient content in cassava roots and in the whole plant at time of harvest, as reported in the literature.

Plant part	Yield (mt ha^{-1})		Nutrient content (kg ha^{-1})					Source/Cultivar
	fresh	dry	N	P	K	Ca	Mg	
Roots	64.7	26.59	45	28.2	317	51	18	Nijholt, (1935) cv. Sao Pedro Preto
Whole plant	110.6	39.99	124	45.3	487	155	43	
Roots	59.0	21.67	152	22.0	163	20	11	Howeler and Cadavid, (1983) fertilized MCol 22
Whole plant	-	30.08	315	37.0	238	77	32	
Roots	52.7	25.21	38	27.9	268	34	19	Nijholt, (1935) cv. Mangi
Whole plant	111.1	44.65	132	48.5	476	161	52	
Roots	50.0	-	153	17.0	185	25	6	Cours, (1953) Madagascar
Whole plant	-	-	253	28.0	250	42	29	
Roots	45.0	-	62	10.0	164	12	22	Amarisisi and Pereira, (1975) Sri Lanka
Whole plant	-	-	202	32.0	286	131	108	

Table 2. Continued

Roots	37.5	13.97	67	17.0	102	16	8	Howeler, (1985b) unfertilized MCol 22
Whole plant	-	22.74	198	31.0	84	102	28	
Roots	~36.0	12.60	161	10.0	53	16	12	Paula et al., (1983) fertilized Branca St. C.
Whole plant	-	20.92	330	20.5	100	88	30	
Roots	32.3	15.39	127	19.1	71	6	5	Cadavid, (1988) fertilized CM523-7
Whole plant	-	25.04	243	34.4	147	56	25	
Roots	31.0	-	31	18l9	47	-	-	Sittibusaya and Kurmarohita, (1978)
Whole plant	-	-	73	31.9	72	-	-	
Roots	~28.5	10.28	100	8.7	107	15	13	Paula et al., (1983) fertilized Riqueza
Whole plant	-	19.56	353	24.8	174	133	37	
Roots	26.6	12.81	91	11.3	47	5	6	Cadavid, (1988) unfertilized CM523-7
Whole plant	-	19.10	167	19.1	76	32	19	
Roots	26.0	10.75	30	8.0	55	5	7	Howeler, (1985a) unfertilized MVen 77
Whole plant	-	17.41	123	16.0	92	67	27	
Roots	21.0	-	21	9.2	44	8	10	Kanapathy, (1974) Malaysia, peat soil
Whole plant	-	-	86	37.2	135	45	34	
Roots	18.3	5.52	32	3.6	35	5	4	Sittibusaya (unpublished) fertilized Rayong 1
Whole plant	-	9.01	95	9.9	65	37	15	
Roots	16.1	3.64	30	4.7	45	9	5	Putthacharoen et al., (1998) 1990/91 Rayong 1
Whole plant	-	10.55	193	27.0	137	122	27	
Roots	~15.9	5.58	66	2.7	17	8	5	Paula et al., (1983) unfertilized Riqueza
Whole plant	-	10.62	197	8.1	61	100	20	
Roots	~9.0	3.24	37	1.5	23	4	2	Paula et al., (1983) unfertilized Branca St. C
Whole plant	-	6.54	93	4.0	40	30	9	
Roots	8.7	2.68	13	0.9	4	3	2	Sittibusaya (unpublished) unfertilized Rayong 1
Whole plant	-	4.23	39	3.2	10	21	8	
Roots	6.0	1.52	18	2.2	15	5	2	Putthacharoen et al., (1998) 1989/90 Rayong 1
Whole plant	-	4.37	91	12.2	55	46	15	
Roots	30.8	-	67	11.7	92.7	-	-	Average 19 sources
Whole plant	-	-	174	24.7	162.4	-	-	

Nutrient Removal by Cassava as compared with other Crops

Earlier reports on nutrient removal by cassava as compared with other crops (Amarasiri and Perera, 1975; Howeler, 1981, 1991a; Putthacharoen et al., 1998) have generally used data from experiments done on experiment stations where yields tend to be much higher than those obtained by farmers. This has resulted in nutrient loss data well above those normally encountered in farmers' fields. Thus, Howeler (1991a) reported that nutrient removal t DM^{-1} of root harvest was on average 4.5 kg N, 0.83 kg P, and 6.6 kg K ha^{-1} as based on an average fresh root yield of 35.7 mt ha^{-1}. If these data had been based on a root yield of 15 mt ha^{-1} (Figure 2) the removal would have been about 5.4 kg N, 0.63 kg P, and 3.6 kg K ha^{-1}, i.e. considerably lower in P and K than previously reported, and well below those of most other crops (Amarasiri and Perera, 1975; Howeler, 1991a). Similar results were reported by Putthacharoen et al., (1998), who compared the nutrient removal of cassava with that of five other crops grown for two consecutive years in the same experiment (Table 4).

Table 3. Average fresh and dry root yield, as well as the amount of nutrients removed when cassava roots or the whole plant are harvested based on data from the literature[1)].

Plant part	Yield (mt ha^{-1})		Nutrient					
	fresh	dry	removal	N	P	K	Ca	Mg
Roots	28.87	11.43	kg ha^{-1}	67.1	11.2	88.1	13.5	7.9
Whole plant		18.99		179.5	22.7	156.1	81.8	25.8
Roots	28.87	11.43	kg mt^{-1} fresh roots	2.32	0.39	3.05	0.47	0.27
Whole plant		18.99		6.22	0.79	5.41	2.83	0.89
Roots	28.87	11.43	kg mt^{-1} dry roots	5.87	0.98	7.71	1.18	0.69
Whole plant		18.99		15.70	1.99	13.66	7.16	2.26

See Table 2. Data are average of 15 data sets which have yields reported in dry weight.

Table 4. Major nutrients removed in the harvested products and returned in the nonharvested products of various crops grown during 22 months in Sri Racha, Chonburi, Thailand from 1989–1991.

Crop	No. of crop cycles	Nutrients removed (kg ha^{-1})					Nutrients returned (kg ha^{-1})				
		N	P	K	Ca	Mg	N	P	K	Ca	Mg
Cassava for roots	2	48	7	60	14	6	236	46	132	154	35
Cassava for forage	1	363	43	240	162	62	17	4	16	24	5
Corn	2	118	44	87	6	11	101	13	269	34	28
Sorghum	2	79	25	51	10	9	147	27	304	51	37
Peanut	2	213	19	53	6	8	133	12	183	87	28
Mungbean	3	117	15	62	9	11	54	7	66	51	14
Pineapple	1	83	15	190	51	19	160	31	176	85	24

Source: Putthacharoen et al., 1998.

Thus, while cassava has a reputation to "exhaust" soil nutrients by excessive nutrient removal in the crop harvest, this is clearly not the case, as N and P removal in the cassava root harvest is much less, and K removal is less or similar to that in the harvested products of other crops. However, if all plant parts are removed from the field (as often practiced in Vietnam and Indonesia) nutrient removal can be substantial and may be similar to, or higher than, those of other crops (Putthacharoen et al., 1998; Amarasiri and Perera, 1975).

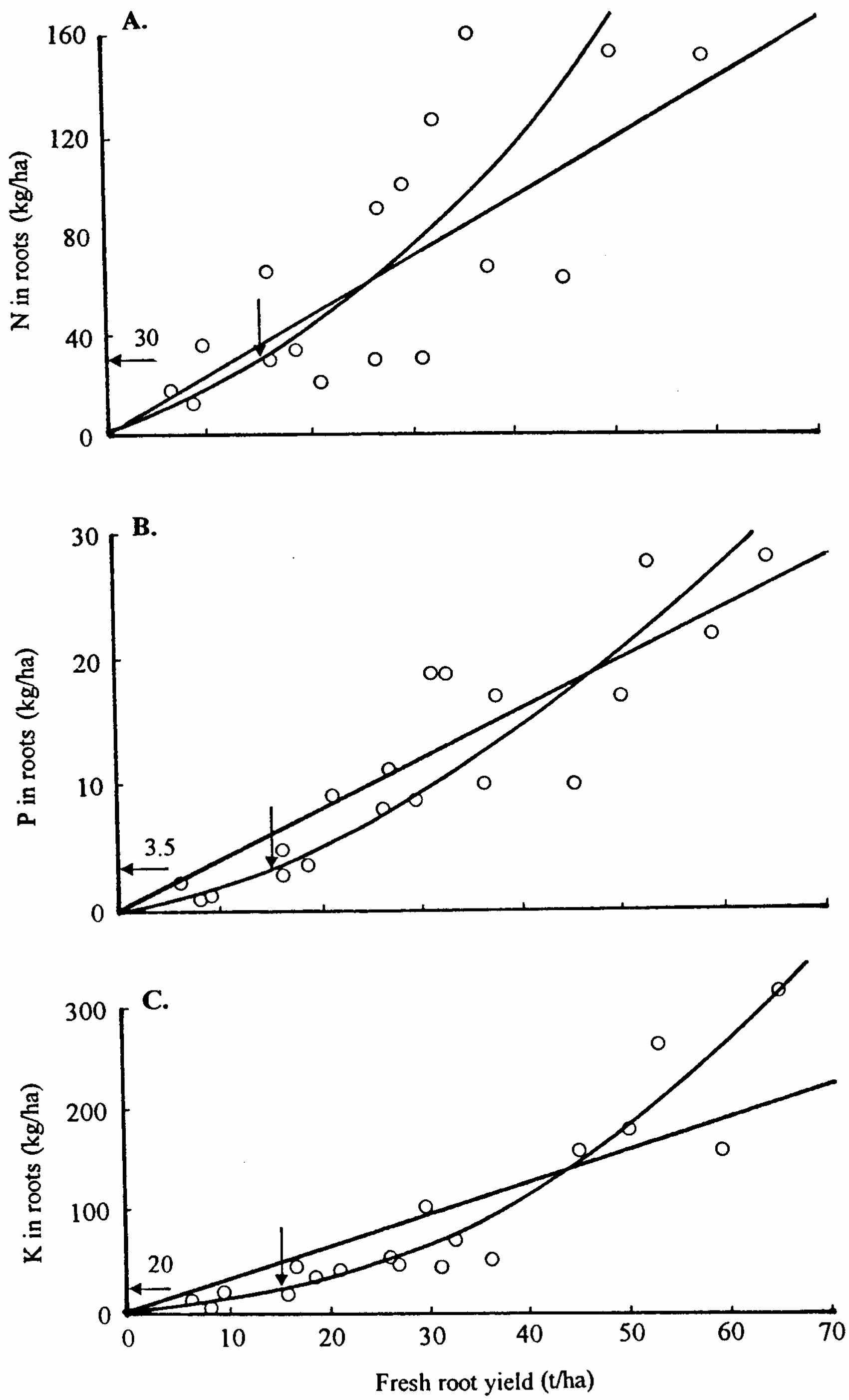


Figure 2. Relation between the N, P and K contents of cassava roots and fresh root yield, as reported in the literature (see Table 2). Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t ha^{-1} *The straight lines indicate the relationship based on the average yield and nutrient contents (see Table 3).*
Source: *Howeler, 2001.*

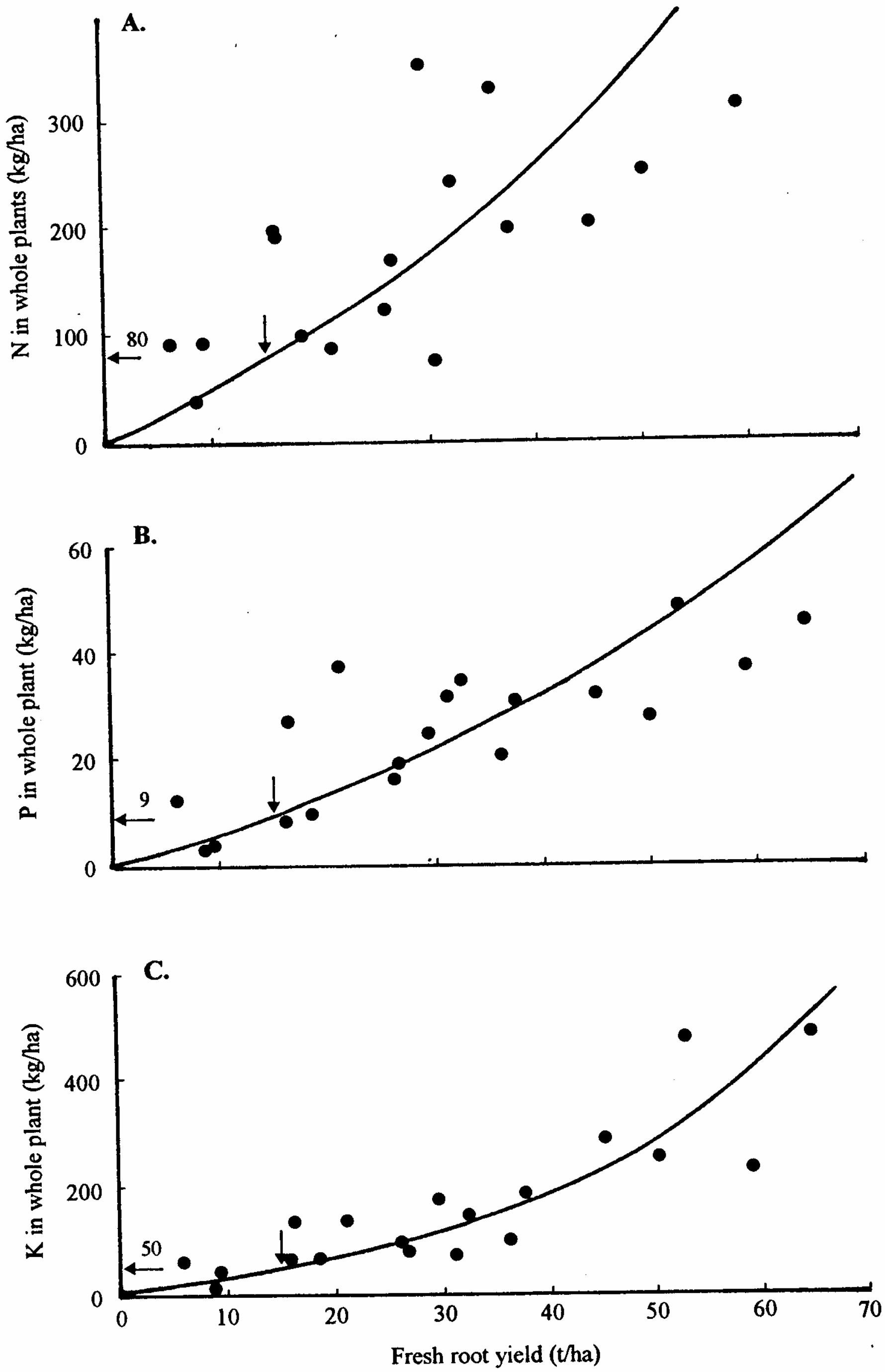


Figure 3. Relation between the amounts of N, P and K in the whole cassava plant at time of harvest and the fresh root yield, as reported in the literature. Arrows indicate the approximate nutrient contents corresponding to a fresh root yield of 15 t ha.$^{-1}$
***Source:** Howeler, 2001.*

Nutrient Losses by Erosion

Nutrients can be removed from the field by soil erosion, either as part of the eroded sediments and crop debris, or dissolved in the runoff water. It is difficult, however, to quantify these losses as soil erosion is highly variable, both over space and time. Nutrient losses may occur in one part of the field where soil is washed away, while they may accumulate in another part of the field or landscape where sediments are deposited. Only a small fraction of sediment losses measured in erosion trials will actually be lost from the landscape and be carried out to sea. Some nutrients dissolved in runoff water may infiltrate into the soil elsewhere and be absorbed by plants, but a large proportion will either seep down below the rooting zone or be transported to the sea. Moreover, erosion depends largely on the frequency and intensity of rainfall, which varies greatly over time. Much of the soil and nutrient loss by erosion may occur during only one or two rainfall events during the year. Thus, nutrient losses by erosion will vary greatly from year to year and from place to place.

Erosion Losses in Cassava as Compared with other Crops

Cassava is often grown on highly eroded slopes, but it is uncertain whether cassava is the cause of erosion or the result, as cassava may be the only crop that can tolerate the low soil fertility and high acidity that are often the result of erosion, especially if the topsoil has been washed away and the subsoil exposed.

Comparing 12 different crops or cropping systems, grown on 8–13 percent slopes in three types of soils for several years in Brazil, Quintiliano et al., (1961) reported that cassava was the third most erosive crop, after castor bean and *Phaseolus* bean (Figure 4). Similarly, Putthacharoen et al., (1998) reported that during a four-year period, four crops of cassava for root production caused 2.5 times more soil loss due to erosion than six crops of mungbean, 3–4 times more erosion than five crops of corn, sorghum or peanut, and five times more erosion than two crops of pineapple, all grown in the same experiment on 7 percent slope in Sri Racha, Thailand (Table 5). Because of the wide plant spacing used and the crop's slow initial growth, cassava plants leave much soil exposed to the direct impact of rainfall during the first 3–4 months of establishment. If this period corresponds with that of heavy rainfall, erosion in cassava fields can be quite severe, especially when the crop is grown on light-textured soils with low levels of OM (as in the east and northeast of Thailand).

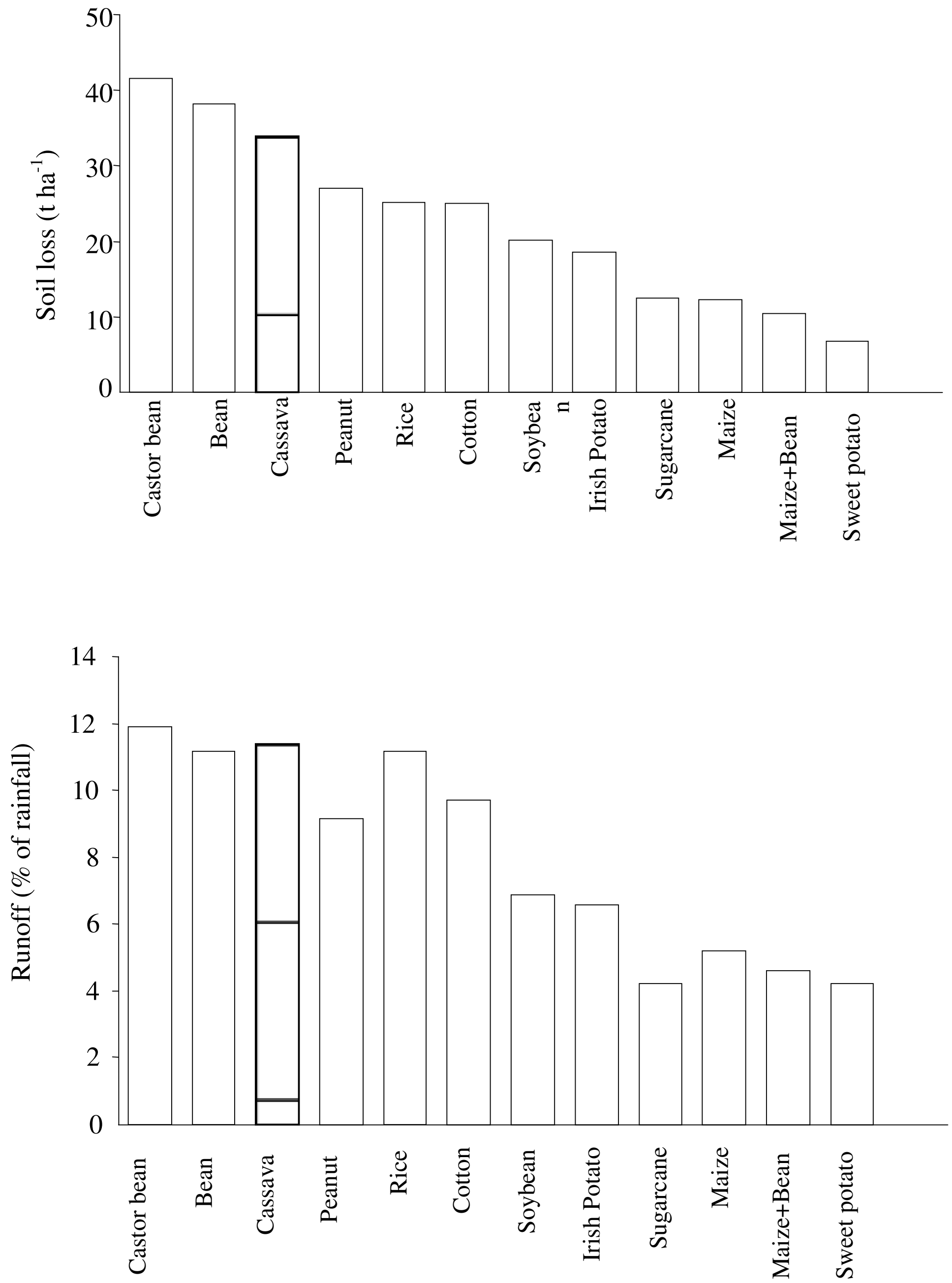


Figure 4. Effect of crops on annual soil loss by erosion (top) and on runoff (bottom). Data are average values (n=48) corrected for a standard annual rainfall of 1,300mm yr^{-1}.

Table 5. Total dry soil loss by erosion (mt ha^{-1}) due to the cultivation of eight crops during four years on 7% slope with sandy loam soil in Sri Racha, Thailand from 1989–1993.

	No. of crop cycles	**First period (22 months)**	**Second period (28 months)**	**Total (50 months)**
Cassava for root production	4	142.8 a	168.5 a	311.3
Cassava for forage production	2	68.8 b	138.5 ab	207.3
Corn	5	28.5 d	35.5 cd	64.0
Sorghum	5	42.9 c	46.1 cd	89.0
Peanut	5	37.6 cd	36.2 cd	73.8
Mungbean	6	70.9 b	55.3 cd	126.2
Pineapple[1)]	2	31.4 cd	21.3 d	52.7
Sugarcane[1)]	2	-	94.0 bc	-
F-test		**	**	
cv (%)		11.4	42.7	

[1)] Second cycle is a ratoon crop; sugarcane only during second 28-month period
Source: Putthacharoen et al., 1998.

Nutrient Losses in Eroded Sediments

The amount of nutrients lost in eroded sediments depends on the amount of soil lost as well as on the nutrient status of the soil. Table 6 shows the loss of total N, available P, and exchangeable K and Mg reported for four experiments conducted in Thailand and Colombia. The amount of nutrients lost depended mainly on the extent of erosion. Management practices that reduced erosion automatically reduced nutrient losses. Annual losses of total N, exchangeable K and available P ranged from 3.5 to 37 kg ha^{-1}, 0.13 to 5.1 kg ha^{-1} and 0.02 to 2.2 kg ha^{-1}, respectively. However, when topsoil is lost by erosion, not only are the available or exchangeable nutrients lost but the total amounts of nutrients in the organic and mineral fraction are lost. Thus, losses of total P, K, and Mg could be considerably higher than those reported in Table 6 (see also Table 7).

Eroded sediments tend to have higher nutrient contents than the original soil they are derived from. This is due to preferential loss of, and nutrient release from, crop residues lying on the soil surface, of clay, and of applied fertilizers or manures. The ratio of organic matter or nutrients in the transported sediments over those in the matrix soil is called the “enrichment ratio”. In a cassava erosion control experiment conducted in Huay Bong, Thailand, the enrichment ratios were 2.0 for OM, 3.4 for available P, 2.0 for exchangeable K, 1.37 for Ca, and 1.06 for Mg (Howeler, 2000). These ratios are similar to those reported by Barrows and Kilmer (1963) and Lal (1976), but were generally higher than those reported by Reining (1992) and Ruppenthal (1995).

Table 6. Nutrients in sediments eroded from cassava plots with various treatments in Thailand and Colombia.

Location and treatments	Dry soil loss (mt^{-1} ha^{-1} yr^{-1})	kg^{-1} ha^{-1} yr^{-1}			
		N[1)]	P[2)]	K[2)]	Mg[2)]
Cassava on 7% slope in Sri Racha, Thailand[3)]	71.4	37.1	2.18	5.15	5.35
Cassava on 5% slope in Pluak Daeng, Thailand[4)]	53.2	22.3	1.25	3.27	-
Cassava planted on 7–13% slope in Quilichao, Colombia[5)]	5.1	11.5	0.16	0.45	0.45
Cassava with leguminous cover crops in Quilichao, Colombia[5)]	10.6	24.0	0.24	0.97	0.81
Cassava with grass hedgerows in Quilichao, Colombia[5)]	2.7	5.8	0.06	0.22	0.24
Cassava planted on 12–20% slope in Mondomo, Colombia[5)]	5.2	13.3	1.09	0.45	0.36
Cassava with leguminous cover crops in Mondomo, Colombia[5)]	2.7	6.5	0.04	0.24	0.20
Cassava with grass hedgerows in Mondomo, Colombia[5)]	1.5	3.5	0.02	0.13	0.10

[1)] Total N; [2)] Available P, and exchangeable K and Mg; [3)] Source: Putthacharoen et al., 1998; [4)] Source: Tongglum et al., 2001; [5)] Source: Ruppenthal et al., 1997.

Nutrient Losses in Runoff

Table 7 shows nutrient losses, both in sediments and in runoff, from an upland rice experiment conducted on a 25 to35 percent slope in Luang Prabang, Laos, both for cropping under traditional farmers' practices and under alley cropping with double hedgerows of vetiver grass. Alley cropping reduced runoff and erosion substantially, especially in the second year of establishment of the treatment. Total N, P and K losses in the runoff ranged from 0.71 to 2.35 kg ha^{-1}, 0.083 to 0.85 kg ha^{-1}, and 6.7 to 26.1 kg ha^{-1}, respectively. Thus, K losses in runoff were much higher than those of N, which in turn were much higher than those of P. In contrast, N losses were sometimes higher than K losses in soil sediments. The losses of "total" P and K in Table 7 are much higher than the losses of "available" P and "exchangeable" K reported in Table 6.

Few reports exist on nutrient losses in runoff from cassava fields. Table 8 shows some data on nutrient losses in runoff and soil sediments during two years of cassava cropping on a 7 to 13 percent slope in Santander de Quilichao and on a 13 to 20 percent slope in Mondomo, both in Colombia (Reining, 1992). When cassava was grown on up-and-down ridges both soil loss and runoff were much higher than when the crop was grown on contour ridges. Losses of P in the runoff ranged from 0.08 to 0.47 kg ha^{-1} those of K from 0.61 to 3.96 kg ha^{-1} those of Ca from 1.29 to 7.56 kg ha^{-1} and those of Mg from 0.14 to 1.22 kg ha^{-1} . Thus, despite severe soil loss and runoff in both locations, nutrient losses in the runoff were minor compared to those in the eroded sediments.

Table 7. Effect of soil/crop management on runoff and soil loss by erosion, as well as the nutrients lost in runoff and eroded sediments during two years of cropping upland rice on 25–35% slope in Luang Prabang, Laos in 1994 and 1995.

	Farmer's practice		Alley cropping[1)]	
	1994	**1995**	**1994**	**1995**
Runoff (m^3 ha^{-1})	**1,475**	**2,119**	**1,296**	**765**
Nutrients lost in runoff (kg ha^{-1}):				
N	0.71	2.35	0.49	0.71
P	0.084	0.85	0.085	0.33
K	7.87	26.12	6.69	7.89
Dry soil loss (mt ha^{-1})	**4.88**	**9.21**	**3.56**	**1.76**
Nutrients lost in eroded soil (kg ha^{-1}): [2)]				
N	17.09	53.92	11.61	7.61
P	1.94	9.28	1.32	1.50
K	43.54	23.96	31.19	2.66

[1)] Using vetiver grass double hedgerows (1 m width) with mango trees; upland rice in 5 m wide alleys between double hedgerows; [2)]Values correspond to total N, P, and K. Source: Phommasack et al., 1995, 1996.

Nutrient Losses by Leaching and Volatilization

Losses of applied N and K by leaching are expected to be substantial if cassava is grown on light-textured soils and all fertilizers are applied at planting. Losses of N by volatilization may also be substantial if N fertilizers are applied on the soil surface, especially in high pH soils. However, no information is available to quantify these losses in cassava fields.

NUTRIENT INPUTS IN CASSAVA-BASED CROPPING SYSTEMS

Cassava farmers tend to be among the poorest farmers in the world, living generally in marginal areas of steep slopes, low-fertility soils, and with low or unpredictable rainfall. They grow cassava because this crop is very well adapted to these conditions and will produce a reasonable yield even without any external inputs. However, numerous experiments have shown that cassava is highly responsive to fertilizer application, and that continuous production of cassava on the same land without adequate application of chemical fertilizers or manures can lead to nutrient depletion and yield declines (Nguyen Tu Siem, 1992; Sittibusaya, 1993; Tongglum et al., 2001). Cassava farmers, however, may not have the resources to buy the chemical fertilizers needed to maintain high yields, or they may not apply the correct balance of nutrients required by the crop.

Table 8. Effect of two contrasting soil/crop management treatments on runoff and soil loss by erosion, as well as the nutrients lost in runoff and eroded sediments during two years of cropping cassava on 7–13% slope in Santander de Quilichao and on 13–20% slope in Mondomo, Colombia, in 1987/88 and 1988/89.

	Santander de Quilichao				Mondomo			
	1987/88		1987/88		1987/88		1987/88	
	T_1[1)]	T_2	T_1[1]	T_2	T_1	T_2	T_1	T_2
Runoff (m^3 ha^{-1})	950	1,750	1,400	2,420	340	1,470	540	1,000
Nutrients lost in runoff (kg ha^{-1})								
Total P	0.16	0.33	0.22	0.47	0.08	0.39	0.13	0.26
Total K	1.49	2.79	1.58	3.08	0.61	3.26	1.47	3.96
Total Ca	2.67	3.50	2.96	5.45	1.29	5.11	2.88	7.56
Total Mg	0.43	0.58	0.30	0.75	0.14	1.22	0.20	1.01
Dry soil loss (mt ha^{-1})	3.0	30.4	5.1	68.0	1.5	33.8	2.6	12.6
Nutrients lost in eroded sediments (kg ha^{-1})								
Available P	0.08	0.41	0.07	1.12	0.01	0.44	0.03	0.18
Exchangeable K	0.34	2.73	0.42	5.05	0.17	3.04	0.27	1.11
Exchangeable Ca	4.08	32.83	6.94	73.44	2.58	31.10	4.47	11.59
Exchangeable Mg	0.25	2.92	0.33	7.08	0.10	3.00	0.19	0.61

[1)] T_1 = cassava on contour ridges; T_2 = cassava on up-and-down ridges. Source: adapted from Reining, 1992.

Nutrient Requirements of Cassava

Cassava tolerates high soil acidity and low fertility better than most other crops because of its exceptional tolerance to low pH and high levels of Al in the soil solution (Howeler, 1991b), and low levels of available P (Howeler, 1990). The latter is due to a highly efficient symbiosis between cassava and vesicular-arbuscular (VA) mycorrhizae, which readily colonize the fibrous roots of the crop in almost all natural soils (Howeler et al., 1981; 1987; Sieverding and Howeler, 1985; Howeler, 1990). Due to this symbiosis cassava is able to absorb P from soils with a very low level of P, and the critical level of available soil P for cassava is only 4–10 μg g^{-1}, compared with 10–20 μg g^{-1} for most other crops (Howeler, 2001). Thus, cassava may not respond to the application of P in a soil where upland rice (and other crops) show a very marked response (Figure 5). On the other hand, cassava absorbs and removes from the field considerable amounts of K when only roots are removed and large amounts of N, K, and Ca when all plant parts are removed. Numerous fertilizer trials conducted in Asia indicate that cassava responds mainly to the application of N and K, but less to that of P. There is almost no response to the application of lime (Howeler, 2001) except for the very acid peat soils in Malaysia (Tan and Chan, 1989; Tan, 1992).

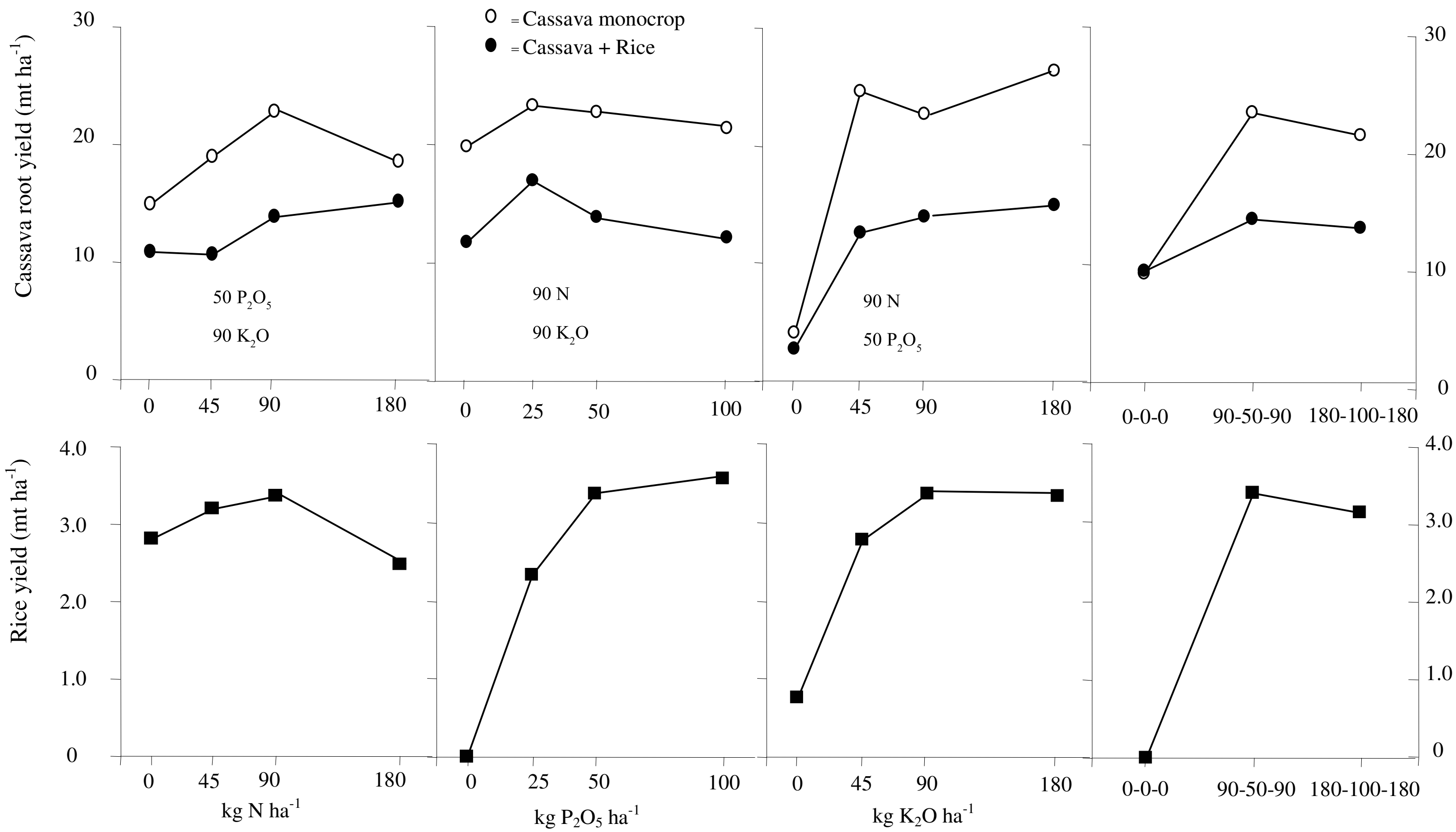


Figure 5. Effect of annual applications of various levels of N, P and K on the yields of cassava (both monocropped and intercropped with rice and upland rice during the 9th consecutive cropping cycle in Tamanbogo, Lampung, Indonesia (1999/2000).

In many countries in Asia cassava farmers apply 5–10 mt ha^{-1} of animal manures, mostly from pigs, cattle or chickens, but few experiments have been conducted to determine the response to different types and rates of animal manures. In Latin America good responses to up to 6 mt ha^{-1} of farmyard manure were obtained in Paraiba state of Brazil (Silva, 1970) and up to 4.3 mt ha^{-1} of chicken manure in Mondomo, Colombia (Howeler, 1985a). The chicken manure was about twice as effective as cattle manure applied at equivalent levels of P. Farmers in Mondomo, Colombia, claim to get much better yields with the application of chicken manure than with chemical fertilizers; the exact reason for this is not clear.

Nutrient Inputs from Chemical Fertilizers, Manures, and Compost

Nutrient inputs from the application of chemical fertilizers, manures or compost naturally depend on the rates applied and the chemical composition of each compound. The nutrient compositions of chemical fertilizers are generally well-defined. Those of the most commonly used fertilizers are shown in Table 9. The composition of animal manures and compost, however, is highly variable, depending largely on their moisture content and the degree of composting or leaching that they have been subjected to. Moreover many manures are composted together with straw, rice husks or lime, changing their nutrient composition markedly. Table 10 shows values reported in the literature. Using the average values for cattle, pig, and chicken manure in Table 10, one can calculate that 1 mt of wet manure contains approximately the following nutrients:

Cattle manure (32% DM):	5.9 kg N, 2.6 kg P and 5.4 kg K
Pig manure (40% DM):	8.2 kg N, 5.5 kg P and 5.5 kg K
Chicken manure (57% DM):	16.6 kg N, 7.8 kg P and 8.8 kg K

This compares with the nutrient content of one bag (50 kg) of 15-15-15 fertilizer which contains 7.5 kg N, 3.3 kg P, and 6.2 kg K, respectively. Thus, while manures tend to be cheap, their cost of transport and application may be 10 to 20 times higher than that of a compound fertilizer like 15-15-15 on an equivalent nutrient content basis. However, in addition to N, P, and K, manures also supply Ca, Mg, S, and micronutrients, and they may improve the organic matter content and physical conditions of the soil. The composition of composts of municipal garbage, rice straw, and peanut residues, as well as that of wood ash are shown in Table 10. These tend to be quite low in nutrients except for wood ash, which contains considerable amounts of K, Ca, and Mg.

Incorporation of green manures can supply large amounts of nutrients to the following crop (Tongglum et al., 1992; Howeler et al., 1999). However, most of these nutrients are merely recycled within the system, except for N, some of which may have been derived from biological N-fixation.

Table 9. Nutrient content (%) of commonly used inorganic fertilizers.

	N	P	K	Ca	Mg	S
Ammonium nitrate	33	-	-	-	-	-
Mono-ammonium phosphate	11	23	-	-	-	-
Di-ammonium phosphate	18	20	-	-	-	-
Ammonium sulfate	20.5	-	-	-	-	23
Calcium ammonium nitrate	20.5	-	-	7-14	-	-
Calcium nitrate	15.5	-	-	20	-	-
Potassium nitrate	13	-	37	-	-	-
Sodium nitrate	16	-	-	-	-	-
Urea	45	-	-	-	-	-
Urea formaldehyde	38	-	-	-	-	-
Simple superphosphate	-	8-9	-	17-22	-	12
Triple superphosphate	-	20	-	12-16	-	-
Basic slag	-	6.5	-	32-35	1-3	0.2
Rhenia phosphate	-	12.7	-	29	0.6	0.4
Potassium chloride	-	-	50	-	-	-
Potassium sulfate	-	-	42	-	-	18
Potassium magnesium sulfate	-	-	18	-	11	22
Magnesium sulfate	-	-	-	-	10	13
Magnesium oxide	-	-	-	-	32	-

Source: adapted from Jacob and Uexküll, 1973.

Nutrient Inputs from N-fixation and from Atmospheric and Soil Sediment Deposits

N-fixation

Not being a legume, it is unlikely that cassava fixes substantial amounts of N. Endophytic N_2-fixation by soil bacteria such as *Acetobacter diazotripicus* was found to be minimal in cassava, intermediate in sugarcane, and quite significant in pineapple (Ando et al., 1999). However, experiments on successive cuttings of cassava top growth for forage production in Colombia showed that about 350 kg N ha^{-1} was removed in the crop harvest, 25 kg in the roots, and 326 kg in four cuttings of tops, while only 100 kg N ha^{-1} had been applied as fertilizer. N-mineralization from soil OM could have accounted for about 175 kg N, while the remaining 75 kg of N might have come from atmospheric deposition or N-fixation (CIAT, 1988). Whether N-fixation by association with N-fixing bacteria is indeed significant in cassava needs further investigation.

Atmospheric Deposits

The deposition of nutrients in rainwater is highly variable and not well quantified. Near industrialized areas this may contribute significant amounts of S, while those of N are usually less than 20–30 kg ha^{-1}.

Soil Sediment Deposits

These are of major significance in lowland rice paddies that undergo regular flooding. In the uplands, where cassava is generally grown, they may be significant at the lower end of slopes where soil eroded from the upper slopes is deposited. This can contribute substantial amounts of nutrients from the eroded soil as well as from washed-out crop residues, ash, manures, and fertilizers.

Table 10. Nutrient content of animal manures and composts, as reported in the literature.

Source of manure/compost	**% Moisture**	**(% of dry material)**						
		C	**N**	**P**	**K**	**Ca**	**Mg**	**S**
Buffalo manure [1)]	60.4	17.4	0.97	0.58	1.28	-	-	-
Dairy cattle manure [2)]	79.0	-	2.66	0.48	2.38	1.33	0.52	0.23
Fattening cattle manure [2)]	80.0	-	3.50	1.00	2.25	0.60	0.50	0.43
Cattle manure [1)]	46.4	16.9	1.11	0.44	1.56	-	-	-
Cattle manure [3)]	-	-	2.00	0.65	1.67	2.86	0.60	0.20
Cattle manure (Dampit, Indonesia) [4)]	-	-	1.43	2.96	1.60	2.13	0.96	-
Cattle manure (Indonesia) [5)]	-	39.1	1.87	0.56	1.09	0.57	0.23	-
Cattle manure (Costa Rica) [6)]	-	-	2.23	0.77	2.25	1.77	0.89	-
Cattle manure [8)]	75.0	-	2.40	0.61	2.67	-	-	-
Cattle manure [9)]	-	-	0.35	0.06	0.16	-	-	-
Average cattle manure	**68.2**	**-**	**1.85**	**0.81**	**1.69**	**1.54**	**0.62**	**0.29**
Pig manure [1)]	29.9	19.0	1.32	2.37	0.96	-	-	-
Pig manure [2)]	75.0	-	2.00	0.56	1.52	2.28	0.32	0.54
Pig manure [8)]	75.0	-	2.80	1.22	1.67	-	-	-
Average pig manure	**60.0**	**-**	**2.04**	**1.38**	**1.38**	**-**	**-**	**-**
Chicken manure [3)]	-	-	5.00	1.31	1.25	2.86	0.60	0.80
Chicken manure (Blitar, Indonesia) [4)]	-	-	1.75	0.23	0.77	6.82	1.46	-
Chicken manure (Blitar, Indonesia) [4)]	-	-	0.43	0.67	0.39	4.93	1.43	-
Chicken manure (Khaw Hin Sorn, Thailand) [4)]	-	-	1.25	0.43	1.27	1.31	0.37	-
Chicken manure (Costa Rica) [6)]	-	-	1.68	2.58	1.19	6.90	0.66	-
Chicken manure (Pescador, Colombia) [7)]	-	-	4.96	1.95	2.27	4.53	0.48	-
Chicken manure (layer) [8)]	70	-	5.00	1.89	2.50	-	-	-
Chicken manure (broiler) [8)]	40	-	4.83	1.82	2.50	-	-	-
Chicken dropping [9)]	-	-	2.80	1.33	1.04	-	-	-

Table 10 Continued								
Chicken manure [9]	-	-	2.87	1.27	1.83	-	-	-
Broiler chicken manure [10]	25.0	-	2.26	1.08	1.67	-	-	-
Hen manure [10]	37.0	-	2.06	1.90	1.81	-	-	-
Average chicken manure	**43.0**	**-**	**2.91**	**1.37**	**1.54**	**4.56**	**0.83**	**-**
Horse manure [2]	60.0	-	1.72	0.25	1.50	1.96	0.35	0.17
Duck manure [1]	22.2	21.4	1.02	1.38	0.90	-	-	-
Sheep manure [3]	-	-	2.00	0.65	2.50	1.78	1.20	0.60
Sheep manure [2]	65.0	-	4.00	0.60	2.86	1.67	0.53	0.26
Average sheep manure	**-**	**-**	**3.00**	**0.62**	**2.68**	**1.72**	**0.86**	**0.43**
Human manure [9]	-	-	1.20	0.06	0.21	-	-	-
City garbage compost (Bangkok)[1]	28.8	17.3	0.97	0.46	0.86	-	-	-
City compost [9]	-	-	1.75	0.44	1.25	-	-	-
Rural compost [9]	-	-	0.75	0.20	0.60	-	-	-
Average city/rural compost			**1.16**	**0.37**	**0.90**	**-**	**-**	**-**
Rice straw compost [1]	73.7	33.8	1.07	0.19	0.69	-	-	-
Rice straw [9]	-	-	0.40	0.10	0.40		-	-
Rice husk [9]	-	-	0.62	0.08	1.25	-	-	-
Peanut stems + leaf compost [1]	58.6	11.6	0.81	0.10	0.38	-	-	-
Water hyacinth [1]	-	-	2.00	1.00	2.30	-	-	-
Ash (rice husks) [4]	-	-	0.03	0.40	1.06	0.47	0.22	-
Fly ash (Nanning, China) [4]	-	-	0.09	<0.10	1.20	4.14	1.14	-
Wood ash (Trivandrum, India) [11]	-	-	-	-	8.70	20.8	1.90	-
Wood ash [3]	-	-	-	0.87	4.17	23.2	2.10	0.40

[1] Suzuki et al., 1988 ; [2] Loehr, 1968; [3] Jacob and Uexkull, 1973; [4] Howeler (unpublished); [5] Rachman Sutanto et al., 1993; [6] Don Kass (personal communication); [7] Amezquita et al., 1998; [8] Scaife and Bar-Yosef, 1995; [9] FADINAP; [10] Perkins et al., 1964; [11] Kabeerathumma et al., 1990

NUTRIENT BALANCES—EXAMPLES FROM VIETNAM AND THAILAND

Nutrient balances should consider all nutrient inputs and outflows. However, quantitative data on nutrient losses due to erosion are highly site- and time-specific, while nutrient inputs from N-fixation, and atmospheric and eroded soil deposits are also very site specific and data are generally not available. While not negating the potential importance of these factors especially that of erosion, nutrient balances in this section are calculated only on the basis of nutrient inputs from manure and fertilizers, and nutrient outflows through crop removal, which can be estimated more easily.

Vietnam

In 1990/1991 a formal survey was conducted in all major cassava-producing areas of Vietnam. A total of 1,117 farmers were interviewed in 45 districts of 20 provinces (out of 43 provinces) in six agro-ecological regions. Among many questions, farmers were asked about fertilizers and manure inputs as well as yields obtained (Pham Van Bien et al., 1996; Pham Thanh Binh et al., 1996). Table 11 shows the average amounts of organic manures and chemical fertilizers applied in each of the agro-ecological regions; from this the total average, inputs of N, P, and K could be calculated. Table 12 shows the average fresh root yields obtained in each region (according to the interviewed farmers), and the nutrient removal in those roots as well as the corresponding tops, assuming that farmers in Vietnam remove both roots and tops from the field. From these data on nutrient outflows and the data on nutrient inputs (from Table 11), the nutrient balance was calculated for each region, for north and south Vietnam, as well as for Vietnam as a whole. It can be seen that the N balance was negative in three of the six regions, the P balance was highly positive in most regions but negative in one region, while the K balance was highly positive in one region but negative in three regions. The nutrient balances were positive for all three nutrients in the Red River Delta, and in the North and South Central Coasts where farmers tend to apply large amounts of manure. In comparison, nutrient balances were negative for all three nutrients in the Central Highlands where farmers apply very little manure and almost no chemical fertilizers. For Vietnam as a whole, as well as for both north and south Vietnam, the balance was positive for P and negative for both N and K. This indicates that cassava farmers in Vietnam, especially in the north, apply too much P (because it is cheap), but not enough N and K to satisfy the requirements of cassava. Many fertilizer trials conducted in Vietnam, both on experiment stations (Nguyen Huu Hy et al., 1998) and by farmers on their own fields (Nguyen The Dang et al., 1998), show mainly a response of cassava to N and K, but little response to P.

Studying the long-term effect of the cultivation of four crops—rubber, sugarcane, cashew, and cassava—in comparison with native forest on soil chemical and physical properties, Cong Doan Sat and Deturck, (1998) reported that after long-term cropping of Ultisols in southeastern Vietnam, soils under rubber and cassava had actually accumulated available P, but those under cassava had the lowest levels of total N and exchangeable Mg, and the second lowest levels of exchangeable K (Table 13). For this reason they concluded that cassava production under currently used practices is unsustainable, leading to soil degradation.

Table 11. Nutrient application for cassava production in various regions of Vietnam according to farm level surveys of 1, 117 households in 20 provinces in 1990/91.

	Organic (kg ha^{-1})	**Chemical (kg ha^{-1})**					**N applied [1] (kg ha^{-1})**					**P [2] applied (kg ha^{-1})**				**K [2] applied (kg ha^{-1})**			
		Urea	**SA**	**SSP**	**KCl**	**NPK**	**Organic**	**Urea**	**SA**	**NPK**	**Total**	**Organic**	**SSP**	**NPK**	**Total**	**Organic**	**KCl**	**NPK**	**Total**
Total Vietnam	**3,400**	**27**	**19**	**30**	**24**	**3**	**31.3**	**12.1**	**3.9**	**0.4**	**47.7**	**28.9**	**2.2**	**0.2**	**31.3**	**22.8**	**12.0**	**0.4**	**35.2**
North Vietnam	*4,426*	*21*	*0*	*61*	*35*	*0*	*40.7*	*9.4*	*0*	*0*	*50.1*	*37.6*	*4.5*	*0*	*42.1*	*29.7*	*17.5*	*0*	*47.2*
-North Mountainous Region	2,389	15	0	37	15	0	22.0	6.7	0	0	28.7	20.3	2.7	0	23.0	16.0	7.5	0	23.5
-Red River Delta	7,452	40	0	79	93	0	68.6	18.0	0	0	86.6	63.3	5.8	0	69.1	49.9	46.5	0	96.4
-North Central Coast.	7,288	22	0	112	36	0	67.0	9.9	0	0	76.9	61.9	8.3	0	70.2	48.8	18.0	0	66.8
South Vietnam	*2,543*	*31*	*36*	*4*	*15*	*5*	*23.4*	*13.9*	*7.4*	*0.7*	*45.4*	*21.6*	*0.3*	*0.3*	*22.2*	*17.0*	*7.5*	*0.6*	*25.1*
-South Central Coast	4,690	33	55	2	20	1	43.1	14.8	11.3	0.1	69.3	39.8	0.1	0.1	40.0	31.4	10.0	0.1	41.5
-Central Highlands	172	8	0	0	0	0	1.6	3.6	0	0	5.2	1.4	0	0	1.4	1.2	0	0	1.2
-Southeastern Region	850	40	27	9	16	14	7.8	18.0	5.5	2.1	33.4	7.2	0.7	0.9	8.8	5.7	8.0	1.8	15.5

[1] Assuming urea to contain 45% N; ammonium sulfate 20.5% N; NPK 15% each of N, P_2O_5 and K_2O; SSP 17% P_2O_5 and KCl 60% K_2O, and that "organic" refers to wet pig manure, which may have a composition (wet weight basis) of : 50% moisture, 0.92% N, 0.85% P and 0.67% K. [2] P and K in elemental form. Source: Pham Van Bien et al., 1996.

Table 12. Nutrient balance as a result of nutrient removal and application in the production of cassava in various regions of Vietnam in 1991/92.

	Cassava root yield (mt ha^{-1})	**Nutrient removal (kg ha^{-1}) [1]**			**Nutrients applied (kg ha^{-1}) [2]**			**Nutrient balance (kg ha^{-1}) [3]**		
		N	**P [4]**	**K [4]**	**N**	**P [4]**	**K [4]**	**N**	**P [4]**	**K [4]**
Total Vietnam	**12.36**	**62**	**7.0**	**40**	**48**	**31.3**	**35**	**-14**	**24.3**	**-5**
North Vietnam	*14.54*	*80*	*8.8*	*49*	*50*	*42.1*	*47*	*-30*	*33.3*	*-2*
-North Mountainous Region	16.26	85	10.0	51	29	23.0	23	-56	13.0	-28
-Red River Delta	11.47	58	6.5	39	87	69.1	96	29	62.6	57
-North Central Coast	12.45	65	7.1	41	77	70.2	67	12	63.1	26
South Vietnam	*10.61*	*57*	*6.0*	*36*	*45*	*22.2*	*25*	*-12*	*16.2*	*-11*
-South Central Coast	9.95	48	5.2	32	69	40.0	41	21	34.8	9
-Central Highlands	8.54	43	4.8	29	5	1.4	1	-38	-3.4	-28
-Southeastern Region	12.37	63	7.0	40	33	8.8	15	-30	1.8	-25

[1] Assuming all plant parts are removed from the field and nutrient removal is read off the curves presented in Figure 3; [2] Nutrients applied as organic manures and chemical fertilizers (see Table 11); [3] Nutrient balance = nutrients applied nutrients removed in harvested products; [4] P and K in elemental form.

Table 13. Chemical properties of various horizons of Haplic Acrisols that have been under different land use in southeastern Vietnam.

	Forest	Rubber	Sugarcane	Cashew	Cassava	CV (%)
Organic C (%)	1.032 a	0.839 ab	0.796 ab	0.579 ab	0.496 b	44.7
Total N (%)	0.058 a	0.054 ab	0.040 abc	0.032 bc	0.022 c	36.7
Available P (Bray 2) (µg g^{-1})						
-1st horizon	5.21 b	20.90 a	20.68 a	4.85 b	15.33 ab	37.5
-2nd horizon	2.48 b	7.03 a	7.92 a	3.19 b	5.31 ab	32.6
-3rd horizon	1.57 b	2.83 ab	3.82 a	1.08 ab	3.82 a	44.6
CEC (meq $100g^{-1}$)	3.43 a	2.94 a	3.24 a	2.39 ab	1.53 b	27.1
Exch. K (meq $100g^{-1}$)						
-1st horizon	0.132 a	0.127 a	0.051 b	0.070 ab	0.060 b	66.3
-2nd horizon	0.073 a	0.046 ab	0.022 b	0.031 ab	0.021 b	75.1
Exch. Mg (meq $100g^{-1}$)	0.145 a	0.157 a	0.055 ab	0.046 ab	0.036 b	89.1

Values are average of 6–10 profiles per cropping system. Within rows data followed by the same letter are not significantly different at the 5% level by Tukey's Studentized Range Test. Source: Cong Doan Sat and Deturck, 1998.

Thailand

In Thailand cassava has been cultivated very extensively and almost continuously for the past 25 years in many areas of the east and northeast. Cassava fields are seldom rotated with other crops, because few other crops can tolerate the poor sandy soils and unpredictable rainfall of those regions. However, since farm size in Thailand is relatively large, farmers may leave some fields under fallow for several years before returning the field to cassava cultivation. A survey conducted in 1990/1991 (DOAE, 1992) indicated that about 50 percent of cassava farmers applied some chemical fertilizers to the crop, usually between 10 and 50 kg of 15-15-15/rai (60–300 kg/ha). Farmers are well aware that cassava yields will decrease if no fertilizers are applied, but often lack the financial resources to buy fertilizers, especially in those years that cassava prices are very low. Thai farmers almost never apply animal manures or compost to cassava fields, and seldom practice green manuring, intercropping or crop rotations. According to data from the Office of Agricultural Economics (1998), cassava farmers spend "on average" 427 baht ha^{-1} on fertilizers, which corresponds to about 70 kg 15-15-15 ha^{-1}. In this case, they would be applying 10.5 kg N, 4.6 kg P, and 8.7 kg K ha^{-1}. Assuming an average yield of 15 mt ha^{-1} and that only roots are harvested and removed (parts of the stems are used as planting material, but as such are also returned to the field), we can estimate an annual nutrient outflow in the root harvest (from the curves in Figure 2) of 30 kg N, 3.5 kg P, and 20 kg K ha^{-1}. This would result in an "average" nutrient balance of –19.5 kg N, 1.1 kg P, and –11.3 kg K ha^{-1}. As in the case of Vietnam, the balance in Thailand is positive for P but negative for N and K, i.e. farmers apply too much P and not enough N and K.

Fertilizer trials have usually shown a response mainly to K and N, with less response to P (Nakviroj and Paisancharoen, personal communication; Tongglum et al., 2001). For this reason, the Departments of Agriculture (DOA) and Agricultural Extension (DOAE) are now recommending the application of 25–50 kg rai^{-1} (150–300 kg ha^{-1}) of 15-7-18, which better corresponds to the nutritional requirements of the crop.

In 1999 Thailand exported 4.34 million mt of cassava pellets and 0.93 million mt of starch, corresponding to about 9.76 and 4.42 million mt of fresh roots, respectively (TTTA, 2000). We may assume that nutrients are exported only in the chips but not in the starch. Each tonne of fresh roots contains about 2.00 kg N, 0.233 kg P, and 1.333 kg K (from Figure 2, assuming an average yield of 15 mt ha^{-1}). Thus, with the export of 4.34 mt of chips, Thailand exported also 19,520 mt of N, 2,270 mt of P, and 13,010 mt of K, with a total value in terms of fertilizers of 581 million baht. The total value of pellet exports was 12,446 million baht (TTTA, 2000). Thus, about 4.7 percent of the export value corresponds to the value of lost nutrients. These nutrients end up mainly in the form of pig manure in the Netherlands, causing a serious environmental problem there, while cassava soils in Thailand become more and more degraded. A shift towards greater use of cassava pellets for domestic animal feeding would help to alleviate this problem, while the export of meat would add value to cassava products, to the benefit of farmers and the country as a whole.

SOURCES OF UNCERTAINTIES AND ERRORS IN THE USE OF NUTRIENT BALANCES

Nutrient balances have been used to determine whether a particular nutrient is accumulating or is being depleted. However, as mentioned above, major errors in calculation can occur because:

1. Nutrient removal in the harvested product is usually calculated from the average nutrient content per tone of product. However, nutrient concentrations in the product tend to increase with increasing yield. This results in the nutrient content not being linearly related to yield, and nutrient removal being overestimated when yields are low.
2. In many crops it is often uncertain which part of the plant is being removed from the field—only the harvested grain (or roots) or also the straw (or other crop residues)?
3. Incorporation of green manures, *in-situ* mulches, and intercrop residues may contribute nutrients to the following crop, but most of these nutrients have merely been recycled and thus cannot be considered as a nutrient input to the system. In fact, the harvest of intercrops is likely to result in a nutrient outflow, unless these intercrops have been adequately fertilized.
4. Nutrient inputs from N-fixation, atmospheric deposits, as well as nutrient losses by leaching and volatilization are very difficult to estimate and are therefore usually ignored.
5. Nutrient losses in eroded soil sediments and runoff, and nutrient inputs from the deposition of eroded sediments are very site-specific and extremely variable over time, making it almost impossible to arrive at meaningful estimates from these sources.
6. Nutrient losses in eroded sediments are often calculated from the analyses of “available” P and “exchangeable” cations in the eroded sediments. However, the loss of total N, total P, and total K in the sediments should be determined to get a more accurate estimate of nutrient losses; these losses can be 5 to 10 times greater than the “available” fraction generally determined.
7. Nutrient inputs from animal manures, compost, ash etc are uncertain due to the variable moisture content and composition of these products.

CONCLUSIONS

1. Nutrient balances, i.e. the difference between nutrient inputs and outflows, are often used to determine whether a particular nutrient is accumulating or is being depleted. In the latter case it may be concluded that the cropping system being used is unsustainable. While this is correct in principle, there are major difficulties in accurately determining all nutrient inputs and outflows. For this reason, nutrient balances are generally "partial" balances, which ignore those sources that are either of minor importance or are difficult to quantify. Thus, care should be taken in the interpretation of results.

2. In the case of cassava, nutrient removal in the harvested roots is generally lower than that in the harvested products of other crops. When cassava yields are high the nutrient contents of the roots are K>N>P, but when yields are low (<30 mt ha^{-1}) nutrient removal is N>K>P. When all plant parts are removed from the field at harvest, the removal of N, Ca, and Mg is greatly increased and nutrient removal is generally N>K>P.

3. Cassava causes more erosion than most other crops, but erosion can be markedly reduced by the use of better management practices. Total nutrients in both eroded sediments and runoff tend to be high in K and N, but low in P. These losses can be as high as, or higher than, losses of nutrients in the harvested products. However, these losses are not uniform over time or space, and therefore are very difficult to estimate.

4. Partial nutrient balances of nutrient inputs in fertilizers and manures, and outflows in harvest products in Vietnam and Thailand indicate that the balances for N and K are usually negative, while those for P are positive. Especially in Vietnam, cassava farmers tend to apply too much P and not enough N and K to the crop. Experiments on farmers' fields generally show that farmers can increase yields and net income by reducing the amounts of FYM and P applied and increasing the application of K in the form of chemical fertilizers. In Thailand, farmers have been applying mainly compound 15-15-15 fertilizers to cassava. With this type of fertilizer farmers apply too much P and not enough N and K. With an average yield of 15 mt ha^{-1} of fresh roots, farmers should apply at least 200 kg ha^{-1} (32 kg rai^{-1}) of 15-7-18 fertilizers to maintain a positive balance for all three major nutrients.

5. Nutrient balances in Thailand indicate that with the annual export of over four million mt of cassava pellets, the country also exports nearly 20,000 mt of N, over 2,000 mt of P, and 13,000 mt of K with a value of about 580 million baht. Unless these nutrients are returned to the soil in the form of chemical fertilizers, there is no doubt that cassava soils will be depleted in nutrients and cassava production may not be sustainable in the long term.

REFERENCES

Amarasiri, S.L.; and Perera, W.R. 1975. Nutrient removal by crops growing in the dry zone of Sri Lanka. *Tropical Agriculturist,* 131: 61–70.

Amezquita, E.; Ashby, J.; Knapp, E.K.; Thomas, R.; Mueller-Saemann, K.; Ravnborg, H.; Beltran, J.; Sanz, J.I.; Rao, I.M.; and Barrios, E. 1998. CIAT's strategic research for sustainable land management on the steep hillsides of Latin America. In *Soil erosion at multiple scales. Principles and methods for assessing causes and impacts*. Oxon, UK: CABI. pp. 121–132.

Ando, S.; Meunchang, S.; Thippayarugs, S.; Prasertsak, P.; Matsumoto, N.; Wadisirisuk, P.; and Yoneyama, T. 1999. Estimation of biological nitrogen fixation in field-grown sugarcane, cassava and pineapple in Thailand. In Suzuki, M. and Ando, S. (Eds.), *Highlight of collaborative research activities between Thai research organizations and JIRCAS.* Bangkok, Thailand: JIRCAS. pp. 44–46.

Barrows, H.L.; and Kilmer, V.J. 1963. Plant nutrient losses from soils by water erosion. *Advances in Agronomy,* 15: 303–316.

Cadavid, L.F. 1988. Respuesta de la yucca (*Manihot esculenta* Crantz) a la aplicación de NPK ensuelos con diferentes caracteristicas. Trabajo Especial. Un. Nacional de Colombia. Palmira,Colombia. 185 p.

Centro Internacional de Agricultura Tropical (CIAT). 1985. Cassava Program. Annual Report 1984.Working Document No. 1, 1985. Cali, Colombia: CIAT.

CIAT. 1988. Cassava Program. Annual Report 1986. Working Document No. 43. Cali, Colombia: CIAT.

Cong Doan Sat; and P. Deturck. 1998. Cassava soils and nutrient management in South Vietnam. In Howeler, R.H. (Ed.), *Cassava breeding, agronomy and farmer participatory research in Asia.* Proc. 5th Regional Workshop, held in Danzhou, Hainan, China. Nov 3–8, 1996. pp. 257–267.

Cours, G. 1953. Le manioc. Recherche Agronomique de Madagascar. Compte Rendu no. 2: 78–88.

Department of Agric. Extension (DOAE). 1992. Summary results: the use of agricultural technology. Vol 6. Bangkok, Thailand: DOAE (in Thai).

Food and Agriculture Organization Statistics (FAOSTAT). 1999. http://www.fao.org//giews/

Howeler, R.H. 1981. *Mineral nutrition and fertilization of cassava.* Series 09EC-4. Cali, Colombia: CIAT. 52 p.

Howeler, R.H. 1985a. Mineral nutrition and fertilization of cassava. In *Cassava: research, production and utilization.* UNDP-CIAT Cassava Program, Cali, Colombia. pp. 249–320.

Howeler, R.H. 1985b. Potassium nutrition of cassava. In *Potassium in agriculture.* Intern. Symp. held in Atlanta, GA, USA. July 7–10, 1985. Madison, Wisconsin: ASA, CSSA, SSSA. pp. 819-841.

Howeler, R.H. 1990. Phosphorus requirements and management of tropical root and tuber crops. In *Proc. Symp. on Phosphorus Requirements for Sustainable Agriculture in Asia and*

Oceania. Los Baños, Philippines: IRRI. March 6–10, 1989. pp. 427–444.

Howeler, R.H. 1991a. Long-term effect of cassava cultivation on soil productivity. *Field CropsResearch,* 26:1–18.

Howeler, R.H. 1991b. Identifying plants adaptable to low pH conditions. In *Plant-soil interaction at low pH.* Netherlands: Kluwer Academic Publisher. pp. 885–904.

Howeler, R.H. 1992. Agronomic research in the Asian Cassava Network – an overview 1987–1990.
In Howeler, R.H. (Ed.), *Cassava breeding, agronomy and utilization research in Asia.*
Proc. 3rd. Regional Workshop, held in Malang, Indonesia. Oct 22–27, 1990. pp. 260–285.
Howeler, R.H. 2000. Report on erosion control demonstration plots at TTDI Research and Training Center, Huay Bong, Daan Khun Thot, Nakorn Ratchasima – third year results, 1998/99. Bangkok, Thailand: CIAT. 5 p.
Howeler, R.H. 2001. Cassava mineral nutrition and fertilization. In *Cassava: biology, production and utilization.* Wallingford, UK: CABI Publishing. (Submitted for publication.)
Howeler, R.H.; and Cadavid, L.F. 1983. Accumulation and distribution of dry matter and nutrients during a 12 month growth cycle of cassava. *Field Crops Research*, 7: 123–139.
Howeler, R.H.; Edwards, D.G.; and Asher, C.J. 1981. Application of the flowing solution culture techniques to studies involving mycorrhizas. *Plant and Soil,* 59: 179–183.
Howeler, R.H.; Sieverding, E.; and Saif, S. 1987. Practical aspects of mycorrhizal technology in some tropical crops and pastures. *Plant and Soil,* 100: 249–283.
Howeler, R.H.; Tongglum, A.; Jantawat, S.; and Utomo, W.H. 1999. *The use of forages for soil fertility maintenance and erosion control in cassava in Asia.* (in press).
Jacob, A; and von Uexküll, H. 1973. *Nutricíon y Abonado de los Cultivos Tropicales y*
Subtropicales (Nutrition and Fertilization of Tropical and Subtropical Crops). 4th Ed. Edicíones Euroamericanas Klaus Thiele, Mexico 19 D.F. 626 p.
Kabeerathuma, S.; Mohan Kumar, B.; Mohan Kumar, C.R.; Nair, G.M.; Prabhakar, M.; and Pillai, N.G.1990. Long range effect of continuous cropping and manuring on cassava production and fertility status of soil. In Howeler, R.H. (Ed.*), Proc. 8th Symp. Intern. Soc. Trop. Root Crops*, held in Bangkok, Thailand. Oct 30 to Nov 5, 1988. pp. 259–269.
Kanapathy, K. 1974. Fertilizer experiments on shallow peat under continuous cropping with tapioca.*Malaysian Agric. J.,* 49: 403–412.
Lal, R. 1976. *Soil erosion problems on an Alfisol in Western Nigeria and their control.* IITA. Monograph # 1. Ibadan, Nigeria: IITA.
Loehr, R.C. 1968. Pollution implications of animal wastes - a forward-oriented view. Prepared for Research Program, Robert S. Kerr Water Research Center, Ada. Okla. US Dept. of Interior. Federal Water Pollution Control Administration.
Nguyen Huu Hu; Pham Van Bien; Nguyen The Dang; and Thai Phien. 1998. Recent progress in cassava agronomy research in Vietnam. In Howeler, R.H. (Ed.), *Cassava breeding, agronomy and farmer participatory research in Asia.* Proc. 5th Regional Workshop, held in Danzhou, Hainan, China. Nov 3–8, 1996. pp. 235–256.
Nguyen The Dang; Tran Ngoc Ngoan; Le Sy Loi; Dinh Ngoc Lan; and Thai Phien. 1998. Farmer participatory research in cassava soil management and varietal dissemination in Vietnam. In Howeler, R.H. (Ed.), *Cassava breeding, agronomy and farmer participatory research in Asia.* Proc. 5th Regional Workshop, held in Danzhou, Hainan, China. Nov 3-8, 1996.pp. 454–470.
Nguyen Tu Siem. 1992. Organic matter recycling for soil improvement in Vietnam. Proc. 4th Annual Meeting IBSRAM *ASIALAND* Network. Bangkok, Thailand: IBSRAM.
Nijholt, J.A. 1935. Opname van voedingsstoffen uit den bodem bij cassave (Absorption of nutrients from the soil by a cassava crop). Buitenzorg. Algemeen Proefstation voor den Landbouw. Korte Mededeelingen No. 15. 1935. 25 p.

Paula, M.B. de; Nogueira, F.D.; and Tanaka. R.T. 1983. Nutrição mineral da mandioca: absorçao de nutrientes e produção de materia seca por duos cultivares de mandioca. Revista Brasileira de Mandioca., Cruz das Almas, Bahia, Brazil. Vol 2 no 1: 31–50.

Perkins, H.F., Parker, M.B.; and Walker, M.L. 1964. Chicken manure – its production, composition, and use as a fertilizer. *Georgia Agr. Exp. Sta. Bull.* N.S. 123.

Plam Thanh Binh; Nguyen Minh Hung; Le Cong Tru; and Henry, G. Socio-economic aspects of cassava production, marketing and rural processing in Vietnam. In Howeler, R.H. (Ed.), *Cassava production, processing and marketing in Vietnam.* Proc. of a Workshop, held in Hanoi, Vietnam. Oct 29–31, 1992. pp. 113–158.

Pham Van Bien; Hoang Kim; and Howeler, R.H. 1996. Cassava cultural practices in Vietnam. In Howeler, R.H. (Ed.), *Cassava production, processing and marketing in Vietnam.* Proc. of a Workshop, held in Hanoi, Vietnam. Oct 29–31, 1992. pp. 58–97.

Phommasack, T.; Sengtaheuanghung, O.; and Phanthaboon, K. 1995. The management of sloping land for sustainable agriculture in Laos. In ASIALAND: *The management of sloping lands for sustainable agriculture in Asia. (Phase 2, 1992–1994).* Network Doc. 12. Bangkok, Thailand: IBSRAM. pp. 87–101.

Phommasack, T.; Sengtaheuanghung, O.; and Phanthaboon, K. 1996. Management of sloping lands for sustainable agriculture in Laos. In *The management of sloping lands in Asia. (IBSRAM/ASIALAND).* Network Doc. #20. Bangkok, Thailand: IBSRAM. pp. 109–136.

Putthacharoen, S.; Howeler, R.H.; Jantawat, S.; and Vichukit, V. 1998. Nutrient uptake and soil erosion losses in cassava and six other crops in a Psamment in eastern Thailand. *Field Crops Research,* 57: 113–126.

Quintiliano, J.; Margues, A.; Bertoni, J.; and Barreto, G.B. 1961. Perdas por erosão no estado de S. Paulo. *Brigantia,* 20 (2): 1143–1182.

Reining, L. 1992. *Erosion in Andean hillside farming.* Hohenheim Tropical Agric. Series #1. Hohenheim Univ., Germany. 219 p.

Ruppenthal, M. 1995. *Soil conservation in Andean cropping systems.* Hohenheim Tropical Agric. Series #3 Hohenheim Univ., Germany. 110 p.

Ruppenthal, M.; Leihner, D.E.; Steinmuller, N.; and El-Sharkawy, M.A. 1997. Losses of organicmatter and nutrients by water erosion in cassava-based cropping systems. *Expt. Agric.,*33: 487–498.

Scaife, A.; and Bar-Yosef. 1995. *Nutrient and fertilizer management in field grown vegetables.* Intern. Potash Inst., Basel, Switzerland.

Sieverding, E.; and Howeler, R.H. 1985. Influence of species of VA mycorrhizal fungi on cassava yield response to phosphorus fertilization. *Plant and Soil,* 88: 213–222.

Silva, L.G. 1970. Adubação NPK na cultura da mandioca em Tabuleiró Costeiro no estado da Paraiba. *Pesquisas Agropecuárias no Nordeste,* 2(1): 73–75.

Sittibusaya, C. 1993. Progress report of soil research on fertilization of field crops. 1992. Annual Cassava Program Review. Jan 19–20, 1993. Rayong, Thailand. (in Thai)

Sittibusaya, C.; and Kurmarohita, K. 1978. Soil fertility and fertilization. In *ASPAC Proc. Workshop on Cassava Production and Utilization*, held in Bangkok, Thailand. May 10–12, 1978.

Suzuki, M.; Teppoolpon, M.; Morakul, P.; and Chotitkun, W. 1988. The chemical properties of various kinds of organic fertilizers in Thailand and the effective use of water hyacinth for composting. Mimeograph. Bangkok, Thailand.

Sutanto, R.; Supriyo, A.; Maas, A.; Masyhuri, B.; Radjagukguk, S.; Kibirun, S.; Hartadi and Soekedarmodjo, S. 1993. The management of upland acid soils for sustainable food crop production in south Kalimantan, Indonesia. In *The Management of Acid Soils (IBSRAM/*ASIALAND*).* Network Doc. #6. Bangkok, Thailand: IBSRAM. pp. 25–42.

Tan, S.L. 1992. Recent progress in cassava varietal and agronomic research in Malaysia. In Howeler, R.H. (Ed.), *Cassava breeding, agronomy and utilization research in Asia.* Proc. 3rd Regional Workshop, held in Malang, Indonesia. Oct 22–27, 1990. pp. 81–95.

Tan, S.L.; and Chan, S.K. 1989. Nutritional requirements of cassava under continuous cropping on peat. In Spigarelli, S.A. (Ed.), *Proc. Intern. Symp. on Peat, Peatland Characteristics and Uses,* held in Bemidji, Minnesota, USA. May 16–19, 1989. Center for Environmental Studies, Bemidji State Univ., MN, USA. pp. 436–449.

Thai Tapioca Trade Association (TTTA). 2000. Year Book 1999. Bangkok. 140 p.

Tongglum, A.; Suriyapan, P.; and Howeler, R.H. 2001. Cassava agronomy research and adoption of improved practices in Thailand – Major achievements during the past 35 years. In Howeler, R.H. and S.L. Tan (Eds.), *Cassava's potential in Asia in the 21st century: present situation and future research and development needs.* Proc. 6th Regional Workshop, held in Ho Chi Minh city, Vietnam. Feb 21–25, 2000. (in press)

Tongglum, A.; Vichukit, V.; Jantawat, S.; Sittibusaya, C.; Tiraporn, C.; Sinthuprama, S.; and Howeler, R.H. 1992. In Howeler, R.H. (Ed.), *Cassava breeding, agronomy and utilization research in Asia.* Proc. 3rd Regional Workshop, held in Malang, Indonesia. Oct 22–27, 1990. pp. 199–223.

Conducting Nutrient Audits at the National Scale in Southeast Asia: Methodology and Preliminary Results

W.F. Sheldrick[1], J.K. Syers[2], and J. Lingard[1]

[1]*Department of Agricultural Economics and Food Marketing, University of Newcastle, Newcastle upon Tyne NE1 7RU, United Kingdom*
[2]*Department of Natural Resources and Environmental Sciences, Naresuan University, Phitsanulok 65000, Thailand*

Nutrient audits have been carried out for China, Indonesia, Malaysia, the Philippines, Thailand, and Vietnam. For comparison, a nutrient audit was also carried out for the Republic of Korea a country, which has reached a nutrient balance. The nutrient audits were carried out using a mathematical model, which incorporates an integrated animal excreta submodel. Agricultural data from the FAO Internet database for the period 1961 to 1998 were downloaded into the model which contains coefficients for estimating nutrient outputs and inputs from these data. The main outputs are a time series of nutrient balances from 1961 to 1998, together with other information on the dynamics of nutrient flow. This type of information is more useful than one-off or snapshot balances, which can be misleading insofar as balances can vary significantly from year to year. It can also help to explain the reasons why nutrient balances vary due to weather, lack of nutrient inputs, and economic factors, such as reduced plantings.

The balances indicate that overall, there is a large deficit of N, P, and K in the region. For each country the size of the nutrient deficit depends upon the types of agricultural production. The N deficits in most countries increased steadily in the 1970s and 1980s but in the last two decades up to 1998 have shown an overall decline. In China and Vietnam a balance for N has been achieved. Deficits of P have increased steadily for most of the countries and although in some countries, such as Thailand and Malaysia, there has recently been some reduction in these deficits, in others, such as Indonesia, the Philippines, and Vietnam, deficits have remained high or have increased. With the exception of Malaysia, K depletion increased steadily between 1961 and 1998. In Malaysia, where relatively large quantities of K are added to commercial plantation crops, annual surplus K has averaged about 30,000 tonnes over the last few years. In regional terms this is small. For example, in 1998, China had a deficit of more than 8 million tonnes, and the deficit in Indonesia was 1.2 million tonnes. Overall, the K deficit in the six countries surveyed amounted to 10.5 million tonnes of K and represented an average annual depletion rate of 60 kg ha^{-1}. In 1998, China had a K fertilizer application rate of 21 kg ha^{-1} but the other countries in the region had an average of less than 10 kg ha^{-1}. Very large application rates of K will be required to eliminate this deficit, within a reasonable period of time, if declining crop yields and soil degradation are to be averted.

The nutrient audit for the Republic of Korea shows that a major K deficit of 60 kg ha^{-1} in 1961 had been reduced to a balance in 1993. Annual K application rates were increased from 8 to 102 kg ha^{-1}. This was associated with an increase in total cereal yield from 3,200 to 6,080 kg ha yr^{-1}. Although much attention has been directed towards nutrient depletion in Sub-Saharan Africa, where depletion of K averages about 20 kg ha yr^{-1}, the situation in Southeast Asia with three times this rate of depletion is much more serious.

NPK Fertilizer Recommendation Systems for Corn: Decision Aids and Test Kits

Attanandana,T[1]., C. Suwannarat[1], T. Vearasilp[2], S. Kongton[2], R. Meesawat[3], P. Bunampol[3], K. Soitong[4], C. Tipanuka[4] and R.S. Yost[5]

[1]*Department of Soil Science, Kasetsart University, Bangkok, Thailand*
[2]*Land Development Department, Bangkok, Thailand*
[3]*Department of Agriculture, Bangkok, Thailand*
[4]*Department of Agricultural Extension, Bangkok, Thailand*
[5]*Department of Tropical Plant and Soil Sciences, University of Hawaii, USA*

ABSTRACT

A simple and rapid soil test is currently being developed for the field determination of nitrogen, phosphorous and potassium (NPK). Correlation studies were undertaken to select a single extracting solution for NPK determination in soils for routine analysis. A highly significant correlation was obtained between extractable-N (ammonium+nitrate) as determined by colorimetric methods and corn dry weight (CDW) with an R^2 value of 0.74. Extractable-N, determined using colorimetric methods, was also highly significantly correlated with N uptake (R^2 value of 0.77). The highest, significant correlations between extractable-K and both CDW and K uptake were obtained using Mehlich 1. Extractable-P and CDW and extractable-P and P uptake were also significantly correlated with Mehlich 1. Mehlich 1 was selected for use as a universal extractant for NPK.

In field experiments, the actual and predicted yield of corn (*Zea mays,* L.) in seven soil series across four provinces was compared. The N fertilizer requirement was generated by the CERES-Maize model while P and K were calculated by a Mitscherlich-Bray equation. An agreement index of 0.86 between actual and predicted yield was obtained. The PDSS (Phosphorus Decision Support System) was used to predict the P requirement and was tested with an on-farm experiment in Nakorn Ratchasima Province in Thailand. The amount of fertilizer P predicted by PDSS was one-half of the amount obtained by calculation with the Mitscherlich-Bray equation. The yield of the CERES-Maize-PDSS prediction was higher than with the farmer's practice. The economic analysis showed that the PDSS treatment gave a higher benefit than the farmer's practice.

INTRODUCTION

Soil analysis is a widely adopted method for the evaluation of soil fertility and, as a tool for fertilizer recommendations. In developing countries, technology transfer is restricted due to a lack of laboratory infrastructure, specialized training, and essential yet time consuming supportive research. Moreover, soil testing is also costly. Consequently, poor farmers cannot usually afford to have the nutrient status (NPK) of their soils evaluated. Currently, soil testing for NPK requires nutrient-specific chemical extractants and determination methods, expensive instrumentation, and highly trained personnel. Universal extractants for P, K, calcium (Ca), and magnesium (Mg), and other micronutrients have been proposed and are widely used in the United States (Jones, 1985). However, a simple, rapid, and accurate method of soil testing which is applicable for field use has not been developed for the Thai situation. The purpose of this research was to identify a single extracting solution for NPK in soils and to evaluate the determination of extractable-N (NH_4+NO_3), extractable-K and extractable-P. Stage 1 of the investigation was to compare the effectiveness of various currently adopted standard extraction methods for P to extract N, P, and K in some important soils for growing corn in Thailand, namely Bray 2, citric acid, Mehlich 1, Morgan, Olsen, and sodium lactate (Kamprath and Watson, 1980; Thompson and Pratt, 1954; Page et al., 1982). Stage 2 was to develop the soil test kit for NPK. Stage 3 was to develop the NPK fertilizer recommendation system using a modelling program and employing a soil test kit for initial nutrient evaluation.

MATERIALS AND METHODS

Pot Experiment

The experiment was a 15 x 5 factorial in a completely randomized design with, three replications. Five soil series which are representative of soils of the major corn production area of Thailand were used in this study. They were Chai Badan series (Cb), fine, smectitic, isohyperthermic Leptic Haplusterts; Takhli series (TK), loamy-skeletal, carbonatic, isohyperthermic Entic Haplusterts; Lop Buri series (Lb), very fine, smectitic, isohyperthermic Typic Haplusterts; Satuk series (Suk), fine, loamy, siliceous, isohyperthermic Typic (Kandic) Paleustults; and Pak Chong series (Pc), very fine, kaolinitic, isohyperthermic Rhodic Kandiustox. Some chemical properties of these soils are shown in Table 1. Three composite samples of each soil, which differed in P content, were collected. The 15 soil samples were used for greenhouse and laboratory study. The treatments were Control, (PK), (NK), (NP), and NPK. Suwan 5 corn variety was used as the test crop. The dry weight of corn and NPK uptake in the plants were recorded.

Table 1. Physical and chemical properties of soils used in the study.

Soil series	pH[1]	Texture[2]	OM[3] ($g\ kg^{-1}$)	P[4] ($mg\ kg^{-1}$)	K[5] ($mg\ kg^{-1}$)	Ca[5] ($mg\ kg^{-1}$)	Mg[5] ($mg\ kg^{-1}$)
Cb – H	8.1	SCL	22	70	280	11,000	340
Cb – M	7.9	C	30	28	140	10,000	260
Cb – L	8.2	CL	22	11	80	13,000	200
Tk – H	8.2	SCL	44	81	200	12,000	210
Tk – M	8.1	C	34	44	130	18,000	220
Tk – L	8.1	C	41	20	210	17,000	260
Lb – H	8.2	C	33	60	280	13,000	350
Lb – M	8.0	C	22	27	90	15,000	520
Lb – L	8.1	C	33	10	90	16,000	530
Suk – H	4.9	LS	04	15	40	160	42
Suk – M	5.2	SCL	11	5	90	520	170
Suk – L	5.4	LS	05	3	40	320	80
Pc – H	7.2	C	35	48	110	3,000	160
Pc – M	5.7	C	32	22	420	3,000	220
Pc – L	6.4	C	18	9	90	3,600	220

[1]1:1 soil:water ratio; [2]hydrometer method; [3]Organic Matter (OM) Walkley-Black method; [4]Bray 2 extraction method; [5]1 M NH_4OAc extraction method.

Extractant Selection

The soils were extracted using 10 different extracting solutions and associated methodologies (Table 2). In each case, the resultant filtrate was analyzed for NH_4, NO_3, P, and K by conventional methods. The N content in the plant was analyzed by the Kjeldahl method, and P and K by double acid digestion (Jones et al., 1991). The uptake of NPK in the corn plants was calculated and the results were correlated with extractable NH_4, NO_3, P, and K in the soils. This was repeated for each extraction method. Each extraction method was assessed by correlating extracted nutrient values with dry matter weight and nutrient uptake of corn in pot experiments. The single extraction and rapid determination methods will be further developed into a soil test kit that can be used in provinces where soil-testing laboratories are not available.

NPK Fertilizer Recommendation Development

The fertilizer recommendation system evaluated in this study was developed using existing decision making aids. The DSSAT-CERES-Maize program version 3.0 was used for N-fertilizer recommendation. Phosphorus requirement was predicted using Phosphorus Decision Support System (PDSS) modelling.

DSSAT-CERES-Maize for determining N-Fertilizer Recommendation

The data from 10 soil series of Petchaboon, Lop Buri, Nakorn Sawan, and Nakorn Ratchasima Provinces were updated and the data of 28 soil series were taken from the database of the Land Development Department. A climatic database including solar radiation, maximum and minimum temperature, rainfall intensity, frequency, and annual distribution was obtained from the Thai Meteorology Department. With the use of the Weatherman program, long-term climatic data were used to predict climatic characteristics for the 1997–2001 period of study. A genetic coefficient study was performed using Suwan 5 and Suwan 3601 corn varieties as the test crops. All necessary data were recorded and calculated to estimate the genetic coefficients of the two corn varieties.

Table 2. The extracting solutions used in the study.

Method	Extracting solutions	Reference
Bray 2	0.03 M NH_4F + 0.1 M HCl, 1:10 soil: solution ratio, shake for 1 minute.	Kamprath and Watson, 1980
Citric acid	1 % citric acid, 1: 20 soil : solution ratio, shake for 30 minutes.	Thompson and Pratt, 1954
Mehlich 1	0.05 M HCl + 0.0125 M H_2SO_4, 1:5 soil: solution ratio, shake for 5 minutes.	Jones, 1985
Modified Mehlich 1	0.05 M HCl + 0.125 M H_2SO_4, 1:5 soil: solution ratio, shake for 5 minutes.	Modified from Jones, 1985
Morgan	0.54 M NH_4OAc + 0.7 M NaOAc pH 4.8, 1: 10] soil: solution ratio, shake for 30 minutes.	Kamprath and Watson, 1980
Olsen	0.5 M $NaHCO_3$, pH 8.5, 1:20 soil: solution ratio, shake for 30 minutes.	Page et al., 1982
Ammonium lactate	0.335 M lactic acid + dil. acetic acid + dil. NH_4OH, 1:20 soil: solution ratio, shake for 4 hrs.	Riehm, 1959
Sodium lactate 1	0.335 M lactic acid + dil. acetic acid + dil. NaOH 1: 20 soil: solution ratio, shake for 30 minutes.	Modified from Riehm, 1959
Sodium lactate 2	0.335 M lactic acid + dil. acetic acid + dil. NaOH 1: 20 soil: solution ratio, shake for 4 hrs.	Modified from Riehm, 1959
Ammonium bicarbonate + DTPA	1 M NH_4HCO_3 + 0.005 M DTPA, pH 7.6, 1: 2 soil: solution ratio, shake for 15 minutes.	Jones, 1985

Phosphorus Decision Support System (PDSS) Program for determining P Requirement

The intended crop, percent clay content, and soil test P of each soil were the only inputs into the program. The program will generate the P requirement for a typical yield. With additional inputs of fertilizer cost, grain price, and interest, estimates of benefit/cost can be calculated.

The On-farm Testing Using the Soil Test Kit and the NPK Fertilizer Recommendation *System*

Farmers' fields were selected to conduct the on-farm test. There were four sites of 1.6, 3.8, 0.8, and 2.1 ha. The soils were Lam Phaya Klang (Lg), Chatturat (Ct), and Lop Buri (Lb) series. Table 3 shows the pH, texture, soil series, and area of the four sites.

Table 3. pH, texture, soil series and area of the four sites, on-farm test.

Farmer	Soil series	pH[1]	Texture[2]	Area (ha)
Saweang	Lg	7.5	C	1.6
Thonglang	Ct	7.0	L	3.8
Oui	Ct	7.0	L	0.8
Perm	Lb	8.0	C	2.1

[1]1:1 soil:water ratio; [2]hydrometer method

RESULTS AND DISCUSSION

Extractant Selection

The Mehlich 1 extracting solution gave correlation coefficients of 0.74 0.50, and 0.66 for NH_4+NO_3 and CDW, P and CDW and K and CDW respectively. Similarly, correlation coefficients of 0.55, 0.59, and 0.64 were obtained for NH_4+NO_3 and CDW, P and CDW, and K and CDW respectively when using the Morgan extracting solution. In turn, the Sodium Lactate 1 extracting solution was associated with correlation coefficients of 0.77, 0.71, and 0.60 for NH_4+NO_3 and CDW, P and CDW, and K and CDW respectively (Table 4). Similar trends were obtained when NH_4+NO_3, P and K soil-extracted values were correlated with the corn uptake of these nutrients. This is with the exception of extractable K and K uptake as determined by Sodium Lactate 1, which resulted in a non-significant correlation coefficient of 0.48 (Table 5). The correlation results indicate that the Mehlich 1, Morgan, and Sodium Lactate 1 extracting solutions are the most promising for NH_4+NO_3, P, and K extraction. Mehlich 1 was chosen as the single extracting solution due to the highly significant correlation between extractable NH_4 +NO_3, extractable K and CDW, N and K uptake. Correlation coefficients of 0.74 and 0.77 were obtained for NH_4+NO_3 and CDW and N uptake, respectively. Further, correlation coefficients of 0.66 and 0.93 were obtained for extractable K and both CDW and K uptake. In addition, a significant correlation between extractable P and both CDW and P uptake was obtained. A correlation coefficient of 0.50 and 0.56 was obtained between extractable P and both CDW and P uptake (Table 5).

Table 4. Correlation coefficients between NH_4 + NO_3, P, and K extracted by 10 different methods and dry weight of corn.

Method	**Dry weight of corn (28 days after planting)**		
	$NH^+_4 + NO^-_3$	**P**	**K**
Bray 2	-	0.64**	0.62**
Citric acid	0.18	0.22	0.65**
Mehlich 1	0.74**	0.50*	0.66**
Modified Mehlich 1	0.21	0.17	0.63**
Morgan	0.55*	0.59*	0.64**
Olsen	-	0.44	0.63**
Ammonium lactate	-	0.58*	0.46
Sodium Lactate 1	0.77**	0.71**	0.60*
Sodium Lactate 2	0.10	0.65**	0.33
NH_4HCO_3 + DTPA	-	0.49	0.62**

* significant correlation at 95% level ** significant correlation at 99% level

Table 5. Correlation coefficient between NH_4 + NO_3, P, and K extracted by 10 different methods and nutrient uptake of corn.

Method	**Nutrient uptake**		
	$NH^+_4 + NO^-_3$	**P**	**K**
Bray 2	-	0.69**	0.96**
Citric acid	0.17	0.21	0.96**
Mehlich 1	0.77**	0.56*	0.93**
Modified Mehlich 1	0.28	0.13	0.95**
Morgan	0.52*	0.71**	0.95**
Olsen	-	0.51*	0.89**
Ammonium lactate	-	0.73**	0.42
Sodium Lactate 1	0.81**	0.82**	0.48
Sodium Lactate 2	0.19	0.75**	0.41
NH_4HCO_3 + DTPA	-	0.63**	0.93**

* significant correlation at 95% level ** significant correlation at 99% level

Soil Test Kit Development

The colorimetric determination of NH_4, NO_3, and P by a spectrophotometer was modified and developed for use with a standard color chart. Suitable correlations were obtained between the spectrophotometer and color chart for the NH_4 determination. For example, on 244 acid soils the correlation coefficients were 0.54, 0.87, and 0.96 for clayey, loamy, and sandy soils, respectively On 41 alkaline soils the correlation was similarly high for clayey and sandy soils. Similar results were obtained in the case of NO_3 and P (Table 6). In the case of K determinations, a highly significant correlation of NH_4OAc extractable K, determined by A.A., was obtained with the amount extracted by Mehlich 1 and determined by colorimetric methods (Table 7). The process of soil analysis was also simplified, e.g. the soil was scooped instead of weighed. All high-tech equipment was replaced by simple plastic bottles and droppers.

Table 6. Correlation coefficients for Mehlich 1 extractable NH_4, NO_3, and P between spectrophotometer and color chart determinations using 285 soil samples.

	Acid soil			Alkaline soil	
	Sandy (n=51)	Loamy (n=55)	Clayey (n=138)	Sandy (n=8)	Clayey (n=33)
NH_4	r = 0.96**	r = 0.87**	r= 0.54**	r = 0.94**	r = 0.79**
NO_3	r = 0.99**	r = 0.98**	r= 0.80**	r = 0.93**	r = 0.86**
P	r = 0.77**	r = 0.54**	r = 0.48**	r = 0.83**	r = 0.50**

* significant correlation at 95% level ** significant correlation at 99% level

Table 7. Correlation coefficients between extractable-K as determined by the Mehlich 1 and NH_4OAc methods as measured colorimetrically and by Atomic Adsorption Spectrophotometery, respectively..

	Acid soil			Alkaline soil	
	Sandy (n=51)	**Loamy (n=55)**	**Clayey (n=138)**	**Sandy (n=8)**	**Clayey (n=33)**
K	r=0.75**	r=0.60**	r=0.73**	r=0.67**	r=0.89**

* significant correlation at 95% level ** significant correlation at 99% level

The accuracy of the Soil Test Kit

The readings for soil NO_3, P, and K of the 15 samples determined by atomic adsorption spectrophotometery and the test kit were compared. The results showed that the test kit and atomic adsorption spectrophotometer (AAS) gave interpretations (low, medium, and high) in 14 of the 15 soils, 13 of the 15 soils, and 13 of the 15 soils for NO_3, P, and K as compared with the spectrophotometer reading (Table 8).

Table 8. Soil test data of the Pioneer Company's plot (before planting) and their interpretations.

No	series	NO_3^- content			P content			K content	
		Spectrophotometer		Test kit	Spectrophotometer		Test kit	Test kit	A.A
		mg N kg^{-1}	Class.		mg P kg^{-1}	Class.		mg K kg^{-1}	mg K kg^{-1}
1	Lb	2.00	VL	VL	4.50	M	H*	M	80
2	Lb	18.00	L	L	0.25	VL	VL	H	130
3	Lb	3.47	VL	VL	3.50	M	H*	M	82
4	Ln	4.38	VL	L	6.75	M	M	M	89
5	Ln	4.37	VL	VL	1.00	L	L	M	71
6	Tk	2.67	VL	L	3.25	L	L	H	277
7	Tk	12.92	L	L	0.56	L	VL	H	174
8	Pc	7.00	VL	L	6.00	M	M	L	39
9	Ct	3.00	VL	VL	2.00	L	L	M*	266
10	Lb	18.00	L	L	19.60	VH	H	H	628
11	Cu	1.25	VL	VL	10.00	VH	H	L	69
12	Lb	1.56	VL	VL	47.50	VH	VH	L*	84
13	Wi	15.00	L	M*	4.41	M	M	H	106
14	Tk	12.00	L	L	1.25	L	VL	H	126
15	Pc	12.00	L	L	9.00	H	H	M	78
			14/15			13/15		13/15	

NB. Class. = Classification

NPK Fertilizer Recommendation using the CERES-Maize Model

The predicted and measured yields of Suwan 3601 hybrid corn on some important soils in the four provinces of the corn belt area using the NPK fertilizer recommendations are shown in Table 9. An agreement index of 0.86 indicated the close agreement between the predicted and actual yield for the seven series (Willmott, 1982). The N fertilizer recommendation was determined by the CERES-Maize algorithm while the P and K fertilizer recommendations came from the Mitscherlich-Bray equation (Dept. of Agriculture, 1966; 1967).

Table 9. Predicted and actual yield of Suwan 3601, tested in the field and the agreement index value.

Soil series	Province	Actual yield	Predicted yield	$N\text{-}P_2O_5\text{-}K_2O$
		kg ha^{-1}		
Cd	Nakorn Sawan	7,225	6,563	94-75-0
Tw	Lop Buri	6,144	6,225	94-75-31
Tk	Lop Buri	5,225	5,475	125-0-31
Wi	Lop Buri	6,469	6,181	125-31-63
Wi	Petchaboon	6,413	6,238	125-75-63
Sat	Petchaboon	6,031	6,194	94-106-63
Suk	Nakorn Ratchasima	5,900	6,513	156-75-63
Ct	Nakorn Ratchasima	7,481	7,000	94-0-31

Mitscherlich-Bray equation = log (100 - y) = log 100 - 0.05419 b - 0.03864 x - P requirement
log (100 - y) = log 100 - 0.00618 b - 0.05132 x - K requirement y = relative yield, b = soil test value, x = fertilizer requirement (Dept. of Agriculture, 1966; 1967).

In the process of making fertilizer recommendations using decision support aids, the soil was identified for its soil series and a composite sample was tested for NO_3, P, and K content. The NPK fertilizer recommendation was then prepared according to the initial nutrient contents and soil series in each province.

NPK Fertilizer Recommendations as determined using CERES-Maize and PDSS Models

For this on-farm study, the CERES-Maize model was used for N fertilizer recommendations, the K fertilizer recommendation were derived from a Mitscherlich-Bray equation (Dept. of Agriculture, 1966; 1967), and the P recommendation was developed using the PDSS system. Four on-farm tests were performed comparing: 1) The current farmer practice, 2) NPK fertilizer recommended by CERES-Maize-Mitscherlich-Bray, 3) NPK fertilizer as recommended by CERES-Maize, PDSS, and (4) Mitscherlich-Bray equation. Tables 10 and 11 show the initial nutrient level, fertilizer recommendations, yields of corn and P after harvesting of the on-farm test. The results indicated a higher yield of corn where the NPK fertilizer recommendation was developed using the decision support aids except at one site that was affected by stem borers, which resulted in a yield that was low compared with the farmer's practice. The P content in the soils, after harvest, of the CERES-Maize-PDSS treatment was medium to high resulting from the addition of the recommended amount of fertilizer. In the case of the farmer's field, one site, however, indicated a low content of P after harvesting. Phosphorus fertilizer recommendations by the Mitscherlich-Bray equation were about twice the amounts of P fertilizer recommended by the PDSS decision support aid.

Table 10. Initial nutrient level, fertilizer recommendation, yield of corn, and P after harvest of the farmer's practice and CERES-Maize-PDSS treatments.

Series	pH[1]	Texture[2]	Nutrient Level (NPK)	Farmer's practice			CERES-Maize PDSS		
				Fertilizer applied	Yield kg ha^{-1}	P after harvest	Fertilizer applied	Yield kg ha^{-1}	P after harvest
Lg	7.5	C	VL-VL-H	25-25-0	2769	L	94-44-0	6063	M
Ct	7.0	L	VL-VL-H	13-19-0	4569	H	94-50-0	4138	H
Ct	7.0	L	VL-VL-H	19-25-0	2925	H	94-50-0	4469	H
Lb	8.0	C	VL-VL-H	69-38-0	2706	H	125-69-0	3425	H

[1]1:1 soil:water ratio; [2]hydrometer method

Table 11. Initial nutrient level, fertilizer recommendation, yield of corn and P after harvest of the CERES-Maize-Mitscherlich Bray treatment.

Farmer	Series	pH[1]	Texture[2]	Nutrient Level (NPK)	CERES-Maize Mitscherlich-Bray		
					Fertilizer applied	Yield kg ha^{-1}	P after harvest
Saweang	Lg	7.5	C	VL-VL-H	94-94-0	5913	M
Thong	Ct	7.0	L	VL-VL-H	94-94-0	3650	H
Oui	Ct	7.0	L	VL-VL-H	94-94-0	4944	H
Perm	Lb	8.0	C	VL-VL-H	125-94-0	4394	H

[1]1:1 soil:water ratio; [2]hydrometer method

Economic Analysis

The profit of the four on-farm tests was calculated as the benefit (crop price x the yield increase minus the fertilizer cost, including basic cost). It is clear that the CERES-Maize-Mitscherlich-Bray (CERES-MB) and CERES-PDSS treatments gave higher profits as compared with the current farmer practice (Table 12). The profit would have probably been greater, however, one of the plots was strongly attacked by stem borers and the yield was quite low.

Table 12. Economic analysis of the four on-farm tests.

	Sawaeng	Thonglang	Oui	Perm	Average
	Baht ha^{-1}				
Farmer's practice	34.8	7,743.0	755.5	-1091.9	1,860
CERES-MB	10,524.8	1,201.2*	6,532.5	3,863.5	5,531
CERES-PDSS	12,277.8	4,210.6*	5,574.3	438.7	5,623

* The profit was low due to the corn plants being attacked by stem borers.

CONCLUSIONS

The Mehlich 1 extracting solution is proposed as a single extracting solution for NH_4, NO_3, P, and K in soils of Thailand. Standard color charts for NH_4, NO_3, P and K were developed and used with a soil test kit for field-based NPK determination. Nutrient interpretations obtained by the soil test kit were comparable to values obtained in the laboratory. The results showed an agreement of 14/15, 13/15, and 13/15 for NO_3, P, and K between the soil test kit and AAS interpretations. The predicted and actual yield of NPK fertilizer recommendations using the CERES-Maize program and the Mitscherlich-Bray equation was performed in the field and an agreement index of 0.86 was obtained. In the case of P requirement, PDSS showed that P fertilizer can be reduced by about one-half the amount obtained from the calculation of the Mitscherlich-Bray equation. Using fertilizer recommendation with decision support aids and test kits, higher profit was obtained as compared to the amount used by the farmers, which did not take the initial amount of nutrients and the sustainability of the soils into account.

Recommendations for further study

The on-farm test has to be further expanded for a larger area of corn production. Adequate amounts of nutrients applied to the soil for corn production and in sufficient quantities for sustainable agriculture should be investigated. Moreover, the economic analysis should be focused and highlighted. The simplified program for NPK fertilizer recommendation should be loaded into laptop computers as an aid for extension workers and agricultural advisors.

ACKNOWLEDGEMENT

The authors would like to express their sincere thanks to the Thailand Research Fund (TRF) for the financial support of this study.

REFERENCES

Department of Agriculture. 1966. Annual Report 1966. Bangkok, Thailand.

Department of Agriculture. 1967. Annual Report 1967. Bangkok, Thailand.

Jones, Jr. J.B. 1985. Soil testing and plant analysis: Guide to the fertilization of horticultural crops. *Horticulture reviews*. Vol. 7. A.V. Publishing Co. 68 p.

Jones, Jr. J.B.; Wolf, B.; and Mills, H.A. 1991. *Plant analysis handbook, a practical sampling, preparation, analysis, and interpretation guide.* Micro-Macro Publishing, Inc. 213 p.

Kamprath, E.J.; and Watson, M.E. 1980. Conventional soil and tissue tests for assessing the phosphorus status of soils. In Khasawneh, F.E., Sample, E.C. and Kamprath, E.J. (Eds.), *The role of phosphorus in agriculture.* Madison, Wisconsin: ASA-CSSA-SSSA. pp 910.

Page, A.L.; Miller, R.H.; and Keeney, D.R. 1982. Methods of soil analysis. part 2. Chemical and microbiological properties. Second edition. Madison, Wisconsin: American. Society of Agronomy, Inc., Soil Science Society of America, Inc.. pp 1159.

Riehm, H. 1959. Die Ammoniumlaktat-Essigsaure-Methode zur Bestimmung der leicht loslichen Phosphorsaure in karbonathaltigen Boden. *Agrochemica* 3: 49–65.

Thompson, L.F.; and Pratt, P.F. 1954. Solubility of phosphorus in chemical extractants as indexes to available phosphorus in Ohio soils. *Soil Sci. Soc. Amer. Proc.,* 18 (4): 467–470.

Willmott, C.J. 1982. Some comments on the evaluation of model performance. *American Meteorological Society,* 63:1309–1313.

Integrated Economic and Environmental Accounting

Felix Moukoko-Ndoumbe[1]

[1] *Senior Officer, Resource Economics, Farm Management and Production Economics Service, FAO, Rome*

ABSTRACT

Land degradation is increasing on a global scale. Desertification, erosion, nutrient depletion, and salinization are undermining the productive capacity of soils. Pollution and over fertilization are affecting the agricultural, recreational, and habitat functionality of the land. In spite of all this, conventional economic accounting (CEA), mainly at the farm level, continues to largely ignore costs associated with the depletion of natural resources, as well as pollution and other non-tangible environmental impacts of farmers' actions and agricultural production activities.

These distortions conceal both the negative impact of agricultural production on the environment and the contribution of nature and environment to production processes, livelihoods and ecosystems services. As a consequence, policies and measures in the agriculture sector taken to protect the environment, often fall short of what would be required if the natural environment is to continue to provide food for human and livestock consumption and fibers for the present and into the future. CEA has continued to measure the performance and efficiency of farming activities essentially in terms of productivity and profitability. In the 1990s, productivity and profitability were no longer the only indicators of farm business efficiency. Ecological issues such as soil mining and associated loss of nutrients in the production process have to be integrated into the efficiency assessment process. To help address these issues, Agenda 21, the Plan of Action of the United Nations Conference on Environment and Development, held in Rio de Janeiro in 1992, urged that conventional accounting systems should be expanded to cover concerns related to the environment and natural resource sustainability. In response, the United Nations Statistics Division issued a Handbook on a System of Integrated Environmental and Economic Accounting (SEEA, 1993). Drawing on SEEA guidelines and other relevant works, the FAO Farm Management and Production Economics Service and the Royal Tropical Institute (KIT) of the Netherlands, have developed a methodology for integrating nutrient inflows, outflows, and balances into conventional farm accounting, at the farm level. This paper outlines this methodology.

In this paper the functions of accounting in general and the process of keeping and verifying financial statements are highlighted. The conventional farm accounting system is characterized in terms of its structure and shortcomings, particularly in relation to the measurement of ecological and natural resource use efficiency and sustainability. An overview of evolving environmental and natural resource accounting is provided, including its justification, development (establishment of nutrient flows and balances in physical terms), and structure. Integrated economic and environmental accounting is then featured and characterized in terms of origin and objectives, the integration process, the integrated accounting structure, and potential applications. Questions and topics for discussion or reflection are suggested.

CONTEXT

The current workshop on Nutrient Balances for Sustainable Agricultural Production and Natural Resource Management in Southeast Asia is structured into two themes:

(i) Case studies—nutrient balances and nutrient studies.
(ii) Nutrient balances in integrated biophysical and socioeconomic approaches.

This paper relates to the second theme, particularly as it concerns socioeconomic approaches. Sustainable agricultural production and improved natural resource management are reviewed in the light of integrated nutrient balance and conventional economic accounting at the farm level.

ACCOUNTING IN GENERAL

Definition and Functions

The Oxford Dictionary defines Accounting as a "process or art of keeping and verifying accounts", that is, "keeping and verifying statements of moneys paid or to be paid, or received for goods or services, with balance". The reckoning of nutrient inflows (services received by the soil) and outflows (services provided by the soil) with nutrient balances, is a fundamental aspect of accounting.

A favorable result (balance) of the reckoning process implies profit. An unfavorable result (balance) implies a loss. Profit and loss are quantitative measures of management performance and achievement. Analogically, a positive nutrient balance would imply a benefit for the soil in terms of nutrient accumulation, while a negative balance would imply a loss (depletion). The function of accounting is therefore to measure performance and efficiency, in physical or monetary terms. To manage a nonfarm business prosperously requires reliable data and information on all aspects of the business including, in particular, all resource stocks, inflows, and outflows. Likewise, to manage a farm business prosperously and sustainably, accurate and reliable information on all aspects of the business are needed, including natural resource stocks and fluxes. Accounting is a unique instrument in this respect.

Questions and Topics for Discussion or Reflection

- Has the art and process of accounting treated human-induced and natural resources on equal terms?
- It would seem that the process is as useful for the management of produced resources as for natural resources. Are there objective reasons that explain the relative backwardness of natural resource accounting?

THE CURRENT FARM BUSINESS ACCOUNTING SYSTEM: AN OVERVIEW

Structure: Nature of Accounts

To perform the functions just described, the existing farm accounting system provides three major reckoning financial statements: the balance sheet (complemented by inventories), the income statement, and the farm budget.

The Balance Sheet: The assets and liability accounts

Assets

Assets accounts describe the destination of funds put into the business—what the funds have been used for—in terms of working and productive capital (cash, machines, buildings, acquired land, etc.). Conventionally, these assets are owned by the business and are measurable in monetary terms. Conventionally also, buildings and equipment are reckoned at their original purchased cost or market value, then depreciated annually according to standing procedures to take into account the loss of their productive capacity or decline in value over time. A compensating financial provision for depreciation is made at the same time to ensure the replacement of the asset so that sustainability in the production process is guaranteed. An important point to be noted in this respect is that the decline in the value of land is not reckoned in any manner, as the land is not subject to depreciation.

Liabilities

Liability accounts represent the claims against the assets owned by the business namely, where the funds put into the business came from. In other words, the business's outstanding debts. The claims against the assets by the farm business owner are called Equity. Equity (E) represents the difference between assets (A) and liabilities (L), resulting in the following accounting identities: E=A-L; A=E+L; L=A-E. These identities are useful in determining whether the business is accumulating wealth or building up potential for sustainable progress (Tables 3 and 4).

The Income Statement.

The Income Statement shows the financial outcome (net farm income) or profit and loss for a business over the period of reference, generally one year. It is a summary of all farm business revenues and expenses, with balance, at the same point in time as for the balance sheet.

An important point to be noted is that by accounting conventions, the allowance for depreciation of human-induced capital is reckoned as an operating expense. This results in a twin effect in that capital accumulation is credited, which ensures future productivity (principle of sustainability) while present income is reduced by the equivalent amount to an income level which is lower but likely to be sustained for the foreseeable future. The same does not apply to land for which, in many instances, the natural productive capacity is being consumed with often no replenishment in sight. In fact no allowance is made for the replacement in due course of the depleted nutrients by appropriate purchased inputs and the natural rebuilding of fertility by appropriate fallow length is often no longer possible due to high population pressure on the land.

The Farm Budget.

The statements just overviewed are standard tools/accounts for *ex post* farm profitability analysis. Of crucial importance is an account that provides for *ex ante* profitability and farm income projections, particularly with regard to agricultural investment projects. The standard tool for judging the potential impact on income and the overall economic development of these projects is the *farm budget.* A farm budget is a projection of inflows and outflows of resources of a farm plan to estimate the incremental net benefit and value added accruing to the farmer (financial budget) and to the society concerned (economic budget) over the life of the plan (project). The budgeting process aims to ensure that such benefit or family satisfaction is maximized (Brown, 1979; and Gittinger, 1982). The farm budget is generally based on a patterned farm plan, a farm model.

Under this projection process, expenditure allowance is made for the purchase of human-induced nutrients in terms of physical fertilizer input. Inflows and outflows of natural nutrients contributing to the production process and affecting the status of land and the soil are not part of the budgeting process as they are considered to be provided free of charge.

Shortcomings of the Current Accounting Systems

Farm production, especially on small farms in many developing countries, is heavily dependent on the stock and flow of natural resources drawn from the natural environment capital. Land and soil typify such capital. Soil depletion and decreasing productivity are key issues in agricultural production. Estimates for 38 countries in Sub-Saharan Africa suggest that the annual net loss of nutrients per hectare during the 1980s was 22 kg of N, 2.5 kg of P, and 15 kg of K ha^{-1} yr^{-1} (Weight and Kelly, 1999). The annual nutrient deficit for a cotton/corn/sorghum rotation in southern Mali was estimated to be about 28 kg ha^{-1} yr^{-1} for N, 18 kg ha^{-1} yr^{-1} for K, and 35 kg ha^{-1} yr^{-1} for lime (van der Pol, 1992). Studies show that 65 to 75 percent of these deficits are induced by exports by crops, residues (biomass), and erosion. Yet conventional accounting systems and analyses of farming systems and agricultural investment projects continue to largely ignore costs associated with the depletion of natural resources, as well as pollution and other environmental impacts of productive activities. Indeed estimates of farm income and profitability based on conventional farm accounting fall short in three respects at least:

- Little attention, if any, is given to the contribution that natural resources make to food and agricultural production;
- The impact of agricultural production on the natural environment capital, e.g. the decline in the soil content of natural nutrients—natural capital consumption—and resulting reduction in the future output-generating capacity, is not taken into account;
- The concept of depreciation, maintenance or replacement is not applied to the natural environment capital, which undermines the search for sustainability;

As a consequence, defensive policies and measures in the agriculture sector often fall short of what is required to ensure that the natural environment continues to provide food, feed, and fibre for the present and into the future. The underlying problem is failure of the market mechanism to give an account of the value of nutrients provided by nature and used in the agricultural production process. As such nutrients are not traded in the market, conventional farm accounting simply and implicitly estimates their value to be zero. Yet the associated output is measured and valued at prevailing market prices. This means that the farm income suggested by existing farm accounting methods is not only inaccurate, but also unsustainable. The related agriculture sector and national accounts then become similarly inaccurate and unsustainable.

Questions and Topics for Discussion or Reflection

Unlike human-induced assets, the decline in the value/productive capacity of land and soil is not reckoned in any manner under conventional accounting and the land is not subject to depreciation.

- Is this appropriate? What impact, if any, has this had on the use and management of land? Should financial allowance be made for replacing nutrient losses? When should the actual expenditure for such replacement occur?

ENVIRONMENTAL ACCOUNTING

Justification

Failure of the market mechanism to give an account of the value of nutrients provided by nature and used in the agricultural production process is no longer accepted as a sufficient reason for valuing them at zero. Concerns have arisen in particular over the following resulting and adverse consequences of continuing to ignore them:

- Lack of or insufficient awareness of the status and issue areas of natural resource degradation, depletion, and management;
- Failure on the part of governments to think out appropriate defensive policies and measures aimed at protecting the environment and the agricultural resource base;
- Inappropriate resource management practices and lack of awareness of the danger of such practices;
- Overuse and depletion of the natural resource base including land, declining productivity, unsustainable production and income, food insecurity, and poverty.

The need to address the identified shortcomings can hardly be overstated. Agenda 21 urged that conventional accounting systems should be expanded to cover concerns related to sustainability and the environment. For a long time, such expansion was constrained by the lack of reliable methods for measuring and valuing environmental and natural resource services. This has changed dramatically in recent years. Significant advances have been made in accounting for basic natural resource and physical environmental processes and in processing the relevant data. Furthermore better basic natural resource and environmental statistics are available or can be made available.

Development

A major challenge that remains is to establish an appropriate environmental accounting framework allowing for the assessment of the impact on the natural productive capital of given farming systems, cropping rotations, projects, etc. Two basic actions are required to this end:

Action 1: Assessment in quantitative and monetary terms of nutrient inflows, outflows, and balances associated with such farming systems, cropping patterns, and projects;
Action 2: Establishment of an integrated framework linking nutrient accounts in physical and monetary terms with conventional socioeconomic accounts at the farm level.

Nature of Environmental Accounts: Accounting for Nutrient Flows and Balances

The Nutrient Balance Sheet in Quantitative Terms

In several countries, institutes have carried out studies to measure nutrients flowing in and out of the soil through various processes. Presenting these data in meaningful accounting structures may enhance their use in decision-making. Table 1 summarizes nutrient flows in physical terms for a hypothetical farming model. The stock of nutrients contained in the soil that is economically exploitable is difficult to quantify. The balance sheet will confine itself, therefore, to reckoning qualitative changes in the stock within the accounting period as well as closing balances. A closing balance for a given year will constitute the opening balance for the following year. Soil erosion which involves quantitative change in the availability of topsoil (soil loss) is treated as depletion of soil just as is qualitative change brought about by direct economic use/exploitation of the soil asset.

Table 1. Physical nutrient asset accounts (kg ha^{-1} yr^{-1}).

	N	P	K	Ca	Mg	Lime
OPENING BALANCE	$\mathbf{X_N}$	$\mathbf{X_P}$	$\mathbf{X_K}$	$\mathbf{X_{Ca}}$	$\mathbf{X_{Mg}}$	$\mathbf{X_{Lime}}$
INFLOW	25.4	4.1	27.4	27.4	9.1	-1.0
Natural inflow	10.0	2.1	6.9	20.1	4.9	
Fixation by crop	1.4	0.0	0.0	0.0	0.0	
Organic manure	0.7	0.1	0.9	0.5	0.2	
Mineral fertilizer	0.1	0.1	0.1	0.0	0.0	-1.0
Restituted residues	13.2	1.8	19.5	6.8	4.0	
OUTFLOW	54.9	8.3	36.7	30.9	12.3	0.0
Crop	9.9	4.1	-8.6	10.5	-0.4	
Stover	21.4	2.6	32.9	10.3	6.6	
Erosion losses	9.2	1.4	10.5	7.9	4.7	
Other losses	14.4	0.1	1.9	2.2	1.4	
BALANCE (-) OR (+)	-29.5	-4.2	-9.3	-3.5	-3.2	-1.0
CLOSING BALANCE	X_N - 29.5	X_P – 4.2	X_K - 9.3	X_{Ca} - 3.5	X_{Mg} – 3.2	X_{Lime} - 1.0

An important feature is that negative balances or depletion are explicitly recorded and subsequently valued as an economic use and consumption of natural capital, implying potential decrease in the short- or long-term productive capacity of the soil. Should a surplus occur—which is rarely the case in developing countries—it will also be explicitly recorded and valued as capital formation/accumulation, implying potential increase in the soil productive capacity.

The Nutrient Balance Sheet in Monetary Terms

Table 2 presents a detailed nutrient flow account in monetary terms for a hypothetical farming model.

Table 2. Nutrient asset accounts in monetary terms (US$ ha^{-1} yr^{-1}).

	Total	N	P	K	Ca	Mg	Lime
OPENING BALANCE	X_T	X_N	X_P	X_K	X_{Ca}	X_{Mg}	X_{Lime}
INFLOW	85	40	7	38	0	0	0
Natural inflow	23	12	2	9	0	0	
Fixation by crop	2	2	0	0	0	0	
Organic manure	9	4	1	4	0	0	
Mineral fertilizer	14	9	2	3	0	0	0
Restituted residues	37	13	2	22	0	0	
OUTFLOW	136	70	6	60	0	0	0
Crop	24	16	2	6	0	0	
Stover	57	19	2	36	0	0	
Erosion losses	31	14	2	15	0	0	
Other losses	24	21	0	3	0	0	
BALANCE (-) OR (+)	-51	-30	+1	-22	0	0	0
CLOSING BALANCE	X_T - 51	X_N – 30	X_P + 1	X_K - 22	X_{Ca}	X_{Mg}	X_{Lime}

Nutrient accounts in physical terms allow for technical sustainability analysis. To allow for integrated environmental and economic analysis, they should be expressed in monetary terms. Valuing the aforesaid flows, applying the replacement cost method, physical flows are converted into such monetary terms. Similarly, the value of an overall nutrient deficit (net depletion) or surplus (net accumulation) can be calculated as being equal to the sum of the values of the specific elements (including that of lime that would be required to prevent acidification). This sum is called the nutrient balance market value (NBMV), mathematically defined (cf. Stocking, 1986) as:

$$NMDV = \sum^{N, P, K, Ca, Mg, CaCO_3} B_i \times V_i$$

where

B_i = the deficit of an element in kg ha^{-1}, and
V_i = the market value of that element in currency kg^{-1}

The value of the nutrient deficit can be regarded as a contribution of the natural nutrient stock in the soil to the agricultural production process. Since it involves a decrease in the value of the soil nutrient stock, it may be considered as soil capital consumption, and thus an environmental cost.

Questions and Topics for Discussion or Reflection

Valuing nutrient flows in quantitative terms to convert them into monetary values applying the replacement cost method as suggested here raises serious financial and economic issues. A major one is that the replacement cost tends to overestimate the value of nutrients and tends to be higher than the value of the production foregone in case the replacement does not actually occur.

- Is there any methodological approach that can be used to address this issue?
- Under which circumstances should the replacement be implemented even if it is not financially justified? Who should bear the cost?
- Should the fact that no single method of valuation is free from weaknesses be a deterrent from valuing nutrient flows?

INTEGRATED ECONOMIC AND ENVIRONMENTAL ACCOUNTING: THE CASE OF NUTRIENTS

Origin and Objectives

Given the establishment of physical nutrient accounts in physical flows and monetary terms, the question arises as to how the resulting changes in the quality of land can actually be integrated into the current accounting system in a meaningful way as a decision support instrument. The framework proposed here is consistent with the paths developed in the Handbook of the United Nations System of Integrated Environmental and Economic Accounting (SEEA). The handbook was issued by the United Nations Statistics Division in response to Agenda 21, which urged that conventional accounting systems should be expanded to cover concerns related to sustainability. The idea is to present the newly established nutrient balance accounts and conventional summary accounts in meaningful formats so as to allow for integration of environmental and natural resource use considerations into economic policy- and decision-making.

The Integration Process

The review of the concepts and principles underlying conventional farm accounting and the evolving nutrient accounts has shown opportunities and the need for some kind of integration. It has become apparent that such integration can be achieved in two ways:

1. Integration by juxtaposition of the evolving nutrient asset flow/balance accounts as Satellite Accounts to conventional Economic Accounts. The UN SEEA uses the term *juxtaposition* to infer that satellite accounts need to be refined and established on a firm footing before actual integration can reasonably occur. This approach has been used in respect of national accounts. Satellite accounts represent a first and necessary step towards actual integration. They provide for cross-account analysis between the two categories of accounts and, as a result, for integrating economic, environmental, and natural resource use analysis in decision- and policy-making.
2. Structural integration through introduction, as appropriate, of a limited number of New Entries into the conventional balance sheets, income statements, and farm budgets. The new entries are nutrient balances or elements of nutrient inflows or outflows. With these entries, the relevant conventional accounts become integrated financial statements as indicated in Box 1. Structural integration allows for intra-account analysis and the reckoning of sustainable income.

Box 1. System Integrated Accounts

Phase I: Integrated Accounts by juxtaposition of (a) and (b)

(a) Conventional economic accounts

1. Balance Sheet
2. Income Statement
3. Farm Budget

(b) Nutrient Accounts as Satellite Accounts

1. Nutrient accounts in physical terms
2. Nutrient accounts in monetary terms

Phase II: Integrated Accounting by New Entries

Main Accounts

1. Integrated Balance Sheet
2. Integrated Income Statement
3. Integrated Farm Budget

Integrated Accounts Structure

The Integrated Balance Sheet

Consistent with the concept of integration by new entries, natural resource accounting elements are introduced into the conventional balance sheet (Table 3). The Integrated Balance Sheet (IBS) provides for new entries into the fixed asset part of the conventional balance sheet. These entries are "change in soil quality" including "nutrient depletion" or "nutrient accumulation", and "net change" also referred to as "nutrient balance".

The introduction of these items shows the extent to which unadjusted farm accounts differ in their measurement of farm business performance, in particular, in their assessment of net capital formation and owner's equity. Owner's equity is an excellent indicator of farm-generated financial progress. In the present hypothetical example, "net fixed assets" and owner's equity are overestimated by US$150 (14.3 percent) in conventional accounting in relation to the situation under integrated environmental and economic accounting. Indeed owner's equity has shrunk over the accounting period.

While soil depletion might have contributed to value added as any productive capital, it must also come to be regarded as capital consumption. Capital consumption needs to be replaced at a cost to sustain the same level of productivity in the future. In fact, nutrient accounts in quantitative terms underline physical depletion as a major feature and indicator of non-sustainable resource use. The accounts in monetary terms introduce the notion of sustainability standards into the concept of integrated accounts, providing a cost and benefit assessment base for ensuring the sustainability of natural capital (allowance for maintenance) already inherent in conventional farm production and income accounting.

Table 3. Balance Sheet for a hypothetical 3 ha farm (US$).

	Conventional	**Integrated**
Current assets		
Cash and bank	250	250
Others	450	450
Total current assets	700	700
Fixed assets		
Buildings and equipment	1,500	1,500
Less depreciation	-450	-450
Change in soil quality		
- Nutrient depletion		-150
- Nutrient accumulation		
- Net change (nutrient balance)		-150
Net fixed assets	1,050	900
Total assets	**1,750**	**1,600**
Total liabilities	600	600
Equity	**1,150**	**1,000**
Total liabilities and equity	**1,750**	**1,600**

The Integrated Income Statement/Farm Budget

The Integrated Income Statement (Table 4) provides for a double entry under the "noncash expenses" part of the Integrated Income Statement. These entries are "nutrient replacement cost" and "allowance for nutrient replacement". The corresponding cost is derived from the information recorded in the IBS. The account shows that the consumption or loss of nutrients must be regarded as a "sustainability cost" to the user. The sustainability cost corresponds to the amount of money actually spent to maintain the soil nutrients at their original level or set aside for doing so at an appropriate time (strong sustainability). For a long time, such natural nutrients were considered as "free" from any economic cost.

Table 4. Integrated Income Statement (hypothetical farm model).

Items	Amount US$
Revenue	
Sale of products	480
Other	120
Total revenue	**600**
Expenses	
Cash expenses	
Fertilizer	70
Seeds	15
Other	40
Total cash expenses	**125**
Income before depreciation	475
Non-cash expenses	
Depreciation allowance	
Buildings and equipment	80
Net income before nutrient replacement	395
Nutrient replacement or allowance for nutrient replacement (sustainability cost)	150
Net adjusted (sustainable) income	**245**

The Integrated Income Statement provides for a "net (adjusted) sustainable income" entry. It can be observed that from the sustainability viewpoint, the net farm income is overestimated by US$150 (about 38 percent) under conventional accounting in comparison to integrated accounting which makes allowance for the contribution of the natural environment. The maintenance of the income at the US$395 level requires that the depleted nutrients be replaced, assuming poor soils. If not, that income will sooner or later shrink to US$245, other things being equal. This amount represents the portion of the net farm income that could be environmentally sustainable under current conditions. For this reason, it is referred to as "Sustainable Income".

Questions and Topics for Discussion or Reflection

- What are the constraints to the development of environmental and integrated environmental and economic accounting?
- What are the specific contributions of integrated economic and environmental accounting?

CONCLUSIONS: POTENTIAL APPLICATIONS

Analysis of outcomes of the calculated physical and monetary accounts may provide a useful insight into technical sustainability, financial sustainability, and nutrient-use efficiency and fertility management. Two types of analyses can be carried out to this effect: analysis of the internal structure of the nutrient accounts (within-nutrient account), and cross analysis of satellite/conventional accounts (cross-account analysis).

Within-Nutrient-Account Analyses

An analysis of the internal structure of the nutrient accounts can be an important step in assessing the strengths and weaknesses of soil nutrient management and, therefore, of soil use and fertility management.

Analysis of Nutrient Balances

Negative balances, which are implicitly recorded as consumption of natural capital (through economic use or loss) imply potential decreases in the short- or long-term productive capacity of the soil. Such balances are signals of a need for remedial or defensive policy and action of one kind or another. Positive balances are implicitly recorded as capital formation/accumulation, suggesting sustainable use. But when associated with high nutrient losses (not taken up by crops) they signal possible over- or unnecessary fertilization and related unnecessary costs, ground water pollution, and inadequate soil management. Such balances are signals of a need and scope for action to improve soil resource use.

Analysis of the Nutrient Inflow and Outflow Structures

Comparing the value of "paid" and "free" nutrients may give an indication of the relative importance of fertilization in the maintenance of soil fertility, i.e. the degree to which the production system is dependent on natural processes. Since natural processes give a fixed contribution per hectare, farmers in natural systems will tend to increase the extent of cultivated areas, to harvest as many of the free nutrients as possible. If the value of mined nutrients is compared with that of the sum of "paid" and "free" nutrients, an impression is obtained of the relative importance of soil mining in the production system.

Cross-account Analyses

Analysis across the accounts coupled with the IBS and Operational Statement Analysis can be carried out based on integrated indicators. These could focus as well on sustainability as on conventional farm management efficiency. The following ratios and indicators can be calculated and analyzed:

The Sustainability Ratio (SR)

The SR is calculated by dividing the “net adjusted income” by the “net income before nutrient substitution”. If, for example, the value of nutrient depletion in a production system would amount to 25 percent of the conventional net income (25 percent of the income can be considered as obtained through soil mining), the sustainability ratio would be 0.75.

Added Value with Respect to Nutrients (AVN)

The AVN is calculated by subtracting the value of all nutrients needed for crop production from the value of the produced crop. This gives an indication of the real added value realized by agricultural production. It may serve as an indicator for the possibility to intensify agricultural production in given circumstances. Since two sources of nutrients (natural inflow and stocktaking) cannot be increased to make yields higher, only "human-induced", "paid" nutrients, can be used for intensifying crop production. Comparing the added value with respect to nutrients with the conventional added value reflects the drop in income when farmers have to intensify their production.

The Natural Resource Contribution Index (NRI)

The NRI is calculated by dividing the value of mined nutrients (US$150) by the sum of purchased fertilizer (US$70) and nutrients provided by nature at no cash expense (US$150). In this hypothetical example, the NRI equals 68 percent. The higher the index, the higher the contribution of nature and risk of unsustainability.

Productivity Foregone and Replacement Cost Ratio (PRR)

The PRR is calculated by dividing the value of production, which would be lost if the replacement of lost nutrients were not undertaken and the cost that would be actually incurred for the replacement. The replacement would be justified if PRR = 1. The assessment entails the use of integrated cost/benefit analysis. This involves, in addition to the use of the replacement cost as provided here, valuation of production foregone through the change-in-productivity method. A ratio smaller than one may represent a hint that maintaining soil fertility is not feasible for farmers. More cost-effective measures for maintaining soil fertility could be a solution (e.g. anti-erosion measures that reduce nutrient losses are always worth consideration as preferable alternatives). Where there are no options, subsidies on soil quality maintenance seem necessary to transfer the avoided social cost of soil degradation to farm households.

Partial Nutrient Balances from Agronomic and Economic Viewpoints: The Case of Corn Cultivation in the Acid Upland Soils of Isabela, the Philippines

Edna Samar[1], Perfecto Evangelista[1], Gavino Urriza, Betty Magno, Pax Blamey[2], and Rod Lefroy[3]

[1]*Bureau of Soil and Water Management, Philippines*
[2]*University of Queensland, Brisbane, Queensland 4072, Australia*
[3]*CIAT, C/-NAFRI, Ban Nongviengkham, Dong Dok, Vientiane, Laos PDR*

ABSTRACT

It is estimated that the acid upland soils in the Philippines cover approximately 12.5 million ha and account for 42 percent of the country's land area. *Inter alia*, these soils are characterized by rapid degradation, toxicities of aluminum and manganese, and deficiencies in a number of elements, with deficiency of phosphorus being a widespread problem. Current efforts to address the nutrient limitations in acid upland soils include the ACIAR Project 9414 which, is a four-year collaborative project entitled 'The Management of Phosphorus for Sustainable Food Crop Production on Acid Upland Soils in Australia, Philippines, and Vietnam'.

The two project sites in the Philippines representative of the acid upland soils are located in Isabela Province in Northern Luzon and Bukidnon Province in Central Mindanao. These soils are extensively cropped to corn (*Zea mays* sp.) with Isabela Province being the leading corn producer in the Philippines. Data sets from the ongoing study in Isabela were utilized to produce partial nutrient budgets as a complementary decision making tool for the selection of 'best option' treatments that will be recommended to farmers, extension workers, and related stakeholders. The partial nutrient balances covered N, P, and K for two crops in six selected treatments. Only the mineral fertilizer, manure, and other organic inputs, and the harvested product and removed crop residues were considered.

The partial N, P, and K balances for corn varied in the two seasons for the different treatments. The results indicate that among the treatments investigated the optimal fertilizer treatment is TSP applied at a rate of 80 kg P_2O_5 ha^{-1}. These results complement the preliminary economic evaluation of yield response. The complementary decision support tool provides strong support for encouraging farmers, extension workers, and related stakeholders to apply the recommended fertilizer rate. It helps in regulating fertilizer usage over time and thus is a tool for precise and sustainable agriculture. From an economic standpoint, the partial nutrient budget is a complementary tool to facilitate partial crop budgeting and a means to evaluate proposed treatments/technologies. The partial nutrient budget provides the technical basis for the farmers to pursue an economic strategy of minimizing capital outlay for fertilizer use and it provides the basis for assessing the economic sustainability of current fertilizer practice.

INTRODUCTION

It is estimated that the acid upland soils of the Philippines cover approximately 12.5 million ha and account for 42 percent of the country's land area. (Evangelista, 1993). These soils are generally infertile and difficult to manage. They are characterized by rapid degradation due to leaching of bases (nutrients); low organic matter content; aluminum (Al) and manganese (Mn) toxicities; and deficiencies of nitrogen (N), phosphorus (P) potassium (K), calcium (Ca), magnesium (Mg), and molybdenum (Mo) (Pushparajah and Bachic, 1985 *In* Evangelista et. al., 1999).

Phosphorus deficiency is the most widespread problem for sustainable food production on acid upland soils. Initial efforts to correct P deficiency in the country were reported by Duque and Samonte (1990), Atienza (1990), and Palis et al., (1997). ACIAR Project 9414 aims to address the nutrient limitations of these areas. This collaborative project on the management of phosphorus for sustainable food crop production on acid upland soils has project sites in Australia, the Philippines, and Vietnam. A multidisciplinary study, this four-year project will end in June 2002 and provide results on the biophysical and socioeconomic evaluation for the various sites. In the Philippines, Isabela (Northern Luzon) and Bukidnon (Central Mindanao) were the representative project sites.

Data sets from the ongoing study in Isabela were utilized to produce partial nutrient budgets as a complementary decision making tool for the selection of 'best option' treatments that will be recommended to farmers, extension workers, and related stakeholders.

BACKGROUND OF THE STUDY

In 1996 Isabela Province was ranked fifth in terms of corn production. By 2000, it had become the leading producer of corn in the country. From 1996-2000 the harvest area for corn expanded from 0.14 to about 0.196 million ha. Prime corn land on the river terraces comprised at least 65,000 ha. Collectively, in 2000 the corn areas contributed almost 71 percent of regional production or 15 percent of the national production. Average yield in the province improved from 2.22 mt ha^{-1} in 1996 to 3.44 mt ha^{-1} in 2000, posting an annual growth rate of 11 percent.

To provide baseline data on P management research, a socioeconomic survey was conducted in October 1997 in 12 barangays (villages) of Ilagan, Isabela covering the 1996 to 1997 cropping period. The study revealed that few changes in the cropping system had occurred over 10 years. The majority of farmers surveyed (86 percent) planted two crops of corn with the remaining 14 percent undertaking a single crop strategy. Only a few farms grew corn in rotation with rice and turnip and in association with rice, mungbean, and vegetables. Table 1 provides some of the economic data generated during the survey. Nutrient application varied widely among farms both in the river and residual terraces. However, there was little difference in the nutrient application by season. On average, on a seasonal basis, farmers applied with 123 kg N, 14 kg P, and 22 kg K ha^{-1}. Farmers did not apply organic fertilizer or lime. Most farmers incorporated corn stover into the soil during land preparation although burning of the stover and use of the stover as feed for livestock was also practiced. Cobs, on the other hand, were mainly sold and used as fuel. However, a number burned the cobs while a minority incorporated them into the soil.

Table 1. Characteristics of corn farms, Ilagan, Isabela, Philippines, 1996–97.

Item	Unit	River terrace			Residual terrace		
		Min	Mean	Max	Min	Mean	Max
		First crop					
n		51			50		
Crop area	ha	0.25	0.95	4.00	0.45	1.200	3.000
Yield	mt ha^{-1}	0.8	3.55	7.04	0.1	3.05	5.63
N	kg ha^{-1}	35	115	200	23	151	318
P	kg ha^{-1}	6	14	20	2	16	24
K	kg ha^{-1}	12	26	39	0	29	46
Fert cost	PhP ha^{-1}	1,460	2,806	4,733	740	3,701	6,600
Other income	PhP yr^{-1}	-	11,394	81,260	-	19,152	185,000
		Second crop					
n		52			51		
Crop area	ha	0.25	0.94	4.00	0.45	1.23	3.00
Yield	mt ha^{-1}	0.38	3.75	9.9	0.11	3.16	7.2
N	kg ha^{-1}	35	116	200	23	154	318
P	kg ha^{-1}	6	14	24	2	17	24
K	kg ha^{-1}	12	26	46	3	30	46
Fert cost	PhP ha^{-1}	1,300	2,894	4,733	740	3,793	6,900
Other income	PhP yr^{-1}	-	11,178	81,260	-	18,777	101,620

Utilization of stover and cobs (percent of total farms)

Item	River terrace		Residual terrace	
	First Crop	Second Crop	First Crop	Second Crop
Stover				
Burned	12	12	19	20
Incorporated into the soil	84	85	81	78
Feed for livestock	4	4	0	2
Total n	51	52	47	50
Cobs				
Burned	16	15	48	47
Incorporated into the soil	8	10	11	10
Used as fuel	34	35	30	33
Sold	36	35	11	10
Mushroom use	6	6	0	0
Total n	50	52	46	51

* Figures may not tally because of rounding.

PhP = Philippine Peso

An inventory of livestock and poultry in Ilagan showed the dominance of backyard husbandry over commercial operations. Animal husbandry, however, was not integrated into the cropping system.

Corn yield averaged 3.83 mt ha^{-1} in the fertile areas associated with river terraces and 2.51 mt ha^{-1} in the less fertile residual terrace areas. On a seasonal basis net crop income from farms in river terraces varied from approximately PhP 8,000 ha^{-1} for share-tenants to almost PhP 10,500 ha^{-1} for owner occupiers. Conversely, on a seasonal basis net crop income from farms on residual terraces varied from PhP 300 ha-1 for share-tenants to almost PhP 2,200 ha^{-1} for owner occupiers.

The results of the study revealed that there is more than twice the yield increase per unit of N application on river terraces as compared to the residual terraces.

The experimental site is located on residual terraces at longitude 121°55'05' and latitude 17°10'12" N at Ilagan, Isabela, Philippines, about 9 km northeast of the town proper and 100 m from the national road.

The surface texture up to about 30 cm is sandy clay loam to clay with a bulk density of 1.58 kg m^{3-1} and total porosity ranging from 40.4 to 50.6 percent. The chemical analysis in Table 2 indicates that the soil is acidic, has low organic matter content, but sufficient Zn and Cu. The soil has a high amount of Fe and excessive amounts of Mn.

Table 2. Chemical analysis of the composite soil sample, Isabela, Philippines, 1996.

Property	**Unit**	**Value**
pH		4.7
Organic matter	%	1.62
Nitrogen	%	0.08
Phosphorus	mg kg^{-1}	0.72
Potassium	cmol kg^{-1}	0.04
Calcium	cmol kg^{-1}	1.43
Magnesium	cmol kg^{-1}	1.1
Zinc	mg kg^{-1}	1.06
Copper	mg kg^{-1}	4.72
Iron	mg kg^{-1}	98.7
Manganese	mg kg^{-1}	145

The ACIAR study completed the omission trial and established five croppings from 1997 to 2000 for 16 treatments each covering 7.5 m^2 in field trials. Within the 16 treatments were three superimposed trials: 1) rate of lime application; 2) calibration of inorganic P application; and 3) inorganic P sources and organic material application and their combination in a 3 x 3 factorial.

Study Coverage and Limitations

Although the agronomic and laboratory results for yellow corn in Isabela cover five croppings, only the two most recent croppings namely, January to May 1999 and August to November 1999 were covered in the partial nutrient budget. Further work may include all the five croppings to show the temporal variations in the partial nutrient balance.

As indicated in Table 2, the laboratory analysis covered major and minor elements, namely, N, P, K, Na, Ca, Mg, Zn, Cu, Fe, and Mn, however, the partial nutrient budget was limited to N, P, and K. The other equally important elements may be considered in understanding the nutrient dynamics in acid upland soils. As stated the ACIAR study covered 16 treatments. However, only selected treatments (Table 3), were included to demonstrate the effectiveness of the partial nutrient budget as a decision support tool.

Table 3. Selected treatments and their details, Isabela, Philippines.

Treatment	Details
T1 Absolute control	Limed to pH 5.5, without NPK
T2 TSP 80	Limed to pH 5.5, 80 kg P_20_5, 100 kg N ha^{-1}, 50 kg K ha^{-1}
T4 Chicken manure (M)	Limed to pH 5.5, 1.6 mt ha^{-1} M, 100 kg N ha^{-1}, 50 kg K ha^{-1}
T5 M + TSP 80	Limed to pH 5.5, 1.6 mt ha^{-1} M, 80 kg P_20_5, 100 kg N ha^{-1}, 50 kg K ha^{-1}
T7 EM	Limed to pH 5.5, 1.6 mt ha^{-1} EM, 100 kg N ha^{-1}, 50 kg K ha^{-1}
T8 EM +TSP 80	Limed to pH 5.5, 1.6 mt ha^{-1} EM, 80 kg P_20_5, 100 kg N ha^{-1}, 50 kg K ha^{-1}
T10 Control	Limed to pH 5.5, 100 kg N ha^{-1}, 50 kg K ha^{-1}
T11 TSP 10	Limed to pH 5.5, 10 kg P_20_5, 100 kg N ha^{-1}, 50 kg K ha^{-1}
T12 TSP 20	Limed to pH 5.5, 20 kg P_20_5, 100 kg N ha^{-1}, 50 kg K ha^{-1}
T13 TSP 40	Limed to pH 5.5, 40 kg P_20_5, 100 kg N ha^{-1}, 50 kg K ha^{-1}
T14 TSP 160	Limed to pH 5.5, 160 kg P_20_5, 100 kg N ha^{-1}, 50 kg K ha^{-1}

EM = Effective Microorganisms, TSP = Triple Super Phosphate

The study recognized the need for accurate measurements of the nutrient contents of the fertilizer inputs, particularly the organic fertilizers, and was limited by one time analysis as follows;

	N (%)	P (mg kg^{-1})	K (cmol kg^{-1})
Chicken manure	6.3	0.67	2.59
Effective microorganisms	1.86	0.66	1.58

Nutrient Budget

Several studies as cited by Konboon et al., (2000) recognize that the nutrient budget can be used as a powerful tool for assessing a critical component of the sustainability of land-use systems. As a decision support tool to multidisciplinary R&D activities, it provides a technical basis for improved management recommendations on fertilizer usage. Winjhoud et al., (2000) provides a conceptual nutrient balance model that includes five nutrient input parameters and five output parameters, as follows:

Inputs:	Outputs:
1. Mineral fertilizers	1. Harvested product
2. Manure and other organic inputs	2. Removed crop residues
3. Deposition by rain and dust	3. Leaching
4. N-fixation	4. Gaseous losses
5. Sedimentation	5. Erosion

Source: Winjhoud et al., (2000)

This study, however, adopted a partial nutrient budget that assessed N,P,K considering the inputs in mineral and organic fertilizers and removal in produce, excluding outputs by leaching, erosion, gaseous losses, and removed crop residues.

RESULTS

Soil Nutrient Stocks

The first soil analysis revealed that initial stocks of NPK were 0.08 % N, 0.17 mg P kg^{-1} and 0.04 cmol K kg^{-1}. The final soil NPK stocks reflect the variability in the soil nutrient stocks over a period of 2.5 years (Figures 1a to 1c and 2a to 2c).

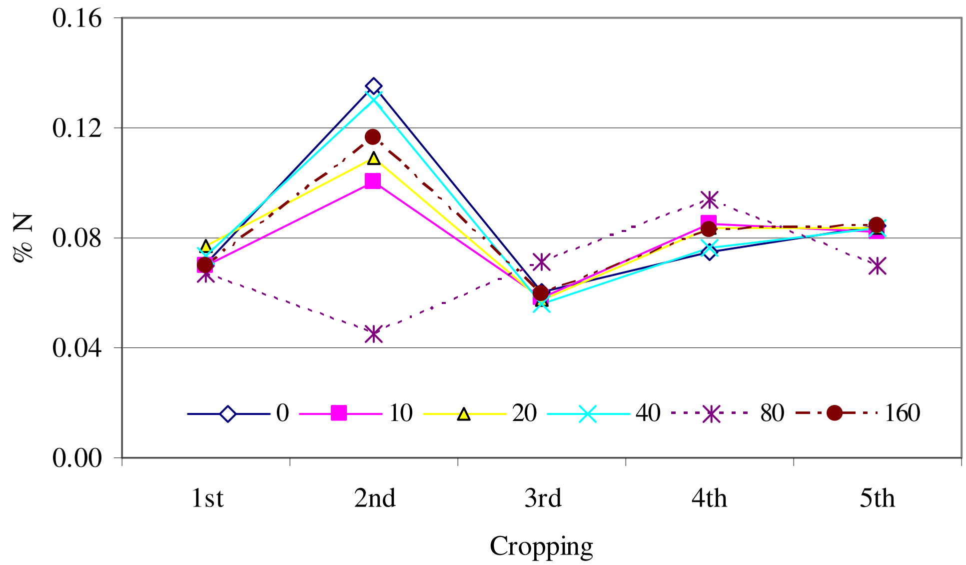


Figure 1a.
Soil N after harvest in corn fields following the application of various rates (kg ha^{-1}) of TSP.

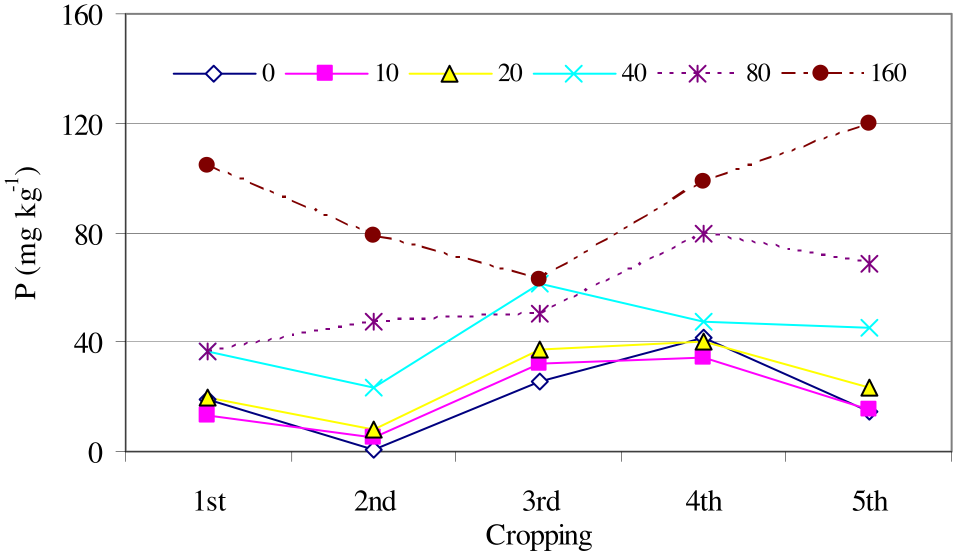


Figure 1b.
Soil P after harvest in corn fields following the application of various rates (kg ha^{-1}) of TSP.

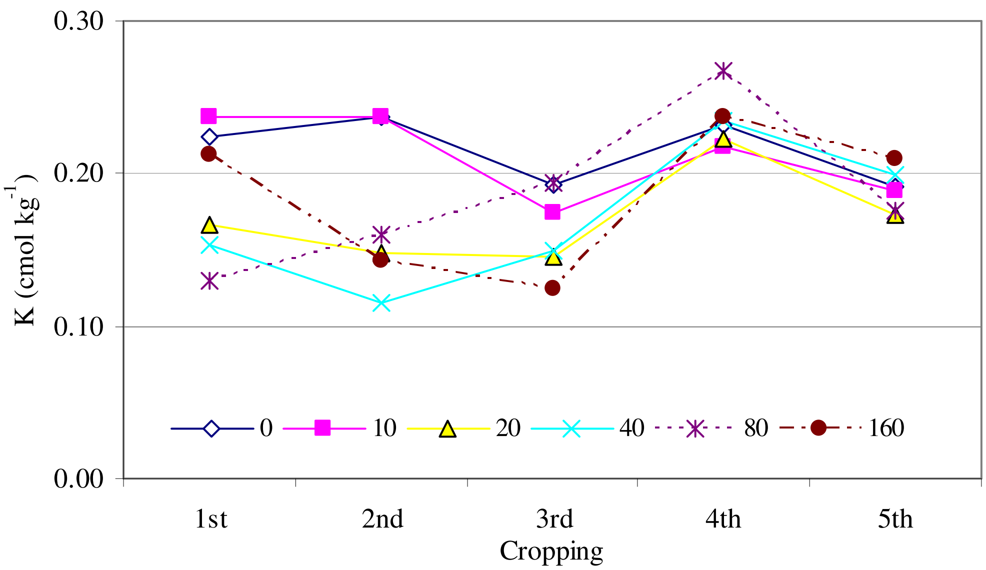


Figure 1c.
Soil K after harvest in corn fields following the application of various rates (kg ha^{-1}) of TSP.

With the application of 100 kg ha^{-1} N from inorganic sources, soil N after the second harvest varied from 0.05 to 0.14 %. In contrast for all other harvests, soil N was similar to the initial soil N (Figure 1a). Combining organic fertilizer with inorganic sources did not show a substantial improvement in the N content of the soil over time (Figure 2a). Without fertilizer, soil N declined by 0.01 to as much as 0.04 % as compared to the initial soil N content indicating the depletion of soil N.

Periodic addition of TSP at increasing rates of application (10, 20, 40, 60, 80 and 160 kg P_2O_5 ha^{-1}) resulted in corresponding increases in soil P content (Figure 1b). Combining organic fertilizer application with the application of TSP at a rate of 80 kg P_2O_5 ha^{-1} showed no marked difference in soil P as compared with to TSP alone (Figure 2b). Without TSP application, soil P content also improved, to values similar to the initial pre-treatment value which corresponds to an application rate of 20 kg P_2O_5 ha^{-1}. Further research is required in order to fully understand P dynamics over time.

With the blanket application of 50 kg K ha^{-1}, the soil available K content in all treatments improved as compared to the initial pre-treatment value (Figures 1c and 2c).

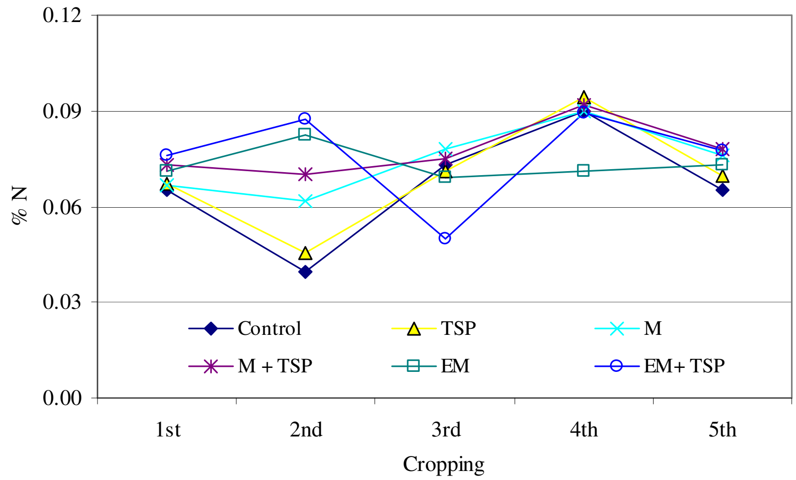


Figure 2a. Soil N after harvest in corn fields following the combined application of organic and inorganic fertilizers. Where M = Chicken Manure, EM = Effective Micro-organisms, TSP = Triple Super Phosphate

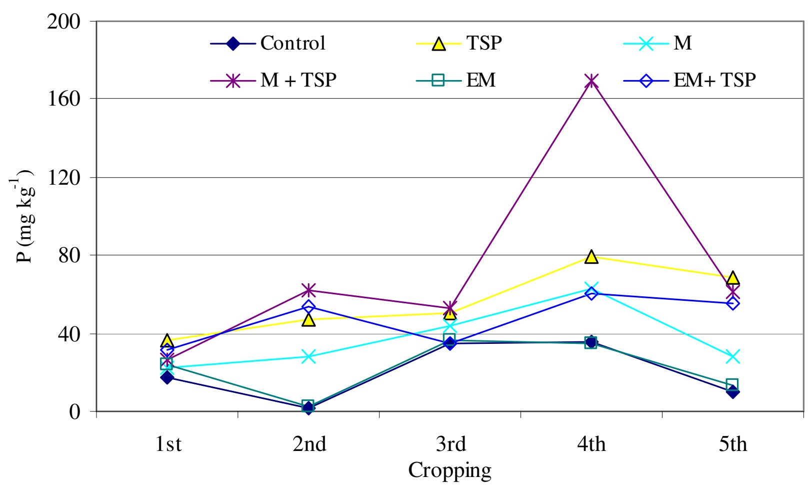


Figure 2b. Soil P after harvest in corn fields following the combined application of organic and inorganic fertilizers. Where M = Chicken Manure, EM = Effective Micro-organisms, TSP = Triple Super Phosphate

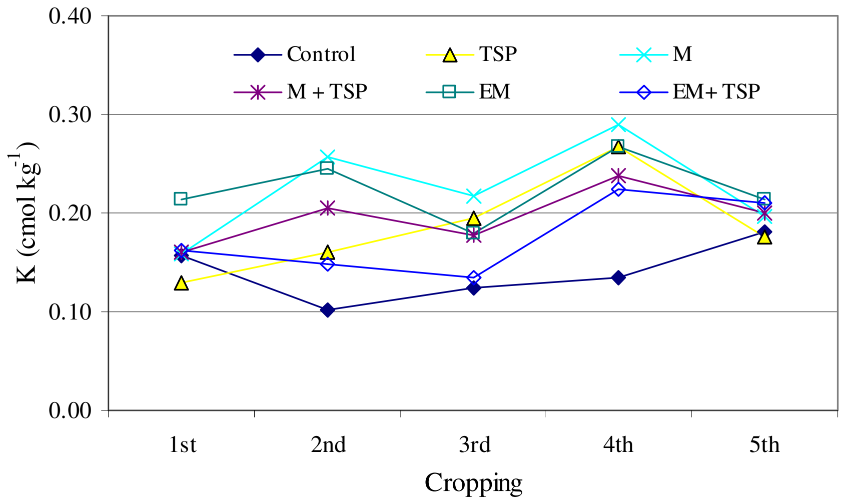


Figure 2c. Soil P after harvest in corn fields following the combined application of organic and inorganic fertilizers. Where M = Chicken Manure, EM = Effective Micro-organisms, TSP = Triple Super Phosphate

Partial Nutrient Balance

Table 4 presents the partial nutrient budget for corn to which both organic and inorganic fertilizers have been applied. The results illustrate the nutrient uptake of the crop relative to the amount of fertilizer applied. Clearly, there was considerable variability in nutrient uptake during the two croppings. In both croppings, P was deposited mainly in the grains while K was mainly absorbed in the stems and leaves. Conversely, N uptake showed no distinct pattern in the two seasons although N content occurred mainly in grains rather than stems and leaves during the dry season (January–May 1999) as compared with the wet season (August–November 1999).

The nutrient budget compares the nutrient balance for different treatments including the combined application of inorganic or organic fertilizers. A positive partial balance denotes that the plant was not able to consume all that was applied during the period. On the other hand, a negative partial balance suggests that the crop uptake exceeded the fertilizer application. The deficit is thus derived from the soil nutrient stock. The partial balance for NPK, depicted in Figures 3a to 3c, showed the temporal variability of these nutrient balances.

Table 4. Partial nutrient budget for corn following the application of the organic and inorganic fertilizer treatments evaluated.

	Jan - May 1999						**Aug - Nov 1999**					
	N (kg ha^{-1})						***N (kg ha^{-1})***					
Item	Control	TSP	Chicken Manure (M)	M + TSP	EM	EM+ TSP	Control	TSP	Chicken Manure (M)	M + TSP	EM	EM+ TSP
Addition												
Organic	0	0	101	101	30	30	0	0	101	101	30	30
Inorganic	0	100	100	100	100	100	0	100	100	100	100	100
Total	0	100	201	201	130	130	0	100	201	201	130	130
Removal												
Grain	28	36	23	72	37	38	19	66	60	49	46	60
Stem & leaves	8	27	23	28	27	36	28	55	69	53	58	57
Cobs & husks	6		6	13	3	4	2	10	10	8	12	18
Total	42	63	52	113	67	78	49	131	139	110	116	135
Partial balance	-42	37	149	88	63	52	-49	-31	62	91	14	-5
	P (kg ha^{-1})						***P (kg ha^{-1})***					
Item	Control	TSP	Chicken Manure (M)	M + TSP	EM	EM+ TSP	Control	TSP	Chicken Manure (M)	M + TSP	EM	EM+ TSP
Addition												
Organic	0	0	11	11	11	11	0	0	11	11	11	11
Inorganic	0	35	0	35	0	35	0	35	0	35	0	35
Total	0	35	11	46	11	46	0	35	11	46	11	46
Removal												
Grain	7	20	15	23	10	17	5	18	15	11	12	15
Stem & leaves	1	4	3	4	3	3	3	4	3	3	3	4
Cobs & husks	2	4	2	5	2	4	0	1	1	1	1	1
Total	10	28	20	32	15	24	8	23	19	15	16	20
Partial balance	-10	7	-9	14	-4	22	-8	12	-8	31	-5	26
	K (kg ha^{-1})						***K (kg ha^{-1})***					
Item	Control	TSP	Chicken Manure (M)	M + TSP	EM	EM+ TSP	Control	TSP	Chicken Manure (M)	M + TSP	EM	EM+ TSP
Addition												
Organic	0	0	41	41	25	25	0	0	41	41	25	25
Inorganic	0	50	50	50	50	50	0	50	50	50	50	50
Total	0	50	91	91	75	75	0	50	91	91	75	75
Removal												
Grain	18	30	26	36	23	29	3	13	12	10	7	12
Stem & leaves	21	64	76	79	32	12	8	18	37	11	29	18
Cobs & husks	8	10	8	11	7	10	3	12	13	8	9	13
Total	47	104	110	126	62	51	14	43	62	29	45	43
Partial balance	-47	-54	-19	-35	13	24	-14	7	29	62	30	32

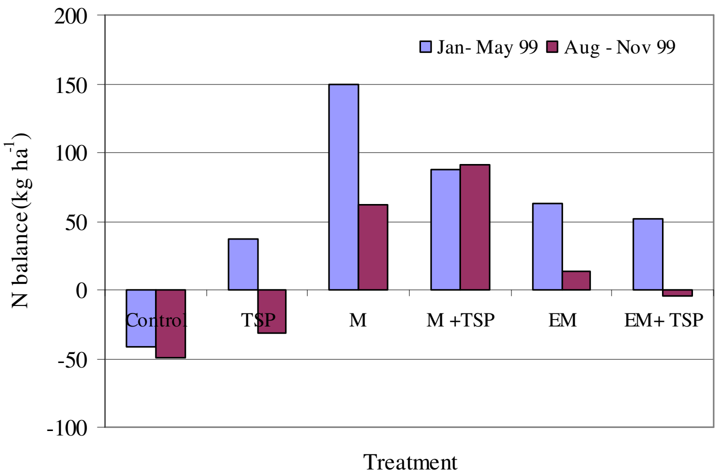


Figure 3a. Partial N balance for the organic and inorganic fertilizer treatments evaluated.

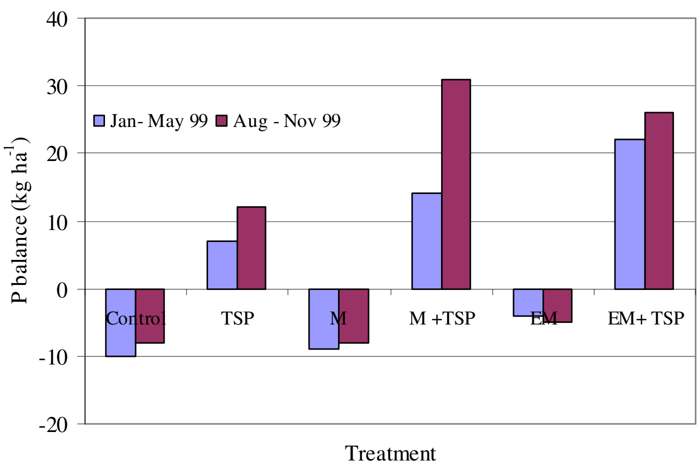


Figure 3b. Partial P balance for the organic and inorganic fertilizer treatments evaluated.

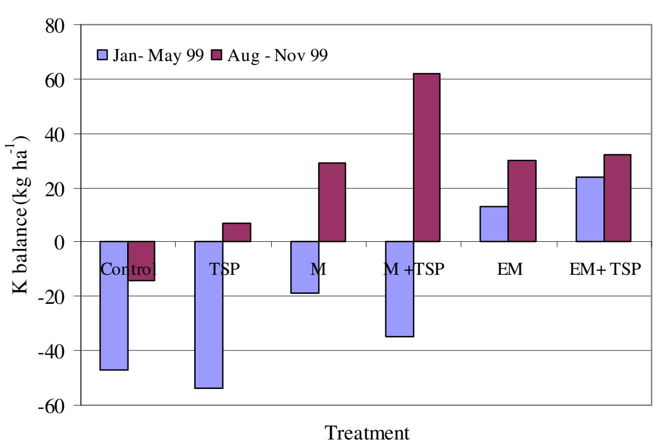


Figure 3c. Partial K balance for the organic and inorganic fertilizer treatments evaluated.

Without fertilizer application, the amount of nutrients removed from the soil was at least 42 kg N ha^{-1}, 8 kg P ha^{-1}, and 14 kg K ha^{-1}. The data for the two cropping seasons showed that applying 100 kg N ha^{-1} and 50 kg K ha^{-1} from inorganic sources may or may not be enough to supply the N and K requirements of corn and therefore may result in a negative partial nutrient balance. Combining organic fertilizer with inorganic fertilizer resulted in substantial increases in the partial N balance. Consequently, one needs to reconsider whether further application is necessary to supply the N demands of the next crop. In the case of K, the combined use of these two sources resulted in either a positive or negative partial K balance.

With 80 kg P_2O_5 ha^{-1} from an inorganic source (TSP), a positive partial P balance resulted, thus indicating that the available P content of the soil had improved. Applying organic fertilizer (Chicken Manure) or Effective Microorganisms at a rate of 1.6 mt ha^{-1} resulted in a negative P balance. However, the combined use of these organic and inorganic fertilizers increased the partial P balance.

Agronomic Perspective

As a decision support tool, the partial nutrient budget provides a basis for selecting and advocating the appropriate treatment/technology. It provides the initial basis for deciding the amount of fertilizer usage for location-specific fertilizer application. The partial nutrient balance shown in Table 4 provides the basis for assessing the sustainability of the farmers' practice presented in Table 1. It encourages farmers, extension workers, and related stakeholders to apply fertilizers whilst considering that a negative nutrient balance may result in excess nutrient removal and 'soil mining'.

The most suitable partial nutrient balance is a neutral or marginally positive balance.. This indicates that the nutrients applied meet the crop requirements. Thus, in deciding which of the six treatments would be appropriate for P-deficient soils, particularly the acid upland soils investigated, TSP at an application rate of 80 kg P_2O_5 ha^{-1} is the optimal option when considering the sustainability of meeting crop P requirement. An alternative option would be the combined use of organic and inorganic sources rather than organic fertilizer alone. Considering the high partial N balance resulting from the combined use of organic and inorganic fertilizer, the rate of organic fertilizer to be applied in the next cropping has to be adjusted. In selecting 80 kg P_2O_5 ha^{-1} from TSP, the N and K application might have to be adjusted accordingly. In essence, the partial nutrient balance is a tool for precision and sustainable agriculture.

Economic Perspective

The partial nutrient budget and the partial crop budgeting are complementary tools to evaluate and decide on proposed treatments/technologies. It provides the basis for assessing the economic sustainability of proposed treatments. The economic evaluation for this study is based on the partial crop budget and the marginal analysis. The results indicate that a TSP application of 80 kg P_2O_5 ha^{-1} is the 'economically' optimal rate. The economic analysis revealed that it is unprofitable to apply organic fertilizer *per se* or combined with inorganic fertilizers. Utilizing the partial nutrient budget, allows the addition of subsequent nutrients to be regulated at a level at which the soil nutrients can be sustainably managed. Corresponding economic evaluation can immediately be undertaken to evaluate the affordability of the proposed technology. The partial nutrient budget clearly provides a technical basis for the farmers to pursue an economic strategy of minimizing capital outlay for fertilizer use.

For the TSP treatment at a rate of 80 kg P_2O_5 ha^{-1} given the partial nutrient budget, the equivalent savings from returning all the stems, leaves, cobs, and husks to the field would be as follows;

Equivalent nutrient supply (kg ha^{-1})		**Equivalent savings: (PhP ha^{-1})**
♦ 65 N	- 50% of N uptake	962
♦ 5 P	- 22% of P uptake	303
♦ 30 K	- 70% of K uptake	456
	Total	1,721*

PhP = Philippine Peso *Equivalent to 44% of total nutrient cost

Future Work

The partial nutrient budget, however, has its limitations and thus should be pursued further to come up with a comprehensive nutrient account. Using the partial nutrient budget as a basis, a simplified nutrient account for available P and K is presented to further illustrate the nutrient flows from the soil to the plants, considering fertility intervention and natural processes.

Table 5 confirms that the negative partial balance is not necessarily detrimental to the crop. Additional work has to be done to fully account for nutrient flows particularly the other processes not captured in the partial nutrient budget. The current effort focused on NPK. Further studies should include other essential nutrients. A follow-up activity would be to determine the partial nutrient balance of the farms covered by the economic survey.

Table 5. Nutrient account for corn applied with organic and inorganic fertilizers, Isabela, Philippines.

Item	Jan - May 99						Aug - Nov 99					
	N (kg ha⁻¹)						*N (kg ha⁻¹)*					
	Control	TSP	Chicken Manure (M)	M +TSP	Compost (C)	C+ TSP	Control	TSP	Chicken Manure (M)	M +TSP	Compost (C)	C+ TSP
Pre-treatment	1,659	1,659	1,896	1,659	1,659	(474)	2,133	2,133	2,133	2,133	1,659	2,133
Addition	0	100	201	201	130	130	0	100	201	201	130	130
Organic	0	0	101	101	30	30	0	0	101	101	30	30
Inorganic	0	100	100	100	100	100	0	100	100	100	100	100
Removal	42	63	46	100	64	74	49	131	139	110	116	135
Grain	28	36	23	72	37	38	19	66	60	49	46	60
Stem & leaves	8	27	23	28	27	36	28	55	69	53	58	57
Cobs & husk	6	0	6	13	3	4	2	10	10	8	12	18
Adjustment	516	437	82	373	(66)	2,551	-662	-443	-299	-328	-14	5
Ending	2,133	2,133	2,133	2,133	1,659	2,133	1,422	1,659	1,896	1,896	1,659	2,133
	P (kg ha⁻¹)						*P (kg ha⁻¹)*					
Pre-treatment	82	119	104	126	86	82	84	231	149	401	82	143
Addition	0	35	11	46	11	46	0	35	11	46	11	46
Organic	0	0	11	11	11	11	0	0	11	11	11	11
Inorganic	0	35	0	35	0	35	0	35	0	35	0	35
Removal	10	28	20	32	15	24	8	23	19	15	16	20
Grain	7	20	15	23	10	17	5	18	15	11	12	15
Stem & leaves	1	4	3	4	3	3	3	4	3	3	3	4
Cobs & husks	2	4	2	5	2	4	0	1	1	1	1	1
Adjustment	13	105	53	261	0	39	-53	-80	-74	-286	-45	-38
Ending	84	231	149	401	82	143	24	164	67	145	32	131
	K (kg ha⁻¹)						*K (kg ha⁻¹)*					
Pre-treatment	111	176	204	167	167	120	130	250	269	222	250	213
Addition	0	50	91	91	75	75	0	50	91	91	75	75
Organic	0	0	41	41	25	25	0	0	41	41	25	25
Inorganic	0	50	50	50	50	50	0	50	50	50	50	50
Removal	47	104	110	126	62	51	14	43	62	29	45	43
Grain	18	30	26	36	23	29	3	13	12	10	7	12
Stem & leaves	21	64	76	79	32	12	8	18	37	11	29	18
Cobs & husks	8	10	8	11	7	10	3	12	13	8	9	13
Adjustment	66	128	84	91	70	69	51	-90	-112	-99	-86	-51
Ending	130	250	269	222	250	213	167	167	185	185	195	195

CONCLUSION

The partial nutrient balance is a decision tool for researchers as well as for farmers, extension workers, and other stakeholders. In the case of the acid uplands of Isabela, the partial nutrient budget provided further complementary support to the earlier economic evaluation that the optimal rate of P application (TSP) is 80 kg P_2O_5 ha^{-1}.

While the partial nutrient budget showed that the combined use of organic and inorganic fertilizer is an alternative option, the economic analysis does not confirm its viability. A full nutrient budget would entail much work but nonetheless be useful to explain further nutrient flows and ultimately nutrient accounting not only of NPK but also for essential and possibly limiting trace elements.

REFERENCES

Atienza, R.N. 1990. Research status on the management and utilization of acid soils in the Philippines. In *Report of the workshop on management and utilization of acid soils.* Laguna: University of the Philippines at Los Baños.

Duque, C.M.; and Samonte, H.P. 1990. Influence of silicate and sulfate on phosphorous solution and yield of corn,.*The Philippines,* 73: 35–46.

Evangelista, P.P.; Urriza, G.I.P; Magno, B.; Samar, E.; Tumamao, D.B.; Crisologo, V.S.; and Ladanga, J. Various dates. Annual report on the management of phosphorous for sustainable food crop production on acid ppland soils in the Philippines.

Palis, M.J.; Grospe, C.C.; Yambot, A.O.; Rubite, L.T.; and Rojales, J.S. 1997. *Lime, phosphorous and micronutrient applications for increased legume production in acid upland soils.* Soils and Fertilizer Research, Bureau of Soils and Water Management, Quezon City, Philippines. pp 28–30.

Winjhoud, J.D.; Konboon, Y.; and Lefroy, R.D.B. 2000. Towards greater sustainability in rainfed lowland rice-based farming systems in Northeast Thailand by assessment of nutrient budgets. In *Proceedings of the international conference on paddy soil fertility (Makati City, Philippines, 24–27 April, 2000).*

Regional Integrated Plant Nutrition Development System (IPNS) Development Program

[1]Peter Hegenbarth

[1]*FADINAP / ESCAP, Bangkok, Thailand*

ABSTRACT

The Fertilizer Advisory Development and Information Network for Asia and the Pacific(FADINAP) is implementing a program entitled Integrated Plant Nutrition Systems (IPNS) in five countries in Asia namely, Pakistan, the Philippines, Nepal, Sri Lanka, and Vietnam. The central theme is to train farmers in combining chemical and organic fertilizer inputs to optimize crop nutrient supply. The program is based on the fact that after more than 20 years of green revolution agriculture, increasing environmental damage has become apparent, which implies that current production patterns are unsustainable. It is envisaged that training farmers to re-integrate organic practices will help to achieve sustainable production and increase rural income.

ORGANIZATIONAL SETTING

FADINAP is a program implemented by the United Nations Economic and Social Commission for Asia and the Pacific (UNESCAP). The work of UNESCAP is carried out through seven substantive divisions, which includes the Population Rural and Urban Development Division (PRUDD).

PRUDD has several sections and FADINAP is located in the Rural Development Section (RDS) where it contributes to sustainable rural development and poverty alleviation by:
Building and improving rural institutions;
- Generating non-agricultural income; and
- Conducting economic analysis and improvement of farming inputs (e.g. fertilizers and pesticides).

Ongoing activities with regard to agrochemicals include:
- Fertilizers: FADINAP;
- Pesticides: Database on Pesticides and the Environment (DPE); and
- IPM: Economic aspects of Integrated Pest Management (IPM).

FADINAP's Focus

FADINAP was started in 1978 as a program to support the green revolution by promoting the use of chemical fertilizers (via research, information, training). Subsequently, it has built a network of 27 member countries in the Asia–Pacific region. The network's focus has shifted over the years and, at present is concentrating on using the income-generating capacity of fertilizers—chemical and organic—to reduce rural poverty and environmental degradation. Currently, FADINAP is concentrating on:
- The promotion of IPNS;
- Collection, analysis, and distribution of agrochemical data though its web site;
- Publication of *Agro-Chemicals News in Brief* (a quarterly journal) for distribution in the region.

IPNS Program

FADINAP, under the sub-component "Development of environmentally sound use of fertilizer", is implementing a program to develop IPNS. Five countries are participating namely, Pakistan, the Philippines, Nepal, Sri Lanka, and Vietnam.

Reasons for and Aim of IPNS

By 2030 the world population is anticipated to have grown by 40 percent to 8.4 billion. No major expansions are expected in cultivatable land area, rather, what can be anticipated are reductions due to erosion. Therefore, increased food supply will have to come from intensification. However, despite growing fertilizer use, yields are stagnating or in some intensively cultivated areas, declining. There are some indications for a second green revolution, e.g. through genetically modified (GM) seeds, but this may still be a number of years in the future, considering the environmental effects they may generate. Therefore, efforts have to start immediately to stabilize agricultural production and to protect the environment against further degradation. Some of the methods may not be new, but have to be reviewed, adjusted, and integrated into modern agriculture for higher fertilizer use efficiency.

Therefore, the aim of FADINAP's IPNS program is to assist member countries in rendering sustainable agricultural production patterns through the stabilization of soil fertility and raising of rural income. This can be achieved by combining the high nutrient concentration of chemical fertilizers with the incorporation of organic matter, i.e. compost, green manure, farmyard manure etc., to improve soil structure and control erosion.

IPNS Structure

After introducing a general framework for what IPNS should cover, FADINAP did not give detailed instructions for implementing the program. As a general guideline, three stages or phases were suggested:

Phase 1 should contain a survey of prevailing farming methods on typical crops and regions and, a study of the state of research and implementation of IPNS, if any. This phase should conclude with a national workshop where the findings of the farming survey and literature and policy study are presented and a national IPNS concept is discussed and adopted, i.e. specifying crops and agroclimatic regions for IPNS trials.

- *Phase 2* should concentrate on the implementation of the IPNS concept in limited trials and small demonstrations, the training of participating farmers, verification to confirm whether the original choices of crops and locations were correct, and the design of extension/training materials.

- During *Phase 3* successful IPNS cases, recommended in Phase 1 and confirmed through field trials in Phase 2, should be propagated at larger scales to groups of farmers through demonstration and training using the extension/training materials prepared in Phase 2.

Implementation

The participating countries followed this general guideline to varying degrees. For instance, in Nepal it was felt that the preparation and use of compost was an important component of an emerging IPNS concept. Therefore, Phase 2 of the program was devoted to trials and comparisons between different methods of compost preparation. Nepal is now making preparations to enter Phase 3, i.e. demonstrations and training of farmers. In Vietnam where combinations of organic and inorganic fertilization practices have remained intact even through periods of rapid expansion of chemical fertilizer use, trials, demonstration and training concentrated more on fine-tuning of and interaction between the different types of fertilization. Vietnam has concluded Phase 2 and is currently entering Phase 3 with a planned series of 12 training courses in different districts. In Sri Lanka the lack of linkages between organic and inorganic plant nutrition was felt most strongly and the need to change this resulted in the development of detailed IPNS concepts for crops and regions. Sri Lanka is presently in the final stages of Phase 2, concluding the development of training material, which will then be used in demonstrations and training of large farmers' groups. The Philippines is expected to conclude Phase 1 soon with the adoption of an IPNS concept and may then proceed, in a similar fashion to Nepal, to intensify training on compost preparation. Pakistan joined the program recently, starting with a field survey of current farming practices and the preparation and testing of IPNS training materials.

Potential for Future IPNS Development

IPNS or IPNM (Integrated Plant Nutrition Management) is by no means a new concept. It rather tries to re-integrate organic forms of plant nutrition into what have become "modern" farming practices. After 30 years of the green revolution this is not a simple task. Techniques for soil fertility maintenance, used by earlier generations, have been forgotten, are considered cumbersome, or have become technically impossible. For instance, in many places farm animals have given way to machinery, and consequently the manure they produced is unavailable. Therefore, the role of the nation-wide farming surveys, as the first phase of the IPNS program, is to detect what is still feasible and practical on farms in terms of organic fertilization.

FADINAP's interest, however, is not primarily technical and the program is not meant to preserve or re-introduce organic practices for their own good. Organic methods are aimed at supplementing inorganic fertilizers, not replacing them, and they should not be promoted only because of their effects on the environment and sustainability of agricultural production. Supplementary organic methods, apart from long-term gains in environmental balances and the sustainability of production, should also offer demonstrable income advantages. For instance, in Nepal, farmers involved in a series of IPNS trials during Phase 2, applying scientifically improved methods of compost preparation and application, succeeded in doubling their production of cabbage. Although final data have not been submitted yet, this should have had a marked income effect, especially for female farmers, who are involved mainly in vegetable cultivation. Similar situations are emerging in Sri Lanka.

Although, FADINAP's program is small and limited to only a few countries, it is hoped that it will promote a review of plant nutrition and rural income generation concepts. FADINAP's resources to support the program have been depleted this year, but it is hoped that the principles of IPNS will be adopted by other agencies, national and international, farmers' groups and put into practice on an increasing scale.

In order to keep the momentum and encourage regional cooperation in IPNS, the current participants and other interested countries will be invited to exchange their experiences with IPNS at a regional meeting in Bangkok, later this year.

FADINAP Spearheads Fertilizer Information Networking on the Web

Edgar Dante[1]

[1] Consultant on Fertilizer Market Information, FADINAP, Population and Rural and Urban Development Division, United Nations, ESCAP, Bangkok

ABSTRACT

FADINAP's web site at www.fadinap.org is the most frequently visited agrochemicals' web site in the region, providing access to its huge agrochemicals' bibliographic database, directory of fertilizer-related information sources, statistical data and many other information resources accumulated over a period of 20 years. The Internet has dramatically transformed FADINAP's ability to disseminate information and has widened its outreach to the fertilizer industry worldwide in times when available resources are very limited

INTRODUCTION

For the past two decades, the Fertilizer Advisory Development and Information Network for Asia and the Pacific (FADINAP) has served as a focal point for regional information exchange on fertilizers and agrochemicals among 28 member countries. Developing a regional information system was the central issue. Information provided through FADINAP has helped to:

- Make the right choices when purchasing fertilizer for the domestic market;
- Analyzed the strengths and weaknesses of the domestic fertilizer sector, e.g., when comparing production costs and prices between countries;
- Found solutions for improving fertilizer marketing systems; and
- Drawn attention when imbalanced fertilizer use damages the environment, reduces crop yields and decreases farmers' earnings.

Formerly, information produced by FADINAP was circulated in printed form, as country profiles, directories, and special reports (e.g. on fertilizer market liberalization and legislative reforms). When time was a major issue, e.g. for price and trade information, FADINAP's data were circulated by fax, the fastest form of information transmission until a few years ago.

However, with shrinking staff and funds some difficult choices had to be made, resulting in a reduced number and selection of publications and orientation towards electronic data exchange through the Internet. FADINAP became aware of the power of the Internet in 1997. Although FADINAP was reasonably well equipped for electronic data processing, most member countries were not. Moreover, our publications had gained recognition over the years as reliable sources of fertilizer information for Asia and the Pacific and it was difficult to discontinue them. Nevertheless, it was perceived that the Internet was cutting edge technology and training was the first step for us and our partners to exploit it effectively.

This paper shares our experiences in integrating electronic networking into FADINAP's regional information system to sustain, or even expand, its services despite reduced staff and funds.

.

THE INTERNET TRANSFORMS FADINAP'S FERTILIZER INFORMATION SERVICES

FADINAP established its website on an experimental basis in 1997. The website served to advertize FADINAP's information services and to provide member countries with updated information. A year later, the rapid development in Internet technology encouraged FADINAP to expand its web-based services and to seriously transform the way it collects and disseminates fertilizer information.

Figure 1. FADINAP Web site at www.fadinap.org

The launching of FADINAP's online agrochemicals' bibliographic database in 1998 marked the beginning of this transformation. The bibliographic database was developed in 1978 at a time when information on agrochemicals was fragmented or nonexistent. At present, FADINAP's database contains over 9,000 citations of published and non-published literature on agrochemicals, with abstracts. Many of these documents, e.g. unpublished country reports presented at various FADINAP-sponsored regional and national meetings, are not available elsewhere. The central database is located in FADINAP's library. A search of the database can be undertaken either by visiting FADINAP's library or consulting the Regional Information Support Service (RISS), a monthly bibliographic abstract journal, produced by FADINAP and made available to a wide target audience.

The demand for the services offered in the abstract journal was high, but with the withdrawal of donor support, FADINAP was forced to seek other alternatives. With the Internet, the development of an online bibliographic database appeared to be the answer. Practically anyone who has an Internet connection can now consult and perform a literature search, 24 hours a day. Hard copies of literature are available upon request for a small fee to cover photocopying and mailing charges.

It became obvious to FADINAP that the Internet offers many possibilities to further improve its information services with minimum cost. Consequently, in 1997 FADINAP embarked on another major project – the launching of the Database on Pesticides and the Environment on the web. Developed through collaboration with ESCAP, the EU and 10 Asian countries from 1992 to 1996, the database contains much technical information pertaining to the agronomic use and adverse effects of pesticides on human and animal health, as well as the environment. The database was distributed on diskettes to cooperating agencies and others who had requested copies. With the web version, the Database on Pesticides and the Environment is now accessible worldwide.

More recently, FADINAP has launched an online Fertilizer Directory and Fertilizer Trade Bulletin Board. The Fertilizer Directory was first published as the Directory of Sources of Fertilizer-related Information with Special Reference to Asia and the Pacific in 1986. The Fertilizer Directory was subsequently revised in 1991, and again in 1995. The publication became a very important reference tool. Governments and FADINAP Technical Liaison Offices were given free copies. The directory holds about 1,800 addresses of producers, traders, government agencies and other institutions involved in the fertilizer sector from about 100 countries worldwide.

The on-line version of the directory allows users to add, update or modify their profiles. It also allows searching by country, product, and type of business. The information provided is a valuable source for both traders and producers. This facility has attracted attention from fertilizer industries worldwide and captured the headlines of the *Fertilizers and Agriculture*, May 2000 newsletter, published by the International Fertilizer Industry Association (IFIA). The Fertilizer Trade Bulletin Board provides a venue to advertize products and services. This facility has greatly assisted FADINAP in satisfying many requests from member countries to advertize their fertilizer tenders and bids.

FADINAP Assists Member Countries to Use the Internet

Parallel to the development of its website, FADINAP conducted a series of Internet training courses in seven member countries namely, India, Indonesia, Nepal, Pakistan, the Philippines, Sri Lanka and Vietnam. The training program consisted of two parts: a one-day Internet orientation session and a three-day website development course. The former served to demonstrate the power of Internet technology to boost efficiency and effectiveness in communication and information management, and to indicate the extent of fertilizer information resources available on the Internet. The orientation session targeted management and technical staff of government and private fertilizer organizations and aimed at increasing their awareness and appreciation of the Internet. Participation ranged from 10 to 35 people in each country, representing senior officials from the Ministry of Agriculture, heads of fertilizer regulatory authorities, fertilizer producers and traders and information officers. A total of 145 people in the seven participating countries benefited from the orientation session.

The majority of those participating appeared to have no background in the Internet, some had used e-mail only, and a few had never used computers before. So it was a real challenge for FADINAP to share its expertise in this area and to assist participants in becoming efficient and effective users of the Internet. It was an even bigger challenge to encourage them to become providers of information on the Internet through the development of national websites.

The second part of the training addressed this more challenging task—a three-day course on website development. This course was restricted to those who were given direct responsibility for the website. The training program resulted in the creation of national web sites, which are linked to the FADINAP website thereby establishing a one-stop information site on the fertilizer sector in Asia and the Pacific. These websites offer numerous benefits to the whole information network. For member countries, it is inexpensive and provides rapid access to FADINAP's online databases, statistical data, and other related information, and to establish contact with numerous organizations worldwide. Through the web, FADINAP has been able to expand its outreach to target clients considerably.

CONCLUSION

The Internet has provided FADINAP's information service with renewed strength in times when available resources are very limited. It has transformed FADINAP's ability to disseminate information and has widened its outreach to the fertilizer industry worldwide, moving from a limited readership to include agricultural/planning ministries in the region, the fertilizer industry, international organizations, universities, and research and development centers. Furthermore, the Internet has empowered FADINAP's member countries to become involved in the supply and dissemination of information by setting up their respective national web sites. Thus, in a limited way, FADINAP has bridged the 'digital divide'. However, as much as we are determined "to go Internet", the advent of the electronic age does not mean abandoning our printed or other forms of publications entirely, as they are still of great use to our members.

Summary Report on Outcomes of Working Group Discussions

Complied by J.D. Wijnhoud[1] and Rod Lefroy[2]

[1]*Netherlands Development Organization (SNV), PO Box 4468, Maputo, Mozambique,* *famwijnhoud@hotmail.com*
[2]*CIAT, C/-NAFRI, Ban Nongviengkham, Dong Dok, Vientiane, Laos PDR,* r.lefroy@cgiar.org

Working Group I: Some items of dispute and/or difficult factors in nutrient balance models and NBA

Nutrient balance studies (NBS) that implicitly or explicitly claim to deal with assessment of full nutrient balances, meaning that they consider all in- and output factors, often appear to lack some of the input or output factors. Further, it may be the case that inclusion of input or output factors may at times be unjustified, incorrectly or doubtful and a matter of discussion.

In general, most nutrient balance studies concentrate on or include one or more of the most relevant *macro-nutrients* for vegetative growth namely Nitrogen (N), Phosphorous (P) and Potassium (K) where N, P and K refer to the nutrients in their pure elemental form.

Stoorvogel and Smaling, (1990) were first to quantify nutrient depletion at a broad scale. Their often cited conceptual "black box" nutrient balance model has proved to be relevant for agronomic and environmental management, as has been utilized to increase awareness and lobby for policy development/revisions. A full nutrient balance in case of a "block-box" complete balance model merely accounts for the net nutrient in- or outflow for a certain system. However, efforts to look inside the box, and undertake studies regarding nutrient pools and nutrient availability may have much more value in terms of practical application. Stoorvogel and Smaling, (1990) assessed the N, P and K balances for roughly defined Land-Use Systems at the national and sub-continental levels in sub-Saharan Africa. They used the following conceptual nutrient balance model, which includes five nutrient input components and five output components:

(1) NB = (IN1+IN2+IN3+IN4+IN5) – (OUT1+OUT2+OUT3+OUT4+OUT5)

Inputs:	Outputs:
1: Mineral fertilizers	1: Harvested product
2: Manure and other organic inputs	2: Removed crop residues
3: Deposition by rain and dust	3: Leaching
4: N-fixation	4: Gaseous losses
5: Sedimentation	5: Erosion

It is suggested that the Stoorvogel and Smaling model may include the most relevant in- and output factors when undertaking reconnaissance studies at large spatial scales. Even if some of the above input or output components are omitted Partial Nutrient Balance Analyses (PNBA) based on the relatively accurate, rapid, and simple assessment of partial nutrient budgets can be of great value if due consideration is given to the plausible magnitude of the (full) balance factors that are not included. However, a more complete set of in and output factors than that used by Stoorvogel and Smaling, (1990) may be required in order to accurately quantify full nutrient balances. The input and output factors of such "Full" Nutrient Balance Analyses (FNBA), are in part sub-divisions of general factors used in the model proposed by Stoorvogel and Smaling (1990). These inputs/outputs may include.

N, P and/or K Inputs:	N, P and/or K Outputs:
IN1: Mineral fertilizers	OUT1: Harvested product
IN2a: Applied Manure & Other Organics	OUT2a: Removed crop residues
IN2b: Tree leaves blown in from outside	OUT2b: Tree leaves blown out
IN2c: On-the-spot manuring (animals)	OUT2c: Processing residues/ vegetation (including grazing / deep ploughing under root zone/ burning)
IN2d: Inputs by seed/seedlings	OUT2d: Weeding / (fire) wood /forage collection
IN3a: Wet deposition by rain	OUT3a: Leaching /subsurface outflow (including groundwater interference)
IN3b: Wet deposition irrigation	
IN3c: Wet deposition run-on / sub-surface inflow (capillary raise / groundwater interference)	
IN3d: Dry deposition (dust, sedimentation)	
IN4a: Symbiotic N-fixation (BNF)	OUT4a: Denitrification
IN4b: Non-symbiotic (N) fixation	OUT4b: Volatilisation
	OUT4c: Gaseous losses and loss of dust by burning
IN5a: Sedimentation	OUT5a: Erosion
IN5b: Run-on	OUT5b: Run-off
IN5c: Weathering / subsurface gains (after erosion top layer/ shifting lower boundary)	OUT5c: Fixation into non-accessible forms
IN6: Recovery by deep rooting weeds /trees	OUT6: Loss by root growth under lower boundary considered for NBA
IN7a: Inflow through/of soil fauna	OUT7a: Removal through/of soil fauna
IN7b: Purchase livestock	OUT7b: Sale livestock (products)
IN8a: Food and fodder; human excreta /sewage ending up within the system	OUT8: Human excreta discharged by sewage / ending up below the lower system boundary (e.g. latrines)
IN9: Other products entering the unit /farm	OUT9: Waste products leaving the farm
	OUT10: Energy maintenance humans and livestock

This is just one way in which more detailed and additional input and output factors for FNBA could be sub-divided and specified. Alternative set-ups are possible for example including the input factor "fallow" which is aimed at estimating the net input of nutrients during one of more years of fallow. However, this is often the net result of a complex set of input (and output) factors. Other complexities are related to the availability of nutrients namely, how to account for less available nutrients in certain resistent soil minerals where in turn availability may depend on variety /crop /plant characteristics. Certain crops (as well as crop varieties/genotypes) are better able to access specific P-pools than other varieties/crops. Another example of the complexities associated with the determination of NBA and/or FNBA is the need to account for nutrients in systems where the majority of nutrients are "stored" for short (leaves) and longer (stems, roots) periods or in systems with large amounts of biomass, such as Tropical Forests. Detailed elaborations on different input and output factors and how to address problems associated with NBA/FNBA requires more in depth study and was beyond the scope of the discussion groups.

In general, it can be stated that soil fertility management recommendations should aim to reinforce input factors that are correlated with positive nutrient balances and eliminate or reduce output factors that are correlated with negative nutrient balances.

Reference:

Stoorvogel J.J., Smaling, E.M.A. (1990) Assessment of soil nutrient depletion in Sub-Saharan Africa: 1983-2000. Report 28, Winand Staring Centre, Wageningen, the Netherlands. 137 pp.

Working Group II: Spatial and temporal scales and related concepts

Group discussion took place on some terms and concepts as related to issues of scale that are considered of utmost relevance for focussed nutrient balance studies. Although most of the concepts and terminology serves a broader spectrum beyond nutrient balance studies alone, often specific reference was made to nutrient balance studies or related subjects. Table A provides an explanatory overview regarding horizontal and vertical spatial scales, as well as temporal scales, and the related spatial or temporal units (periods) and levels as relevant for decision making about the spatio/temporal dimensions of NBA. Suitability, appropriateness or preferences for certain scales/ (time) units/levels will depend on the scope and objectives of a given study, available resources, time and capacity/capability of the implementing agency. Integration of horizontal and vertical spatial scales could be considered as a 4D spatio-temporal scale (3D space + 1D time) providing 4D spatio-temporal systems as study units.

Spatial and temporal scales and related concepts
Horizontal (spatial) scale and related concepts.
Spatial scale:
Level/dimensions of spatial scope; will become larger if going from local (site, plot, and farm) to national and global level.
Map scale:
Ratio between dimensions on map and those in reality.
Spatial boundaries:
Boundaries and the units they separate/distinguish could be based on a wide range of (*taxonomic* or *classification*) criteria, also called *diagnostic criteria*, as based on a wide range of objectives. Nutrient budgets in general reflect the net effect of nutrients crossing boundaries in various directions by a variety of mechanisms/processes. As such the nutrient balance does not directly tell you anything about volatility of nutrients, as a 0-balance may exist in a system experiencing highly dynamic input/outputs as in the case of *dynamic equilibrium*. Nutrients may also move within spatial boundaries (i.e. spatial units) and /or transform (change from nutrient pool). The chemical composition, in which (elemental) nutrients are leaving or entering a spatial unit (system), i.e. cross boundaries, may vary. Boundaries may be <u>clear</u> /<u>sharp</u> when there is an abrupt transition towards an adjacent spatial unit (system) or may be <u>diffuse</u> when there is a broader less clear transition (zone) in between two adjacent units.
Edge effects:
The delineation of altering of a given process along and because of a boundary, where a spatial unit interacts with an adjacent one. Edge effects may be of biophysical, socioeconomic or more integrated in character depending on the (diagnostic) criteria used for distinguishing spatial units.
Heterogeneity:
Heterogeneity may be defined as a measure of spatial variability (within spatial units). Its degree depends on variability in reality and the level of (taxonomic) generalization applied when defining diagnostic criterion/criteria for establishing spatial units and boundaries. Heterogeneity up-to a certain level is always present and needs to be dealt with within research activities. Heterogeneity is not always easy to estimate, let alone to measure. Moreover, there exist different patterns of heterogeneity or variability, varying from completely gradual to completely abrupt variation and from completely random to completely systematic variability. If heterogeneity for diagnostic criteria within units does not significantly differ from that between units, then units / boundaries may need to be joined or redefined using different diagnostic criteria.

Spatial sampling:
Sampling method (sampling pattern) used to assess spatial variability (of e.g. nutrient balances). Spatial sampling methods include completely random, random block, stepwise and nested sampling. Appropriate spatial sampling/measurements or units of study will depend on the objectives, accuracy pursued, availability of suitable sampling methods, perception or pre-knowledge on spatial variability, and existing capacity. The pre-perceived understanding about the system under research, the objectives of the study and related choice of diagnostic criteria will determine the horizontal (spatial) scale/units used for NBA.

Space has 3 dimensions and in addition to the horizontal dimension, a decision about the vertical dimension is essential for an accurate assessment of NBA. It may not always be easy to choose the vertical spatial unit as defined by lower and upper boundaries based on certain criteria (colour, texture, structure) and an arbitrary decision may have to be made. As the most relevant layer for crop growth often the top-soil (Ap Horizon) is considered for NBA. However, crop varietial differences in rooting depth msut also be considered. Such decisions get even more complex when multiple cropping systems are studied. Nutrients are flowing from the top-soil into the sub-soil by the process of leaching. In turn, they may be subtracted from the sub-soil and brought in the system again by deep rooting crops, but also through capillary rise, meaning not all leached nutrients will be automatically lost.

It was considered in Working Group II that most of the terms and concepts discussed for horizontal (spatial) scale can also be applied for vertical scale. Vertical units have (horizontal) boundaries that distinguish/separate them from adjacent vertical spatial units. Similarly edge-effects and heterogeneity may exist. In general, vertical spatial units (often one or more soil layers/horizons) have much smaller dimensions than horizontal spatial units (in general covering a subplot or larger areas depending on diagnostic criterions by which they are classified).

For NBA involving land-use systems with perennials namely. rubber trees, one could argue that the most appropriate upper boundary of the vertical reference unit for NBA will be the top of the bio-mass layer. Nutrients taken from the soil are retained within (largely) perennial biomass. This means there is a vertical shifting of the upper system boundary and an increasing spatial vertical unit as crop growth proceeds.

For annuals and perennials the choice of the lower boundary will depend on crop type (and varieties) and agricultural system. The maximum rooting depth of a full-grown crop could be chosen as lower boundary, or the depth were e.g. 75 or 90 % of the roots of mature crops are encountered. The choice on the lower system boundary gets more complex in case of multiple-cropping systems. This includes very complex situation of mixtures between relatively shallow rooting annuals and deep rooting perennials. For realistic and accurate analysis as in the case of modelling plant-nutrient interactions, one single and/or static lower boundary may result in incorrect or insufficiently accurate results. This may be exacerbated in complex systems or those characterized by large temporal variations.

Time scale and related concepts:

Time scale:
Dimension of time unit (interval) must be considered within the scope of a given study.
Time boundaries:
Edges (moments) of time intervals
Temporal variability:
Variability of studied (simple or complex) parameters in time. May vary from abrupt to gradual and from completely random to systematic (deterministic).
Monitoring (temporal sampling):
Measuring temporal variability can be achieved by continuous screening (continuous monitoring) or by snapshot measurements. A one-time instantaneous or snapshot measurement determines merely the state of a system parameter (e.g. nutrient pool) at a certain moment. In contrast, continuous monitoring allows changes in the state of a system parameter to be evaluated. Periodical measurement may fall in between continuous screening and a one time snapshot measurement. It could be done for equal time intervals (daily, weekly etc) or unequal time intervals tailored towards the 'system' under research. Examples for the latter case are e.g. crop development stages (of unequal duration) and measurement before and after certain (management) interventions or climatic changes (e.g. fertilizer application, rainfall, flooding etc.). Note that in the case of periodical monitoring processes/parameters are followed continuously in time on a periodical basis.

It may be clear that appropriate temporal sampling/measurements depend on the research objectives, accuracy pursued (i.e. accepted levels of temporal generalization), availability of suitable monitoring methods, perception or pre-knowledge on temporal variability, and available capacity. Instantaneous measurement may be appropriate in case of measuring the effects of clearly recognizable single events like in the case of erosion and overland flow caused by a thunderstorm. Periodical measurement may be appropriate where pre-perceived gradual processes (without too much random and abrupt changes), need to be better quantified. If not, all potential variability is pre-perceived or recognized, e.g. when temporary peaks or dips are overlooked or mistakenly sampled, misperceptions and wrong conclusions may be the result.

Table A provides an explanatory overview on horizontal and spatial scales, temporal scales and more or less related "spatial" and “temporal” units (periods)/levels at which NBA, can be evaluated. No judgement is made on which scale/unit/level best suits certain research objectives.

Table A: Spatial and temporal scale, boundaries and units

Spatial Scale (temporal scale)	**Horizontal spatial units** based on diagnostic and/or administrative boundaries	**Horizontal spatial units** based on Biophysical (BP), Farming System (FS) and/or socioeconomic (SE) boundaries and criteria (Administrative (ADM) boundaries may be part of the criteria)	**Vertical spatial units** as (potentially) relevant for NBA.	**Time units / intervals**
Very small (short) ↓ Very large (long)	1. Sub-plot 2. Field 3. Farm 4. Village 5. Sub-district 6. District 7. Province 8. National Region 9. Country 10. International Region 11. World	1. Smallest biophysical unit / (poly) pedon (BP) 2. Land Utilization Type (SE/FS) 3. Land-Use System (SE/FS/BP) 4. (Farm) Household (SE/ FS /ADM) 5. Farming system zone (BP/ FS/ SE) 6. Agroecosystem (BF/SE) 7. Community (SE) 8. Catchment/Watershed (BP) 9. Development zones (concentration areas) (SE/BP) 10. Resource Management Domain (SE/BP/ADM) 11. Agro-ecological zones (BP/SE) 12. Ecoregional zone/ecoregions (BP/SE/ADM) 13. Agroclimatic zones (BP/SE)	1. Top-soil 2. Part of rooting zone (e.g. where 90% or roots occur) 3. Complete rooting zone 4. Soil profile 5. From upper boundary standing biomass to lower boundary of rooting zone	1. Instantaneous 2. Per minute 3. Per hour 4. Rainfall event 5. Daily 6. Weekly 7. Monthly 8. Crop growth stage 9. Quarterly 10. Annually 11. Perennial (periodically)
	In general scale-related, although e.g. the size of a sub-district in one country may be the size of a province in another.	*With some exceptions not all directly scale related (e.g. 3, 4, 5, 6, 7,8, 9, 10 and 11 depend on level of generalization applied as related to the objectives and site-characteristics).*	*Relatively small spatial scales with less scale variations than for horizontal scales.*	*In reality processes may range from abrupt to gradual and random to systematic*

Working Group III: Needs, collection, measurement, sources and accuracy of data for nutrient balance analyses

Working Group III discussed the data needs and the feasibility and challenges associated with collecting data of sufficient accuracy for NBA. In spite of the relatively simple logic of determining nutrient balances, NBA is data intensive and based on a complex reality of nutrient flows and pools (see report of Working Group I). Good NBA performance requires insight into the underlying complexity of flows (and pools), the methods with which to capture, measure and quantify such flows (and pools), the accuracy of the quantitative results and the benefits and constraints of various nutrient specific analytical methods, flows and pools. The assessment of one of the in- or ouput factors of a general, "black-box", nutrient balance model, may require the determination of a whole set of underlying parameters, which may vary, as may their relative importance, per nutrient and spatial/temporal system studied (see report of Working Group II).
In general, strict priority setting follows a trade-off between expected result accuracy and resource investment, i.e. human, financial, time allocation. Decisions following trade-offs between accuracy and resource allocation will depend on the type and objectives of the NBA. A general trade-off between accuracy and resource investment will rely on a wide range of sub- or internal trade-offs. The "internal trade-offs" mainly apply to methodological choices, and are in part related to existing knowledge and perceptions regarding:

- Nutrient flows and pools and the spatio-temporal systems involved and conceptualized.
- The relative importance of each of the factors, as well as their underlying parameters
- The feasibility, considering the overall capacity available, to measure or collect data on nutrient balance factors and underlying parameters, as primary or secondary data sources
- Data accuracy; which partly relates back to investment in measurement/collection efforts, including source and referencing of secondary data (defaults).

Nutrient balance studies should pursue a data set that matches best the data requirements for an envisaged nutrient balance study according to its objectives. It is the pre-perceived understanding on data and measurement accuracy, as mainly derived from basic and strategic research efforts and expert-knowledge, which will determine the success and quality of the final outcomes.

Each well-planned nutrient balance study should initially look into primary data needs and the feasibility to obtain primary and secondary data with sufficient accuracy for the pursued objectives. This involves considerations about when and where (assumptions, referencing) defaults/secondary data and transfer functions may be used. This should be followed by prioritizing data collection and data collation efforts, as based on the study objectives and with available capacity and resources obtain the most appropriate data set. Efficiency and effectiveness of Research & Development (R&D) activities pivoted around NBA or with a NBA component could be improved by better research coordination and improved and increased data sharing i.e. by not only making research findings but also broad data sets accessible to a wide group of actors, which in part is hampered by competition among actors due to competition for acknowledgement, funding, and commercialization of R&D efforts.

Tables B1, B2 and B3 provide a brief schematic overview about (perceived) feasibility for measurement of required data parameters for NBA, including indications about expected data accuracy and secondary data sources that could provide defaults values for some of the input and output factors and related parameters.

Tables B1, B2 and B3 may be useful for initial (rough) planning assessments of NBA activities. They could be used to define a minimum data set (requirements), time allocation/requirements, financial, human resource and overall logistical planning. However, it needs to be emphasized that Tables B1, B2 and B3 only provide a generalized picture, ignoring some of the inherent variability on the appraised items as related to NBA methodology and the type of system studied. This is with regards to thematic attributes spatio-temporal dimensions and conceptualization/generalization,. Another component of the inherent trade-off process at the basis of each NBA is the measurement and/or assessment or not, of "complex" factors as compromised by the relative importance of each of the factors (see report of working Group I).

Table B1: Feasibility for monitoring (data collection) and for management (possibilities to influence) input parameters

Parameter	Dimension	Monitor	Manage	Availability of Secondary Data
Fertilizer	Rate/source	++	++	Only for large scale based on regional / (inter) national agricultural statistics; e.g. National Agricultural Statistics; FAO, FADINAP, IFA.
Organics	Residues /rate /quality/ contents	+	++	Inputs: For large scale based on regional / (inter)national agricultural statistics Quality: Based on existent databases literature at regional, national and international levels.
BNF	Cropping system	+	++	Literature / databases on fertility / BNF experiments /trials
Irrigation	Quantity /contents.	±	+	Possibly as based on national /regional databases with analytical data of irrigation.
Rainfall	Quantity /contents	–	–	Only if analytical data may be available from nearby measurement locations
Sedimentation	Quantity /contents	±	+	General tendencies may be estimated from data for identical land-use systems

Table B2: Feasibility for monitoring (data collection) and for management (possibilities to influence) output parameters

Parameter	Dimension	Monitor	Manage	Availability of Secondary Data
Product	Harvest	+	++	Only for large scale NBA based on regional / (inter) national agricultural statistics; e.g. National Agricultural Statistics and FAO
Residues	Residue cycling	+	++	Only for large scale based on regional / (inter) national agricultural statistics; e.g. National Agricultural Statistics and FAO
Run off, Erosion, Leaching	Cropping system /tillage/mulch, ground cover / irrigation/ soil characteristics	±	+	Erosion maps and data about physical characteristics available from soil maps and / or extrapolation based on measurements from geo-referenced sites by using topographical, slope, soil, land use /cover maps etc.
Gaseous losses	Quantity /contents	±	+	Extrapolation of existent data based on measurement for similar land-use systems

Table B3: Feasibility for monitoring (data collection) and for management (possibilities to influence) other parameters that indirectly influence input and/ or output parameters.

Parameter	Dimension	Monitor	Manage	Availability of Secondary Data
Climate	Rainfall, Intensity, Wind	+	-	National Meteorological Institutes, IWMI, FAO
Soil	Characteristics /composition / nutrient availability	++	+	National, FAO, USDA etc.
Cropping Area / Harvest Index	Area / Harvest Index	-	-	National Agricultural Statistics, FAO, literature and databases of agricultural research centres.
Livestock	Number/quantity /contents	+	++	National Agricultural Statistics, FAO, literature and databases of agricultural research centres (e.g. ILRI).
Burning	Gaseous and losses of solid particles /dust	_	_	Only if analytical data may be available from measurements for identical land-use systems.

Programme International Workshop on Nutrient Balances for Sustainable Agricultural Production and Natural Resource Management in Southeast Asia

For up to date contact details please refer to the 'List of Participants' and 'Contacts' Links on this CD-ROM

Tuesday 20 February

Chair: Yothin Konboon

8:30 Opening .... *Suthep Limthongkul (Rice Research Institute-DOA, Thailand)*

9:00 Nutrient balance studies: General use and perspectives for SE Asia. .... *Rod Lefroy and Danny Wijnhoud (IBSRAM)*

Case-studies - Nutrient balances and nutrient studies

9:30 Sustainability analysis of existing land-use systems in Northeast Thailand .... *Viriya Limpinuntana, Patma Vityakorn, Vidhaya Treloges and Aran Patanothai (Khon Kaen University, Thailand)*

10:00-10:30 Coffee break

Chair: Danny Wijnhoud

10:30 Nutrient balance studies at the field and farm level in Northeast Thailand... .... *Yothin Konboon (URRC, Thailand), Danny Wijnhoud and Rod Lefroy (IBSRAM)*

11:00 Accumulative nutrient balance on a toposequence of sloping land used for upland crop production in Northeast Thailand ……………….……*Sawaeng Ruaysoongnern (Khon Kaen University, Thailand) and Andrew Noble (CSIRO)*

11:30 Discussion

12:00-13:00 Lunch

Chair: Aran Patanothai

13:00 Amelioration of potential acid sulfate soils and a mechanization system for food crop plantations .... *Azwar Maas (University of Gadjah Mada, Indonesia)*

13:30 Nutrient budget considerations for the Lao PDR .... *Pheng Sengxua (NAFRI, Lao PDR)*

14:00 Water and nutrient flows under different farming systems on sloping lands in Northern Vietnam................ ....*Nguyen Cong Vinh and Thai Phien (NISF, Vietnam)*

14:30 Discussion

15:00-15:30 Coffee break

Chair: Keith Syers

15:30 Nutrient balance in a rice-vegetable system: A case study of an intensive cropping system in Batac, Ilocos Norte, Philippines ....*Raj Kumar Shrestha (NARC, Nepal)*

16:00 The influence of soil surface management practices on the nutrient status and physical properties of calcareous soils in Western Thailand .... *Ian Grange (Mahidol University, Thailand)*

16:30 Soil degradation assessment for natural resource management: The case of Haplic Acrisols in South Vietnam. ....*Phan Thi Cong (IAS, Vietnam)*

17:00 General discussion

Programme International Workshop on Nutrient Balances for Sustainable Agricultural Production and Natural Resource Management in Southeast Asia

Wednesday 21 February

Chair: Rod Lefroy

8:30 The role of organic matter management on the nutrient balance and change of soil chemical properties for maize fields in Northeast Thailand.. *Naruo Matsumoto (JIRCAS)*

9:00 Nutrient inputs and losses in cassava-based cropping systems in Vietnam and Thailand .... *Reinhardt Howeler (CIAT)*

9:30 Methodology for studying nutrient balances in swiddens and wetland rice fields in the Northern Mountains of Vietnam... *Nguyen Van Dung (HAU, Vietnam)*

10:00-10:30 Coffee break

Chair: Azwar Maas

Tools and methodologies at multiple scales

10:30 Conducting nutrient audits at the national scale in Southeast Asia: Methodology and preliminary results .... *W.F. Sheldrick, J.K. Syers, and J. Lingard* (*Naresuan University, Thailand*)

11:00 NPK fertilizer recommendation system for corn using the DSSAT and PDSS modeling approach ....*Tasnee Attanandana (Kasetsart University, Thailand)*

11:30 Discussion

12:00 - 13:00 Lunch

Chair: Tasnee Attanandana

Nutrient balances in integrated biophysical and socioeconomic approaches

13:00 Integrated economic and environmental accounting.................................... *Felix Moukoko Ndoumbe (FAO)*

13:30 Accounting for socioeconomic and environmental sustainability: Towards a Decision Support Tool for farmers and extension workers.. ....*Danny Wijnhoud, Rod Lefroy (IBSRAM) and Yothin Konboon (URRC, Thailand)*

14:00 Partial nutrient balances from agronomic and economic viewpoints: The case of corn farming in acid uplands of Isabela, Philippines.. *Edna Samar (BSWM, Philippines)*

14:30 Discussion

15:00-15:30 Coffee break

Data and Information management for nutrient balances

Chair: Felix Moukoko Ndoumbe

15:30 Regional Integrated Plant Nutrition Development System (IPNS) Development Programme ....*Peter Hegenbarth (FADINAP / ESCAP)*

16:00 Web-based fertilizer information management and dissemination ....*Edgar Dante (FADINAP / ESCAP)*

14:30 Discussion and planning for working groups

19:00 Workshop dinner

Programme International Workshop on Nutrient Balances for Sustainable Agricultural Production and Natural Resource Management in Southeast Asia

Thursday 22 February

8:30 Working group sessions: 3-4 working group sessions will be convened to discuss important topics of nutrient balance assessment, fertility management recommendations; sustainability assessment, etc. Likely topics for discussion are:

(i) Data and information management (collection, database building and data sharing)
(ii) Issues of accuracy (partial and full balances, use and abuse of secondary data, etc.)
(iii) Assessment of factors in nutrient balances that are difficult or expensive to assess
(iv) Issues of time and spatial scales
(v) Applications for nutrient balance assessment
(vi) Nutrient budgets in interdisciplinary and participatory R&D activities

10:30-11:00 Coffee break

11:00 Working groups continue

12:00- 13:00 Lunch

13:00 Plenary session.

Working group conclusions

Discussion of research gaps and needs, and possibilities for future activities, networking and collaboration.

14:30 Conclusions, recommendations, decisions on follow-up and close

---

Participants List

Please note that where possible contact details of participants have been updated
**** Contact details no longer valid***

1. **Trina Allen** (Intern Student)*
IBSRAM, PO. Box 9-109, Jatujak, Bangkok 10900, Thailand
E-mail: trina_erin@hotmail.com

2. **Tasnee Attanandana**
Kasetsart University, Department of Soil Science, Phaholyothin Road, Bangkok 10900, Thailand. Tel: 66-2-9428104 Fax: 66-2-9428106 E-mail: agrtna@ku.ac.th

3. **Pax Blamey**
University of Queensland, Brisbane, Queensland 4072, Australia.
Tel: 61-07-33652081 Fax: 61-07-33651188 E-mail: p.blamey@uq.edu.au

4. **Phan Thi Cong**
Institute of Agricultural Science of South Vietnam, Department of Soils and Fertilizers, 12 Nguyen Chi Thanh St., District 10 Ho Chi Minh City, Vietnam.
Tel: 84-08-8393707 Fax: 84-08-8297650 E-mail: congphanthi@hcm.vnn.vn

5. **Eric Craswell**
Center for Development Research (ZEF), Walter-Flex-Strasse 3, 53113 Bonn, Germany. Tel: 49-0-228736188 Fax: 49-0-228 7360834
E-mail: eric.craswell@uni-bonn.de

6. **Edgar Dante**
FADINAP / UNESCAP, United Nations Building, Rajdamnern Nok Avenue, Bangkok 10200, Thailand. Tel: 66-2-2881346 Fax: 66-2-2881056
E-mail: dante.unescap@un.org

7. **Nguyen Van Dung**
Hanoi Agricultural University, Gia Lam, Hanoi, Vietnam
Tel: 84-4-8765607 Fax: 84-4-8766642 E-mail: lenam@netnam.org.vn

8. **Ian Grange**
Faculty of Rural Management, University of Sydney – Orange, PO Box 883
Orange, NSW 2800, Australia. Tel: (61 2) 6360 5484 (direct), 6360 5667 (Home)
Fax: (61 2) 6360 5590 Email: igrange@orange.usyd.edu.au

9. **Peter Hegenbarth**
FADINAP / UNESCAP
United Nations Building, Rajdamnern Nok Avenue, Bangkok10200, Thailand
Tel: 66-2-2881394 Fax: 66-2-2881056 E-mail: hegenbarth.unescap@un.org

10. Reinhardt Howeler
CIAT, Department of Agriculture, Phaholyothin Road, Bangkok10900, Thailand.
Tel: 66-2-5797551 Fax: 66-2-9405541 E-mail: howeler@cgiar.org

11. Yothin Konboon
Ubon Rice Research Center (URRC), Department of Agriculture, P.O. Box 65, Ubon Ratchathani 34000, Thailand. Tel: 66-45-344103 Fax: 66-45-344090
E-mail: urrc@loxinfo.co.th

12. Siegfried Lampe
FADINAP / UNESCAP United Nations Building, Rajdamnern Nok Avenue, Bangkok10200, Thailand. Tel: 66-2-2881346 Fax: 66-2-2881056

13. Rod Lefroy
CIAT, C/-NAFRI, Ban Nongvienkham, Dong Dok, Vientiane, Laos PDR
Tel: 856-21-222796 Fax: 856-21-222797 E-mail: r.lefroy@cgiar.org

14. Viriya Limpinuntana
Khon Kaen University, Faculty of Agriculture, 123 Friendship Highway Road
Amphoe Muang, Khon Kaen 40002, Thailand.Tel: 66-43-241146 Fax: 66-43-243097
E-mail: viriya@kku.ac.th

15. Azwar Maas
University of Gadjah Mada, Center of Land Resources Study, Komplem UGM Kuningon Jl. Cvolombo, Yogjakarta, Indonesia. Tel: 62-214-546388
Fax: 62-214-546328 E-mail: amaas@mailcity.com

16. Felix Moukoko Ndoumbe
FAO (AGSP), Via Delle Terme Di Caracalla Odioo, Rome, Italy.
Tel: 39-06-57053010 Fax: 39-06-57056799 E-mail: felix.moukokondoumbe@fao.org

17. Kobkiet Paisancharoen
Soil Science Division, Department of Agriculture, 180/7 Mittaphab Road, Khon Kaen, Thailand. Tel: 66-43-246658, 246669 E-mail: kobkiet@kknet.co.th

18. Aran Patanothai
Khon Kaen University Department of Agronomy, Faculty of Agriculture, 123 Friendship Highway Road, Amphoe Muang, Khon Kaen 40002, Thailand
Tel: 66-43-342949 Fax: 66-43-364636 E-mail: Aran@kku.ac.th

19. Roland Poss
IRD, 911 Avenue, Agropolis BP64501, S-34394, Montpellier, Cedex 5, France
Tel: 33-4-67149061 Fax: 33-4-67149068 E-mail: Roland.Poss@msem.univ-montp2.fr

20. Ivy Rodricks
FADINAP / UNESCAP United Nations Building, Rajdamnern Nok Avenue, Bangkok10200, Thailand. Tel: 66-2-2881348 Fax: 66-2-2881506
E-mail: rodricks.unescap@un.org

21. Sawaeng Ruaysoongnern
Khon Kaen University, 123 Friendship Highway Road, Amphoe Muang
Khon Kaen 40002, Thailand. Tel: 66-43-364639 Fax: 66-43-243097
E-mail: sawaeng@kku.ac.th

22. Edna Samar
Bureau of Soil and Water Management, SRDC Bldg., Elloptical, Diliman, Quezon City, Philippines. E-mail: resbswm@pworld.net.ph

23. Pheng Sengxua
National Agriculture and Forestry Research Institute (NAFRI), Soil Survey and land Classification Centre, Vientiane, Lao PDR.

24. Raj Shrestha
NARCED, Soil Science Division, Khumaltar, Latipur, Nepal. Tel: 977-01-521197 Fax: 977-01-521149 E-mail: shrestha@infoclub.com.np

25. Ben Sivak (Intern Student)*
IBSRAM, PO. Box 9-109, Jatujak, Bangkok 10900, Thailand.

26. T.B. Subedi
Department of Agriculture, Soil Testing and Service Section, Department of Agriculture, Harbihar Bhawan, Katmandu, Nepal E-mail: psussmp@wlink.com.np; subeditb@yahoo.com

27. Nopporn Surrapoj
Ubon Rice Research Center (URRC), Department of Agriculture, P.O. Box 65, Ubon Ratchathani 34000, Thailand. Tel: 66-45-344103 Fax: 66-45-344090
E-mail: urrc@loxinfo.co.th

28. J. Keith Syers
Naresuan University, Muang, Phitsanulok 65000, Thailand. Tel / Fax: 66-55-261005
E-mail: keiths@nu.ac.th

29. Vidhaya Trelo-ges
Khon Kaen University, Faculty of Agriculture, Department of Land Resources and Environment, 123 Friendship Highway Road, Amphoe Muang, Khon Kaen 40002 Thailand. E-mail: vidtre@kku.ac.th

30. Nguyen Cong Vinh
National Institute of Soils and Fertilizers, Department of Land Use Research
Tu Liem, Hanoi, Vietnam. Tel: 84-4-8385635 Fax: 84-4-8343924
E-mail: ncvinh-nisf@vnn.vn

31. Patma Vityakon
Khon Kaen University, 123 Friendship Highway Road, Amphoe Muang, Khon Kaen 40002, Thailand. E-mail: patma@kku.ac.th

32. Gadsaraporn Wannitikul (Intern Student)*
IBSRAM, PO. Box 9-109, Jatujak, Bangkok 10900, Thailand.

33. Danny Wijnhoud
Netherlands Development Organization (SNV), PO Box 4468, Maputo, Mozambique.
E-mail: famwijnhoud@hotmail.com