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

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** 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.

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

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.

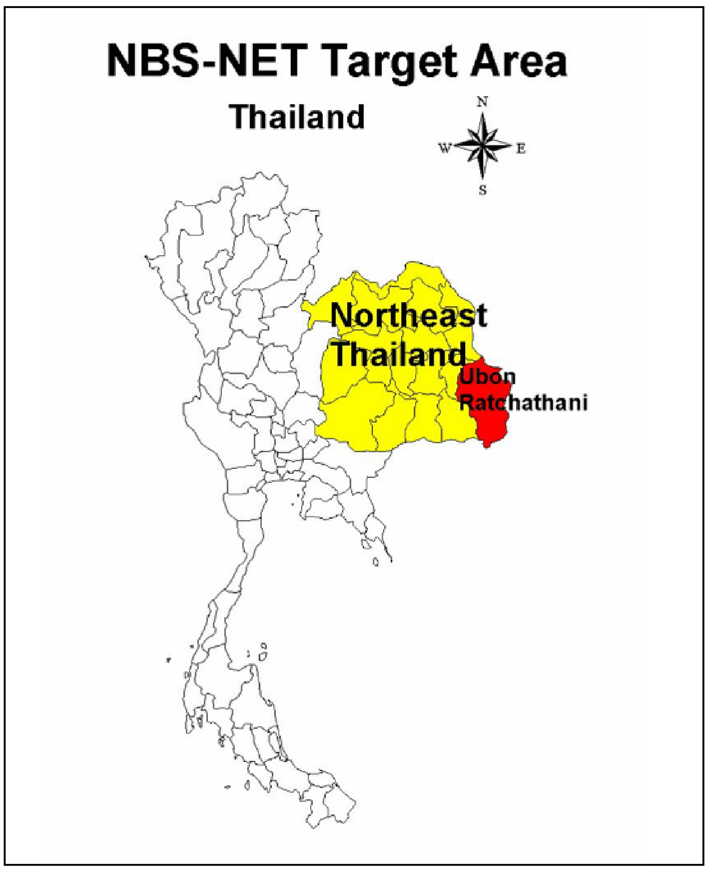


Figure 1. Map of Thailand indicating the target area of NBS-NET in Northeast Thailand, Ubon Ratchathani Province.

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).

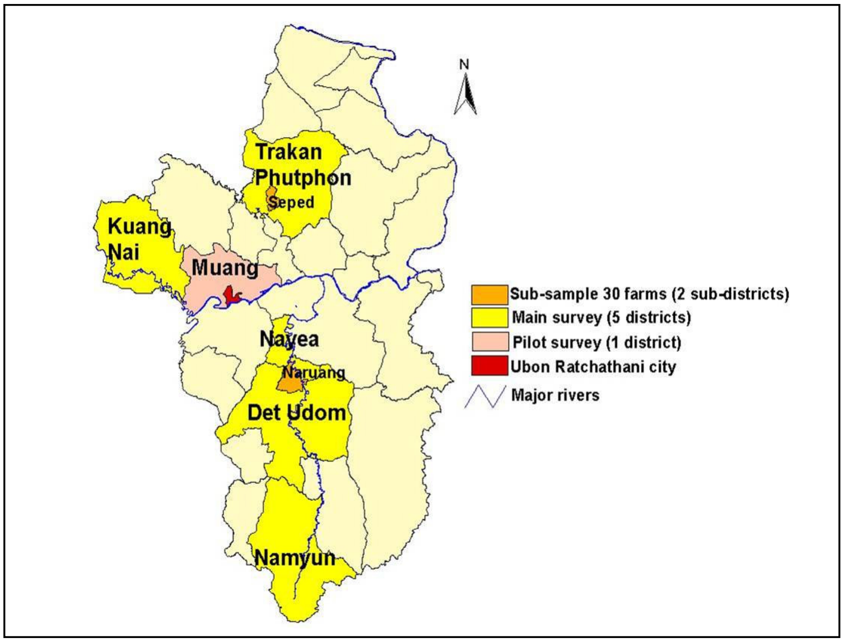


Figure 2. Map of Ubon Ratchathani Province indicating the (sub-) districts where primary data were collected for NBS-NET.

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.

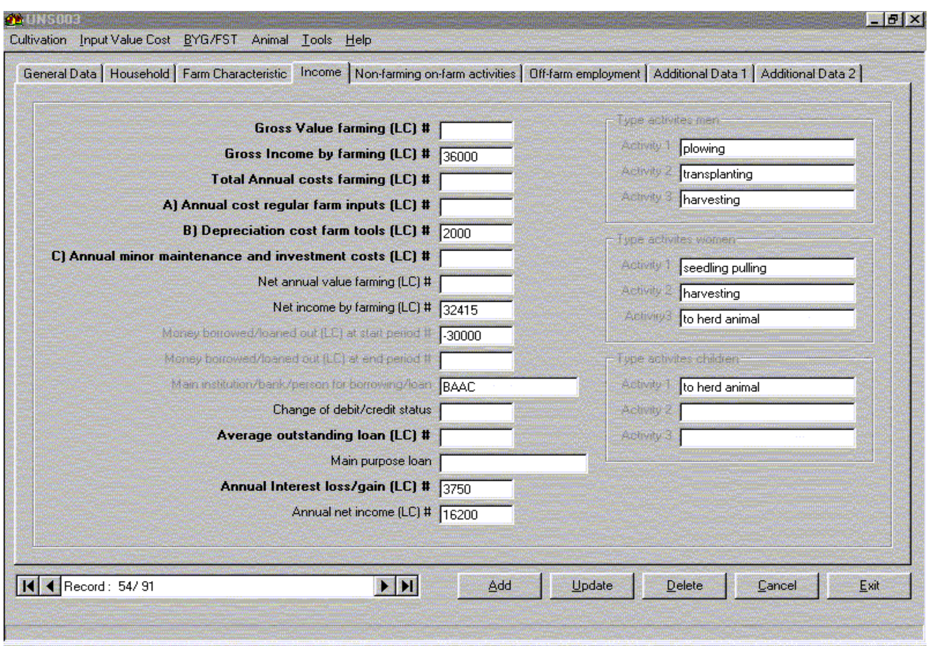


Figure 3. An example of one of the user-interfaces (front-end) developed in Visual Basic® that is compatible with the Farm Inventory Forms used for data collection.

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".

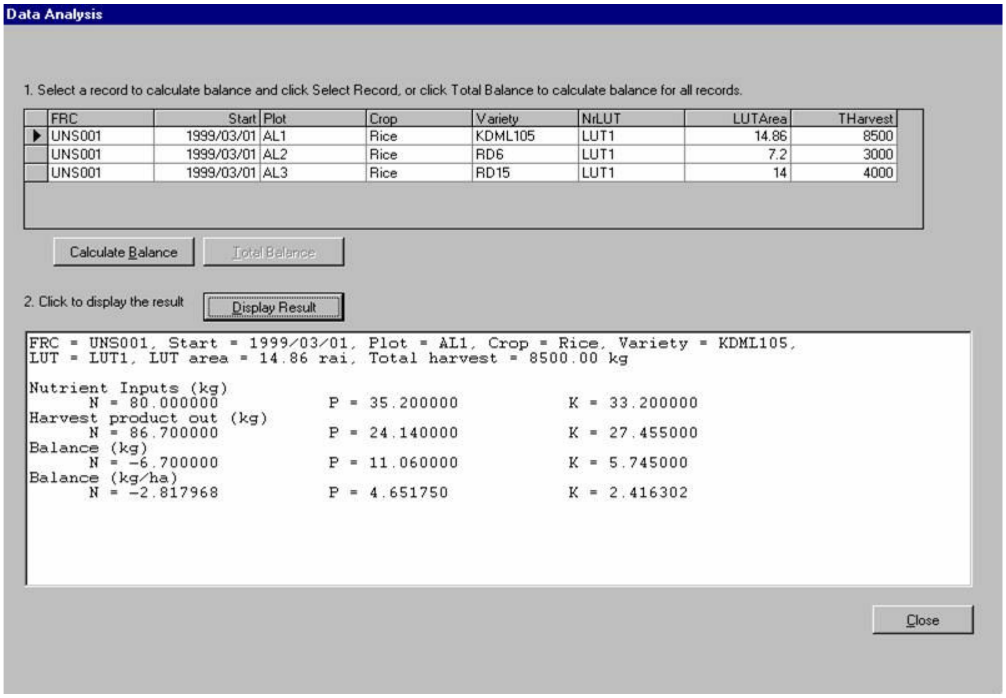


Figure 4. Example of data analysis utility for generating partial nutrient balances semi-automatically within the RDBS.

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.

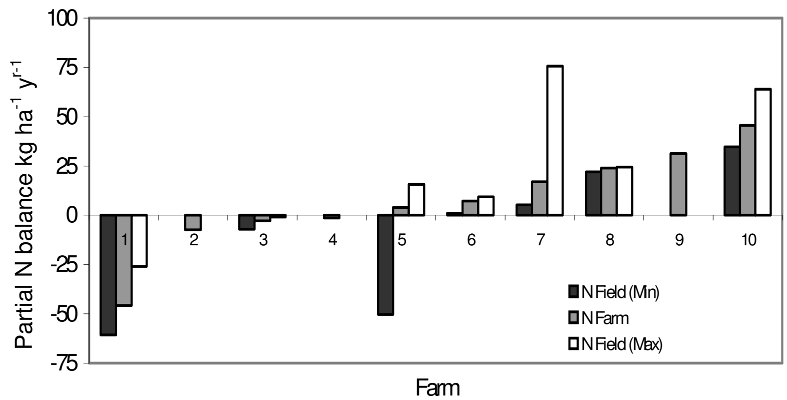


Figure 5a. The variation in partial N balances among different fields of 10 farms in Muang District, Ubon Ratchathani Province (adapted from Wijnhoud et al., 2000)

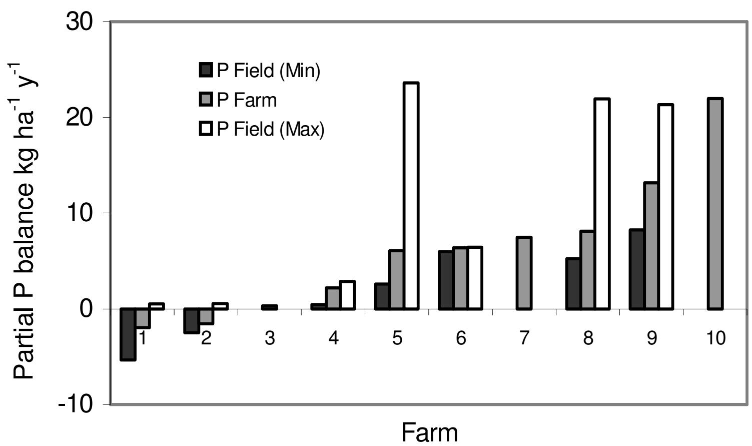


Figure 5b. The variation in partial P balances among different fields of 10 farms in Muang District, Ubon Ratchathani Province (adapted from Wijnhoud et al., 2000)

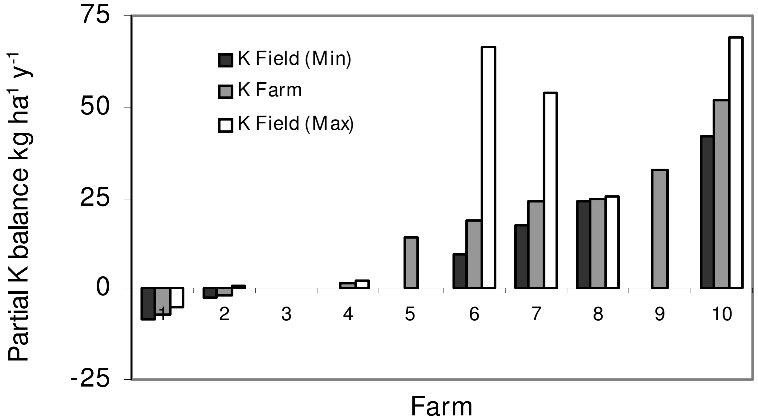


Figure 5c. The variation in partial K balances among different fields of 10 farms in Muang District, Ubon Ratchathani Province (adapted from Wijnhoud et al., 2000).

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).

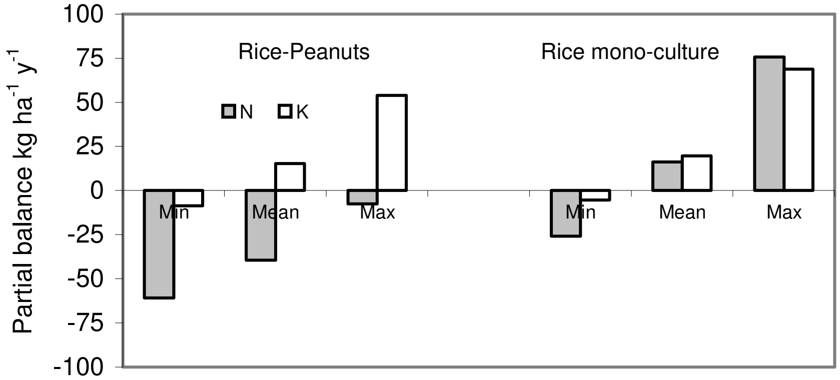


Figure 6. Partial N and K balances for rice-peanut systems and mono-crop rice systems on 18 fields in Muang District, Ubon Ratchathani Province (adapted from Wijnhoud et al., 2000).

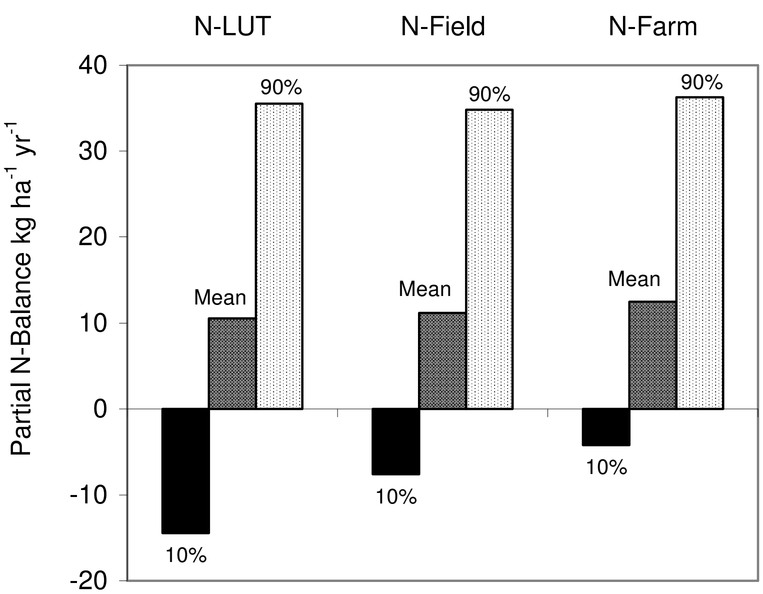


Figure 7. Partial N balances at the LUT (n=78), field (n=59) and farm (n=30) level (including 10 and 90 percentiles) for 30 farms in two sub-districts in Ubon Ratchathani Province.

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).

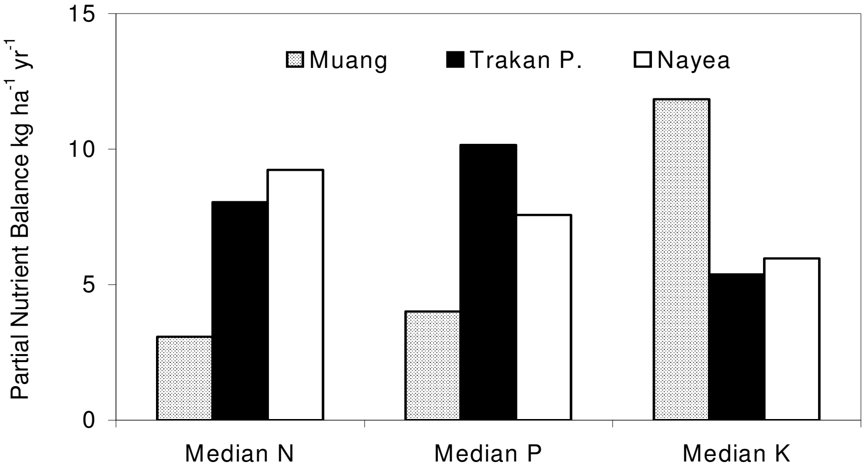


Figure 8. Median N, P and K partial LUT balances for 3 Districts in Ubon Ratchathani Province.

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.

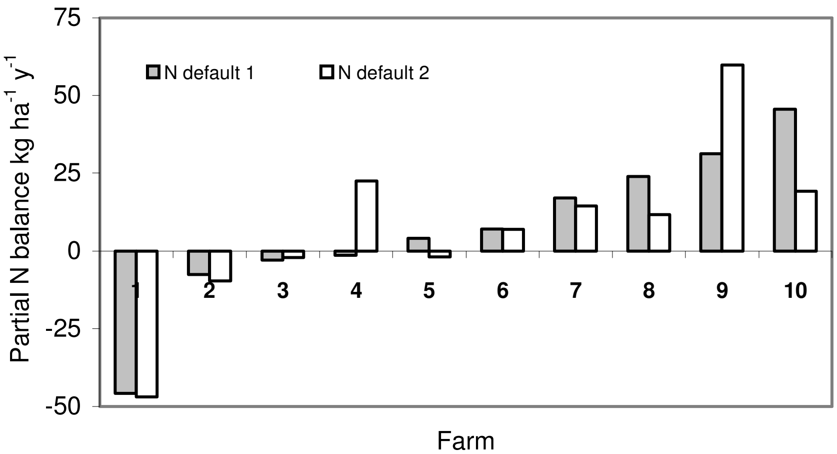


Figure 9. The effect of using different default values of N contents in manures on the range of partial N balances for the 10 farms (adapted from Wijnhoud et al., 2000). NB: Default 1: cattle manure N (%) = 1.58 (Dhanyadee, 1984), poultry manure N (%) =1.23 (average for chicken and duck manure according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

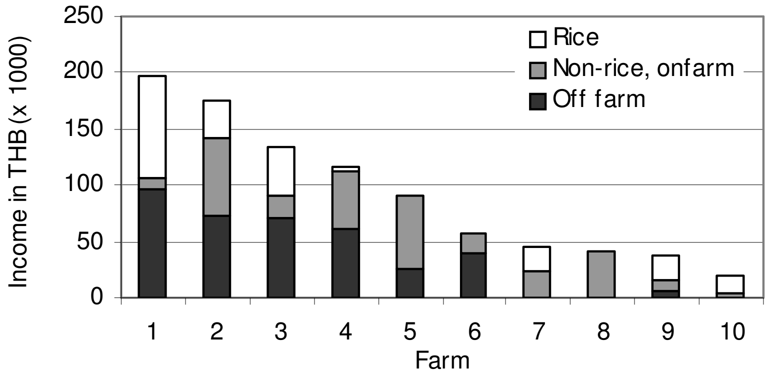


Figure 10. Components of annual farm income for 10 farms surveyed in Muang District, Ubon Ratchathani Province, Northeast Thailand.

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.

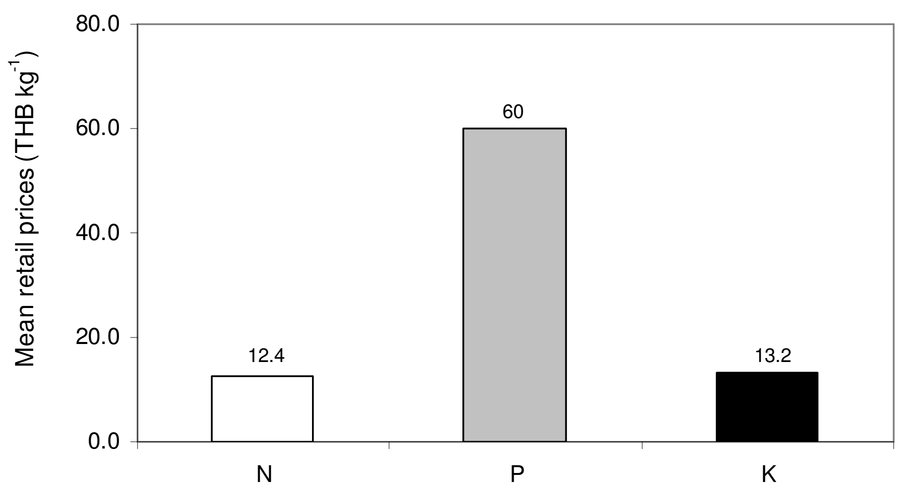


Figure 11. Mean retail prices of elemental N, P and K as based on prices of raw materials and mineral fertilizers and their relative consumption. Price ratio of N:P:K = 1:4.83:1.06

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.

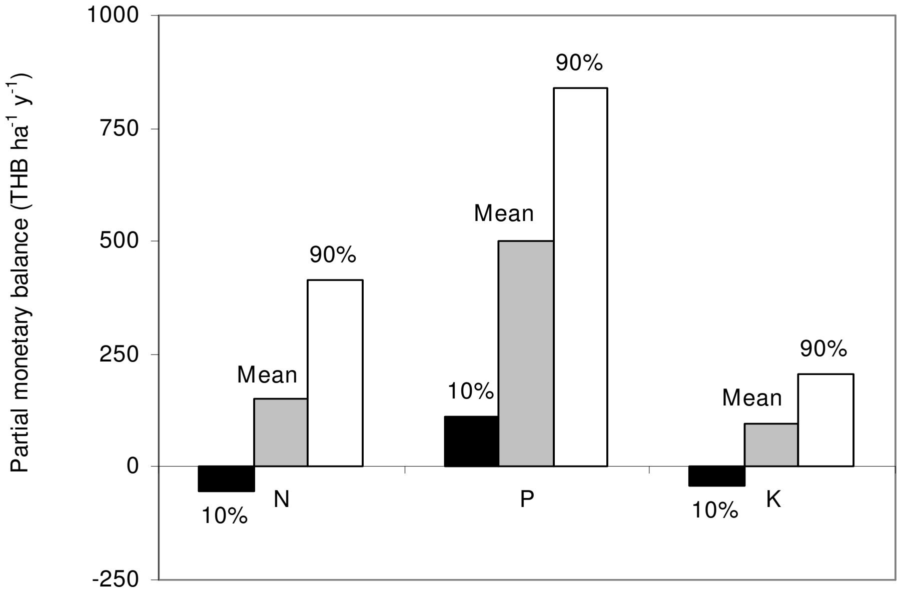
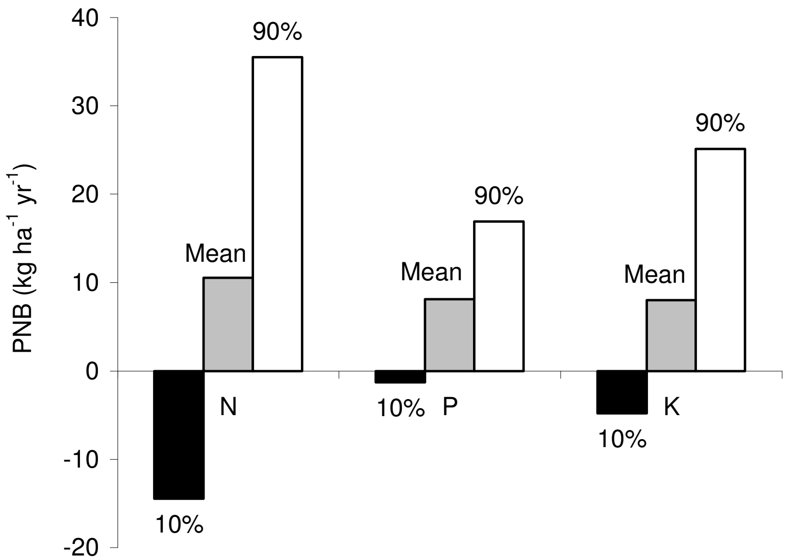


Figure 12. Partial monetary N, P and K farm balances for 30 farms (including 10 and 90 percentiles) based on average market prices of nutrients.

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).



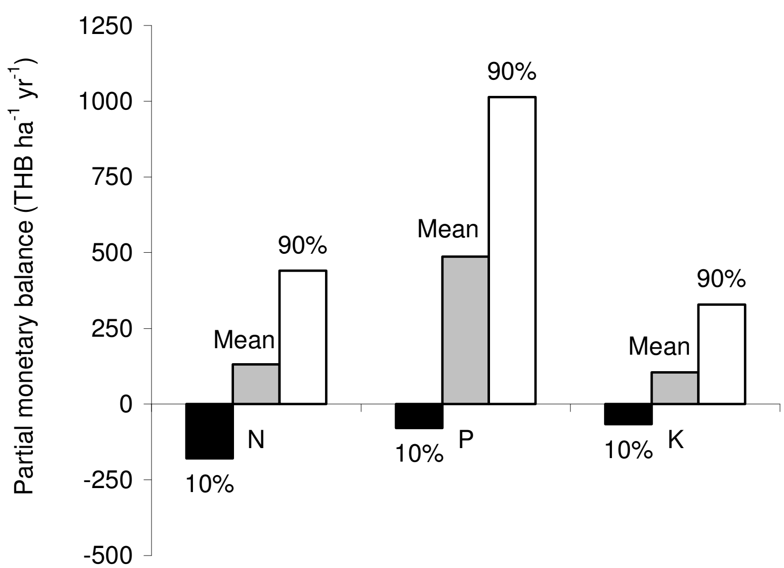
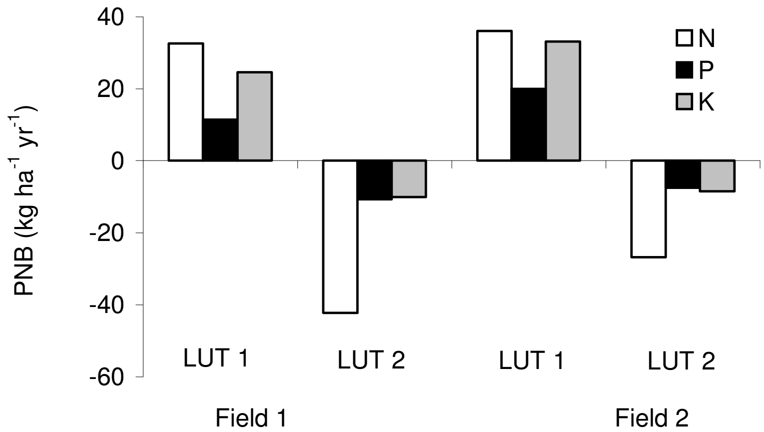


Figure 13. Comparison of biophysical PNBs and their monetary values/costs, based on average market prices of nutrients for 78 LUTs on 30 farms (including 10 and 90 percentiles) (PNB graph adapted from Wijnhoud et al., 2003).



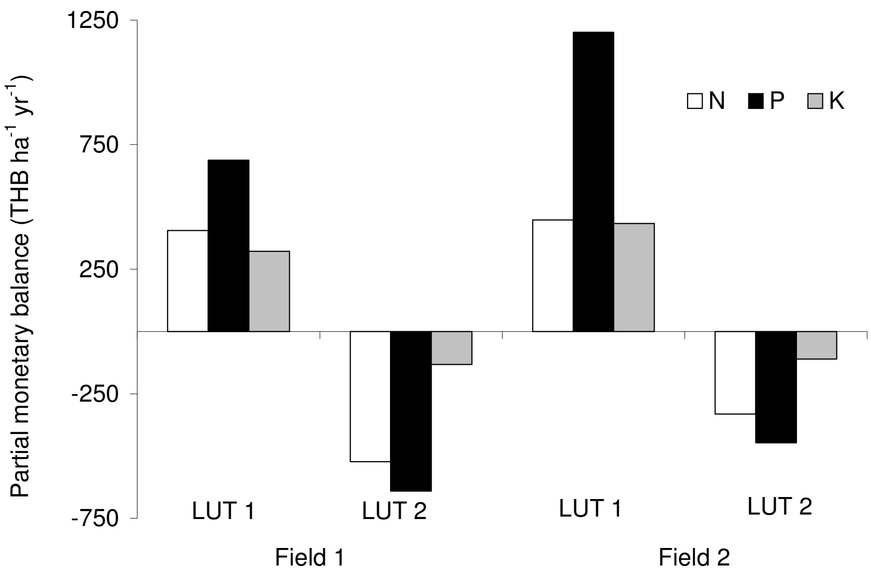


Figure 14. Comparison of biophysical partial balances and their monetary values/costs, based on average market prices of nutrients for 4 LUTs, 2 each on one field, of one farm (PNB graph adapted from Wijnhoud et al., 2003).

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.

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