Introduction

Fertiliser use in agriculture increased rapidly during the green revolution: global fertiliser use increased by about 310% from the mid-1960s to the end of the 1980s (Pandey, 1999). Vietnam did not become part of this development until the end of the 1980s, when the Vietnamese government began to apply the reform policy '*doi moi*'. This resulted in the de-collectivisation of agriculture and the elimination of most subsidies and price controls. The opening up of the economy entailed the introduction of new crops and new fertilisers, and agriculture in some areas in Vietnam shifted from low input agriculture with a close cycling of nutrients (Nguyen van Bo, 2001) to high input agriculture that resulted in an increase in the consumption of mineral fertilisers by 350% between 1990 and 1999 (FAO; http://apps.fao.org;11-Mar-2002). This development also entailed increased agricultural production and the paddy rice yield increased by 129 % during the same period (FAO; http://apps.fao.org;17-Oct-2003). But high input systems may also have adverse effects on ground- and surface waters through leaching and runoff. It has been shown, for example, that nitrate concentration in ground and drinking water exceeded the critical WHO value for drinking water (11.3 mg NO_3-N L^{-1}) in half of 110 locations in an intensive vegetable production area in Beijing and Habei provinces in North China (Zhang, Stuetzel, & Kolbe, 1998). This situation may eventually be repeated in Vietnam and may then provide the impetus for a change in the Vietnamese agricultural policy towards improved nutrient use efficiency. As well as being determined by agricultural policies, on-farm nutrient management is also a result of the farmer's knowledge, which is mainly based on practical experience (Gerber, 1992). Rapid changes put new demands on farmers' knowledge, and a policy of improved nutrient use efficiency would subsequently put an increasing demand on their knowledge of efficient nutrient management technologies. In this process farmers' knowledge may need to be complemented with scientific knowledge, which is difficult for the farmers to generate themselves (Gerber, 1992). A scientific definition of efficient nutrient management is one that balances the optimum effect of the nutrient inputs to crop production with the economic and environmental cost of that input (Whitmore & van Noordwijk, 1995).

Objectives and research frame

The overall objective of this thesis was to characterise nutrient management in a peri-urban village in southern Vietnam and to understand the farmers' underlying rationale. The methods used were calculations of nutrient budgets and balances to evaluate the nutrient management (Watson & Atkinson, 1999) and Participatory Rural Appraisal and Rapid Rural Appraisal (PRA/RRA) methodology to gather information on farmers' concepts about soil fertility and fertilisers and their access to information. Participatory Rural Appraisal and Rapid Rural Appraisal methodology has proved successful in revealing farmers' knowledge (Chambers, 1994). The results presented in this thesis are based on three field surveys: the first conducted in March-May 1997 surveyed nutrient inputs to different crops by means of semi-structured interviews and questionnaires; in the second in November 1997-March 1998 it was intended to conduct a fertiliser experiment to find suitable nutrient input levels for Pak-Choi (*Brassica chinensis*); and the third in June-September 2000 was intended to establish nutrient balances and investigating the farmers' rationales for their nutrient management. The first field survey formed a basis for the nutrient management study carried out in 2000, but the fertiliser experiment was destroyed by larvae. Complementary laboratory experiments were also conducted in Sweden on soil samples collected at the field site in Vietnam.

The field surveys were conducted in co-operation with the University of Agriculture and Forestry in Thu Duc, Ho Chi Minh City, Vietnam.

Background

Nutrient management in Vietnam

Nutrient management in Vietnam dramatically changed after the government introduced the reform policy '*doi moi*' in 1986. Farmers moved away from traditional nutrient management whereby most organic waste products and wastewater were recycled to agricultural land (Nguyen van Bo, 2001) due to the increased availability of cheap chemical fertilisers and decreased availability of farm labour. The most input intensive farming systems in Vietnam are found in the peri-urban areas (*i.e.* areas which are affected by urban market forces; Aldington, 1997), and the densely populated river deltas (the Red River delta and the Mekong River delta), while nutrient management by swidden agriculture and limited use of fertilisers is still the most widespread system in the three quarters of Vietnam that comprise hills and mountains, (Wezel, Luibrand & Le Quoc Thanh., 2002). Thus nutrient management in some areas of Vietnam is characterised by low input of nutrients with the risk of nutrient depletion, while other areas may be characterised by high inputs of nutrients due to the import of livestock feed and fertilisers.

On a national level on-farm nutrient management is also related to the trade balance because most of the fertiliser consumption in Vietnam is met by imports. However, the Vietnamese government controls the fertiliser supply as it owns most of the fertiliser companies and regulates imports through quotas to different fertiliser companies (FERTECON, 1999). It is possible to find almost any fertiliser formula you wish in Vietnam, and there were no less than 290 NPK formulas available in 2000, but the most commonly used fertiliser is still urea, although the consumption of diammonium phosphate (DAP), and NPK is increasing. The most popular NPK formulas are 16-16-8, and 20-20-15 (Ha Trieu Hiep, pers comm., 2000)

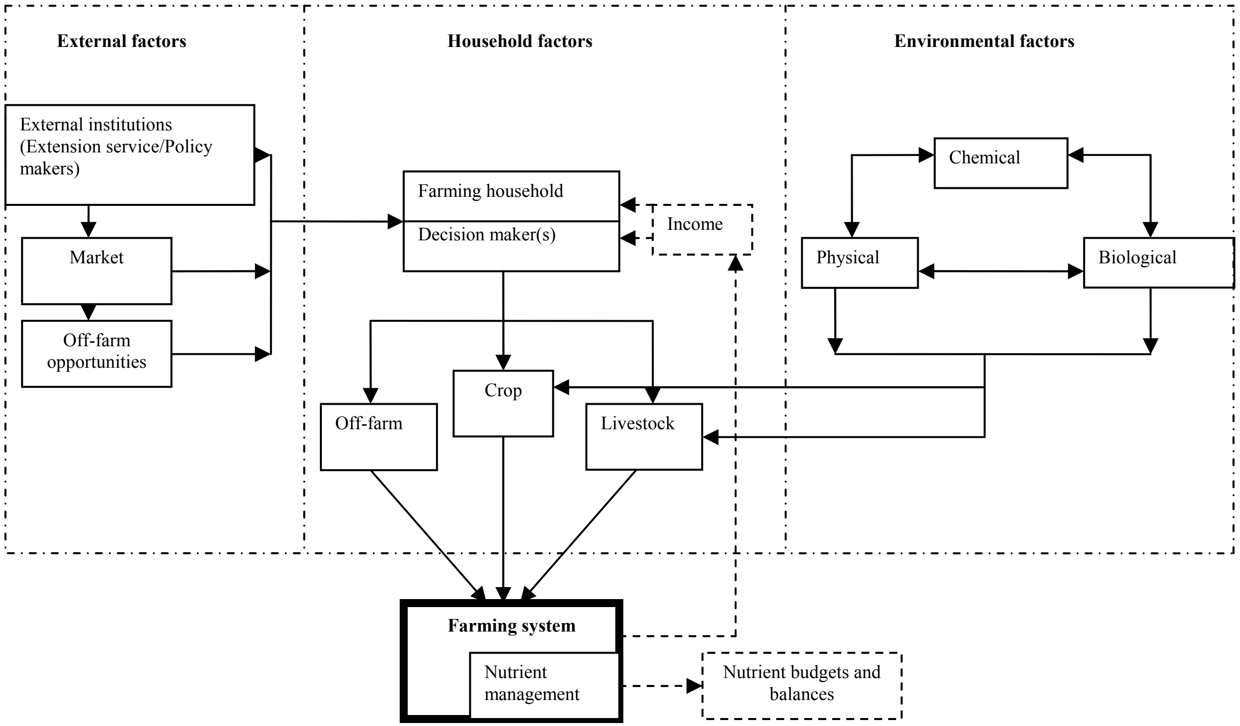

Figure 1. The major determinants of a farming system affecting the nutrient management on a farm (modified from Norman, 1980). The arrows show how the different determinants relate to each other. Broken lines represent results of the farming system.

Methods to study nutrient management

Nutrient management is just one aspect of farm management and has to be seen in the context of the farmers' struggle to adjust investments in crop and livestock production to the market and legislation, the needs, knowledge, interests and health of all members of the household. Therefore the study of nutrient management was done in the context of a farming system (Figure 1). A farming system is a unit consisting of the household (household factors) that manages its resources such as crop, livestock and off-farm resources in an environment that is dependent on *e.g.* climate, topography, and soil (environmental factors). The farming system is also a part of a larger society (external factors) that affects the farming system *e.g.* by policy, access to external information, market facilities and off-farm opportunities. The nutrient management is a part of the resulting farming system, and can be quantitatively evaluated by means of nutrient budgets and balances.

Nutrient budgets and balances

A nutrient budget is a procedure that accounts for inputs and outputs of nutrients in a defined system, and the nutrient balance refers to the difference between the sum of inputs and outputs (Janssen, 1999). Nutrient inputs and outputs that may be considered in a field balance/soil surface balance are shown in Table 1, but nutrient balances may also be established for other systems with other input and output flows, *e.g.* farm-gate balances or balances for different farm units. The kind of nutrient balance to be established is determined by the purpose of the study, the type of data available, and the boundary of the system. Nutrient budgets and balances at farm level can be used as tools to analyse the whole system, to identify unutilised nutrient sources or nutrient accumulations, and to assess the level of integration between farm units. Field balances, on the other hand, can be used to identify whether nutrients are accumulated or depleted from the soil, and to assess the risk for nutrient losses to the wider environment. A field balance can be established for a single crop, or for a whole crop rotation and thereby serve as an evaluation of the cropping system. Nutrient budgets can be seen as a point of departure for further analyses of the system. They have, for example, been used to identify and optimise flows between different trophic levels in Asian rice-based agroecosystems (Dalsgaard & Prein, 1999). A nutrient budget is rarely complete and, consequently, can be used to estimate flows that are otherwise difficult to measure. Stoorvogel & Smaling (1990), van der Pol (1992) and Krogh (1997), for example, used nutrient balances to quantify subsoil nutrient depletion in the Sahel and sub-Saharan Africa, while Powers & van Horn (2001) estimated nutrient excretion from a livestock unit on the basis of a nutrient balance approach.

Table 1. *Nutrient inputs and outputs in field nutrient budgets and balances (from Smaling, Nandwa, & Janssen, 1997)*

Nutrient inputs	
IN 1	Mineral fertilisers
IN 2	Organic inputs (manure, feeds, waste, etc.)
IN 3	Atmospheric deposition in rain and dust
IN 4	Biological nitrogen fixation
IN 5	Sedimentation by irrigation and natural flooding
Nutrient outputs	
OUT 1	Harvested products
OUT 2	Crop residue removal
OUT 3	Solute leaching
OUT 4	Gaseous losses
OUT 5	Runoff and erosion.

Nutrient use efficiency

Nutrient budgets may be used to calculate nutrient use efficiency, which is the efficiency with which a nutrient is transferred from one pool to another. It may, for example, be used to calculate the percentage of applied fertiliser that is taken up by the crop or exported from the farm in crop products. Similarly, it may be used to calculate the efficiency with which nutrients in animal feeds are converted to animal products. Nutrient use efficiencies may differ greatly between crops and farming systems and there are as yet no standard values for these efficiencies. Comparison of the NUE for the same crop but between farming systems, or for different crops on the same soil type provides a basis for further studies to reveal the causes of the observed differences. The nutrient use efficiency was used as a means to compare different rice-based cropping systems (Pascua *et al.*, 1999) and in mixed crop-livestock systems in Africa (Brouwer & Powell, 1998).

Retention capacity and availability of nutrients in soil

A common way of expressing NUE is as the ratio between nutrient output and input (nutrient output/nutrient input x 100). For the crop system this way of calculating NUE does not take into account the availability of the nutrients to the crop. Thus the NUE calculated may need to be evaluated in relation to the retention capacity and availability of nutrients in the soil. High nutrient retention and/or low reserves of available nutrients would require higher nutrient additions in order to meet the crop need (Johnston, 2000), which would result in a low NUE. The soil's ability to deliver or retain nutrients depends on soil type, nutrient management history and the prevailing soil processes. The fate of the most common nutrient elements included in the nutrient balances (N, P and K) are: sorption as exchangeable cations (NH_4-N and K), and sorption to aluminium and iron oxides (P). The latter process may in acid soils render P virtually unavailable for crop uptake. Nitrogen and P may also be accumulated in the soil by incorporation in organic matter. Conversely, NO_3-N may be lost from the system by leaching below the rooting depth or by denitrification.

Participatory methods to understand farmers' rationales

Nutrient management is affected by the farmer's decisions, which in turn depend on several socio-economic factors including income, his/her knowledge, perceptions about soil fertility and fertilisers and access to external information on crop nutrient need. Participatory methods enable people to share, enhance and analyse their knowledge (Chambers, 1994), which also makes them useful for gathering information about farmers' rationales for their decisions. The common feature of participatory methods is that the active participation of the farmers or the rural communities is required. The participatory methods reported have been collectively referred to as rapid rural appraisal (RRA) or participatory rural appraisal (PRA), and have been developed from the areas of agroecosystem analysis, applied anthropology and field research on farming systems (Chambers, 1994). Participatory rural appraisal can be seen as a further development of RRA, and there has been a debate concerning the differences between PRA and RRA methods. One way of defining them in a continuum has been suggested by Chambers (1994), and is shown in Table 2.

Table 2. *The RRA-PRA continuum (from Chambers, 1994)*

	RRA			PRA
Mode	Extractive	Elicitive	Sharing	Empowering
Outsiders role	Investigator	---		Facilitator
Information analysed, owned and used by:	Outsiders	---		Local people
Methods used	Mainly RRA	---		Mainly PRA

Participatory rural appraisal methods have been used in various areas of study spanning from soil and water conservation to adult literacy programmes (Chambers, 1994). Examples of PRA tools are livelihood analysis, institutional diagramming, wealth ranking, matrix scoring and ranking, *etc.* (Chambers, 1994). Central to the participatory approach is the attitude towards the local community (Table 3), in which the 'appropriate attitude' emphasises the farmers' competence and the importance of communication rather than the outsiders' competence and the delivering of knowledge or prefabricated technological packages. In PRA the researchers work closely with local people to determine conditions, evaluate perceptions and preferences and to share knowledge with the local people (Goma *et al.*, 2001).

Participatory rural appraisal may be conducted with individuals or in groups, and in general it is better to collect specific 'household' details from individuals, while general information is most successfully collected from groups (Nabasa, 1995). "Truth" is approached by *e.g.* triangulation, by using multiple sources, methods and investigators, and by actively searching for discrepancies (Pretty, 1995).

Table 3. *Different attitudes when using participatory methods (From Nabasa, 1995)*

Inappropriate attitude	Appropriate attitude
Farmers are reluctant to adopt, they are 'lazy', and 'stupid'	Farmers have good reasons for non-adoption
We know best	Farmers know their own working environment
Farmers should learn from us	Learning is a two-way process with ourselves and the farmers
We must tell farmers	We must listen to farmers
'Modern' methods must be superior to 'traditional'	'Traditional' methods can be as good as 'modern' methods
Over-emphasis on quantitative data	Emphasises use of qualitative data or indicators.

Materials and methods

Site description

The study was carried out in the village of An Son, which is situated in a peri-urban area in Binh Duong province, about 30 km northwest of Ho Chi Minh City (11^{o} N and 106^{o} E) on a flood plain of the Saigon river (0.5-2 m a s l). An Son has 1100 households, of which about 50 % derive their main income from farming activities. The village is divided into five hamlets (An Phú, An Quói, An My, An Hoà and Phú Hung) (Figure 2). The climate is tropical with an average yearly precipitation of ca 1900 mm (SIWRR, 2000), and two seasons: a rainy and a dry season. The village is protected against flooding by a dyke, and the land is drained by a network of canals and ditches which also serves as an irrigation system during the dry season. Some flooding, nevertheless, occurs every year during the rainy season and lasts for 2-3 days each time. The soils are classified as Sulfic Endoaquents or Sulfaquents (Soil Survey Staff, 1999), depending on the altitude and the land use. The soils have a pyrite layer at a depth of between 30 and 45 cm which, in combination with drainage to about 40 cm causes the soil to be acidic due to oxidation of the sulphidic material (van Breemen, 1982). Consequently, the soil has a low pH that varies between 3.9 and 6.6 (Paper II), and the crops have a shallow rooting depth (ca. 15-40 cm). This soil type is commonly called Acid Sulphate Soils (ASS), and covers about 1.7 million ha of Vietnam (Vo-Tong Xuan & Tran Kim Tinh, 1994). It is mostly found in the Mekong River delta, which is an important area for agricultural production in Vietnam.

An Son is situated in a renowned orchard area close to Lai Thieu, and fruit (such as jackfruit (*Artocarpus heterophyllus* Lam.), durian (*Durio zibethinus* Murr.) and mangosteen (*Garcinia mangostana* L.)) is a traditional crop in the area. The orchards in part of the village were destroyed during the Vietnam War (1964-1975), and the farmers in this area (Phú Hung and An Quói) mostly grew rice

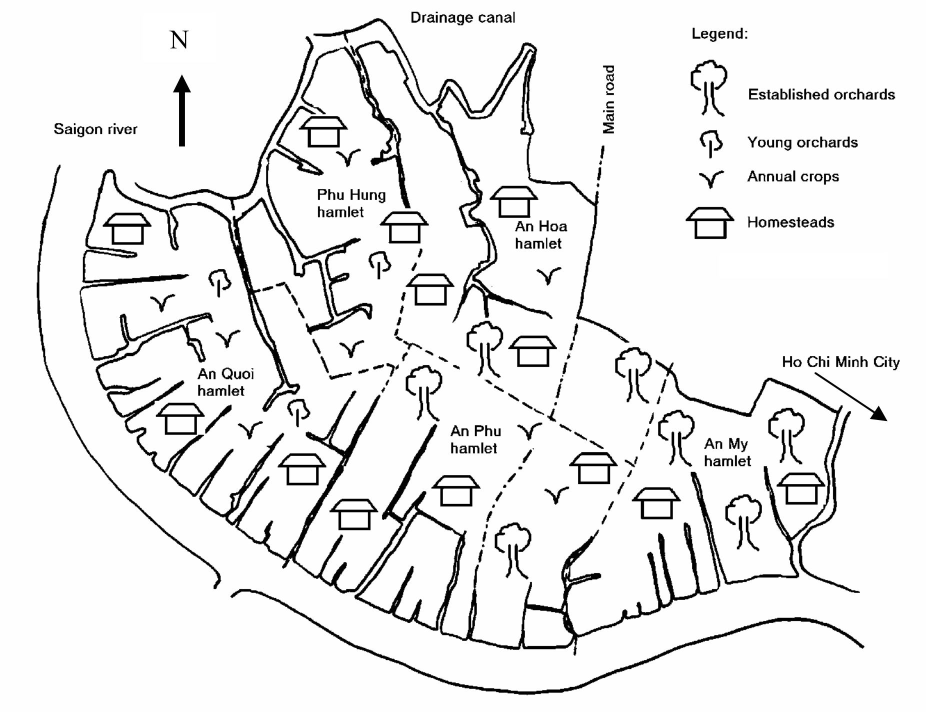

Figure 2. The village of An Son borders on the Saigon River and is protected by a dyke. The land is drained by a network of drainage canals. The western part of the village consists mainly of established orchards while the eastern part comprises young orchards and annual crops.

(*Oryza sativa* L.) and sugar cane (*Saccarum* spp.) before 1990 (Fermskog & Johansson, 2003). The tendency since then has been to increase the area with other annual crops such as taro (*Colocasia antiquorum* S), maize (*Zea mays* L.), different vegetables, jasmine (*Jasminum multiflorum* L.) and orchards (Table 4). This characterises the village, which is divided between old orchards and newly established orchards in combination with different annual crops (Figure 2).

The farms in the village were small (Table 4), and some of them comprised livestock production. The most common livestock were pigs, scavenging chickens and ducks. A few farms had industrial production of broilers and eggs. Chickens and ducks usually scavenged in the gardens and the ditches and were kept mostly for home consumption. The pigs were kept in pig pens for production of piglets or fattening pigs. Two pig raising systems existed: either keeping sows for production of piglets that could be sold or further raised as fattening pigs, or buying in piglets to rise as fattening pigs. The pigs were of improved breeds (*e.g.* Yorkshire, Landrace and Duroc) and were mostly fed with purchased feed concentrate. Off-farm opportunities for employment were good; as farm labourers, middlemen, or as factory workers in the nearby industrial area (Table 4).

Table 4. *General description of the farming systems in An Son village (information obtained from interviews and group meetings)*

Farm unit	Description
Whole farm	
Farm size	0.9-30 sau[1]
Availability of labour in family	1-4 persons
Cash need	To purchase food, fertilisers, pesticides, livestock feed, veterinary medicine, firewood/kerosene
Market facilities	Access to market in the village, 3 km to district town, 6 km to provincial town, 30 km to Ho Chi Minh City
Commodities	Radio, TV, motorbike, bicycle
Indicators of high wealth (*khá/giàu*)[2]	Access to labour in the household, big landholdings (40-50 sau[1]), knowledge and education that gives good off-farm opportunities
Indicators of low wealth (*nghèo*)[2]	Lack of labour in the household, lack of land (<1 sau[1]), have to take low income off-farm jobs, too many children (~4)
Off-farm opportunities	As middlemen, farm labourers, or factory workers in the industrial area near the village
Extension service	The village is supported by the extension service centre of Binh Duong province
Crop unit:	
Field size	0.9-20 sau[1]
Annual crops (2-5 harvests per year)	Sugar cane (*Saccarum* spp.), taro (*Colocasia antiquorum* S), rice (*Oryza sativa* L.), pak-choi (*Brassica chinensis* L.), holy basil (*Mentha* sp.), aubergine (*Solanum melongea* L.), calabash (*Lagenaria vulgaris* L.), sponge gourd (*Luffa cylindrica* L. Roem.), cucumber (*Cucumis melo* L.), and maize (*Zea mays* L.).
Perennial crops	jackfruit (*Artocarpus heterophyllus* Lam.), durian (*Durio zibethinus* Murr.), rambai (*Baccaurea sapida* Muell.-Art.), areca nut (*Areca catechu* Murr.), rambutan (*Nephelium lappaceum* L.), mangosteen (*Garcinia mangostana* L.), and langsat (*Lansium domesticum* Jack), banana (*Musa sapientum* L.), lime (*Citrus limon* L.), calamondin (*Citrus microcarpa* Bunge), jasmine (*Jasminum multiflorum* L.)
Hired labour	0-200 man days per year for preparing the soil, weeding and cleaning the ditches
Livestock unit:	
Livestock	Pigs, ducks, chicken
Livestock density	0-7 sows year around, 0-100 fattening pigs per year and farm, 0-100 ducks year around (10-30 most common), 10- 60 scavenging chickens year around and industrial production of chicken
Fish pond unit	
Species	*e.g.* cat fish (*Pangasius hypophthalmus*) and elephant ear (*Osphronemus gouramy*)

[1]1 sau = 1000 m^2

[2]According to wealth rankings done in An Quoi, Phu Hung and An My, 2000.

The village was served by an extension service centre, which was common for the whole province. The duty of the extension service centre was to serve the farmers and to transfer technology. In Binh Duong the extension service centre had 29 staff members who served 70 villages through the local farmers' associations. The farmers' associations organized short training courses, mainly through so-called extension clubs. The extension clubs had their origin in "Integrated Pest Management" groups organised by a former FAO project.

Research frame and methods

The study was carried out within the frame of a farming system analysis because the nutrient management on each farm is dependent on factors ranging from the information flow and policy from external institutions to the chemical and biological processes in the individual field (see Figure 1). The study was carried out in three parts: part one included nutrient management in different farming systems; in part two the factors that could influence the farmers' decisions on nutrient management were identified; and in part three the retention capacity and availability of nutrients in the soil were examined.

Nutrient management in different farming systems

In the first part, I started to identify the farming systems in the whole village in order to identify the dominant crop and/or livestock systems. This was done with PRA/RRA methods in groups of 7-13 well-informed farmers, who were willing to participate, in each hamlet of the village. The effect of the nutrient management was quantified by calculating nutrient budgets and balances on representative individual farms (n=9) representing the following crop and/or livestock systems: annual crops; annual crops in combination with pig production; perennial crops; perennial crops in combination with pig production (Paper I). Farm-gate balances were calculated based on balances for each of the farm units; crop unit, livestock unit and/or fishpond. Nutrient balances were done for nitrogen, phosphorus and potassium for the preceding year (July 1999 - July 2000). Nutrient use efficiency (nutrient output/nutrient input x 100) was calculated on the basis of the nutrient inputs and outputs in the different farm units.

Farmers' rationales for their nutrient management

The second part was carried out with a PRA/RRA approach and dealt with the farmers' perception about fertilisers and information sources (Paper II). Four group meetings were held with farmers in which each group (of 6-9 farmers) represented each of the following farming systems: annual crops; annual crops in combination with pig production; perennial crops; and perennial crops in combination with pig production. The PRA/RRA tools included ranking and scoring procedures (Chambers, 1994; Nabasa 1995). A complementary study using the ranking exercise was done with seven representative individual farmers participating in the nutrient balance study to obtain a better understanding of farmers' concepts regarding the quality of plant nutrient sources. To cross-check, fill information gaps and to complement the problem identification, a group meeting with key informants, including all hamlet leaders and vice hamlet leaders, who were all experienced farmers, was held. For the same reason semi-structured interviews with three fertiliser retailers, two fertiliser agents, and one extension worker in the area were carried out. This part also involved the identification of problems with soil fertility in the village, which were done at the same time as the identification of farming households (part one) in three of the hamlets: Phu Hung, An Phu and An Hoa (Paper II). The PRA/RRA tools used were problem and solution flows.

Retention capacity and nutrient availability in the soil

Part four comprised soil analyses and laboratory incubations. In connection with the nutrient balances soil samples were collected and further analysed at 6 of the 9 farms participating in the nutrient balance study. The variables analysed were pH, carbon content, extractable phosphorus and exchangeable cations. The pH was analysed in a 1:2 water extract, and the carbon content was analysed on a LECO analyser by dry combustion. Bray-1 phosphorus was extracted as described by Bray and Kurtz (1945) and determined by the molybdenum blue method (Murphy and Riley, 1962). Exchangeable cations were extracted in 0.10 M $BaCl_2$ (Hendershot and Duquette, 1986) and analysed on an atomic absorption spectrophotometer (AAS). CEC at ambient pH was calculated by summing the exchangeable cations, and % base saturation was calculated as Σ (Ca^{2+} + Mg^{2+} + K^+ + Na^+)/CEC x 100. Sampling was stratified by fertilised and unfertilised areas, which were identified with help from the farmer.

Phosphorus sorption may be an important retention process in acid sulphate soils (Sanyal, De Datta & Chan, 1991). Therefore phosphorus sorption-desorbtion isotherms were established on three separate soil samples from An Son with a pH of 4.4-4.7. Procedures described by Fox & Kamprath (1970) were used, but adjusted to a smaller amount of soil. A 30 mL solution of 0.01 M $CaCl_2$ containing $Ca(HPO_4)$ corresponding to 0, 2, 12, 20, 40, 120 and 240 mg P kg^{-1} soil was added to 3 g of soil. Two drops of toluene were added to avoid biological immobilisation of P. The soil slurry was allowed to equilibrate for 10 days after which the slurry was centrifuged and phosphorus in the supernatant was analysed by flow injection analysis. Thereafter 28 mL 0.01 M $CaCl_2$ was added for another 5 days equilibration after which phosphorus concentration was again determined in the supernatant to establish the desorption isotherms.

Since all the N fertilisers used in An Son contained N in the form of urea or NH_4, nitrification was an important process to study because it determines the extent to which the N added could be lost by denitrification or leaching. Potential nitrification was analysed by the shaken-slurry method (Hart *et al.*, 1994) on soil samples from three sites in An Son with a pH of 4.4-4.7. A 100 mL buffered solution (pH 7.2), containing 0 or 21 ppm NH_4-N was added to 3 g soil. The slurry was incubated on an orbital shaker for 2 hours after which the slurry was centrifuged and the supernatant was analysed with respect to NO_3-N by flow injection analysis.

Table 5. *A summary of the main issues and the methods used in this thesis*

Parts of the study	Issue	Method		Paper no
Nutrient management in different farming systems	Identification of farming systems	Ranking	Group meeting (n=7-13)	I, II
	Management of nutrient inputs	Nutrient budgets and balances	Individual farmers (n=9)	I
Farmers' rationales for their nutrient management	Identification of problems regarding soil fertility	Problem flows	Group meeting (n=7-13)	II
	Farmers' use of different plant nutrient sources	Scoring	Group meeting (n=6-9)	II
	Farmers' criteria when selecting plant nutrient sources	Scoring	Group meeting (n=6-9)	II
	Farmers' evaluation of different plant nutrient sources in relation to different criteria	Matrix scoring	Group meeting (n=6-9)	II
	Farmers' evaluation of information sources	Pair-wise ranking	Group meeting (n=6-9)	II
Retention capacity and availability of nutrients in soil	Nutrient availability	Soil analyses	Individual farmers (n=6)	I
	Nutrient retention: Phosphorus sorption-desorption	Laboratory incubations	Soils from 3 sites in An Son	
	Nutrient losses: Nitrification	Laboratory incubations	Soils from 3 sites in An Son.	

Results and discussion

Nutrient management in different farming systems

Nutrient balances at farm level

Nutrient management as affected by the farming system determinants may be evaluated and quantified by the establishment of nutrient budgets and balances (Figure 1). The nutrient balances showed that the surveyed farms comprised high input systems, although levels of nutrient input varied greatly among the farms (Paper I). On the livestock farms nutrient input ranged from 209 to 2113 kg N, 76-771 kg P and 84-1167 kg K ha^{-1} year $^{-1}$. On the farms without pig production the figures were generally somewhat lower, *i.e.* 38-928 kg N, 25-656 kg P, and 32-486 kg K ha^{-1} year $^{-1}$. Feedstuffs were an important source of input of N, P and K on the livestock farms, but inputs through fertilisers were nevertheless high. Farm-gate balances were positive on all farms: 31-868 kg N, 23-644 kg P and 9-770 kg k ha^{-1} per year.

Nutrient balances in the different farm units showed that many of the farming systems in An Son superficially appeared to be integrated. They seemed integrated because they consisted of several farm units such as livestock units (pigs or chicken), different crop units and sometimes even a fishpond. Nevertheless, the nutrient output from one farm unit seldom matched the nutrient use in the next unit, which implied instead that the integration was poor and nutrients were subsequently lost to the environment. Nutrient losses were not measured explicitly, but one important loss on livestock farms was liquid manure, resulting from the hosing of the pig pen, that was often washed directly into the ditch. This pathway represented nutrient losses of 26-643 kg N, 6-99 kg P, and 24-528 kg K ha^{-1} year $^{-1}$. There were only two farms with a fishpond, which showed low nutrient use efficiencies of 22-32%, 2-13% and 1-2% for N, P and K, respectively (fish products calculated as output). So even if a fish pond was added it only improved the integration and the overall nutrient use efficiency to a limited degree. The addition of a bio-digester is sometimes proposed to increase the integration on the farm, but it does not affect integration from a nutrient point of view since the bio-digesting process does not consume or add any nutrients. Nevertheless, the addition of a bio-digester proved to have a negative effect on the nutrient use efficiency on the farms in An Son. The reason was that liquid manure does not contain enough carbon for effective bio-gas production so the solid manure, which could otherwise be used to fertilise the fields, was instead used for the bio-gas production.

Nutrient balances at field level

The cropping systems also comprised high input systems. Except in one rice field, the nitrogen balances were positive in all fields with surpluses of between 31 to 1736 kg N ha $^{-1}$ and year. This may be compared to N surpluses of 110-130 kg N ha^{-1} and year for arable crops in Germany; and 125-230 kg N ha $^{-1}$ and year for winter wheat-summer maize double cropping in Yangling, and 217-335 kg N ha^{-1}

and year for irrigation summer rice-upland winter wheat in Jiangsu, China (Richter & Roelcke, 2000). The P balances were positive in all fields with surpluses of between 20 to 1292 kg P ha^{-1} and year, while the K balances were somewhat lower with surpluses of 9 to 913 kg K ha^{-1} and year. The K balance was negative in two fields: in one orchard and one rice field.

The field balances showed that N and P output with fruit was much lower than output with other crops, while in all systems the output of K was much higher than the output of N and P. This was also reflected in the nutrient use efficiency (NUE), which showed that the NUE of fruit production was generally lower than that for the other crops (1-19%, 1-7% and 9-72%, for N, P and K, respectively). Rice and taro in particular had a higher NUE (5-73%, 3-51% and 8-61%, for N, P and K, respectively). The lower NUE of the orchard crops compared to that of the other crops was largely due to much lower nutrient outputs, while inputs were not correspondingly lower. Among the orchards, orchard 7 (F7:Paper I) and orchard 2 (F2:Paper I) achieved the highest NUE, which was mainly due to different nutrient management than in the other orchards. Orchard F7 was only fertilised with a limited amount of mineral fertiliser and F2 with manure combined with only a small amount of urea. Nutrient outputs in orchards 2 and 7 were no lower than those in the other orchards, which indicate that the yield was maintained and demonstrates the potential for more efficient nutrient management in the area.

Farmers' rationales for their nutrient management

Farmers' concepts of fertilisers and soil fertility

The farmers' concepts about fertilisers, the effect of fertilisers and their perception of soil fertility may be an important part of their rationale for a certain form of nutrient management. In Paper II it was shown that the farmers' concept of fertilisers deviated from the scientific concept of fertilisers as primarily plant nutrient sources. The farmers' concept was broader and they comprehended the fertilisers as amendments that were added to promote good conditions for plant growth, either directly ('promotes fast growth') or indirectly by improving soil fertility, alleviating soil acidity or reducing pests, which would subsequently lead to increased crop yields. Thus it may be concluded that the farmers' management concerns were the fertilisers rather than the nutrients they contain. The fertilisers used were both single functional, like urea which only promoted fast growth, and multifunctional, like the traditional fertilisers (Table 6). The farmers preferred to use multifunctional fertilisers such as wood ash, NPK, and stored pig manure on the farms where pigs were kept.

In Paper II problem flows also showed that the farmers' perception of soil fertility was connected to observation of yields. A low yield was an indication of poor soil fertility; acid soil and poor soil structure were soil factors mentioned that affected the yield. But poor soil fertility could also be an effect of flooding, climate, and an unstable market because it caused a lower yield. The farmers knew how to improve the soil by adding lime, super P or manure to alleviate the soil acidity, or ash to improve the soil structure.

Table 6. *Farmers' characterisation of different fertilisers. The matrix presented is an average of a matrix scoring procedure in three groups of farmers (A, Pe, PePi) whereby each farmer scored 0-3 for each combination of fertiliser and criteria. The result presented is an average per farmer and is shown qualitatively: values less than 0.1 are indicated with 0, values between 0.1-1 *, 1.1-2 with **, and 2.1-3 with ***. A higher value indicates better correspondence. Combinations that were not mentioned in any of the groups are indicated with –*

Fertiliser	**Urea**	**NPK**	**DAP[1]**	**SP[2]**	**Lime**	**WA[3]**	**RA[4]**	**PM[5]**	**CM[6]**	**QM[7]**	**PC[8]**	**LP[9]**
Criteria						Matrix score						
'Practical'												
Cheap	**	*	*	***	**	*	***	**	***	0	*	0
Easy to find	***	***	***	***	**	**	***	**	**	0	*	0
Easy to use	***	**	**	0	*	*	**	**	**	**	*	*
'Pest management'												
Kills pests	0	0	0	0	***	0	0	0	0	0	0	0
Repulses termites	-	0	0	-	***	0	0	0	0	-	-	-
'Functional'												
Promotes grain filling	0	***	**	0	*	***	0	0	0	0	0	-
Promotes good fruit quality	-	***	**	-	**	***	0	0	0	-	-	-
Promotes fast growth	***	*	*	**	*	*	*	**	*	0	***	**
Promotes root growth	0	**	**	***	0	***	**	*	*	*	***	-
Reduces soil acidity		*	*	***	***	*	*	***	*	**	0	**
Makes the soil soft	0	0	0	0	0	*	***	**	***	*	*	0
Long term effect	*	*	*	**	*	***	**	**	**	***	***	*
Promotes soil fertility	0	*	*	-	*	***	*	**	**	-	***	**

[1]Diammonium phosphate
[2]Super phosphate
[3]Ash from firewood
[4]Ash from rice husks
[5]Stored pig manure
[6]Stored chicken manure
[7]Stored quail manure
[8]Peanut cake – a residue from peanut oil production
[9]Liquid pig manure.

Access to information about nutrient management

Access to information may be an important determinant affecting the farmers' decisions on nutrient management. In An Son the farmers' access to external information on farm management was mainly through the extension service centre in Binh Duong province and through radio and TV. The extension service centre operated in An Son through the extension club, which had about 40 members, and also through brochures with management recommendations. The information from radio and TV and extension was considered to be too general by most of the farmers, instead they valued information sources that provided specific information, adapted to local conditions (Paper II). This kind of information was best provided by tradition, neighbours and their own experiments. Paper II also revealed an interesting information system whereby some innovative farmers used unspecific information provided by the extension service centre, the extension club or the radio and TV for their own experiments, the results of which they shared with their neighbours in coffee shop discussions. This shows the usefulness of farmer-to-farmer extension and has potential for the introduction of improved technology.

There was also a lack of information on nutrient requirements of different crops because recommendations were only available for 4 of the 21 crops grown in the area. Although the farmers did not really express any wish for more or better information on nutrient management, this may, nevertheless, be a potential need, and providing them with knowledge that they cannot generate themselves would assist their efforts at development. Instead the farmers requested new crop varieties and better post-harvest techniques to improve their competitiveness in the market.

Market and off-farm opportunities

It was shown in the problem flow presented in Paper II that the market prices had a strong effect on nutrient management. The farmers expressed frustration about the unstable market, and claimed that the low price for their products made them less inclined to invest in the fertiliser inputs they perceived were needed. Thus they would have probably added more fertilisers if the prices for their products had been higher. The farmers in An Son had just experienced a price decline in fruit after newly established orchards in another area had started to produce. Also the prices of rice and sugar cane were low at the time of the study.

The most important off-farm activity in An Son was to be a wage earner and the off-farm opportunities were good. On most farms one or more of the members of the family worked off-farm *e.g.* as middlemen or in the nearby industrial area. This caused a shortage of on-farm labour, which was also shown in the problem flow (Paper II). The lack of on-farm labour was a reason why most farmers with annual crops aimed at increasing the area with orchards on their farms. It was also a reason mentioned for making them less inclined to use liquid manure as fertiliser, even though it was considered to be a reasonably good fertiliser (Table 6), since it was laborious to use.

Income

Income level is a factor that affects investment capacity and thereby the possible input level in nutrient management. Income level may also serve as an evaluation of the farming system. The total income level on farms in An Son was not investigated explicitly, but an economic balance was done on the basis of the nutrient balances on 7 of the 9 farms participating in the nutrient balance study. The economic balance showed that the economic inputs were better balanced with the economic outputs than the nutrient inputs were with the nutrient outputs. The purchase cost of fertilisers varied between 5 and 53% of the income from the crop sold (Figure 3); the highest economic inputs were to newly established orchards (Orchard 1:1, and Orchard 9:2), and may thus be considered as investments, and also to crops where the economic return was high, such as vegetables, jasmine and taro. Otherwise the input cost varied between 5 and 10 % of the income from the crop. This indicates a low incentive to reduce fertiliser inputs, and contradicts the farmers' view that low prices for the agricultural products affected their willingness to invest in fertilisers negatively. It also shows that fertiliser inputs were adjusted to expected income. The fertiliser price varied between 0.03 USD (wood ash) to 0.23 USD per kilo (super P). Rice husk ash and composted livestock manure were even cheaper.

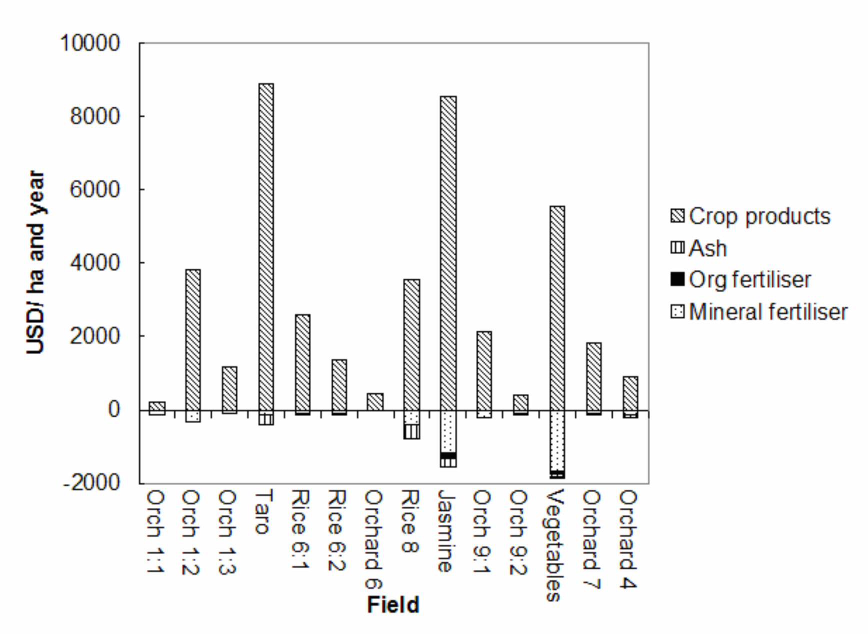

Figure 3. An economic balance based on the nutrient inputs and outputs in the fields of 7 of the farms participating in the nutrient balance study. The index of the different fields follows the same system as in table 6 Paper I.

Retention capacity and nutrient availability

The retention capacity and nutrient availability in the soil determine the recovery of added nutrients in the crop (*i.e.* NUE). Drained acid sulphate soils may suffer from unavailability of phosphorus, low base saturation and nutrient deficiencies (Dent, 1992), which may warrant high nutrient inputs to promote good conditions for plant growth and would result in a low NUE. The soil analyses on Bray-P and exchangeable K showed, however, that the labile fractions of phosphorus were relatively large in the fertilised areas of the fields (23-222 mg P kg^{-1}) as well as the exchangeable potassium (0.22-0.96 cmol K kg^{-1}). Also the base saturation was very high in the fertilised areas (50-100%). The nutrient concentration was much lower in the non-fertilised areas though: 2.4-36 mg P kg^{-1} and 0.14-0.33 cmol K kg^{-1} and a base saturation of 34-83% (Table 7). It is therefore possible that high nutrient application rates reflect past experience of low soil fertility in this area, which, as indicated by soil analysis, may now no longer be warranted. Bray-P values above 30 mg P kg^{-1} are considered to be high (Kamprath & Watson, 1980), and exchangeable K values above 120 ppm, which corresponds to 0.30 cmol kg^{-1}, is considered to be good (Mengel & Kirkby, 1987). On the individual farms the soil analyses showed that the nutrient management had increased the pH, the P and K status, and the base saturation in all the fields except field 1, where instead all the variables had decreased. In field 6 the K and P status was still below the recommended values, despite the enormous inputs of N, P and K. There were, however, no data available on the nutrient status of the unfertilised soil at this site.

Table 7**.** *Soil chemical data from fertilised and unfertilised soils at a depth of 0-15 cm*

Fields[1]	1[3]	2[2]	3[3]	4[3]	5	6[4]
Fertilised soil						
pH_{H2O}	4.0	4.8	6.6	4.1	5.1	4.7
C (%)	4.4	4.9	6.5	4.6	5.0	4.8
Bray-P (mg kg^{-1})	222	156	-	167	110	23
K (cmol kg^{-1})	0.58	0.96	0.67	0.43	0.59	0.22
Base saturation (%)	50	90	100	66	96	79
Unfertilised soil						
pH_{H2O}	4.7	4.3	5.1	4.0		
C (%)	3.7	5.2	6.3	4.0		
Bray-P (mg kg^{-1})	36	11	-	2.4		
K (cmol kg^{-1})	0.32	0.33	0.15	0.14		
Base saturation (%)	71	41	83	34		

[1] Index for different fields in Paper I: 1, Orchard 1:2; 2, Orchard 2; 3, Taro; 4, Orchard 7; 5, Jasmine, 6, vegetables
[2] Fertilised 6 weeks before sampling
[3] Fertilised Sept. 1999
[4] Fertilised 3 days before sampling.

The behaviour of the added phosphorus is largely governed by the hydrous oxides of Fe and Al in the soil and the Bray-1 extraction will mainly extract the aluminium phosphates. The degree of P saturation on soil surfaces is the most important soil parameter regulating the P level in the Bray-1 extract (Kuo, 1996). The fate of added phosphorus may also depend on the sorption-desorption behaviour of the individual soil (*e.g.* Fox & Kamprath, 1970; Sanyal, De Datta & Chan, 1991). The P adsorption capacity shown by the phosphorus sorption-desorption isotherms in Figure 4 demonstrated that there was a linear relationship, with a slope of 0.0025, between the added P and the P remaining in the soil solution, up to the addition of 240 mg P kg^{-1}. This means that more than 99% of the phosphorus added (up to 240 mg P kg^{-1}) was adsorbed during the 10-day equilibration, and it could not be desorbed again in a 0.01 M $CaCl_2$ solution. This shows a strong affinity for phosphorus in the soil, but it does not mean that the added P becomes completely unavailable to plants because 0.01 M $CaCl_2$ is a rather weak extractant. When the phosphorus saturation of the soil increases, the sorption affinity of the soil will eventually decrease. The phosphorus status of the incubated soils was about 10 times lower than that of the fertilised soils in the nutrient balance study, as analysed by the AL extraction method (Egnér, Riem & Domingo, 1960). This implies that the P sorption capacity should have been lower in those soils. The P sorption-desorption isotherms indicate a need for special management practices with regards to the P-application, *e.g.* placement rather than broadcasting of P fertiliser, addition of slow-releasing P sources, and addition of P at growth stages when the plant is able to most successfully compete for the added P (Sanyal, De Datta & Chan, 1991). Placement is already a widely spread practice in An Son.

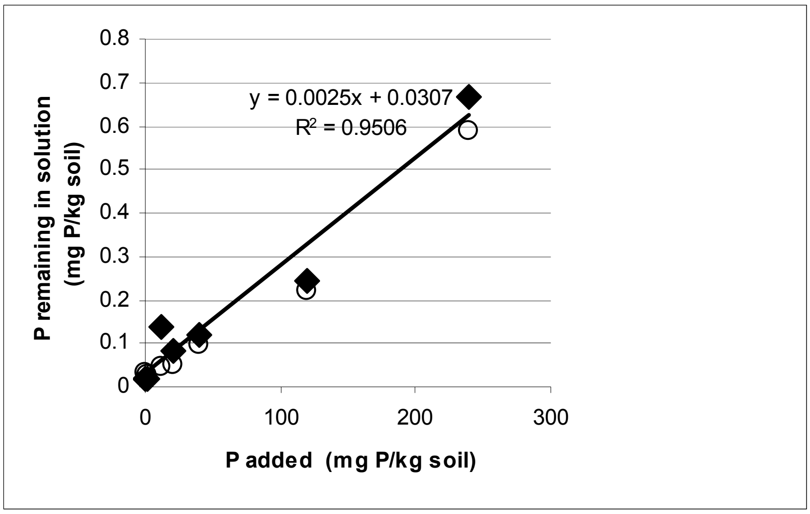

Figure 4. Phosphorus sorption (filled symbols) and desorption (empty symbols) isotherms up to an addition of phosphorus corresponding to 240 mg P kg $soil^{-1}$. The chart shows an average of three soils with pH 4.4-4.7.

The biological process of denitrification could account for considerable losses of nitrogen and thereby explain some of the excessive inputs of nitrogen. The soils in An Son have conditions favourable for denitrification such as a high content of organic carbon (Table 7) and a very shallow groundwater table (15-40 cm). However, this process was unlikely to have been important for the fertilisers added as they were only added as urea, or as NH_4-N, and the potential nitrification proved to be negligible, possibly due to the low pH. Perhaps the importance of this process will increase as the pH of the soil increases due to management practices.

There are also other biological processes that may account for the low NUE, for example the total nutrient uptake and storage by the crop. The nutrients in the trunk of the fruit trees do not leave the field and were not included in the nutrient budgets, but they are withdrawn from circulation for a long period of time. A study on durian in Malaysia showed that a 7-year-old plantation had retained 40 kg N, 9.1 kg P and 44.3 kg K ha^{-1} in the trunk, root, and leaves, respectively (Yaacob, 1983). This corresponds to an uptake of 6 kg N, 1.3 kg P and 6.3 kg K ha^{-1} per year. Fruit trees were being established in four fields in the study presented in Paper I (Orchard 1.1 and 1.2, Orchard 6, and Orchard 9.2; Paper I) but on the basis of the data by Yaacob (1983), the amounts taken up by non-harvested crop parts are too small to make any substantial difference to the nutrient balance and NUE of these orchards. For mature fruit trees, Huett & Dirou (2000) suggested that the fruit nutrient output is a sufficient guide for nutrient demand. It therefore seems that the nutrient inputs shown in Paper I were excessive at least in the orchards.

Reasons for the existing nutrient management

On the basis of the soil fertility data it would seem to be sufficient to fertilise the crop so that the output through harvest is replaced, unless the crop was grown on a field or a part of the field that have not been fertilised before. So why did the farmers practice nutrient management that resulted in large nutrient surpluses when they perceived that they fertilised too little due to low investment capacity? One reason may be the paradigm of input expansion that is common in areas that have recently experienced a ‘green revolution’ (Pandey, 1999), which may make the farmers feel that they ought to invest more in inputs. Another reason is likely to be that the farmers had no information on the nutrient flows; they did not know that their nutrient management resulted in large surpluses. Instead they could have perceived that the price of their products declined and that they consequently needed larger harvests to maintain a stable income. And perhaps adding fertilisers that promote a set of good conditions for plant growth was perceived as an assurance of an acceptable income. In conclusion, the farmers just responded rationally to what they could see and experience: the paradigm, the cost, the income and the observed soil- and plant performance.

One reason for low NUE at farm level on livestock farms was the high stocking rate in relation to farm size and the import of livestock feed. Externally produced feedstuff is a prerequisite for the level of pig production on the small areas that characterise the farms in An Son since these farms are not big enough to produce enough fodder themselves. Livestock production was also a strategy to increase agricultural production and the income from a small piece of land. The management of the by-products from livestock production to a large degree determines the NUE on livestock farms. The farmers’ perceived low investment capacity could be relieved by efficient use of the excreta; a large portion of the excreta was still being wasted. However, the low cost of fertiliser and lack of labour do not provide any strong incentive for carrying 400 L of liquid manure to the field every day. It is also easier to carry solid manure to the nearest field, resulting in a positive nutrient balance, rather than to spread it on several fields.

Since the farmers saw a liming effect from the added manure, to them adding solid manure that provides nutrients in excess of the crop need is not bad practice. Manure is perceived to alleviate soil acidity, make the soil soft, and promote soil fertility (Table 6) thereby creating a fertile field.

Environmental aspects of the nutrient management

The positive nutrient balances, both at farm and field level, will increase the risk for adverse effects on the ambient environment. At farm level the disposal of the liquid manure in waterways will add to the progressive eutrophication of rivers and lakes in Vietnam. In Saigon River eutrophication already exceeds the national standard by 1.4-2.6 mg NH_4 L^{-1} and 2-4 mg BOD (biochemical oxygen demand) L^{-1} (Ministry of Natural Resources and Environment, 2003). Furthermore the nutrient load to the sea from the river mouth of Saigon River is 28 000 ton phosphate and 19 000 ton nitrate per year (Ministry of Natural Resources and Environment, 2003) and this will affect corals and sea grasses negatively (CPACC; http://www.cpacc.org; accessed 21-Nov 03).

At field level the shallow rooting depth of most crops and a high groundwater table means that excessive nutrients may easily leach beyond the rooting depth, and thereby be lost from the plant system. Estimates of nutrient leaching in three orchards in An Son (Fermskog & Johansson, 2003) showed amounts of about 50 kg N, 100 kg K, and 0.9 kg P ha^{-1} and year. All three orchards had positive nutrient balances of between 67-285 kg N, 70-130 kg P and 55-284 kg K ha^{-1} and year (including the leaching output). Thus the positive nutrient balances shown in Paper I may lead to substantial nutrient leaching. Apart from the financial loss, leaching of nutrients could also eventually lead to contamination of groundwater and drinking water. A sample (n=6) of drilled water-wells (16-25 m deep) in the Red River delta showed NH_4 levels of between 0.02-1.03 mg L^{-1} (Vo Thi Thanh Huong, 2000), while the background level seldom exceeds 0.2 mg L^{-1} (WHO, 1993). High NH_4 levels are not a problem in themselves, but they indicate bacterial contamination from sewage and animal waste (WHO, 1993). Nitrate levels were not analysed.

Potential for improving nutrient management

One important prerequisite for achieving improved nutrient management is that the nutrient flows are made transparent to the farmers. In order to reduce their fertiliser inputs farmers need to think in terms of nutrients instead of (or in combination with) the concept of fertilisers as amendments that improve the conditions for plant growth. One way of elucidating nutrient flows would be to label the nutrient content of fertiliser bags as % pure N, P and K instead of P_2O_5 and K_2O as it is today. Other important information is the nutrient content in manure and ash, and the nutrient requirement of the crop. As shown in this study the nutrient requirement of the crop may be based on the nutrient content of the crop (Table 8) and the expected size of the harvest. This provides a potential for the extension service centre to develop nutrient recommendations for the crops grown in the area, without having to do time consuming and expensive field experiments.

On a national level a way to increase incentives for more efficient fertiliser use would be to increase fertiliser prices. This is a measure that has been suggested by Pandey (1999) to increase the incentive for adoption of nutrient management technologies that would improve nutrient use efficiency. It is, however, important to remember that in some areas, *e.g.* in upland areas, high fertiliser inputs may be warranted while the farmers' financial margins are small. A higher fertiliser price could, however, be compensated for by subsidies on fertilisers in such areas.

A solution to counteract the low integration between the livestock unit and crop unit practised in, for example, Sweden is to limit the stocking rate per unit area to 2.2 sows or 10.5 fattening pigs per hectare to balance the nutrient output from the livestock unit with the crop nutrient need, based on the P content in the excreta and the P output with a cereal crop (SJVFS 1999:79). However, in Vietnam this would prevent farmers on small pieces of land from complementing their income with livestock production. A regulation practised in Vietnam today that limits the stocking rate is that farmers are forced to reduce the smell from animal production if the neighbours complain about it (Bui Xuan An, pers comm., 2003.). One measure to reduce the smell is the installation of bio-digesters to process the livestock excreta; effluent from a bio-digester smells less than fresh excreta. This will, however, further reduce the nutrient integration between the livestock unit and the crop unit because bio-digesters have to be loaded with manure that otherwise could have been used to fertilise the fields.

A measure at village level that could better integrate the livestock units with the crop units is that livestock farmers share the excess manure produced with their neighbours without livestock. What was striking in An Son was that the manure produced on some livestock farms was sometimes transported all the way to Da Lat (300 km away) by a middleman, while the transport of manure within the village was very limited, and instead the farmers transferred the entire amount of solid manure produced the crop unit on the livestock farms.

There are also some practical measures that would make it easier for the farmers to manage the fertiliser inputs more efficiently. Today the fertiliser types and packaging are more suited for large-scale agriculture. Since highly concentrated fertilisers have to be added in such small amounts to the small fields that characterise the farms in An Son, it would be easier to use, and evenly distribute, fertilisers with lower nutrient concentrations. This is also the kind of fertilisers that the farmers have used traditionally, *i.e.* ash and manure. Moreover mineral fertilisers are soluble salts that are always distributed in 50 kg bags, which may be too much for a small piece of land, but too hazardous to store in a humid tropical environment. Therefore the farmer chooses to empty the bag rather than store it for the next crop.

Table 8. *Nutrient content in different crops grown in An Son*

Crop		Nutrient content			Source
English	***Latin***	**N %**	**P %**	**K %**	
Aubergine	*Solanum melongea*	0.16	0.03	0.27	Ministry of Health. Vietnam (1995)
Banana	*Musa sapientum*	0.14	0.03	0.36	Ministry of Health. Vietnam (1995)
Calabash	*Lagenaria vulgaris*	0.10	0.03	0.15	Ministry of Health. Vietnam (1995)
Calamondin	*Citrus microcarpa*	0.25	0.03	0.34	Analysed at EPCAF[1]-lab 2000
Durian	*Durio zibethinus*	0.24	0.04	0.44	USDA (2001)
Egg plant - small	*Solanum melongea*	0.24	0.02	0.22	Ministry of Health. Vietnam (1995)
Jack fruit	*Artocarpus integrifolia/heterophylla*	0.10	0.03	0.41	Ministry of Health. Vietnam (1995)
Jasmine	*Jasminum multiflorum*	0.51	0.08	0.70	Analysed at EPCAF-lab 2000
Langsat	*Lansium domesticum*	0.26	0.04	0.38	Analysed at EPCAF-lab 2000
Lime	*Citrus limon*	0.14	0.02	0.46	Ministry of Health. Vietnam (1995)
Maize	*Zea mays*	1.38	0.19	0.31	Ministry of Health. Vietnam (1995)
Mango	*Magnifera indica*	0.08	0.01	0.16	USDA (2001)
Mangosteen	*Garcinia mangostana*	0.15	0.02	0.5	Analysed at EPCAF-lab 2000
Mint leaves	*Mentha sp.*	0.32	0.05	0.18	Ministry of Health. Vietnam (1995)
Pak choi	*Brassica chinensis*	0.19	0.03	0.47	Analysed at EPCAF[1]-lab 2000
Rambai	*Baccaurea sapida*	0.08	0.03	0.3	Analysed at EPCAF[1]-lab 2000
Rambutan	*Nephelium nappacum*	0.15	0.02	0.14	Analysed at EPCAF[1]-lab 2000
Rice	*Oryza sativa*	1.28	0.10	0.56	Ministry of Health. Vietnam (1995)
Rice		1.26	0.23	0.24	Analysed at SLU[2] 2000
Taro	*Colocasia antiquorum*	0.29	0.08	0.45	Ministry of Health. Vietnam (1995)

[1] Environmental Protection Centre
[2] Swedish University of Agricultural Sciences.

Relevance of the study

The farms participating in the study comprised a representative section of farming systems in the village since they were selected from a thorough survey of the farming systems. The result of the study gives a fair description of nutrient management in An Son, which was characterised by great variations in the fertiliser inputs that were not correlated to the nutrient output with the crop harvest. The great variation makes it difficult to make general conclusions about the fertiliser management for similar cropping systems. It shows instead that there was no common base of knowledge among the farmers with regards to the nutrient demand even for similar crops. Fertiliser management was based on the individual farmer's personal judgement directed by individual knowledge, experience, and ability to find relevant information. An Son is situated in an area where many villages have similar farming systems. Thus great variations and large nutrient inputs may be expected even in other villages in the area.

The study also shows the importance of using methods to understand the farmers' rationale for their management of fertilisers that may otherwise seem confusing and irrational. This understanding is a condition for knowing what measures are needed to help farmers improve their management of nutrients.

Conclusions

Livestock farms in this area in southern Vietnam comprise high nutrient input systems, with a poor integration between farm units, resulting in low nutrient use efficiencies and a risk of nutrient losses to the wider environment. The intense production of livestock with import of livestock feed and a high stocking rate produces excreta that contain nutrients in excess of crop need. Even though the solid manure is used to fertilise crops, the liquid part of the excreta is still washed into waterways. This constitutes a risk of a nutrient load to the waterways with eutrophication of rivers, lakes and sea as a possible result. A solution for improving nutrient use efficiency on intensive livestock farms is to find better ways to utilise the excreta, for example by distributing it over a larger crop area including stockless farms, and by finding ways to utilise the liquid part of the excreta. An alternative is to reduce the stocking rate by legislation.

Stockless farms in this area in southern Vietnam also have high input systems and the nutrient input often exceeds nutrient output with the crop harvest. There is little evidence that shows that this high input level is needed. The observed low nutrient use efficiency is largely due to the fact that farmers cannot observe the nutrient flow and therefore do not know that their inputs create surpluses. Other factors are also the lack of fertiliser recommendations and the low price of fertilisers. The farmers respond rationally to what they can see, and from their practical experience, and with sufficient information on the nutrient content of different fertilisers as well as the crop need of nutrients they may act accordingly and reduce their inputs. Although the price of fertiliser is low, the farmers would still benefit financially from reducing inputs.

On the acid sulphate soils that prevail in An Son, the high P sorption capacity shows the importance of proper P management techniques, such as placing of fertilisers, split applications and proper timing of application in order to increase the P use efficiency. It is also important to select appropriate fertilisers to alleviate soil acidity since the application of, for example, manure to alleviate the negative impact of the acid soil may have a negative impact on the N balance, while lime or super phosphate will have a limited effect on the nutrient balances as long as the P sorption capacity is high.

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The river below shines like a mirror, spotless and clean.
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