The C.T. de Wit Graduate school for
Production Ecology & Resource Conservation

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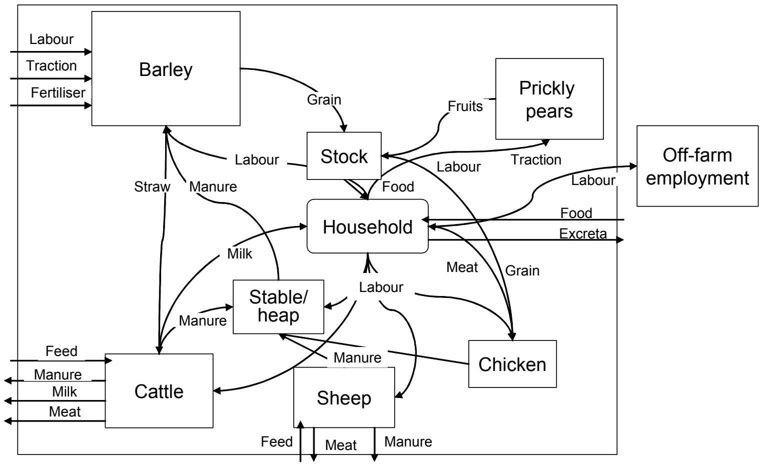

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Evaluation of economic and environmental performance of two farm household strategies: diversification and integration

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Hans Langeveld[1], Mariana Rufino[1,4], Huib Hengsdijk[1], Ruerd Ruben[2], John Dixon[3], Jan Verhagen[1] & Ken Giller[4]

1 Plant Research International; Wageningen UR
2 Centre of International Development Studies Nijmegen, Radboud University Nijmegen, formerly Development Economics Group; Wageningen UR
3 Impact Targeting and Assessment Programme, CIMMYT, Mexico, formerly Agricultural Services Division, FAO
4 Plant Production Systems Group; Wageningen UR

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Office C.T. de Wit Graduate School for Production Ecology & Resource Conservation (PE&RC)
Haarweg 333
NL-6709 RZ Wageningen
The Netherlands
Phone: 31(0).317.485116/485414
Fax: 31(0).317.485572
E-mail: Office.PE@wur.nl

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Abbreviations and acronyms

FAO	Food and Agriculture Organization of the United Nations
IFPRI	International Food Policy Research Institute
IRMLA	Systems research for integrated resource management and land use analysis in east and south-east Asia
IRRI	International Rice Research Institute
MDG	Millennium Development Goal
PAIA	Priority Area for Interdisciplinary Action
PIMEA	Policies for Sustainable Land Management in the East African highlands
PRODS	Integrated Production Systems
RESPONSE	Regional Food Security Policies for Natural Resource Management and Sustainable Economies
RTDP	Reversing Trends of Declining Productivity
RTOP	Reaching Toward Optimal Productivity
WUR	Wageningen University and Research Centre

Preface

Hunger and poverty stalk the world; despite decades of development efforts, more than 800 million people are under-nourished. Against this backdrop, the community of nations in 2005 renewed its commitment to sustainable development and the achievement of the Millennium Development Goals (MDGs), including the halving of hunger and poverty. The complex context in which MDGs are to be achieved is characterised by changes in demography, socio-cultural development, economic, policy and institutional setting, climate, natural resources and technological development. This context frames the design of sustainable development pathways and options to achieve the MDGs.

While the need for increased food and other agricultural produce to feed future generations is generally recognized, it is not always appreciated that in the next 25 to 30 years agricultural output has to double without significant additional land resources. For this reason, agricultural intensification is inevitable. Historically, however, intensification all too often was associated with resource depletion. Agriculture has the potential and the responsibility to find ways to design sustainable agricultural systems that not only increase food and fibre production but at the same time reduce the negative environmental impacts and are equipped to cope with economic and environmental shocks. A systems approach offers options to acknowledge interactions and arrive at integrated resource management options that address these concerns.

Noting the importance of integrating production systems for agricultural development and food security, FAO established a priority area to foster inter-disciplinary studies and action on integrated production systems, called Integrated Production Systems (PRODS). FAO invited Wageningen University and Research Centre to establish a multi-disciplinary research team to investigate the economic and environmental dimensions of farm household performance under different scenarios related to intensification and diversification. As a result, the report presents analyses, results and implications of the studies of the integrated production systems.

Lessons drawn from the analysis include:

- quantification of economic and environmental performance of more or less diversified farm household systems yields relevant information for the evaluation of development strategies and potential policies;
- positive environmental impacts of farm level diversification only can be attained if farming activities are sufficiently integrated. In practice, the level of integration of farm systems generally is low to very low;
- results from the case studies suggest that diversification at the farm household relates positively to farm income and food attainability, and thus can be considered as a meaningful strategy to improve food security;
- farm household diversification, further, is positively correlated to farm size (larger farms realising more diversity) and labour productivity, but negatively to land productivity;
- no clear relations were found between farm household diversification on the one hand and nitrogen and carbon management on the other hand.

The report identifies a number of potentially valuable follow up actions, including:

- application of the developed methodology to more case studies in order to check whether the findings can be applied more widely (i.e. in more regions, for more farm types);
- use quantified case study data to study the relation between farm size and diversification, interactions between stocks and annual flows, water use efficiency, integrated resource management, effects of non-farm activities on economic and environmental performance, behavioural aspects of decision making, consumption effects of diversification and effects on common resources management.

FAO welcomes feedback on the conclusions of the study and the proposed follow up actions.

D. Baker
Chair
PRODS PAIA - FAO

Acknowledgments

The report results from intensive cooperation between Plant Research International, the Plant Production Systems Group, the Development Economics Group (all part of Wageningen University and Research Centre - WUR) and the Food and Agriculture Organization of the United Nations (FAO). The authors are grateful to their institutions for providing them the opportunity to develop a methodology for evaluating economic and environmental performance of farm household strategies. Case study data for Ethiopia and Honduras have kindly been made available by the WUR-IFPRI research program RESPONSE.

In the course of the investigation a wide range of sources were consulted and many research and development professionals contributed. In particular, the authors acknowledge the contributions of Roel Bosma, Hugo van der Meer, Jenny Ordoñez, Rob Schipper, Tri Van Pham Dang and Willem Visser for their assistance in obtaining, arranging and explaining case study data. The authors are further indebted to Herma Mulder (for clarifying issues related to the Teghane dataset), Girmay Tesfay (for his expert knowledge on yields, labour allocation and market prices in Teghane), and to Wang Guanghuo (for his assistance on the use of the Pujiang dataset).

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This report has been prepared under the aegis of the Agricultural Management, Marketing and Finance Service of the Rural Infrastructure and Agro-Industries Division of FAO. The analysis was originally conceived in FAO by John Dixon (now with CIMMYT) and the report benefited from the review by Claire Bishop. Many thanks go to Doyle Baker, Chief of the Agricultural Management, Marketing and Finance Service, for his support and advice.

The study would not have been possible without financial contributions from FAO and the climate research programme of the Dutch Ministry of Agriculture Nature and Food Quality (LNV), which is gratefully acknowledged. The WUR-IFPRI research program RESPONSE has been supported by the Dutch Ministry of Foreign Affairs and the European Union. The research team would like to express their appreciation to the professionals who collected the data used in the case studies within the projects ‘Policies for sustainable land management in the East African highlands (PIMEA)’ and ‘Systems research for integrated resource management and land use analysis in east and south-east Asia (IRMLA)’.

Finally, special thanks are extended to all farmers and their families who took the time to share with us their experiences on field management, animal and crop production, off-farm employment and household matters. We hope that the result gives heed to their efforts.

1. General introduction

1.1 Introduction

With the adoption of the Millennium Declaration by the General Assembly of the United Nations the joint realisation of poverty alleviation and sustainable development received renewed attention and support worldwide (UN, 2000). The declaration resulted in the formulation of eight Millennium Development Goals (MDGs), the most important of which are the halving of hunger and poverty by 2015, which in developing countries are both strongly linked to agriculture. Other MDGs relate to primary education, environmental sustainability, child mortality and the creation of a global partnership for development. Through the MDGs, clear and quantifiable targets have been set that can be used to guide policy formulation.

The dynamic context in which these MDGs are to be achieved is characterised by ongoing changes in demography, socio-cultural development, economic, policy and institutional setting, environment resources and technological development. This context frames the design of sustainable development pathways, which are critically linked to local societal and political processes and stakeholder involvement. To meet the challenges posed by the MDGs will require major investment, appropriate technology development and transfer, and human and social capacity building (Halsnaes and Verhagen, 2005). With 75% of the world's poorest people still living in rural areas and primarily dependent on agricultural production for their livelihood, intensification of farming systems may be expected to play a central role in establishing pathways to achieve the MDGs. Whether the process of intensification is sustainable will depend on the way it is implemented. Intensive systems are not, by definition, sustainable (nor, for that matter, are extensive systems). The sustainability of a given system depends on how effectively it makes use of inputs (external or internal), irrespective of the level of inputs applied. More specifically, it demands putting serious limits on emissions (nutrients, agro-chemicals), while increasing input use efficiency.

Traditionally, agriculture underpins the key livelihood strategies for most people living in rural areas. Beyond agriculture's main function in the provision of food and fibres, it also contributes to economic development by providing employment in and income from value chains.

In the context of the ambitious goals captured in the MDGs, agricultural development faces considerable threats such as climate change, population increase and urbanisation, as well as the effects of globalisation and poor health (e.g. HIV/AIDS). Climate change will have a negative impact on crop yields in many tropical regions (IPCC, 2001). Globalisation of markets may push more households into poverty, especially those living in marginal areas, where production conditions are less favourable. Labour and health are intrinsically linked; malaria and the increase in HIV/AIDS infections will have a strongly negative impact on the availability of labour and capital resources in affected households (FAO, 1997). The prospects for many of these drivers are unfavourable, especially in developing countries (IPCC, 2001; IMF and World Bank, 2005; UN, 2005).

Given the (potential) impact of these threats, the ability of agriculture to withstand shocks or external changes has become the subject of intensive study. Following analyses of ecological systems, resilience as applied to agricultural systems has been defined as the potential of a particular system configuration to maintain its structure and function in the face of disturbance, and its ability to re-organise following disturbance-driven change (Holling, 1973; Carpenter *et al*., 2001). Appropriate policies are required to foster the development of a more resilient form of agriculture against the backdrop of increasing threats and disturbances by processes of global change. It is in this light that the Food and Agriculture Organization (FAO), amongst others, identified diversification of on-farm activities as an important strategy for further exploitation with the aim of increasing yields and production in a sustainable way, especially in developing countries (Dixon *et al.*, 2001; Barrett *et al*., 2001a).

Diversification is defined as the increase of the number of activities generating farm output or added value for the farm household. This includes activities generating off-farm income, be it in the form of business, local employment or remittances from family members. It is recognised that diversification is sometimes used in the more restrictive sense of the adoption of high-value crops, livestock or other production activities.

Diversification can be defined at different levels of aggregation - e.g. field, farm, region or country. The concept of diversification at field level is often associated with the use of mixtures of varieties of one crop species or mixture of different crops or other useful plants, such as practised in agro-forestry or intercropping. Diversification at the field level can also be expressed in the diversified use of production factors, e.g. the use of manure and fertilisers. In agricultural systems, it is the household level that provides the entry point for policy and man-environment interactions. Diversification at this level refers to combinations of different crops or types of crop production (e.g. cereals, pulses, tree crops), animal production, other on-farm activities (e.g. trading or other commercial activities) as well as off-farm activities. Within this study, the focus is on diversification within the farm household.

Current research on diversification generally takes a mono-disciplinary (either economic or agronomic) approach, often focusing on a single element of diversification (e.g. crop diversification, crop-livestock interaction, off-farm employment or migration). Quantitative studies generally follow an economic or econometric approach (e.g. Reardon and Taylor, 1996; Deininger and Olinto, 2001; Okike *et al*., 2001), while only few agronomic studies can be found (e.g. Rothuis *et al.*, 1998). Generic studies are rarely based on detailed case studies. Most attention is given to the income-generating effect of diversification. Other aspects, such as internal competition (e.g. for labour) have so far received much less attention. The World Bank study on diversification by McIntire *et al*. (1992), which contains general case studies and discusses internal competition, is one of the few exceptions to this.

While clear ideas have been presented on the relationship between diversification and, for example, resource productivity (for which often a negative relation is supposed (e.g. Ellis (2000), and Deininger and Olinto (2001), but which under conditions of market-led diversification driven by urbanisation and economic growth also may be positive), relatively little empirical evidence has been given to support them. Further empirical research is also needed to study necessary conditions for promoting adoption of diversification (see e.g. Reardon and Taylor, 1996; Barrett *et al.*, 2001a) and for identifying processes that channel returns of diversification into improved livelihoods and sustainable production systems (Ellis and Allison, 2004). More generally, there is a need for a quantified, multidisciplinary approach that can be applied to multiple regions, each with different agro-ecological and economic conditions.

One should, however, be careful when comparing the performance of farming systems (e.g. specialised *vs.* diversified systems) subject to different resource availability and external conditions (environmental as well as economic). While this problem is not exclusively related to research on diversification (or MDGs or policy analysis), any policy related to agricultural development should be based on a thorough analysis of the way prevailing systems around the world perform under a wide range of external conditions. This is also the case for policies to promote diversification and on-farm integration. Integration is defined as the state of inter-dependence between productive activities within a farm household system, occurring through input or product flows, some of which may be intermediate. In some cases, integration reinforces diversification, and thus may be viewed as an element of diversification. This analysis focuses on nitrogen flows.

1.2 Scope and aim of the study

The current report presents a framework to assess and compare the economic and environmental performance of farm household systems, characterising diversification and integration at household and farm scales. In developing this framework, the broader concept of the farm household system is used, thus including (besides agricultural production activities) the activities of household members, such as off-farm employment. Recent literature has shown the importance of off-farm activities on the performance of agriculture in Africa (Reardon *et al*., 1994; 1999), Asia (Pingali, 2001; Hengsdijk *et al.,* 2004) and Latin America (Deininger and Olinto, 2001).

The aim of the study is to evaluate diversification and integration as potential strategies for farm households to sustainably increase productivity and, hence, reduce hunger and poverty. The evaluation of farm households includes their economic performance (including the ability to produce or purchase food, generate income and factor productivity), environmental performance (including the use and management of nitrogen and energy inputs) and level of diversification and integration. Applying the framework, farm household strategies for different types of households can be compared under a broad range of (ecological, economic) conditions, yielding valuable information for the design of policies that may help realise the first MDG.

While there have been many studies involving nitrogen or energy flow analysis (e.g. Baird and Ulanowicz, 1993; Cavero *et al*., 1998; De Ridder and Van Keulen, 1990; Finn, 1980; Fluck, 1979; Fores and Christian, 1993), few have applied this type of analysis in a combined economic and environmental framework. Moreover, none have used it to compare farm household integration in farming systems as diverse as the ones described here (for China, Ethiopia and Honduras, respectively, see section 1.3). Further, as noted above, the ambitions set in the Millennium Declaration - especially in combination with threats posed to their realisation by processes of global change - justify a fresh look at farm performance assessment.

1.3 Background, concepts and definitions

The farm household is defined as a social and economic unit undertaking any kind of agricultural and other income generating activities. Household members generally live together, managing resources to obtain food, clothing, housing and other necessities. These members combine available skills and energy-use endowments under prevailing ecological, economic and social conditions and current objectives. Given the problems faced by farm households and the objectives defined in the MDGs, many changes may be expected in agricultural production over the coming years. Which specific changes occur will depend on the type of farm household, the ecological and economic conditions and the threats and opportunities they face. Five main strategies for the improvement of farm household livelihoods can be identified (Dixon *et al*., 2001):

- Expansion of land holding or herd size,
- Intensification of production systems (based on the existing enterprise pattern),
- Diversification (increasing the number of economic activities at farm or household level),
- Increase off-farm income (both agricultural and non-agricultural), and
- Complete withdrawal from the agricultural sector.

Expansion of the size of the land holding (both rented and owned) or the number of animals is one of the most common strategies to improve income. Often, however, available land is scarce, and availability of feed restricted, thus increasing dependency on external feed. Nevertheless, expansion of land is an increasingly observed phenomenon in some regions, as inhabitants that migrate to urban centres abandon their land holdings to those who stay, often without compensation (Rozelle *et al*., 2002; Kung, 2002). Labour and capital shortages may constrain poor farm households from benefiting substantially in such situations (Hengsdijk *et al*., 2004). Another source of extra land is the encroachment of public, non-agricultural land (e.g. forests), although these resources often have limited production potential. Expansion of the herd size on common grazing lands is another option, but this may easily result in overgrazing.

Intensification may be defined as the increase in factor productivity as a result of greater use of external inputs per unit area or per animal. It is associated with the use of more productive varieties and breeds, combined with improved farm management (e.g. irrigation practices, increased use of fertilisers, or pest control), but may also result from realising the same production level with reduced input levels.

Diversification refers to the allocation of production resources to different output or added value generating activities, both on- and off-farm. Multiple and contrasting motives prompt households to diversify assets, incomes and activities, but risk reduction and increase of income are among the major reasons. As a risk-reducing strategy, income diversification usually implies a trade-off between a higher total income, which involves a greater probability of income failure, and a lower total income, which involves a lower probability of income failure (Abdulai and CroleRees, 2001). Risk adverse households are those willing to accept lower income for greater security (Ellis, 2000). As a risk-seeking and income increasing strategy, diversification may be induced by favourable external conditions such as nearby urban centres, which offer market opportunities for new products or employment.

As was stated before, diversification refers to both off-farm income generating activities and activities such as new elements of farm production, on-farm processing and other farm-based activities aimed at adding value to commodities produced on the farm. From a natural resource perspective, diversification may enable the realisation of complementarities between different production activities, such as crop and livestock production under which crops may produce fodder for animals, which in turn produce manure to fertilise crops or provide draught power for field operations. Thus, the concept of diversification is closely related to the concept of *integration*, which refers to the inter-dependency and synergy of activities within farm household systems as depicted by input or product flows. Integration may also refer to financial connectivity, for example when off-farm earnings are invested in the development of on-farm activities.

Diversification and integration are often associated with sustainable and resource-use efficient systems (Dalsgaard and Oficial, 1997), although diversified systems are not necessarily integrated. Farm households may undertake diverse activities without real connectivity between the activities, while effective integration of relatively inefficient systems may also be found (e.g. fully integrated intensive crop production and animal production systems each, individually, showing low resource-use efficiency). For this reason, in the case studies a distinction is made between diversification and (degree of) integration within farm households.

The way farmers and their households *withdraw* from agriculture may differ from region to region and from year to year. Generally, land and farms are abandoned, the families often moving to other homesteads (generally nearer to alternative sources of income). Withdrawal may be - but is not necessarily - a poverty-driven strategy. In some cases farmers can no longer manage to cultivate their land, for example because they cannot afford the necessary inputs nor need cash, for which they hire out their labour. In other cases, farmers just seek more lucrative uses for their labour.

Apart from the exit strategy, all strategies are not mutually exclusive, and often members of farm households simultaneously pursue a mix of several strategies. Also, farm households not choose to either pursue or ignore any of the strategies. They may choose any combination of strategies which may permanently be subject to change.

1.4 Case studies

A limited number of farm households has been analysed in three contrasting areas with markedly different environmental and socio-economic characteristics: Teghane in Ethiopia, Pujiang in China and the country of Honduras in Central America. Each farm household was analysed according to the procedure described in Chapter 2. The farm household systems selected were ranked according to resource use and economic performance; over-simplification of categories and general statements have been avoided. In the process, two main issues were addressed: farm diversification and integration.

The nature and prevalence of integrated production systems depends on the local agricultural context. The three case studies analysed in this report can be related to the eight global farming system categories described in Dixon *et al*. (2001):

- irrigated smallholder farming systems (in large irrigation schemes);
- wetland rice-based farming systems – the China case study;
- rainfed farming systems in humid areas – the Honduras case study;
- rainfed farming systems in steep and highland areas – the Ethiopia case study;
- rainfed farming systems in dry or cold areas;
- dualistic farming systems with both large-scale commercial and smallholder farms;
- coastal artisanal fishing/ mixed farming systems; and
- urban-based farming systems.

The relative importance of each of these global farming systems is shown in Table 1, which provides an indication of the domain to which the findings from each case study might be applied. The table contrasts two important attributes of farming systems: underlying natural resource endowment and access to agricultural services, notably input (including fertiliser) and produce markets. This two-variable simplification of the domains covered by the farming systems categories echoes Boserup (1965) and some recent studies of smallholder development (see Wiggins, 2002).

The China (Pujiang) case is part of a wetland rice-based farming system that supports an estimated agricultural population of 860 million on 155 million hectares of crop land. This farming system is characterised by diverse forms of integration, including crop rotations (especially cash crops), provision of feed, integration of fish culture, and close links with input and output markets. The Honduras case is part of a humid rainfed farming system that supports 400 million people on 160 million hectares. Integration often incorporates agro-forestry and high value plantation crops such as coffee. The Ethiopia case is an example of rainfed highland systems, in which precipitation and soil moisture often limit agricultural production. In this system, some 520 million people depend on 150 million hectares; mixed crop-livestock systems prevail.

Table 1 Case studies and the global farming systems categories.

Category characteristic	Smallholder irrigated schemes	Wetland rice based	Rainfed humid	Rainfed highland	Rainfed dry/cold	Dualistic (large/ small)	Coastal artisanal fishing	Urban based
Cultivated area (million ha)	15	155	160	150	231	414	11	n.a.
Irrigated area (million ha)	15	90	17	30	41	36	2	n.a.
Agricultural population (millions)	30	860	400	520	490	190	60	40
Market surplus	high	medium	medium	low	low	medium	high	high
Case study	-	China	Honduras	Ethiopia	-	-	-	-

Source: Dixon et al., 2001, based on FAO data and expert knowledge
Note: Cultivated area refers to both annual and perennial crops

Average household resource endowments underpin the supply-side potential of on-farm intensification of existing patterns of production and of on-farm diversification to incorporate new farm components, which happen to be two of the most common strategies followed by farmers to escape poverty. Production system integration can underpin both intensification and diversification; intensification by improving effective use of increased levels of applied (external) inputs, and diversification by assuring optimal exchange of inputs and intermediate products among different activities within the system. The literature on population-driven intensification is substantial, most of it based on pioneering work by Boserup (1965) and Ruthenberg (1980), and carried forward by a number of researchers, including Pingali *et al.* (1987); a considerable proportion of development effort is directed to intensification of production processes in a sustainable way. Farm enterprise and income diversification is a common farmer response to changing resource ratios and market access (Delgado and Siamwalla, 1999), and many governments support farm level diversification. Diversification is an important strategy. Depending on the type and character of the production system, it is expected to contribute 20 to 30% to the realisation of the first MDG of halving the proportion of people living in poverty by 2015, which makes it a more promising strategy than intensification. Relative importance of diversification and intensification in the case study areas is given in Table 2.

Table 2 Relative importance of intensification and diversification for poverty reduction (%).

Poverty reduction strategies	Wetland rice based	Rainfed humid	Rainfed highland
Intensification	17	19	9
Diversification	34	27	27
Other strategies	49	54	64
Case study	China	Honduras	Ethiopia

Source: Dixon et al. (2001), based on expert panel judgements

1.5 Outline of the report

The analytical framework is presented in Chapter 2 and is applied to the case studies in Chapters 3 to 5. This is followed by a discussion on the outcome of the case studies (Chapter 6), and implications for research and policy (Chapter 7).

2. Methodological framework

2.1 Introduction

A practical and successful assessment methodology of economic and environmental performance of farm household systems needs to fulfil certain requirements. First, it should combine and integrate knowledge from various disciplines (economics, social sciences, environmental sciences, soil science, agronomy, animal husbandry and fisheries). Second, the methodology should describe existing variability in farm livelihood strategies in relation to household endowments and prevailing external conditions, and it should allow testing of the robustness (or vulnerability) of these strategies by using scenarios. This information is needed to analyse and explore policy measures that may induce desired changes. The description of farm household systems (i.e. systems performing well under existing and future conditions), as well as the identification of desired policy measures can assist other less successful households to improve their performance. Finally, the methodology should not be too data intensive. In other words, implementation of the methodology should be possible using data that is generally available; it should not require costly collection of additional data.

One problem that must be solved relates to desired scales of time and space for the analysis. Agricultural systems can be diversified at different spatial scales: regional, farm household and field. The basic principle of diversification is that, in theory, the physical/economic performance of one activity can be compensated by the performance of other activities. At a regional or national scale, for example, local food shortages may be compensated by food surpluses in other areas, or by the import of food from other regions using earnings generated by other sectors, such as industry and services. At farm household level - the focus of this study - diverse agricultural activities can take place, such as the production of grains, milk or meat, which can serve directly as food for self-sufficiency but can also be sold to generate income, thus enabling the purchase of food and other consumption goods. In addition, household members may have the opportunity to work off-farm and, hence, generate income that can be used for consumption or investment in their farm.

In this report a methodology for the assessment of economic and environmental performance of farm household systems is described. The methodology is based on (i) identification of farm typologies, (ii) graphical representation of resource stocks and flows, and (iii) calculation of indicators evaluating major characteristics of system components and the entire farm household system. The analysis is restricted to well known inputs like nitrogen, carbon, energy, cash and labour flows. These were chosen because they allow basic analysis of farm household production and input-use efficiency. Nitrogen and energy can be considered as the key defining aspects of interdependence in integrated systems. Analysis of these two inputs underpins a full appreciation of integration and the role it can play in supporting, in many instances, intra-farm household diversification.

The indicators used allow assessment of economic and environmental performance of farm household systems over a range of conditions. This chapter describes the subsequent steps of the methodology in detail. An illustration of its application is given in subsequent chapters, which compare farm household performance in three contrasting regions: Tigray in Northern Ethiopia, Pujiang County in Zhejiang province of China, and the country Honduras. The datasets that were used for this exercise were made available from other, existing projects; no further data collection was undertaken. Given the diverse backgrounds of these projects (see Chapters 3 to 5 for details), this provided a thorough opportunity to test the applicability and robustness of the methodology. In the remainder of this chapter, the principles of farm typology characterisation (Section 2.2), setup and application of the approach, including definition of indicators (Section 2.3), and data requirements (Section 2.4) are discussed.

2.2 Typology of farm household activities

To evaluate the effects of diversification on the performance of farm households, their activities must be identified and evaluated. Two classification criteria for farm household activities were applied, based on economic and/or bio-physical disciplines. First, activities should, directly or indirectly, contribute to household consumption. Thus, both income-generating activities (such as sales of agricultural products) and activities providing products for home consumption were included. Second, activities should have an impact on natural resource management, i.e. there should be a direct link between the activity and quality or quantity of the resources. On the basis of these two criteria, four major types of activities were identified; a fifth activity type fulfilled the first criterion (directly contributing to consumption) but did not entirely fulfil the second (only indirectly affecting natural resource management).

The following activity types, referred to as farm household 'components', are found in farm household systems:

- Activities aimed at the production of agricultural products for consumption within the farm household. Such products may include staple grains, vegetables and fruits, but also wood for cooking, milk, manure, etc. This activity includes the production of all those products that are not traded at markets.
- Activities aimed at the production of agricultural products for cash. In principle, these activities produce the same products as under the first type (above), but in this case they are sold on the market and contribute to the income of households. Note that in good years, surpluses are often sold.
- Activities aimed at the production of agricultural products that are not intended for consumption within the farm household, such as cotton, tea and coffee, but also wood for timber. In general, these are agricultural products that need to be processed before they can be used.
- Activities aimed at remunerative natural resource management (ecosystem services), i.e. services for which farm households are rewarded, such as carbon sequestration, maintenance or improvement of local biodiversity, and water conservation. At the bottom end of this type of activities are 'food for work' programmes in which farmers receive food for working in soil and water conservation activities.
- Activities aimed at generating income by renting out resources such a labour, land, oxen and other farm household resources. Hiring in (or out) of resources, such as off-farm employment activities (where labour is hired out), or the hiring of land, oxen and other resources may only indirectly affect natural resource management. Taking an off-farm job may affect availability of on-farm labour, but it will also increase cash flows needed for the purchase of external inputs or the hiring in of external labour (e.g. in times of labour shortage).

The distinction that is made is not absolute. Some activities may, depending on farm household and marketing conditions, be sold at one time but consumed at another. Activity types can be applied simultaneously by different household members or even by one member on his or her own. The range of activities chosen fits with the strategy the household and its members have selected to fulfil their needs given available endowments and (ecological, economic and social) conditions, but the role and contribution of an individual activity may differ. One additional type of activities has to be mentioned here. Because relatives living outside the region do not claim household resources they are not included as part of the farm household. Remittances generated by relatives living outside the region co-determine consumption and investment opportunities for the households, and they are considered external monetary flows to the farm household system.

2.3 A multi-step approach

The methodology consists of five steps: (i) developing a farm household typology, (ii) quantifying resource flows in representative farm households, (iii) calculating performance indicators both at the level of farm households and their activities/components, (iv) using results of the calculations to analyse and compare different farm household systems, (v) identifying policy lessons, including exploring scenarios. Subsequent sections each describe one of the steps.

Step i: developing a farm household typology

Performance of farm household systems is determined by the fit of farm characteristics with bio-physical and economic conditions. Farm households can be characterised by describing (i) resource endowments (land, labour, capital), (ii) production goals and aspirations, (iii) production structure (type of crops, animals, etc.) and so on (Norman *et al.*, 1995). In the adopted approach, farm households are described through their resource endowments rather than goals and aspirations, as the former are easier to measure, provide a useful link to socio-economic conditions of the farm household (poor, rich, short of labour or not), and form important information for policy formulation and evaluation.

Each activity contributing to consumption and affecting resource management can be considered as a separate farm household component, which is subsequently quantified in terms of inputs and outputs. Land use activities include soil management, although it is difficult to explicitly take relevant soil-related processes into account (leaching, denitrification, sedimentation, etc.) as information on the magnitude of these processes is scarce and incomplete. Given the importance, however, of these processes - representing important inflows and outflows - it is expected that the methodology will be extended in the near future to include a simplified strategy to account for (nutrients involved in) soil processes.

Representing system components alone is not sufficient for the characterisation of a farm household system. It is equally important to determine the relationships between the components as this may determine performance of the system as a whole (i.e. the farm household). Thus, the description of internal organisation is equally important as the description of the individual components. An example of material flows within a farm household, represented by its components and their relations, is given in Figure 1. Internal interactions of farm household components to be considered are partly determined by the scale of the farm. Similar flow diagrams have been constructed for labour and cash flows.

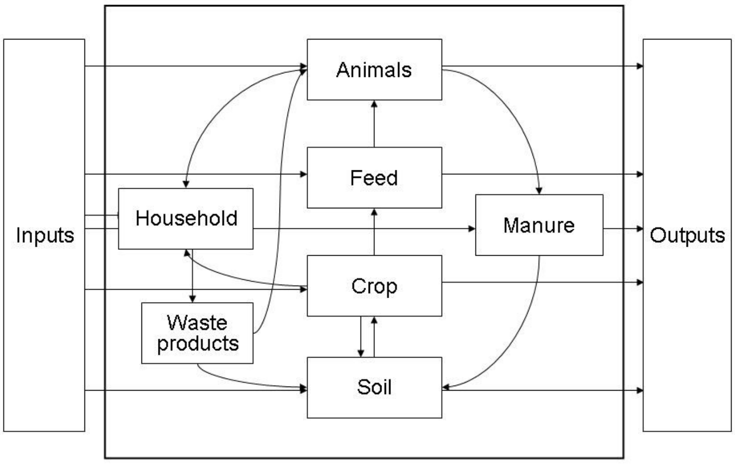

Figure 1 Simplified material flow diagram.

Step ii: quantification of resource flows

The second step involves the mapping of resources inflows, outflows and cycles within the farm household system using flow charts. This study focuses on nitrogen, carbon, energy, cash and labour flows, but the method can easily be expanded to include (for example) water and other nutrient flows. Individual resource flow charts are drawn annually for each farm household system, indicating internal flows as well as flows entering and leaving the system. In this way, internal recycling and dependency on external inputs can be visualised (Figure 2). All indicators refer to annual flows, unless otherwise stated.

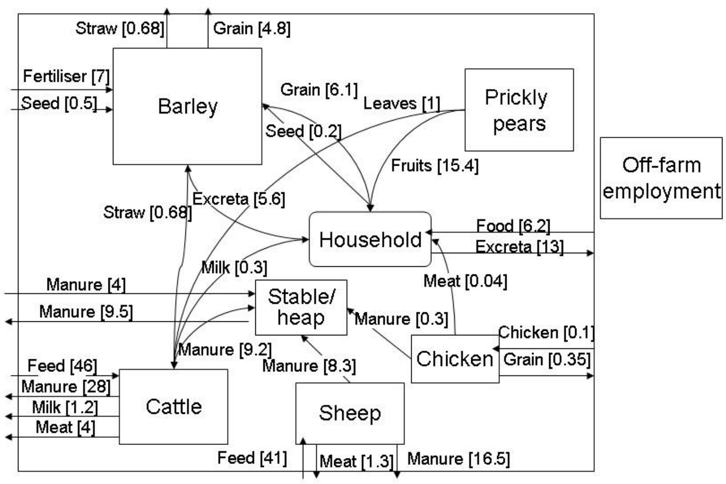

Figure 2 Example of a resource flow chart for nitrogen of an Ethiopian farm household. Numbers between brackets indicate kg N ha-[1].

Step iii: calculation of indicators

In the third step, flows are used to calculate indicators to measure and compare the economic and environmental performance of different farm household components and systems (Pacini *et al.*, 2003). Obviously, performance indicators must correspond to system characteristics that have been determined for policy evaluations. In this section, the indicators used in the case studies (Chapters 3, 4 and 5) are discussed. Clearly, depending on the goal or information availability of a given study, the set of indicators can be expanded or narrowed. It is therefore crucial that indicators used be explicitly defined to enable comparison of results among different studies.

In this study, indicators are calculated for fulfilment of household energy (food) requirements, income generation, factor productivity, environmental performance and diversification and integration of farm household activities. These components are discussed briefly below; detailed description and calculation methods will be discussed in the case studies. Unless indicated otherwise, all indicators refer to annual flows.

Fulfilment of energy requirements
Food availability at farm household level depends on two factors: the amount of food produced, and income generated to purchase additional food.

Energy home-grown crops [GJ]: includes energy contained in all the agricultural products of the farm that are used for home consumption. This may be all or part of annual food production, the remainder being sold.

Household energy requirements [GJ]: energy required for feeding the farm household members.

Energy balance [GJ]: the difference between the energy contained in all the agricultural products for home consumption and household energy requirements. The energy balance can indicate a surplus or deficit. It shows whether a farm household is able to fulfil its own energy needs from home production. In the case of food deficiency (a negative energy balance), it is checked whether product sales generates sufficient cash to allow supplementary food purchases.

Income
Economic profitability is evaluated using indicators related to income generated by both on-farm and off-farm activities, calculating household net household income by deducting expenditures and variable production costs.

Total gross income [$]: this indicator refers to total on-farm plus off-farm income generated by a farm household.

Total on-farm income [$]: the monetary value of agricultural production refers to total on-farm income, including crop (grain and feed) and animal production (eggs, milk, meat, hides, traction etc.). The value of products that are used for on-farm consumption (including feed for animals) is calculated using reported market prices for the period of analysis. Stored grain is not included and is considered an addition to capital stocks.

Total off-farm income [$]: this relates to income that is generated with off-farm (wage and non-farm self-employment) employment. Remittances are also included.

Share animals gross income [-]: animal production is the most common farming activity found next to cropping. Therefore, most integrated systems include both animal and crop production. This indicator refers to the role of animal production in on-farm income generation and includes animal products such as milk and meat, as well as income generated by hiring out animals for traction. It may be used to compare the role of animal production in farm household systems.

Household expenditure [$]: this includes farm household expenditure for food, health care, education, recreation and gifts; it gives a measure of household prosperity.

Variable production costs [$]: costs for all inputs (fertilisers, biocides), including costs for family labour (based on average local wage rates).

Net income [$]: total gross income minus household expenditure and variable production costs.

Productivity

The amount of income that is generated and the way in which this is done, especially the efficiency input use are of interest in the analysis. Performance of farm households is, therefore, evaluated by comparing factor productivity: income generated per unit of input used. In this study, factor productivity of land, labour, nitrogen and energy inputs were calculated. The benefit-cost ratio refers to productivity of all inputs used.

Land productivity [$ ha^{-1}]: the land productivity indicator calculates the monetary value of agricultural production that is generated per unit of land. It is only calculated for cropping systems, because animal production and off-farm employment cannot be related directly to a specific piece of land.

Labour productivity [$ man-day^{-1}]: labour productivity refers to the monetary value of the agricultural production that is generated per unit of labour used. It is a measure of efficiency of labour use and can be compared for all kind of farm and off-farm activities.

Nitrogen productivity [$ kg N^{-1}]: comparison of nitrogen productivity, i.e. the monetary value of agricultural production that is realised per unit of purchased nitrogen input, allows efficiency of nitrogen input to be evaluated. Inherent natural fertility and nitrogen release from mineralisation of (soil) organic material are not considered.

Energy productivity [$ MJ^{-1}]: this indicator expresses the quantity of a given product (in monetary terms) that is produced per unit of energy input used (Fluck, 1979). It indicates the efficiency of energy input use.

Benefit-cost ratio [$ $$^{-1}$]: this relates to the ratio between the monetary value of agricultural production and all variable input costs; it indicates the productivity of different farm households.

Environmental performance

Producing food and generating income, even if this is done effectively, is no guarantee for sustainable production. Effective but unsustainable systems may put production elsewhere - or even future production - at risk by degrading resources or by using non-renewable resources in large amounts. Therefore environmental performance is evaluated by calculating indicators referring to input use, stocks, application and management. Nitrogen has been selected since it is the most commonly used external input, being crucial for crop and animal production. Nitrogen is often one of the limiting production factors in low input farming; the productivity of most ecosystems depends to a large extent on available nitrogen. Once depleted, soils deprived of nitrogen can be replenishhed by leaving them fallow for a long time, by planting leguminous crops or by applying (external) fertilisers. Focus is also on management of carbon, due to its role in soil fertility (soil organic matter is critical in defining physical and chemical soil properties) and climate change, including carbon sequestration. Energy inputs and carbon management are used to evaluate the dependency of systems on external inputs to sustain farm household production.

N stock [tonne N ha^{-1}]: this refers to total nitrogen contained in the upper soil layer (30 cm). It is calculated using information on soil profile depth, bulk density and total nitrogen content of the soil.

N import [kg N farm^{-1}]: nitrogen import from external sources, with the exception of nitrogen deposition. This indicator is calculated only at the farm level.

Partial N balance [kg N ha^{-1} or kg N farm^{-1}]: partial N balance is calculated as the difference between easily measurable nitrogen inputs and nitrogen outputs at field or household level. Inputs include nitrogen in applied manure, mineral fertilisers and seed; outputs include nitrogen in harvested grain and straw removed from the field. Additional nitrogen from deposition, nitrogen fixation and losses through leaching, volatilisation and denitrification, all difficult to quantify, are excluded from the calculations. Household systems or components with positive balances therefore may still deplete (soil nitrogen) stocks if non-estimated losses are large, i.e. leaching in sandy soils that receive heavy rainfall. Although the outcome of the calculations thus is expected to differ from more detailed analysis, it is felt that this indicator provides a quick and relevant reference for farm household nitrogen management practices.

C stock [tonne C ha^{-1}]: this indicator refers to soil carbon contained in the upper soil layer, as defined by soil depth (30 cm), bulk density and total carbon content of the soil.

C-import [tonne C ha^{-1} or tonne C farm^{-1}]: C-import refers to the carbon added to the system and is calculated from total carbon imports by assuming that half of the carbon import in applied manure and straw left on the field is lost during decomposition (Kolenbrander, 1974), while a given, crop-specific, percentage of the carbon in crop residues is further lost through burning of such residues.

Energy Input-Output ratio: this indicator calculates the ratio of all inputs to outputs, both expressed in terms of energy, and measures the degree of energy dependency of the farming system. Inputs representing energy values for crop components include manure, mineral fertilisers, seeds, labour and animal traction. Energy outputs of crop production consist of harvestable crop parts, as well as non-harvestable biomass products (in the case of annual crops this refers to crop residues, while for perennials it represents pruning material or added standing biomass). Energy inputs for animal components are feed and labour; traction, milk, eggs, meat and manure are outputs. The largest source of energy inputs, incoming radiation, is not included in the analysis. This may seem strange, but - as the analysis is partly economic and policy oriented - it was decided to consider only energy inputs bearing costs for the farm household.

Diversity and integration

To answer the question of whether diversification is appropriate and successful, two aspects are evaluated: income diversification (as a measure of how individual activities actually contribute to farm household income), and integration of individual components in the entire system (as a measure to evaluate how effective individual activities make use of available inputs, which in this case is limited to nitrogen use).

As a specific diversity index for agricultural production systems was lacking, the Shannon diversity index (Magurran, 1988) was adapted to calculate the contribution of individual activities to the total monetary value of agricultural production ($H = - \sum p_i \ln p_i$, where p_i indicates the relative importance in monetary terms of the production of the i^{th} activity (n_i/N) and N is the monetary value of on-farm production). Two levels for calculation of this index are distinguished, the farm level, including on-farm activities (crops, animals, and cash generated using own or rented land) and the household level, further including off-farm activities (income generated from off-farm employment).

Finn's flow analysis method (Finn, 1976; 1980) is used to evaluate integration of farm household systems with respect to internal recycling of nitrogen. This method has been widely applied to marine ecosystems (e.g. Baird and Ulanowicz, 1993; Whipple and Patten, 1993; Hinrichsen and Wulff, 1998), but rarely to agro-ecosystems (Fores and Christian, 1993; Fores *et al*., 1994; Dalsgaard and Oficial, 1997). In theory, it could be applied to any type of recyclable resource, but in most cases it is applied to energy and/or nutrient flows.

Major inflows and outflows of all (*n*) components of the farm household system are recorded, where state and rate estimates for a component apply to a given (arbitrary) period in which flows have been recorded. Various indicators are calculated to define internal recycling. Their combined analysis provides insight into and allows comparison of farm-household nitrogen recycling:

- ***Throughflow*** refers to the sum of all flows into a component H_k minus the sum of all flows out of H_k during a well-defined period of time. The change in state indicates a modification of N stocks, for example, the net loss or accumulation of soil N during a growing season.
- ***Total system throughflow*** is the sum of all throughflows in the system. It is the sum of all flows passing through all systems components during a given time step. This indicator is a measure of the activity of the system, and it is sensitive to the number of components, as (generally) more components mean a higher throughflow of the system. It can be considered the mobile N pool in the system associated with the system's actual production.
- ***Total inflow/outflow*** is the total inflow of a system taking into account changes in stocks of individual components. When this figure is compared to the total system throughflow, it indicates the dependency on external inputs to achieve actual production.
- ***Path length*** is the average number of components that an inflow passes during the period of analysis (one time-step). It is calculated as the total system throughflow divided by the total inflow and it highlights the intensity of nitrogen cycling. Part of the nitrogen entering the system may flow through a (number of) component(s) and leave, while another part may be recycled repeatedly before leaving the system. The path length is sensitive to the number of components in a system.
- ***Recycling index*** is the proportion of total system throughflow that is recycled. Recycling efficiency (the fraction of throughflow that returns to a component) represents the outflow of a component that is generated by an extra input of one unit of nitrogen. The recycling index is calculated by dividing the relative recycling efficiency of all components by the total system throughflow. It yields values between 0 and 100, with these extremes indicating either no or full recycling. Values for natural ecosystems (generally referred to as the *cycling* index) may be as high as 75% (Finn, 1980). As agricultural systems remove harvested products, which withdraw considerable amounts of nitrogen, recycling index values here are expected to be much lower. Values for agricultural systems in the Philippines of 25 to 45 have recorded by Dalsgaard and Oficial (1997).

Annex I presents a mathematical description of the approach, as well as an example of the calculation procedure.

Step iv: analysis and synthesis

The next step in the analysis is to determine how values of these calculated indicators relate to attaining or producing food and economic or environmental performance. An overview of the indicators that are used and the range of values they may have, as well as information on their interpretation, is given in Table 3.

Table 3 Indicators for the analysis of economic and environmental performance of farm household systems.

Indicator	Unit[1]	Interpretation
Fulfilment of energy requirements		
Energy in home-grown crops	GJ	Energy value of on-farm food production.
Household energy requirements	GJ	Energy required to meet energy needs of farm household family members.
Energy balance	GJ	Indicates whether sufficient food is produced to cover household requirements.
Income		
Total gross income	$	Indicates how much gross income is generated.
On farm income	$	Indicates how much income is generated on-farm.
Off-farm income	$	Indicates how much income is generated by off-farm activities.
Share animals gross income	-	Proportion of income generated by animal production.
Household expenditure	$	Indicates how much money is spent for the household.
Variable production costs	$	Indicates how much money is spent for production activities.
Net income	$	Indicates how much money is earned.
Productivity		
Land productivity	$ ha^{-1}	High productivity indicates efficient land use.
Labour productivity	$ man-day^{-1}	High productivity is indicates efficient labour use.
Nitrogen productivity	$ kg N^{-1}	High productivity is indicates efficient nitrogen use.
Energy productivity	$ MJ^{-1}	High productivity is indicates efficient energy use.
Benefit-cost ratio	$$$^{-1}$	High values show that activities are highly profitable in economic terms.
Environmental performance		
N stock	kg N ha^{-1}	High stocks indicate relatively fertile soil resources, in theory allowing high production levels.
Partial N balance	kg N ha^{-1}	A positive balance indicates a relatively favourable influence on N soil stocks (N losses not included).
C stock	kg C ha^{-1}	High stocks indicate high organic matter concentrations in the soil.
C import	tonne C ha^{-1}	High C imports indicate high dependency on external sources for organic matter.
Energy input-output ratio	-	A high ratio indicates that farm household is energy efficient.
Diversity and integration		
Income diversity (farm and household levels)	-	High values indicate many different activities generating farm household income.
Recycling index	-	High values indicate high levels of internal N recycling.

[1] *Unless otherwise indicated, all indicators refer to annual flows*

The indicators are used to value and compare system performance. Clearly, indicators relating to energy, economic profitability, factor productivity, environmental performance, and diversification and integration of farm household activities all provide specific information on farm household performance. This is most clear for energy and profitability, both factors that are directly linked to food availability and income, but also indicators related to factor productivity, environmental performance and diversification/integration provide valuable information on the performance of farm households. An analysis of the way in which farm households perform can, therefore, be based on comparison of individual categories for each indicator type, but may further include cross cutting analyses. Other indicators help to identify opportunities for improvement of overall farm economic performance related to factor constraints, e.g. productivity indicators related to energy, land, nitrogen and labour use. However, the choice of productivity indicators depends on the area under study and its goals. It may be relevant to calculate water productivity in a region with water scarcity or for farm household systems that depend critically on water for production.

A combined analysis of economic and environmental indicators, for example, allows identification of tensions, trade-offs and potential win-win situations between economic and environmental objecttives. The integrated and simultaneous analysis of both economic and environmental performances of farm households may help to support the sustainable development of farm households.

Indicators refer to both the component and the farm household level. Component analysis refers to identification of opportunities for improvement in design of farm household systems; farm household analysis can be used to target policies for different strata of the rural community. Some indicators - such as balances - are expressed as absolute figures, while others - such as productivity indicators - are scale independent. Both types were used to assess farm household performance.

Most successful farm households are food secure either due to own food production or through generation of off-farm income that enables food purchases and make efficient use of inputs (as depicted by favourable factor productivity figures). Success in this respect, however, does not necessarily mean that these farm households are able to withstand shocks and bear the effects of (external) change.

Diversity of farm and farm household income is a proxy for a certain level of robustness in income generation, while sufficient integration of internal nitrogen flows (in combination with moderately positive nitrogen balances and sufficient nitrogen productivity) is an indication of stable and effective nitrogen use. Special attention may be needed for farm households that are deficient in food production and/or income generated, or that make less efficient use of inputs, have low nutrient stocks, and/or negative or extremely positive nutrient balances, while low income diversity and integration make farm household systems less stable and resilient to economic shocks and more prone to risk related to nutrient losses and resource depletion.

Step v: conclusions and recommendations

Clearly, a distinction needs to be made between farm households that are sufficiently productive and those that are not; the latter may be targeted by production stimulating measures while the former do not require such policies. Regarding efficient input use, a distinction between internal (such as land, but especially labour) and external inputs is made. Further, it is clear that farm households that are diversified may benefit more from different programmes than those that are not,

while other, specific policies may be pursued for farm households that do lack sufficient integration among components.
The main focus in this report is on diversification and integration and, to a lesser extent, sensitivity to external changes. Analyses and recommendations on these issues are discussed collectively for all case studies (Chapters 6 and 7, respectively).

2.4 Data requirements

The methodology is designed with the idea that it can be applied using generally available data. The minimum dataset required includes quantitative (physical and economic) information on major input-output relationships of farm household activities, household composition (number of people), and off-farm employment and wages. Additional information on household consumption will increase the accuracy of economic analysis, while information on natural resource availability may improve the accuracy of biophysical analyses. In practice, however, datasets often are biased towards one (type of) discipline (be it bio-physical or economic), so that assumptions and simplifications are required to compensate for the shortcomings and allow both disciplines to be fully represented. This is done using generic databases and simple estimation rules.

The data quality determines the detail of the analysis. Any study should, however, try to seek a balance between the biophysical and socio-economic farm household components, both in detail and quality. Detailed analysis requires detailed data inputs (which often are not available), while aggregation to the farm level (focal point of most policies and poverty evaluations) would mean that much detail is lost.

3. Teghane, Tigray, Northern Ethiopia

3.1 Introduction

The state of Tigray is situated in Northern Ethiopia, sharing a common border in the north with Eritrea. Up until 1990, Tigray had been subjected to a long period of economic, political and military oppression. The extreme poverty of the region is rooted in the combination of a war that took place in the 1980s, a series of severe droughts, deforestation and a natural resource base that was already low.

In the north-east of Tigray lies the village of Teghane (13° 45'N, 37° 41'E), which belongs to the Golgol Nae'le community, located in the Atsbi Wenberta district. Teghane includes 463 farm households, 104 of which are landless. Almost half (44%) of those farm households with land holdings are headed by females. The average farm size is less than 0.5 ha, of which less than 0.3 hectare is cultivated. Many farm households produce insufficient food to feed themselves and depend on off-farm employment via *food-for-work* and *cash-for-work* programmes. Access to the local market is relatively good, but opportunities for employment outside agriculture remain limited.

The terrain, soil and climate of Teghane are not particularly favourable for agriculture. Steep slopes, stony soils, frost-risk for part of the year and rainfall limited to a short period of the year constrain agricultural production. Long-term average annual rainfall is 780 mm, the majority of which falls during a period of only 75 days (end of June to the beginning of September). A reservoir does allow irrigation of some of the agricultural lands.

Farming systems are mixed crop-livestock with mechanisation limited to land preparation using oxen and a plough. Oxen and other livestock (dairy and beef cattle, donkeys, and sheep) graze on communal pastures. Farm household activities that are found in village of Teghane are listed in Table 4.

Table 4 Farm household activities in Teghane, Tigray, Ethiopia.

Crop	Animal	Other activities
Barley (with or without irrigation)	Oxen	Renting in/out land
Black wheat	Cows	Renting in/out oxen
Faba bean	Donkeys	Renting out mules/donkeys for transport
Field bean	Mules	Renting in/out labour to neighbouring farmers
Flax	Sheep	Off-farm employment
Wheat (with or without irrigation)	Chicken	
Prickly pears	Bee-keeping	

3.2 The multi-step approach

During the growing season of 2002, a farm household survey was conducted in the region as part of the research programme ‘Policies for sustainable land management in the Ethiopian Highlands’ (PIMEA, 2005; Mulder, 2003). For three farm households (out of 80 surveyed), resource flows have been mapped and indicators calculated and analysed according to the methodological steps described in Chapter 2.

Step i: developing a farm household typology

Three household wealth categories were identified in Teghane using a rapid diagnostic appraisal with and by local people. The first category represents poor households, with no or few animals and little land. The second category represents average households, which typically own an ox, one or two donkeys and a few sheep, their own land and have no labour shortage. The third category represents rich households, which own two oxen, at least one cow and a heifer, a donkey and about 10 sheep. Rich farm households are most of the time self-sufficient in their food needs, in contrast with other household categories (Mulder, 2003). All farmers in this class have access to irrigation water, making an extra crop after the main season possible.

In this study, three farms were selected to represent these wealth categories. Farm data, collected using the participatory nutrient monitoring (NUTMON) approach (De Jager *et al*., 1998; Van den Bosch *et al*., 1998a,b), were used to identify resource use and flows.

Step ii: quantification of resource flows

This step includes identification of farm household components and quantification of the resource flows (inputs and outputs) between the various components. Underlying assumptions and conversion factors to quantify input and output flows have been extracted from the NUTMON toolbox (see Annex II). All figures refer to annual flows, unless otherwise stated.

Step iii: calculation of indicators

In addition to the general indicator description presented in Chapter 2, some specific comments related to Teghane indicator calculations are presented here.

Income and economic performance indicators are based on an exchange rate of 1 Ethiopian Birr = 0.10 €. To estimate on-farm income, products consumed on-farm (including animal feed) are assigned a monetary value using prevailing market prices. The cost of family labour is based on a local wage of 8 Birr man-day^{-1} for male labour, 7 Birr man-day^{-1} for female labour and 30 Birr month^{-1} for child labour (livestock herding). Manure has a market price of 20 Birr per tonne.

Partial N balance [kg N ha^{-1}]: nitrogen imports consist of mineral fertilisers, manure, feed and seeds. The outputs are determined by the harvested products and crop residues that are removed from the field. Addition of nitrogen through deposition, nitrogen losses through leaching, volatilisation and denitrification are excluded from the calculations, since accurate information on these flows is lacking. In Teghane, the largest nitrogen inputs are related to feed input via grazing on communal rangeland and the nitrogen in purchased food or food provided through *food-for-work* programmes. Major nitrogen outputs are manure deposited on communal rangelands and the burning of manure to provide energy for cooking.

C import [tonne C ha^{-1}]: it is assumed that 75% of the carbon in residues of cereals is lost during burning (Biederbeck *et al*., 1980; Lefroy *et al*., 1994).

Energy input-output ratio: the ratio of all inputs to outputs expressed in terms of energy (energy input-output ratio) indicates the efficiency with which energy is used to produce outputs. Energy inputs for crops are manure, mineral fertilisers, seeds, labour and animal traction. Energy outputs are produced grain and straw. Energy inputs for the animal components are feed and labour; outputs are traction, milk, eggs, meat and manure. For these calculations, all material inputs and outputs were converted into energy units using the general conversion tables provided in Annex II.

Step iv: analysis and synthesis

Referring to input-output relationships of individual household components that have been quantified above, performance of farm households is analysed. First, productivity and environmental performance is evaluated (this section). Next, nitrogen management and integration are discussed (section 3.3), after which general performance and sensitivity to external changes are evaluated (sections 3.4 and 3.5, respectively).

Farm household 1: average household
The average farm household has a large number of farm components (0.66 hectare, 2 oxen, 2 cows, 2 calves, a mule, a donkey, 15 sheep, a bee hive and 6 chickens). Animals are fed using some farm resources (mainly crop residues) but most of their feed requirement is met by grazing on communal rangelands. Some feed and vaccines are purchased. Manure is collected from the stable and composted in heaps and used as fertiliser for crops. Oxen provide traction; milk is partly sold and partly consumed, while all eggs are sold. The donkey is used for transport within the farm and the mule is rented out for transport (Figure 3).

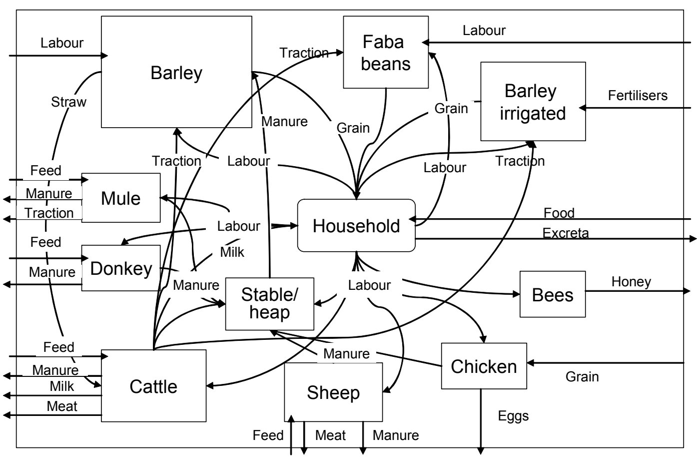

Figure 3 Energy flows for an average farm household.

Two crops, i.e. barley and faba bean, are cultivated by the average category farm household. Mineral fertilisers are applied to irrigated barley only. A considerable amount of crop residues is used as animal feed. Food is purchased, but most of household consumption is met by on-farm production. Most labour demand is met by family labour, although some labour is hired in during peak labour demand. Cash is generated through the sale of honey, eggs, sheep hides, and leasing out the mule.

The partial nitrogen balance of individual crop components is generally positive, as large amounts of manure are applied (Table 5), while losses are not considered. The difference in land productivity between both barley components is due to yields of the irrigated crop being surprisingly low. Faba bean is grown in the direct vicinity of the homestead and consequently receives a large amount of manure (containing 280 kg N ha^{-1} and 5.4 tonne of C ha^{-1}), assuming no nitrogen fixation at given high N application rates. This explains the high nitrogen and carbon balances.

The energy content in the applied manure and the energy content in the feed explain the low energy productivity of most components. The production of honey is energy-efficient as the only labour input is harvesting. Components having an energy input-output ratio lower than 1 are those that receive few inputs (mainly just labour or manure).

Donkeys and mules provide transport, which has a high price (it was assumed the same price as for oxen traction) resulting in a high labour productivity. Chickens have a low benefit-cost ratio because of the high input costs (wheat grain) and the low product value (mainly eggs). The manure produced is assumed to have an economic value, which contributes to the gross income of animal components.

Table 5 Indicators of the average farm household category in Teghane.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	N stock (tonne ha^{-1})	C import[3] (tonne ha^{-1})	C stock (tonne ha^{-1})	Energy I-O ratio	Energy productivity (Birr MJ^{-1})	Labour productivity (Birr man-day^{-1})	Land productivity ('000Birr ha^{-1})	Benefit-cost ratio
Barley	4.851	66	5.101	1.127	42.148	1.22	0.07	33	5.602	2.1
Barley irrigated	0.950	1	9.520	0.182	247.442	0.12	0.73	115	3.632	2.9
Faba beans	0.750	257	4.655	2.471	40.213	70.0	0.004	12	1.800	0.7
Stable/heap	1	33.7		1.609		1.49	0.002	4		1.2
Bee hives	1	-0.002		0		0.05	17.5	29		3.7
Chicken	6	0.40		0.705		1.90	0.023	2		0.1
Sheep	15	18.2		1.883		2.07	0.015	3		2.3
Donkey	1	8.3		0.797		1.86	0.036	19		8.0
Mule	1	9.9		0.950		1.70	0.061	24		12.9
Tropical cattle	6	26.0		33.823		2.03	0.023	5		2.3

1 *For animal components and stable/heap units.*

2 *Denitrification, leaching, volatilisation, etc., losses are not considered. For animal components (including stable), balances are expressed per component.*

3 *Carbon is used to cover energy maintenance requirements and animal growth.*

Farm household 2: poor household

This farm household owns 0.31 hectare, one cow and a calf, six sheep and a few chickens (Figure 4). Its animals consume crop residues and graze on communal lands. No inputs are purchased for animal production. Manure from the stable is used for fuel and is not applied as nutrient input on the arable land. Because there are no oxen, traction for ploughing has to be hired in. Milk is mainly sold; a small portion is used for household consumption.

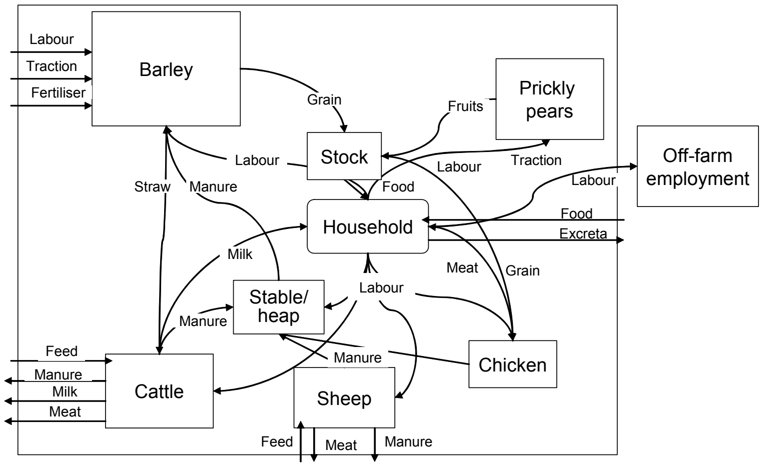

Figure 4 Energy flows for a poor farm household.

Two crops, barley (irrigated) and prickly pear are cultivated. Part of the barley harvest is exchanged for labour and traction by means of sharecropping. Mineral fertilisers are applied to the irrigated barley crop. A considerable amount of crop residues is used to feed the livestock. A large amount of food is imported because on-farm production can not meet household consumption. The actual amount of purchased food or food received via *food-for-work* programmes was not reported in the dataset.

The family labour force is not able to meet on-farm labour requirements and, therefore, some labour is hired during labour peaks. A significant amount of cash comes from off-farm employment of the family head, who is absent from the farm most of the time. There are no other important sources of income. Manure is mainly used as fuel, leaving little for fertilisation. Consequently, nitrogen and carbon imports are substantially lower than those of the average household (Table 6).

Prickly pear fruit accounts for one-third of the annual biomass accumulated (Inglese *et al*., 1999). Although prickly pear may appear to be an interesting activity for earning income, the fact that inputs other than labour are hardly used results in a negative nitrogen balance and a very low energy input-output ratio. This poses questions as to how long production levels may be sustained. Sheep graze on communal land, with labour being the only farm household input. Production is represented by annually produced lambs. The value of the stable/heap component was estimated from the price paid for manure used for fuel.

Table 6 Performance indicators of the poor farm household category in Teghane.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	N stock (tonne ha^{-1})	C import[3] (tonne ha^{-1})	C stock (tonne ha^{-1})	Energy I-O ratio	Energy productivity (Birr MJ^{-1})	Labour productivity (Birr man-day^{-1})	Land productivity ('000Birr ha^{-1})	Benefit-cost ratio -
Barley irrigated	2.317	8	8,739	0.522	136.370	0.14	0.54	34	7.035	1.9
Prickly pears	0.750	-219	8,967	0	164.347	0.08	4.61	15	4.416	1.9
Stable/Heap	1	14.5		0.413		0.84	0.003	1.2		1.2
Chicken	2	0.1		0.007		1.84	0.04	1.9		0.2
Sheep	11	6.9		0.775		2.04	0.03	4.3		4.3
Tropical cattle	2	5.4		1.019		1.04	0.07	2.1		1.0

[1] *For animal components and stable/heap units;*

[2] *Denitrification, leaching, volatilisation, etc., losses are not considered. For animal components (including stable), balances are expressed per component;*

[3] *Carbon is used to cover energy maintenance requirements and animal growth.*

Farm household 3: rich household

The rich farm household owns 1.17 hectares and rents in another 1.24 hectares. It also possesses 3 oxen, 1 cow, 2 heifers and a calf, 33 sheep, 2 donkeys and 13 chickens (Figure 5). The animals are fed on crop residues and graze on communal land. Vaccines and additional feed are purchased. Stable manure is partly applied on the fields (owned land only) and partly burned as fuel. There are no nutrient inputs to the rented land. Milk is used for home consumption.

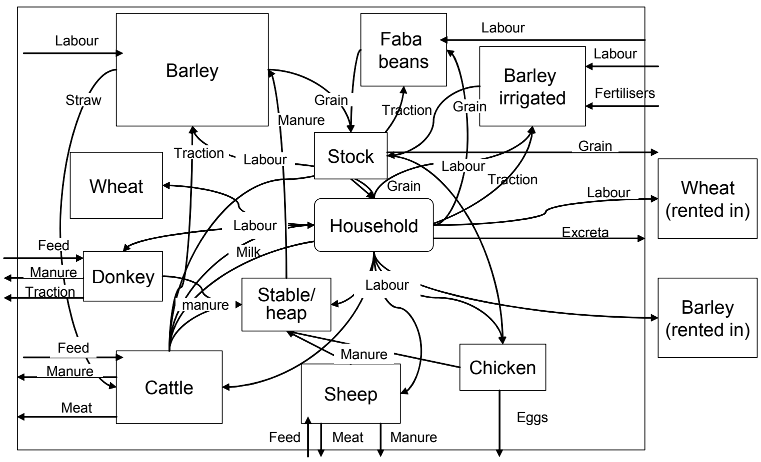

Figure 5 Energy flows for a rich farm household.

Four crops are cultivated: wheat, black wheat (a crop with a higher market price than common wheat), barley and faba beans. Half of the grain production of the rented land is used to pay the rent. Mineral fertilisers are applied solely on irrigated plots. A considerable amount of crop residues is fed to the animals; the remainder is applied to the land. Household food requirements are largely met by on-farm production, while selling any excess food generates extra cash. No records could be obtained on actual food purchases, so these had to be estimated. Family labour does not meet all household labour requirements and, therefore, some labour is hired during peak periods.

The partial nitrogen balance is positive; nitrogen in the harvested output being compensated for by external inputs (either manure or mineral fertilisers; Table 7). Productivity indices for rented land are relatively low. As half of the harvested grain and straw is used to pay the rent, nitrogen, carbon and energy outputs from these plots are high and input costs are not compensated for by the production. As was the case for the poor farm household (household 2), the benefit-cost ratio of chicken production is low.

Step v: conclusions and recommendations

The analysed sample characterises major farm household categories, but can give no representation of the variation between farm households of the same category. Here, some observations will be made. With respect to partial nitrogen cereal balances, these are positive or slightly negative due to the fact that manure is applied and losses are not accounted for. Still, the amount of available manure is limited (burning of manure for cooking, for example, is reported for several households), and only the rich household is applying sufficient nitrogen through sources like urea and human excreta to keep the partial balance positive. Full nitrogen cycles on this farm may obviously become negative, as losses through leaching, denitrification and volatilisation will probably exceed the current surplus of the partial balances.

All household categories depend heavily on input of nitrogen and carbon from communal rangelands to sustain production (Step iii). The effect of this practice on resource stocks of communal rangelands was not studied but it must lead to a depletion of the nutrient stocks. Positive partial nitrogen balances of faba beans are caused by high manure applications rather than nitrogen fixation. Labour productivity of animal production generally is below that of crop production. This could be caused by the relatively high labour requirements for herding, although this often is done by children. Benefit-cost ratios of chicken production are less than one. High benefit-cost ratios for mules and donkeys stress their importance as means of transport in this remote area.

Table 7 Performance indicators for components of the rich farm household category in Teghane.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	N stock (tonne ha^{-1})	C import[3] (tonne ha^{-1})	C stock (tonne ha^{-1})	Energy I-O ratio	Energy productivity (Birr MJ^{-1})	Labour productivity (Birr man-day^{-1})	Land productivity ('000Birr ha^{-1})	Benefit-cost ratio -
Barley	5.495	39	5.148	0.863	48.349	1.18	0.10	27	5.978	1.6
Barley irrigated	3.822	22	8.001	0.226	62.909	0.15	0.56	15	4.300	1.4
Faba beans	0.987	109	5.985	0.340	37.345	14	0.02	11	2.523	0.8
Wheat	1.445	50	5.148	1.036	48.346	1.65	0.05	20	4.464	1.2
Rented land										
Black wheat	6.785	-31		0.120		0.11	0.99	17	3.581	0.9
Barley	5.650	-30		0.118		0.11	0.96	19	4.053	0.9
Chicken	13	0.57		0.087		1.93	0.02	1.9		0.1
Sheep	33	65.8		6.515		2.08	0.002	1.4		1.4
Donkey	2	6.9		0.644		1.61	0.06	13		6.0
Stable/heap	1	29.2		2.543		1.16	0.006	16		1.8
Tropical cattle	7	36		4.553		1.98	0.03	6		1.6

[1] *For animal components and stable/heap units;*
[2] *Denitrification, leaching, volatilisation, etc., losses are not considered. For animal components (including stable), balances are expressed per component;*
[3] *Carbon is used to cover energy maintenance requirements and animal growth.*

While these findings are generally in line with expectations, activities and flows as they have been presented can be used for further analysis.

3.3 Nitrogen management and integration

This section presents the results of calculations of integration of nitrogen flows. First, the farm household categories are compared; next, the effects of three scenarios on nitrogen-flow integration are described. Calculations are based on actual nitrogen flows as reported by farmers - with exception of food consumption. Food demand, consequently, had to be calculated.

Farm household 1: average household
Animals graze on communal rangelands, while crop residues are used to support livestock in the dry season. It was assumed that half of the excreta of grazing animals are left behind on the communal lands. The remainder of the faeces are collected and stored on a manure heap; urine is lost due to poor manure management. Stocks and flows are given in Figure 6. There are 11 components. Recycling within the system is limited.

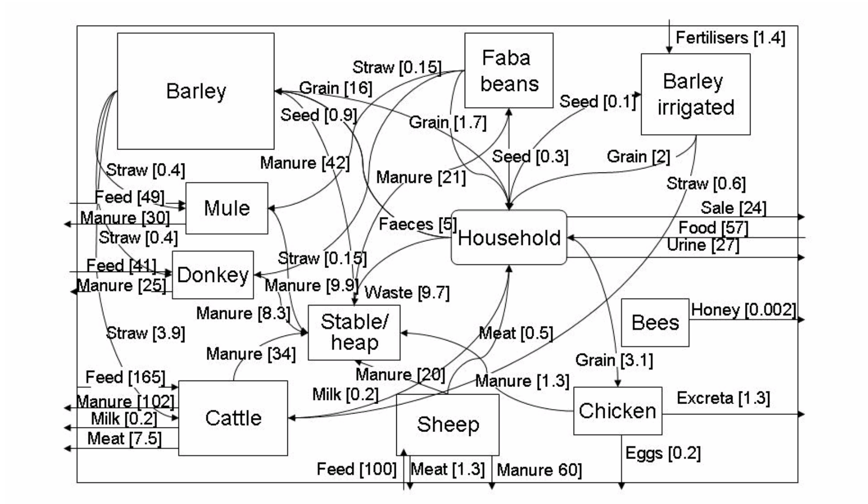

Figure 6 Nitrogen flows of the average farm household category under current nutrient management. Values in brackets in kg N ha^{-1}.

Most activity in this household category is supported by nitrogen inflows, much of which is imported from communal lands. The low values for path length and recycling index that were calculated (Table 8) suggest that little of total nitrogen inputs to the system is recycled among the subsequent components.

Table 8 Integration indices for the three farm households in Teghane under current management.

Farm household category		Total N inflow	Total system N flow	Path length	Recycling index
Average	Current situation	415	596	1.44	2.4
Poor	Current situation	127	183	1.44	2.4
Rich	Current situation	636	885	1.39	2.1

Farm household 2: poor household

As was the case for the average farm household, livestock energy needs are mainly met by feed inputs through grazing on common rangelands. Barley straw and prickly pear leaves are used as supplementary feed during the dry season. Animal faeces are collected on-farm and on rangelands, contributing to the manure heap, but generally urine is lost. Manure is used as fuel only; fertilisers used comprised household waste, human excreta and mineral fertilisers. On-farm production is insufficient to meet household needs and consumption is largely met through grain input (Figure 7). The system consists of eight components, with some nitrogen recycling within the system. Nitrogen flows from burning of manure is depicted as loss.

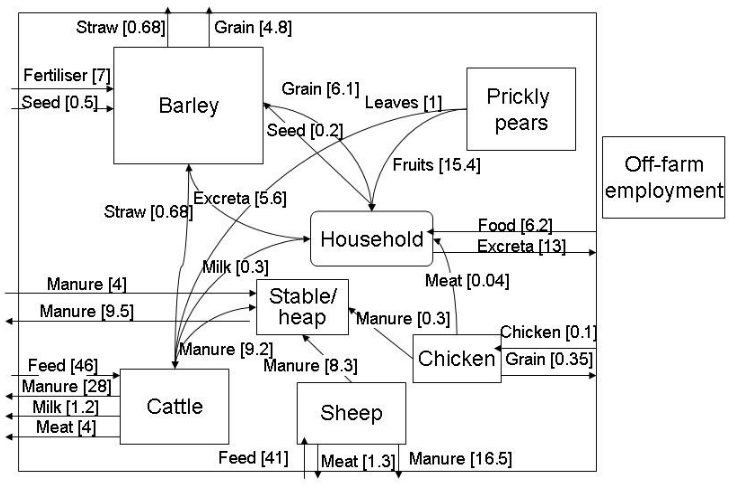

Figure 7 Nitrogen flows of the poor farm household category for current nutrient management. Values in brackets in kg N ha^{-1}.

Nitrogen import is restricted to 127 kg of N per year (Table 8), mostly through grazing. Total nitrogen system flows are limited to 183 kg. Path length (1.4) is comparable to that of the average farm household. The low level of nitrogen cycling (2%) could be increased by applying manure to barley and/or prickly pear, which would allow yields to increase, reduce the need to purchase grain and, consequently, reduce the need for part of the current nitrogen inflow.

Farm household 3: rich household

As in the other households, animal energy needs are mainly met through grazing on common rangelands. Part of the crop residues are used to feed animals during the dry season. Animal faeces are collected on-farm and on the rangelands, which contributes to the manure heap, while all urine deposited on-farm is lost. Manure is used both as fertiliser for crops and as fuel. The household is self-sufficient in food; grain surpluses are sold (Figure 8). There are 12 components and some nitrogen recycling occurs within the system.

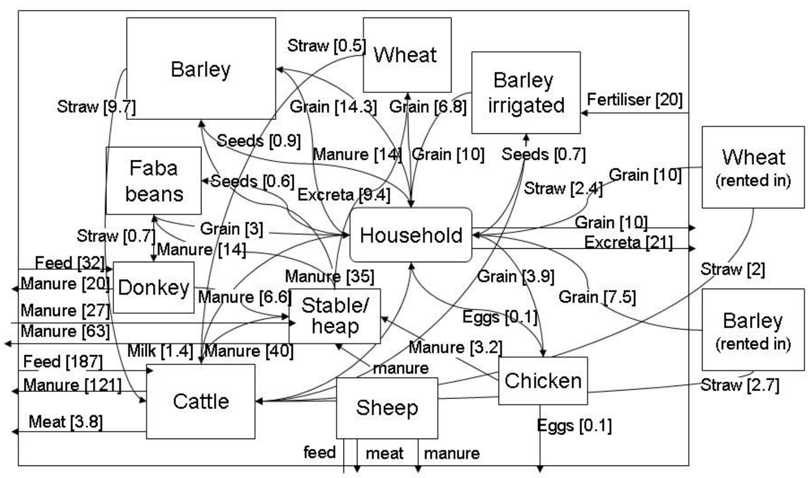

Figure 8 Nitrogen flows of the rich farm household under current nutrient management. Values in brackets in kg N ha^{-1}.

Nitrogen import amounts to 636 kg of N per year (Table 8), most of which is supported by a large inflow through grazing. Nitrogen flows within the system (885 kg), indicating crop production exceeds that of the other two household categories. Still, recycling of total N remains very limited.

Improving nitrogen management

There is ample room for improvement of nitrogen management. Three scenarios will be explored. First, it is examined how the definition of grain storage as a separate component would influence the outcome of the integration indices calculations. This is done, as the outcome of such calculations is sensitive to the number of components defined in the farm household and the number that is chosen to some extent is arbitrary. The second and third scenarios evaluate the effect of improved nitrogen management. Calculations for the scenarios are limited to the average farm household category.

Adding the **cereal storage** component to represent stored harvest, sowing seed, food grains and feed (Figure 9; a role that earlier was implicitly fulfilled by the household) affects, as to be expected, the nitrogen dynamics of the system. Total throughflow (+33 kg N) and path length (+0.08) are increased, but the recycling index is reduced (-0.5), as nitrogen re-utilisation does not change, while the number of components increases (Table 9). The question as to whether or not this storage facility should be defined as a separate component depends on the way it is utilising resources and generating income. As such, facilities in most farm households do not seem to make use of resources or generate income, there is no need to define them as a separate component. In specific situations, however, this may be different.

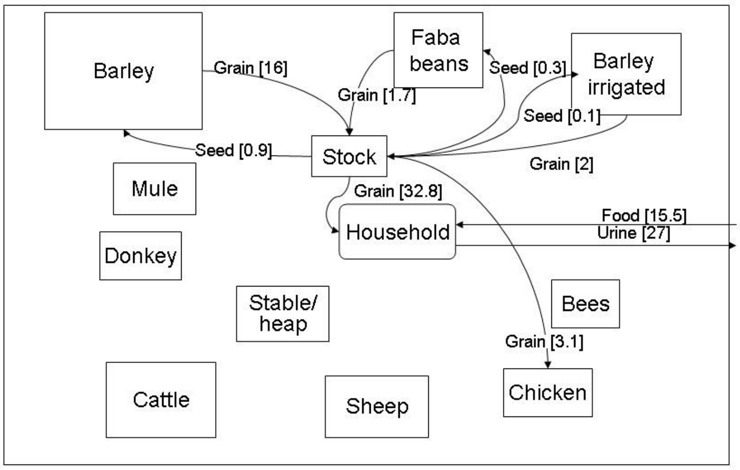

Figure 9 Nitrogen flows of the average farm household category in the first scenario (i.e. defining grain stock as a separate component).
Values in brackets in kg N ha-1.

Table 9 Integration indices for the average farm household category n Teghane under different scenarios.

Scenario	Total N inflow	Total system N throughflow	Path length	Recycling index
Actual recycling, no storage component	415	596	1.44	2.4
Actual recycling, storage component added	415	629	1.52	1.9
Improved manure management	415	667	1.61	3.4
Improved manure management + 20% increase in yields	408	677	1.66	5.4

The second scenario considers **improved manure management**. Conserving animal manure, recycling manure through bedding in the stall, daily collection plus anaerobic composting to prevent ammonia losses through volatilisation (Figure 10) leads, as would be expected, to increased nitrogen throughflow, path length and recycling index. Although changes in throughflow and path length are limited (+6%), the effect on the recycling is considerable, leading to a 78% improvement.

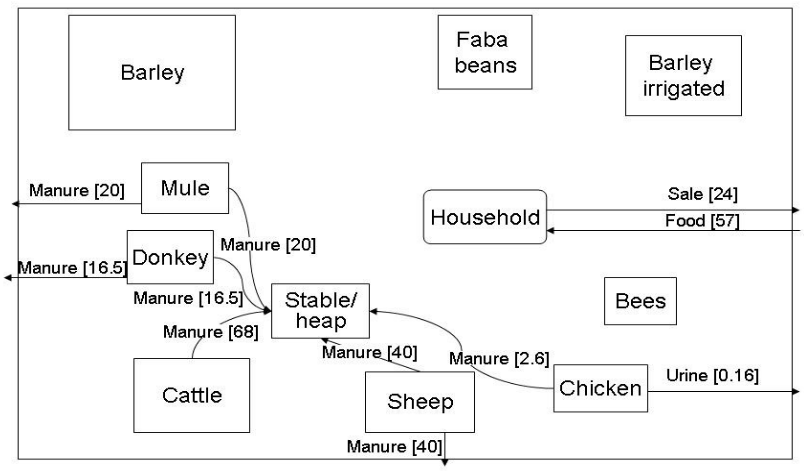

Figure 10 Adjusted nitrogen flows of the average farm household category in the second scenario, applying improved manure management.
Values in brackets in kg N ha-1.

The third scenario introduces **further efficiencies in manure management** (conserving urine), which leads to 20% higher crop yields and allows a small reduction of food purchases (Figure 11). Cycling within the system is increased through improved management and yields increase in response. These changes lead to improvements in the path length and especially the recycling index, which shows a further increase of 60% - as compared with the second scenario - to a value of 5.4, almost triple the original value. This scenario demonstrates that relatively small changes in nutrient management can have considerable impact on resource use efficiency.

Still, although the connection between farm household components improves, real integration (measured with the recycling index) remains low. This is because the system depends greatly on nitrogen inflows from common rangelands, while faeces and urine deposited there during grazing are lost. The household has, therefore, limited options to improve component integration since the number of animals cannot be supported by feed available on the farm. Increased yields would, however, reduce food purchases and generate more crop residues that can be used to feed the animals, and thus substitute for the import of fodder from rangelands. Scenario 1 shows the importance of defining components in an unambiguous way. Although absolute changes in the recycling index are limited, the relative change is considerable.

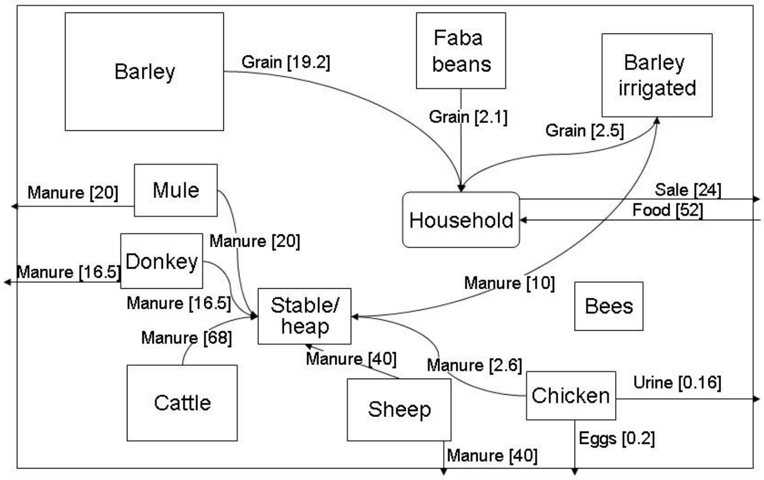

Figure 11 Adjusted nitrogen flows of the average farm household category in the third scenario. Values in brackets in kg N ha-1.

3.4 Performance of farm household systems

The number of animals determines to a large extent the magnitude of the imports of N and C into the farm household system. Therefore, the partial N balance for the rich and the average households show larger surpluses than those of the poor farm household (Table 10). The rich farm household also imports large amounts of energy, although this is not reflected in the energy input-output ratio because part of the manure is burned as fuel, as is also the case in the poor households.

Renting in land resources reduces the benefit-cost ratio of the rich household because the costs of production are relatively high: half the harvest has to be paid as rent. Rich and average households applied relatively large amounts of N inputs and therefore their N productivity is lower than that of poor households.

The on-farm production of the average and poor households is not sufficient to cope with the household food energy demands, in contrast with the rich household, which generates a surplus that can be sold at the market, i.e. 750 kg barley at 1.8 Birr kg^{-1}. The cash generated in the average household through the sale of farm products other than grain would allow the purchase of grain to meet the energy deficit (e.g. 840 kg wheat grain at 1.6 Birr kg^{-1}) and still leave a cash surplus to cover other needs. The poor household may also cope with the energy deficit by purchasing grain with the cash generated through off-farm employment (e.g. 320 kg wheat grain at Birr 1.6 kg^{-1}) leaving a very small surplus to meet other household needs.

Although the rich household generates cash surplus that allows savings, all productivity indices are higher for the average household, which suggests that their livelihood strategy gives a more efficient use of the limited resources.

Income diversity is highest for the rich farm household, as this is able to make use of more alternative sources of income (reflected by the large number and diversity of animals). This could be different if more opportunities would exist for off-farm employment, since poor households tend to profit more from this situation. As a rule, low income diversity poses high income risks (and vulnerability), as household incomes are based on few activities.

Table 10 Comparison of performance indicators of three farm household categories in Teghane.

Indicators	Average household	Poor household	Rich household
Characteristics:			
Area ('000 m^2)	6.551	3.067	11.749
Household members	9	4	10
Cattle	2 oxen, 2 cows, 2 calves	1 cow, 1 calf	3 oxen, 3 cows, 1 calf
Other livestock	1 donkey, 1 mule, 15 sheep, chicken	11 sheep, chicken	2 donkeys, 33 sheep, chicken
Energy in home-grown crops (GJ)	20.484	6.183	43.156
Household energy requirements (GJ)	29.893	13.286	33.215
Energy balance (GJ)	-9.409	-7.103	9.941
Total on-farm income ('000 Birr)	10.350	3.967	16.708
Cash generated by farm products ('000 Birr)[2]	3.847	0	1.814
Total off-farm income ('000 Birr)	0	1.300	0
Land productivity ('000 Birr ha^{-1})	4.881	6.395	4.956
Labour productivity (Birr man-day^{-1})	7.4	4.6	9.6
N productivity (Birr kg N^{-1})	25	35	27
Energy productivity (Birr MJ^{-1})	0.026	0.058	0.029
Benefit-cost ratio	2.6	1.6	1.3
N import (kg)	415	110	621
C import (tonne)	6.662	1.690	10.575
Partial N balance (kg) [1]	144 (5,691)	20 (8,795)	185 (6,147)
Energy input-output ratio	1.31	0.90	1.27
Income diversity[3] (farm level)	1.8	1.3	2.1
Income diversity (household)	1.8	1.6	2.1
Recycling index	2.4	2.4	2.1

[1] *Denitrification, leaching, volatilisation, etc., losses are not considered. N and C stock (kg ha^{-1}) indicated in parentheses.*

[2] *Grain surplus is not included.*

[3] *$H = - \sum p_i \ln p_i$, where p_i quantify the relative importance (in monetary terms) of the production of the ith activity= (n_i/N). N is the monetary value of the on-farm production.*

3.5 Sensitivity to external changes

Changes in external conditions such as prices of inputs or outputs, regulations imposed by national or local authorities, or the availability of new technologies will all affect the performance of farm households differently because objectives and factor endowments differ among households. To gain a better understanding of the performance of households under changing external conditions, the effects of a change in grain prices are analysed. In the analysis, the market prices of grains (barley and wheat) are changed from -99% up to +200% of the current market price, which are used in the base calculations. It is assumed that no other changes take place within farm household systems.

In all analysed farm households, productivity indices (land, N, labour) respond linearly to price changes. However the magnitude of the changes in productivity indices varies among households and is related to the relative contribution of grain to total farm household income (Figure 12). Income from grains represents 63, 41 and 30% of the total household income for the rich, poor and average farm households, respectively, at current market prices (0% change).

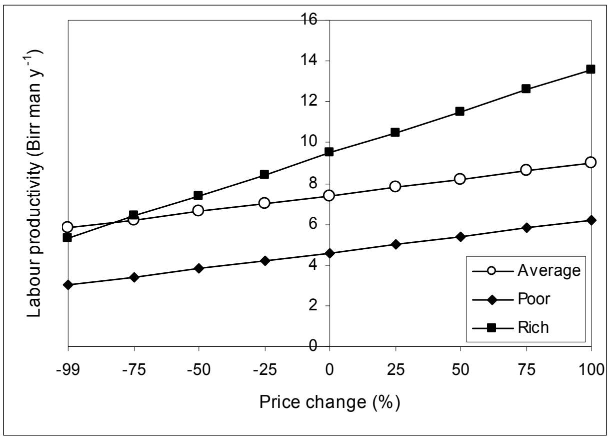

Figure 12 Effect of grain price change on labour productivity for the three categories of households in Teghane.

The effect of price change on benefit-cost ratios also varies among farm household categories. The effect is linear for the average household (Figure 13). Because rent for land and services are paid with grain, the effect of a price change becomes non-linear for the other two farm household categories, which rent land. Price reductions affected the most affluent household more because of the larger share of grains in the total income. If grain prices drop more than 50%, benefit-cost ratios drop below 1.

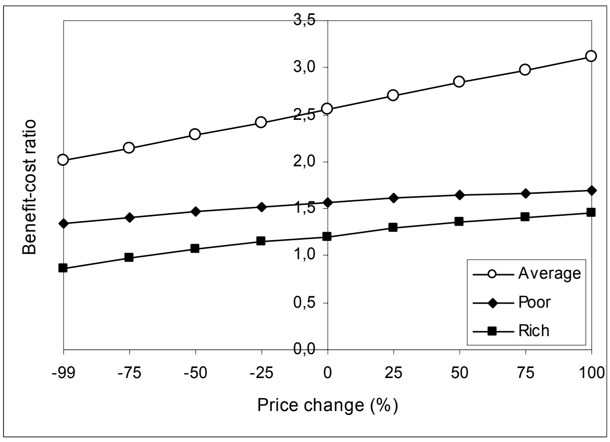

Figure 13 Effect of grain price change on benefit-cost ratio for the three farm household categories in Teghane.

On the one hand, poor and the average households benefit from a decrease in grain prices because they are net-buyers of grains and all grain produced on-farm is consumed on-farm. On the other hand, these two households absorb price increases through the cash generated with the sale of farm products or through income from off-farm employment, until a certain threshold is reached (Figure 14). Grain prices would have to increase to unrealistically high values exceeding +125% for the poor and +175% for the average household before their food situation would become insecure.

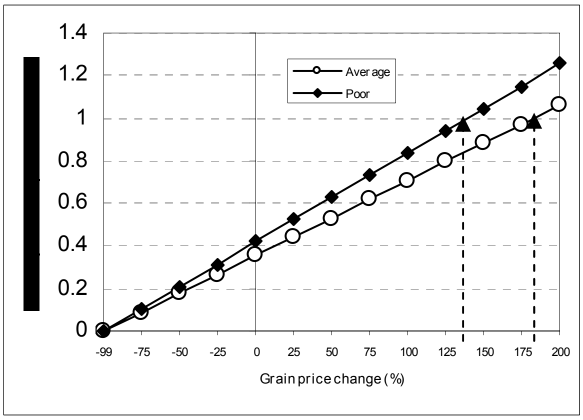

Figure 14   Effect of grain price change on the capacity of poor and average farm households to cope with the household energy deficit (proportion of cash generated at household level used to purchase grains).

The rich farm household benefits from an increase in grain prices because it produces more grain than the household needs, which can be sold at a higher market price. These changes the amount of cash generated through farm products (Table 11). In addition, most productivity indices increase relatively more for this household category than for the others.

Income diversity indicates both the number of components and their importance in contributing to the farm household income. Price changes modify income diversity. The effect depends on the number of income generating activities and the relative contribution of the each affected activity to total income (Figure 15).

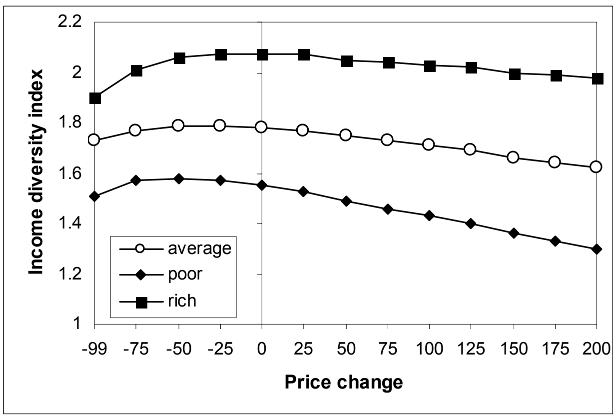

Figure 15   Effect of a change in grain prices on income diversity for the three farm household categories in Teghane.

Table 11 Effect of changes in grain prices for the performance indicators (% change) in Teghane.

	Average household					Poor household					Rich household				
Price change	-99	-50	25	75	100	-99	-50	25	75	100	-99	-50	25	75	100
Indicators:															
Total on-farm income (Birr)	-22	-11	5	16	22	-35	-17	9	26	34	43	-22	11	33	44
Cash generated by farm Products[2] (Birr)	0	0	0	0	0	0	0	0	0	0	-41	-21	10	31	41
Land productivity [Birr ha^{-1}]	-70	-35	18	35	70	-69	-35	17	52	69	61	-31	15	46	62
Labour productivity (Birr man-day^{-1})	-22	-11	5	16	22	-35	-17	9	26	35	44	-22	10	33	43
N productivity [Birr kg N^{-1}]	-22	-11	5	16	22	-34	-17	8	26	34	43	-22	11	33	44
Energy productivity (Birr MJ^{-1})	-21	-13	4	12	21	-33	-17	10	27	35	43	-21	14	36	46
Benefit-cost ratio (Birr Birr^{-1})	-21	-11	6	16	22	-16	-8	2	6	8	27	-11	7	17	22
Income diversity[1] (farm level)	-3	0.6	-0.6	-3	-4	-0.8	4	-3	-9	-12	-8	-0.5	0	-1.4	-2
Income diversity[1] (household)	-3	0.6	-0.6	-3	-4	-3	2	-1.3	-6	-8	-8	-0.5	0	-1.4	-2

[1] *$H = -\sum pi \ln pi$, where pi quantifies the relative importance (in monetary terms) of the production of the ith activity= (ni/N). N is the monetary value of the on-farm production.*

[2] *Cash surplus after grain has been purchased to supply household energy deficit.*

Price increases have the largest impact on the income diversity of the poor, least diverse, household (Figure 16). Grain price reductions, on the other hand, mostly affect the rich households' income diversity since most of its income is based on cereal sales.

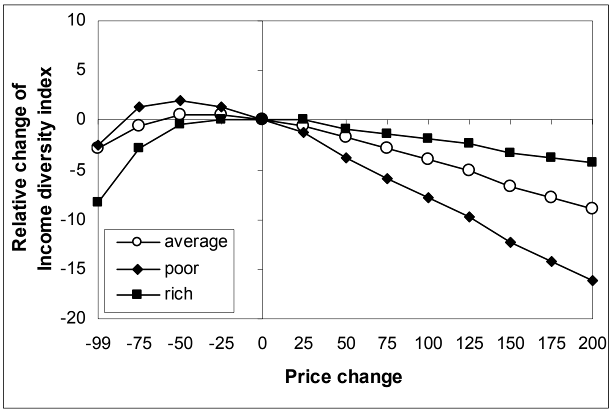

Figure 16 Relative change of income diversity with grain price change for the three farm household categories.

4. Pujiang, East China

4.1 Introduction

Pujiang county (119° 79’E, 29° 31'N) has an area of about 91,600 hectares and is located in the centre of Zhejiang province in East China, about 100 km southwest of the provincial capital and metropolis Hangzhou (Figure 17). Pujiang is located in the subtropical climate zone, with mean temperatures ranging between 16°C and 18°C and annual rainfall ranging between 1100 mm and 1900 mm.

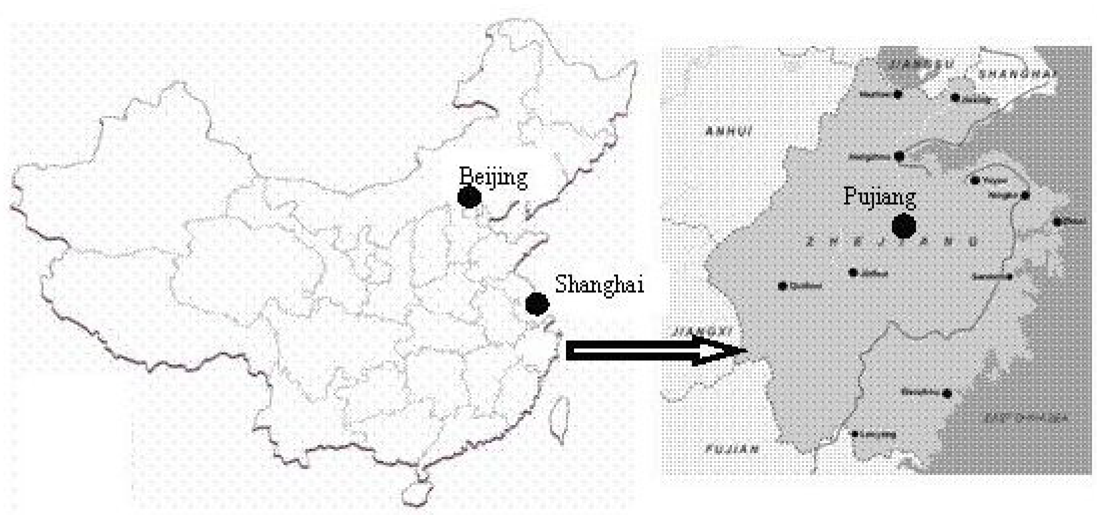

Figure 17 Pujiang county, Zhejiang province, P.R. China.

Farm household systems in Pujiang are predominantly intensive rice-based systems that are favoured by the subtropical climate. Farmers grow rice mainly for home consumption because of low market prices. Increasingly, farmers are diversifying their production portfolio with vegetables, fruits, animals and ornamentals (Table 12), which is supported by the local government through technical and financial programs. In Zhejiang province, the area under vegetables almost tripled between 1990 and 2002 (Figure 18).

Table 12 Farm household income generating activities found in Pujiang.

Food crops	Farm animals	Other activities
Rice Wheat Barley Vegetables Taro Watermelon Potatoes Sweet corn Fruit (citrus, pears, grapes) Strawberries	Pigs Chicken Fish, shrimp, turtle Cattle Goats Ducks Rabbits	Tea Ornamentals (woody and cut flowers) Sugar cane Mulberries leaves (for silk worms production) Bamboo shoots (timber) Off-farm work

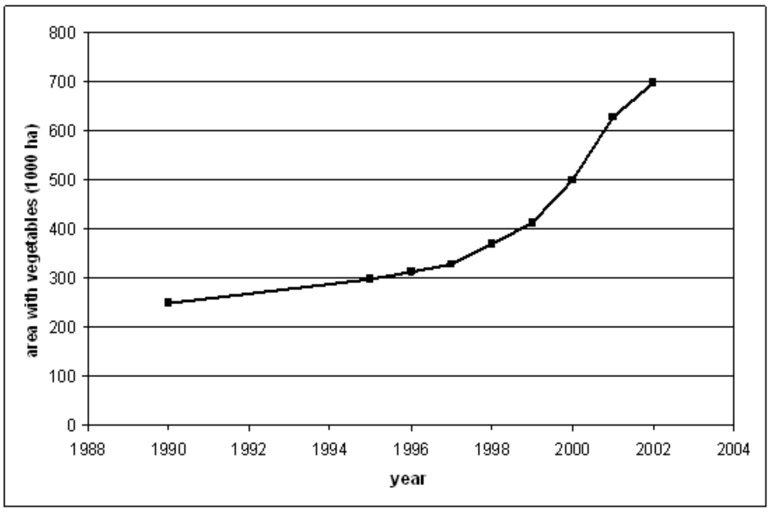

Figure 18 Area under vegetables between 1990 and 2002 in Zhejiang province, P.R. China.

The nearby-industrialised zone around Hangzhou offers ample off-farm employment opportunities, which has led to an increase in the number of part-time farmers in Pujiang. Policy objectives for the county concern, among other things, improvement of farmers' incomes through portfolio diversification, increased production of environmentally friendly and high quality products, and regional self-sufficiency in rice production (IRMLA, 2002).

Vegetables, leafy vegetables, eggplant, kidney beans, gourds, radish and tomatoes are cultivated in the lowlands (altitude <150 m). Fruits (grapes, Chinese plum, pears and almonds), tea, cut flowers and other ornamentals are more dominant in the higher altitude zones. These products are destined for the Chinese market. Despite the declining area under rice, single and double rice cropping remain the major agricultural activities. About 57% of the 18,000 hectares of cultivated land consists of rice land, while the remainder is used for other crops.

4.2 The multi-step approach

The analysis is based on a household survey data set compiled as part of the project ‘Integrated Resource Management and Land use planning in South East Asia’ (IRMLA) from November 2002 to February 2003. In total 107 households distributed over 16 townships in Pujiang were interviewed and their characteristics recorded.

Step i: developing a farm household typology

The average farm household consists of 4 persons, owning 0.81 hectare. Out of the 107 farm households, 19 own more than 1 hectare; the largest household occupies 9.3 hectares. In Pujiang, 64% of the surveyed households cultivate rice (Figure 19). A lower percentage cultivates rice only (22%). Households (36% of total) that do not grow rice are either engaged in livestock activities (ducks, pigs, chicken) and off-farm employment, own little land or have large land holdings (> 1 hectare) and cultivate fruit, vegetables and tea.

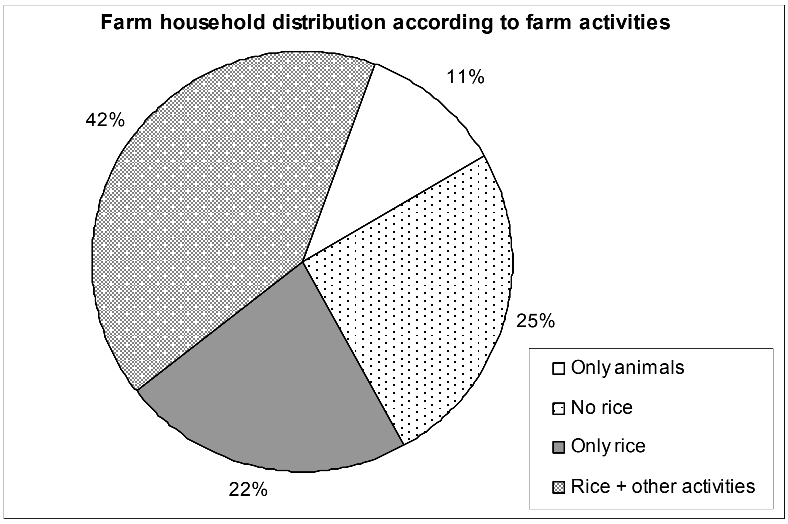

Figure 19 Distribution of activities of 107 sampled farm households in Pujiang.

On the basis of differences in land holding size and income generating activities, six farm households have been selected for this analysis. These households are mainly located at altitudes of > 150 m and have an average family size of about 4 persons (Table 13).

Table 13 Major characteristics of selected farm households in Pujiang.

Township	Off-farm employment	Land holding (ha)	Crops	No. of Plots	Animals
1 Zhengjiawu	Yes	0.13	Single rice	1	Pigs
2 Zhengzhai	Yes	0.32	Double rice, sugar-cane	2	Sow + piglets
3 Punan	Yes	0.57	Double and single rice, pears, oranges	4	Pigs
4 Tangxi	Yes	0.75	Single rice, tea, mulberries, bamboo	4	Pigs
5 Huangzhai	No	2.00	Grapes	1	Pigs
6 Tangxi	No	3.67	Tea	1	-

Step ii: quantification of resource flows

Energy flows are used to show resources flows between household components and with the exterior, since all material and non-material flows can be expressed as energy. Off-farm employment is conceptualised as a component outside the farm household system, but there is an energy flow to the household component. The energy flow charts of individual farm households are shown in step iv. All figures refer to annual flows, unless otherwise stated.

Step iii: calculation of indicators

In addition to the general description of and discussion on performance indicators of farm households systems in Chapter 2, here, only specific information is provided for the indicators used in the Pujiang case study. All indicators refer to annual flows, unless stated otherwise.

Economic performance indicators are based on an exchange rate of 1 Yuan (CNY) = € 0.10. The costs for family labour are based on a local wage rate of 20 CNY man-day^{-1}. Pigs and manure can be sold to the market at 8.5 CNY kg^{-1} and 60 CNY tonne^{-1}, respectively.

Soil carbon and nitrogen stocks of land-related components have not been estimated because relevant soil characteristics were not available for this case study.

Partial N balance [kg N ha-1]: In Pujiang, generally, crop residues of rice are burned after harvest in order to facilitate ploughing for the next crop. Sugarcane residues are also burned after harvest. It is assumed that 70% of the nitrogen in rice residues is lost due to burning (Biederbeck *et al*., 1980; Lefroy *et al*., 1994) and 73% of the nitrogen in sugarcane residues (leaves + tops; Basanta *et al*., 2003).

As most farm household systems in Pujiang are connected to the sewage system, excreta from household members are not used as inputs of other household components. The household organic waste is also assumed to be lost from the farm household system. It is assumed that manure of animals is collected and sold. In the exercise where nitrogen use within the farm household is optimised through recycling (section 4.8), all organic nitrogen sources are reutilised within the farm household system.

Pigs are fed with a purchased corn-based concentrate. For calculation of feed requirements and manure production of pigs it is assumed that piglets of 20 kg live weight are purchased and sold when the animals reach a weight of 100 kg. A simple model was used to calculate feed requirements and nitrogen excretion of animals (Ketelaars and Van der Meer, personal communication). Model parameters (length of the production cycle and feed conversion rate) are further calibrated with data from Kamphuis *et al*. (2004).

C import [tonne C ha-1]: It is assumed that 75 and 83% of the carbon in rice and sugarcane residues, respectively, is lost during burning (Basanta *et al*., 2003, Biederbeck *et al*., 1980; Lefroy *et al*., 1994). The carbon in biomass growth of perennial crops is not considered an input as it either is pruned and removed from the field in the same year (e.g. for pears) or represents a small amount which is pruned and removed once every 20 years (e.g. citrus). Shoots are the harvestable product of tea, mulberry and bamboo crops. It was assumed that in these crops all annual biomass is harvested and, therefore, there are no net carbon additions to the system.

Step iv: analysis and synthesis

Referring to input-output relationships of individual household components that have been quantified above, performance of farm households is analysed. First, productivity and environmental performance is evaluated (this section). Next, nitrogen management and integration are discussed in a separate section (4.3), after which general performance is evaluated in section 4.4, and sensitivity to external changes in section 4.5.

Farm household 1: very small farm
This farm household has only one plot (0.13 hectare), which is cropped with single rice; two pigs are kept. Two members of the family are permanently engaged in off-farm employment: the head of the household and his daughter with a university degree (Figure 20). The household does not hire in labour.

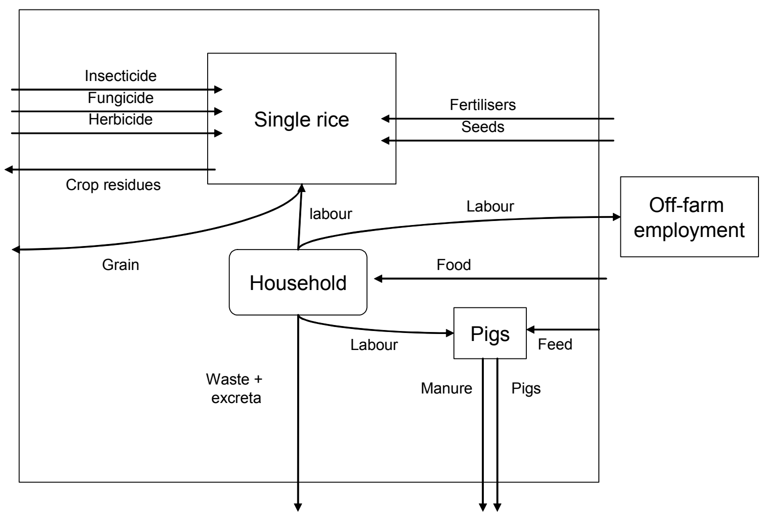

Figure 20 Energy flows for a very small farm.

Rice yields are 7.5 tonne ha^{-1}, which is within the range characteristic for the region (IRMLA, 2002). Large amounts of mineral fertilisers (247 kg N ha^{-1}) and biocides are applied to the rice crop. The high input use results in a surplus of N in the rice component (Table 14).

Since animals are sold and the manure nitrogen is not used within the farm, the nitrogen balance is nil. Recycling of manure nitrogen within the farm could substitute 11 kg fertiliser N that is applied to the rice crop. The benefit-cost ratio has been calculated assuming a price for animals and sold manure and the cost of all inputs used. Feed and labour are the major inputs. The energy input/ output ratio of pigs is relatively high because the energy conversion of feed into meat and manure is inefficient.

Table 14 Performance indicators in the very small farm household in Pujiang.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	C import (tonne ha^{-1})	Energy I-O ratio	Energy productivity (CNY MJ^{-1})	Labour productivity (CNY $manday^{-1}$)	Land productivity ('000CNY ha^{-1})	Benefit-cost ratio
Single rice	1.330	139	0.389	0.10	0.5	88	8.421	2.3
Pigs[3]	2 units	0	0.261	2.12	0.1	77		1.1

[1] *Animals in units.*
[2] *Not considering losses through denitrification, leaching, volatilisation, etc.*
[3] *Nitrogen balance and carbon import are expressed per animal component.*

Farm household 2: small farm
This household owns 2 plots totalling 0.32 hectare one plot is cropped under what is known as the double rice system, comprising an early and late rice crop, and the other plot is cropped with sugar-cane (Figure 21). The household has a sow producing on average 25 piglets per year, which are sold when they reach 100 kg. One of the four family members is permanently employed off-farm.

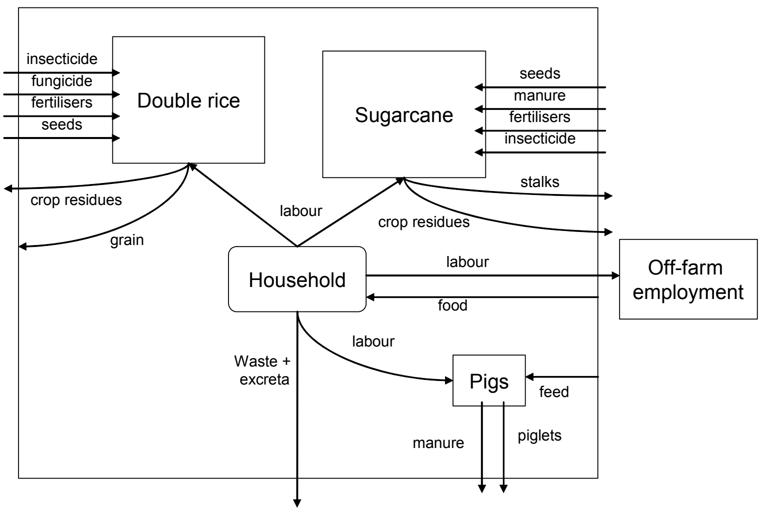

Figure 21 Energy flows for a small farm household.

Yields of the early and late rice crop are 4.5 tonne ha^{-1} and 6.7 tonne ha^{-1}, respectively. Input use in both rice and sugar-cane are high. Sugar-cane yields 60 tonne fresh stalks ha^{-1}. Crop residues are burnt after harvest and, therefore, most of the nitrogen in crop residues is lost. The partial N balance is positive for rice and strongly positive for sugar-cane because of differences in the use of fertilisers. Rice and sugar-cane receive 200 and 882 kg N ha^{-1}, respectively. Carbon imports are manure and crop residues that are not burnt. Energy inputs for the rice crops are much lower than those for sugar-cane, mainly because of the lower use of fertiliser (Table 15). The pig component results in a slightly positive nitrogen balance since piglets are sold. Feed and labour are the main inputs. Based on its benefit-cost ratio, sugar-cane is the most profitable activity of the farm household.

Table 15 Performance indicators in the small farm household category in Pujiang.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	C import (tonne ha^{-1})	Energy I-O ratio	Energy productivity (CNY MJ^{-1})	Labour productivity (CNY manday^{-1})	Land productivity ('000 CNY ha^{-1})	Benefit-cost ratio
Double rice	1.200	43	0.578	0.06	0.8	54	12.327	1.9
Sugar-cane	2.000	622	0.880	0.40	0.5	168	60.000	2.6
Sow + piglets[3]	1+25	1	0.758	2.28	0.2	190		1.1

1 *Animals in units.*

2 *Not considering losses through denitrification, leaching, volatilisation, etc.*

3 *Nitrogen balance and carbon import are expressed per animal component.*

Farm household 3: medium-size rice farm

This farm household has four plots (0.57 hectare), which are cropped with double rice, single rice, pears and oranges. The family owns one pig and none of the family members works off-farm (Figure 22).

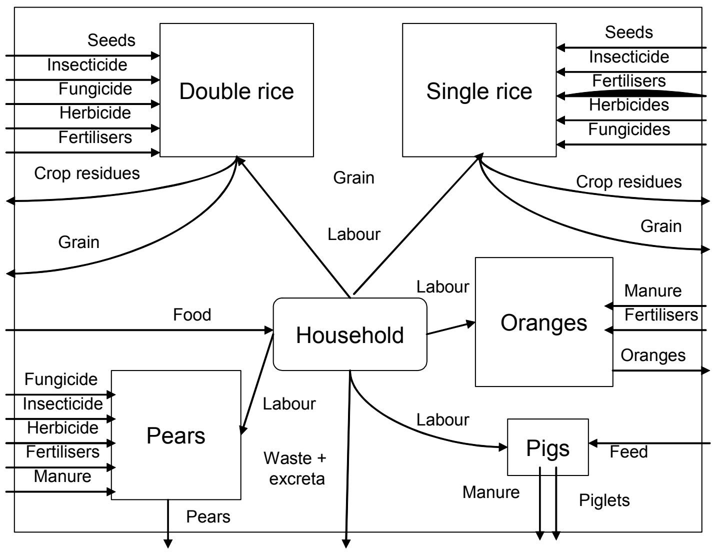

Figure 22 Energy flows for a medium-size rice farm household.

Yields of early and late rice are 4.3 tonne ha^{-1} and 2.3 tonne ha^{-1}, respectively. The farmer uses several biocides (fungicide, insecticide and herbicide) but very little mineral fertiliser explaining the negative partial nitrogen balance and the high energy productivity in rice (Table 16). Biocides are used in smaller amounts than fertilisers and, therefore, the amount of energy in inputs is also smaller.

Single rice yields 8.5 tonne ha^{-1} and receives slightly more nitrogen fertiliser than both rice crops in the double rice system (48 versus 30 kg N ha^{-1}). However, both rice components have a negative nitrogen balance, suggesting that nitrogen removal exceeds supply for each component. Due to higher yields and lower labour requirements, labour productivity is much higher for single rice. Oranges receive both inorganic and organic fertilisers, totalling 832 kg N ha^{-1}, while at harvest only little nitrogen is removed, which results in strongly positive nitrogen balances.

Table 16 Performance indicators in the medium size rice farm in Pujiang.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	C import (tonne ha^{-1})	Energy I-O ratio	Energy productivity (CNY MJ^{-1})	Labour productivity (CNY manday^{-1})	Land productivity ('000 CNY ha^{-1})	Benefit-cost ratio
Double rice	1.33	-77	0.389	0.04	1.2	34	8.211	1.2
Single rice	1.00	-74	0.440	0.03	1.5	67	9.520	2.2
Pears	1.33	1548	0.098	1.13	0.4	77	52.909	2.2
Oranges	2.00	738	1.181	0.64	0.6	166	54.000	3.2
Pig[3]	1	2	0.131	2.10	0.2	75		1.1

[1] *Animals in units.*

[2] *Not considering losses through denitrification, leaching, volatilisation, etc.*

[3] *Nitrogen balance and carbon import are expressed per animal component.*

The difference between oranges and pears relates to the source of nitrogen used, i.e. in organic form in oranges, while pears receive large amounts of mineral nitrogen fertiliser (around 1.5 tonne ha^{-1}). This also explains the differences in carbon import between both perennials. Several biocides are applied in pears, while oranges do not receive any biocide. The different use of inputs in both fruit crops explains the difference in benefit-cost ratio because land productivity is approximately the same.

Farm household 4: medium-size tea farm

This farm household has 2 pigs and 4 plots (0.75 hectare in total) that are cropped to rice, tea, mulberries and tea. One member of the family is engaged in off-farm casual work (Figure 23).

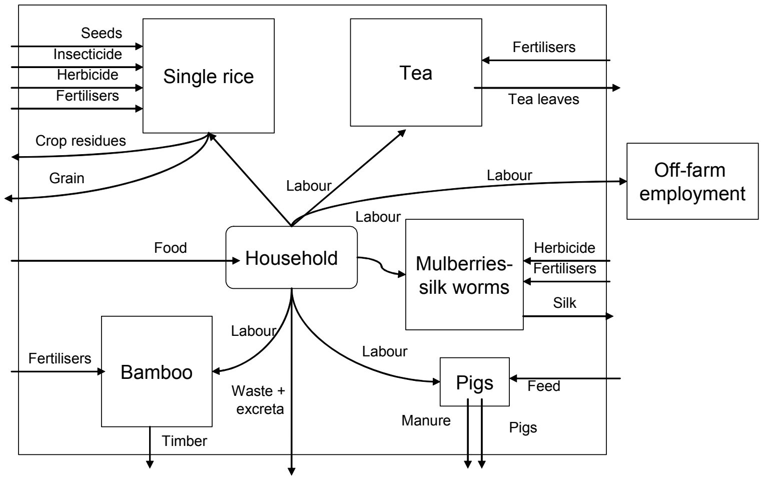

Figure 23 Energy flows in a medium-size tea farm household.

The rice plot receives a considerable amount of external inputs (165 kg N ha^{-1} and several biocides) and its yield is 4.7 tonne ha^{-1}. The yield of the tea crop (0.4 tonne ha^{-1}) is low compared to other farms in the region (around 1 tonne ha^{-1}). This farmer applies large amounts of urea-nitrogen to tea, conditions under which potassium may become relatively scarce, something which can limit crop production. Imbalanced fertilisation is a reported cause for low yields in tea (Jianyun Ruan *et al*., 1997). The tea crop requires a lot of labour, which results a high energy I-O ratio and low labour productivity (Table 17).

Table 17 Performance indicators in the medium size tea farm in Pujiang.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	C import (tonne ha^{-1})	Energy I-O ratio	Energy productivity (CNY MJ^{-1})	Labour productivity (CNY man-day^{-1})	Land productivity ('000 CNY ha^{-1})	Benefit-cost ratio
Single rice	3.170	83	0.294	0.10	0.5	135	6.360	3.0
Tea	1.300	278	0	6.82	0.3	30	7.692	1.0
Mulberries[3]	2.670	n.a.	0	n.a.	n.a.	108	18.727	3.3
Bamboo	0.330	158	0.368	0.06	0.7	119	15.152	4.5
Pigs[4]	2	15	0.261	2.10	0.2	75		1.1

1 *Animals in units.*

2 *Not considering losses through denitrification, leaching, volatilisation, etc.*

3 *N.a. = not available.*

4 *Nitrogen balance and carbon import are expressed per animal component.*

Mulberry leaves are used to feed and produce silk worms, the cocoons of which are used to spin silk. Some productivity indices of mulberry have been calculated on the basis of cocoon production and market prices. Since not all inputs and outputs of the mulberries component were known, calculation of resource use indicators is incomplete. Bamboo culms (15 tonne ha^{-1}) are comer-cialised for timber. Since bamboo leaves and branches are left in the field, there is a net C import of approximately 15% of the total above-ground biomass.

Farm household 5: large grape farm

This farm household is specialised in the production of grapes (2.0 hectares) and has 2 sows and a boar. Family members are not engaged in off-farm employment (Figure 24).

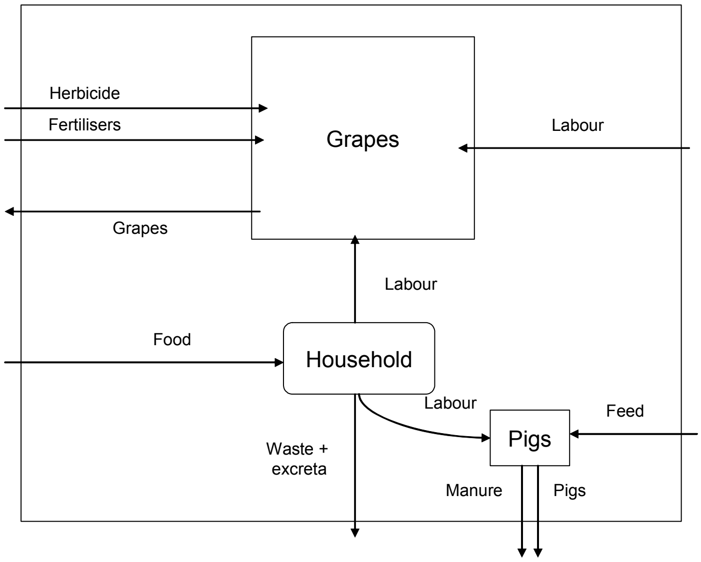

Figure 24 Energy flows for a large grape farm household.

After harvest of the grapes, the annual above-ground biomass is pruned and removed from the field to avoid the spread of pests and diseases. Therefore, net carbon imports are negligible in the vineyard. Grapes receive annually 194 Kg N ha^{-1}, of which little is removed through harvest and pruning (Table 18). The dataset does not distinguish between family and hired labour, but family labour cannot meet on-farm labour demand, so most likely labour from outside the farm household is hired during peak periods. For pigs the value of production includes animals sold at the market and the value of the boar as if sold.

Table 18 Performance indicators in the large grape farm household in Pujiang.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	C import (tonne ha^{-1})	Energy I-O ratio	Energy productivity (CNY MJ^{-1})	Labour productivity (CNY man-day^{-1})	Land productivity ('000 CNY ha^{-1})	Benefit-cost ratio
Grapes	20.00	152	0	0.21	2.6	51	59.156	2.1
Pigs[3]	3	1	0.392	1.91	0.2	87		1.3

[1] *Animals in units.*

[2] *Not considering losses through denitrification, leaching, volatilisation, etc.*

[3] *Nitrogen balance and carbon import are expressed per animal component.*

Farm household 6: large tea plantation

This household owns a large tea plantation and has no animals. The farm area is 3.67 hectares. None of the family members works off-farm (Figure 25).

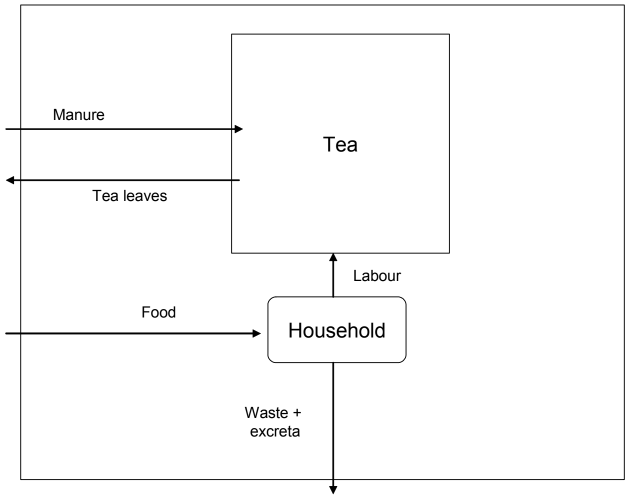

Figure 25 Energy flows for a large tea plantation household.

Manure and labour are the only inputs to the tea crop, the yield of which is low (0.3 tonne ha^{-1}). Since little nitrogen is removed at harvest, the partial nitrogen balance of tea is close to zero (Table 19). The addition of carbon to the system is also low because the annual biomass production is almost all harvested, while the amount of manure applied is low (0.8 tonne ha^{-1}).

Table 19 Performance indicators in the large tea plantation household in Pujiang.

Component	Area ('000 m^2)	N balance[1] (kg ha^{-1})	C import (tonne ha^{-1})	Energy I-O ratio	Energy productivity (CNY MJ^{-1})	Labour productivity (CNY man-day^{-1})	Land productivity ('000 CNY ha^{-1})	Benefit-cost ratio
Tea	36.700	1	0.014	0.57	8.2	71	13.624	2.2

[1] *Not considering losses through denitrification, leaching, volatilisation, etc.*

Step v: conclusions and recommendations

Differences in partial N balances for rice components are explained by differences in the use of mineral fertilisers. This is related to the existence of alternative uses for fertilisers, as there seems to be a tendency to apply less nitrogen fertilisers to rice when other, more profitable crops (i.e. fruits, sugar-cane) are grown on the farm. The same is true for carbon import, because residue management, i.e. burning of rice straw, is a common practice in the region. Energy I-O ratios of rice components are similar, but slightly lower for household 3 which applies little nitrogen fertiliser and has a negative nitrogen balance. Productivity indices are, in general, higher for single rice than double rice, because of both higher yields and lower use of inputs (mainly labour).
Differences in management determine large differences in performance indicators for pears and oranges. Partial nitrogen balances are highly positive for both crops, but in pears they are twice as high as in oranges, due to the use of more mineral nitrogen fertiliser and, to a lesser extent, lower removal of nitrogen at harvest. Carbon import in oranges is much higher than in pears because an important part of the nitrogen is given in organic form. Productivity indices vary mainly according to

input use (more expensive fertilisers in pears) since both crops produce high (and comparable) gross income.

Yields of tea are relatively low for the studied cases. The differences between the large and average farm household 4 and 6 are related to input use (labour and fertilisers) and the selling price of the product.

Most farm households have animal components, such as pigs. Performance indicators for these pig components are similar because all households follow similar management practices, i.e. the purchase of feed, allocation of little labour and sale of animals when finished. Pig production is not a very profitable activity because the price of the product is low and farmers depend on external inputs (feed and vaccinations).

4.3 Nitrogen management and integration

Calculations of integration indices (based on nitrogen flows) for farm households 1, 2 and 3 are presented in this section. To calculate integration indices, the same components as in the analyses of the household components are used. First, integration indices were calculated on the basis of current nitrogen management. Subsequently, scenarios for modified nitrogen management were defined to provide insight into the possible consequences of management changes on integration indices.

Farm household 1: very small farm
In the current situation, manure, human excreta and household waste are not (re)used within the farm household, rice is sold to the market, and nitrogen requirements of family members are met by purchasing food (Figure 26). There are three components and no recycling of nitrogen within the farm household system; total nitrogen flow depending entirely on the inflow of nitrogen (Table 20). About 30% of the nitrogen input in the household relates to nitrogen in food items, while human excreta are not recycled within the farm household.

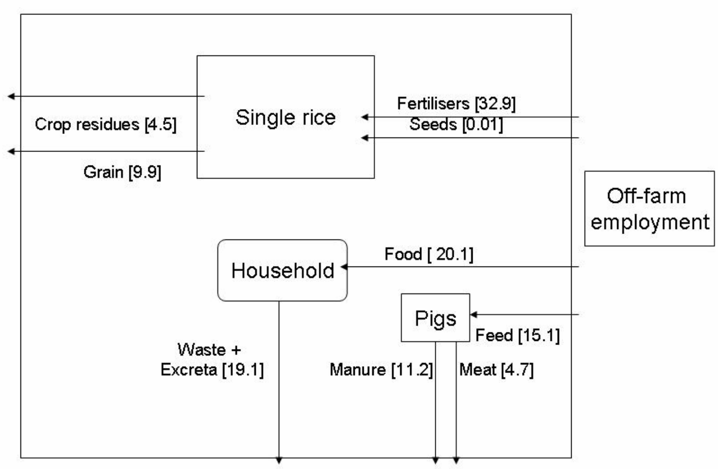

Figure 26 Nitrogen flows of the very small farm household category under current nutrient management. Values in brackets in kg N ha^{-1}.

In the first scenario, manure and human excreta are partly applied to rice. It is assumed that not all nitrogen in manure and excreta can be recycled efficiently because unavoidable losses occur, especially for nitrogen in urine. As a consequence of the partial recycling of nitrogen in manure and excreta, use of fertiliser nitrogen is reduced (by approximately 50%) in this scenario. In addition, household waste is used to feed pigs, so the import of feed is reduced. Moreover, rice produced by the household is used to meet the rice demand of family members (135 kg person^{-1} year^{-1}) and the rest is sold. The rest of the nitrogen requirements of household family members are met through purchasing food (Figure 27).

On the basis of these management changes in this scenario, 6.8% of the total nitrogen flow can be recycled within the household and the import of nitrogen can be reduced by 36% (Table 20). More recycling would be possible if rice-crop residues are fed to pigs, but common management practice includes burning to facilitate soil preparation.

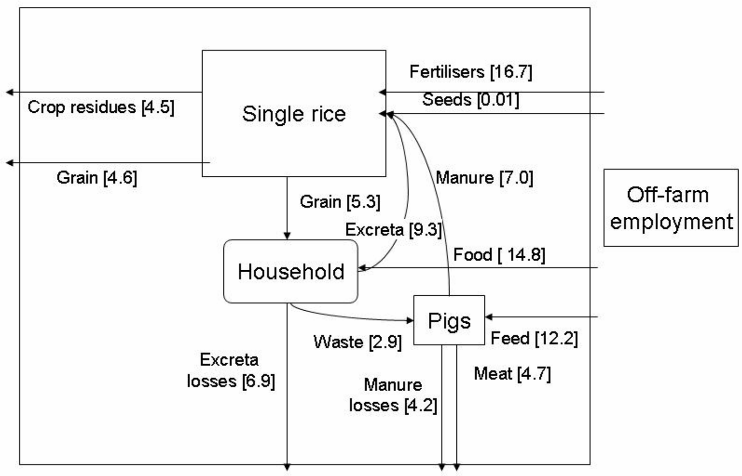

Figure 27 Nitrogen flows of the very small farm household category in the alternative scenario. Values in brackets in kg N ha^{-1}.

Farm household 2: small farm

As for farm household 1, manure and human excreta are also not (re)used within the farm household. Rice and sugar-cane stalks are sold to the market. Nitrogen in crop residues is mostly lost to the environment as straw is burned. Nitrogen requirements of the household family members is met through purchase of food (Figure 28). As a consequence, the recycling index is 0 for this farm household.

In the alternative management scenario, manure and human excreta are recycled within the farm household by using them in the rice and sugar-cane component. Consequently, the use of fertiliser nitrogen is reduced in this scenario. In addition, household waste and sugar-cane stalks are used to feed pigs. On-farm produced rice is used to meet the rice demand of household family members (180 kg person^{-1} year^{-1})[1] and the rest is sold. The rest of the nitrogen requirements of household family members are met by purchasing food (Figure 29).

1 *Based on survey data. Rice consumption in farm households 1 and 3 is 135 kg person^{-1} yr^{-1}.*

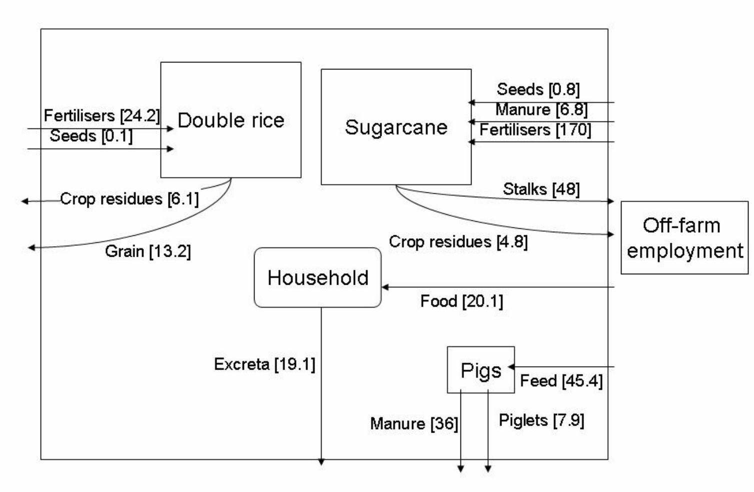

Figure 28 Nitrogen flows of the small farm household category under current nutrient management. Values in brackets in kg N ha^{-1}.

On the basis of these management changes in this scenario, 6.6% of the total nitrogen flow can be recycled within the farm household and the import of nitrogen can be reduced by 23% (Table 20)

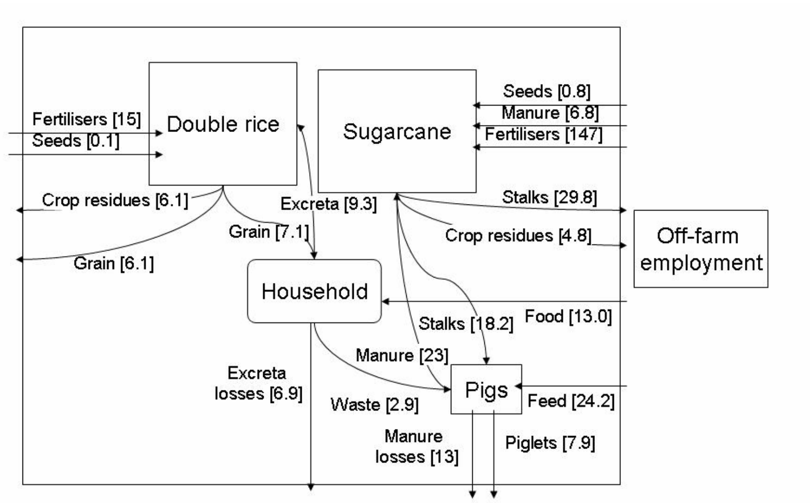

Figure 29 Nitrogen flows of the small farm household category in the alternative scenario. Values in brackets in kg N ha^{-1}.

Farm household 3: medium size rice farm

As in farm household 1 and 2, manure and human excreta are not (re)used within the farm household. Rice, oranges and pears are sold to the market. Nitrogen in crop residues is partially lost due to burning. Nitrogen requirements of household family members is met through purchasing of food (Figure 30). There are six components and no recycling of nitrogen within the system.

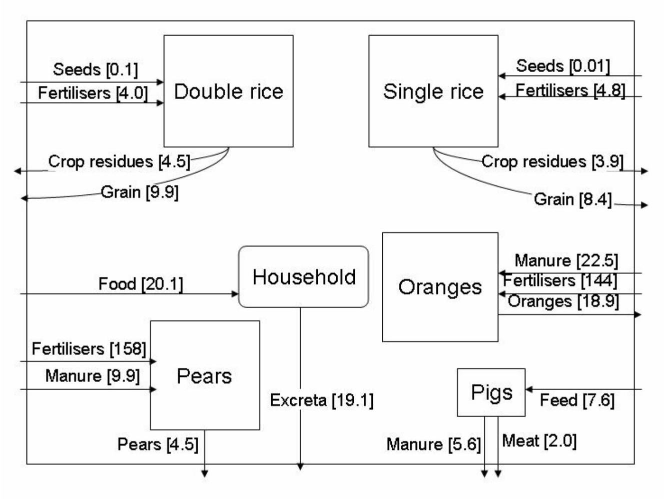

Figure 30 Nitrogen flows of the medium size rice farm household category under current nutrient management.
Values in brackets in kg N ha^{-1}.

In the alternative management scenario, manure and human excreta are applied to rice, oranges and pears. As a consequence, the use of nitrogen fertiliser is reduced. In addition, household waste is used to feed the pigs. Rice produced on-farm is used to meet the rice demand of household family members (135 kg person^{-1} year^{-1}) and the rest is sold. The rest of the nitrogen requirements of household family members are met by purchasing food (Figure 31).
In this scenario, the amount of nitrogen flow that can be recycled remains low (recycling index <1%). More recycling in this farm household would only be possible through urine conservation. The total nitrogen flow in this farm household depends heavily on the fertiliser input to both fruit crops, which is only reduced to a limited extent in this scenario (Table 20). Lower nitrogen inputs in both fruit crops would improve the recycling index and most likely would not harm the economic outputs of both components since current nitrogen inputs seem exaggerated.

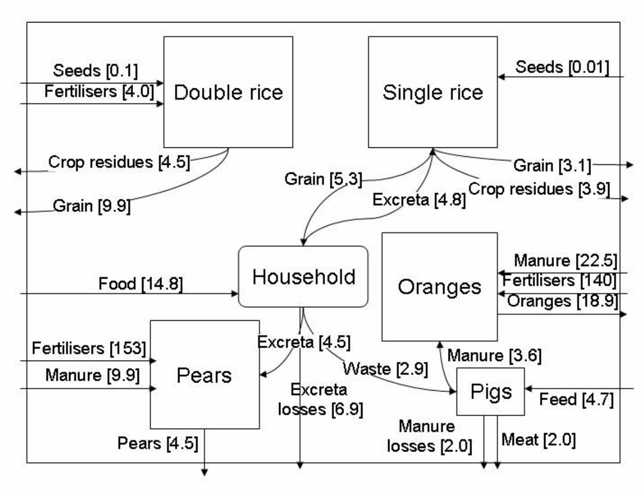

Figure 31 Nitrogen flows of the medium size rice farm household category in the alternative scenario.
Values in brackets in kg N ha^{-1}.

Table 20 Integration indices for three farm households in Pujiang.

Farm	Scenario	Total N inflow	Total system N flow	Path length	Cycling Index (%)
1	No recycling	69	69	1.0	0
1	Rice, manure and human excreta and waste recycled	44	69	1.6	6.8
2	No recycling	267	267	1.0	0
2	Rice, sugar-cane, manure, excreta and waste recycled	207	267	1.3	6.6
3	No recycling	433	433	1.0	0
3	Rice, manure, human excreta and waste recycled	412	433	1.1	0.8

4.4 Performance of farm household systems

Large nitrogen surpluses are observed in farm households that cultivate perennial crops, especially in farm household 3, where large amounts of both manure and inorganic fertilisers are applied to pears and oranges (Table 16). Despite the high nitrogen inputs in household 3, nitrogen productivity is not different from households 1, 2 and 4, due to the high commercial value of fruits. Nitrogen productivities of household 5 and 6 are much higher, due to the high value of grapes (household 5) and the low nitrogen input for tea (household 6). In general, all households use fertilisers (and biocides), which result in similar energy input-output ratios across farms. Within farm household systems, crops with the highest economic returns receive most inputs (fertilisers and biocides), probably even beyond the crops' requirements, suggesting that there is scope for improving factor productivity. Energy productivity increases with land holding size, which may either relate to a more efficient use of resources or the value of the type of crops cultivated (e.g. fruits versus rice).

In general, farm households with rice and tea have low land productivity. Rice yields are relatively high but prices are low, while for tea it is the opposite. This explains the low land productivity of farm household 4, which allocates 60% of its land to rice and tea. Fruit production and the production of mulberry-silk worms are economically attractive activities that offer high rates of return, but they require specific skills and management.

Off-farm employment is crucial for the subsistence of households with little land. Off-farm employment contributes 86% and 29% of the total gross incomes of farm households 1 and 2, respectively. Family members of medium-sized farm households are often engaged in various activities, as indicated by the high income diversity indices, but the income generated does not cover household expenditure and variable production costs. Although farmers do not put a value on family labour, which represents 50% of the variable costs, medium-sized households face a financial deficit under the current production structure. It is not clear whether this is due to a flaw in the dataset used or whether these households really face a financial deficit.

Farm households which combine large land holdings with a specialised production structure, such as household number 5 and 6, generate considerable profit, which allows savings to be used for future investments. Household expenditure of these farm households represents between 23% and 27% of their gross on-farm income.

Integration indices calculated for current management are related to both crop type and management practised (Section 4.6). Total nitrogen inflow and total system flow are mainly determined by purchases of mineral fertilisers, which are preferentially applied to fruit or industrial crops (Table 21). Optimising nitrogen recycling leads to an increased total inflow and recycling index. The fact that only some 7% of the total flow may be recycled does, however, indicate that connectivity between compartments (activities) within these farm households is relatively low. Opportunities to increase recycling and reduce inflow may include, for example, urine conservation and a better targeting of nitrogen management, resulting in higher yields.

Table 21 Comparison of performance indicators of six farm household systems in Pujiang.

	Very small farm	Small farm	Medium size farm	Medium size tea farm	Large grape farm	Large tea plantation
Area ('000 m^2)	1.330	3.200	5.700	7.500	20.000	36.700
Household members	4	4	4	4	4	4
Livestock	2 pigs	1 sow, 25 piglets	1 pig	2 pigs	3 pigs	-
Crops	Single rice	Double rice, sugar-cane	Double and single rice, pears, oranges	Single rice, tea, mulberries, bamboo	Grapes	Tea
Total gross income ('000 CNY)	19.683	25.023	20.731	10.687	121.286	50.000
Total on-farm income ('000 CNY)	2.883	17.823	20.731	10.237	121.286	50.000
Total off-farm income ('000 CNY)	16.800	7.200	0	0.450	0	0
Share animals gross income	0.61	0.24	0.04	0.17	0.02	0
Household expenditure ('000 CNY)	11.395	14.844	19.849	24.770	28.044	13.420
Variable production costs ('000 CNY)	2.117	9.234	8.681	4.765	58.067	22.268
Net income ('000 CNY)	6.171	0.944	-7.799	-18.848	35.165	14.312
Land productivity ('000 CNY ha^{-1})	8.421	42.123	35.125	17.742	59.156	13.624
Labour productivity (CNY $man\text{-}day^{-1}$)	81	147	97	84	51	71
N productivity (CNY kg N^{-1})	42	67	50	41	282	1253
Energy productivity (CNY MJ^{-1})	0.26	0.34	0.49	0.40	2.07	8.21
Benefit-cost ratio	1.4	1.9	2.4	2.2	2.1	2.2
N import (kg)	68	267	416	248 [1]	430	40
C import (tonne)	0.313	1.003	0.242	0.481	0.392	53
Partial N balance (kg)	17	132	338	102 [1]	323	4
Energy input-output ratio[1]	0.39	0.48	0.45	0.27	0.21	0.36
Income diversity (farm level)	0.51	0.82	1.13	1.48	0.08	0
Income diversity (household)	0.38	1.18	1.13	1.65	0.08	0
Recycling index (%)	0	0	0	0	0	0

[1] *Nitrogen import in mulberry system was taken into account for nitrogen input, but its nitrogen output wais not taken into account for nitrogen balance.*

4.5 Sensitivity to external changes

Changes in external conditions such as prices of inputs or outputs, regulations imposed by national or local authorities, or the availability of new technologies will not all affect performance of farm households in a similar fashion as objectives and factor endowments differ among households. To get a better understanding of the effect changing conditions may have on farm household performance, two situations are analysed: the effects of a change in cereal prices and of an improved nutrient management technology. Both situations illustrate how performance varies under certain external changes; these are referred to as scenarios in the remainder of this chapter.

Effect of changes in grain prices

In this scenario, the rice market prices are assumed to vary from -99% up to +200% of the price used in the baseline calculations. To assess the sensitivity of a given farm household for such changes, it is assumed that no other changes take place within the farm household systems. There is, in other words, no adjustment to the price changes. While under real-world conditions farmers would obviously adapt (e.g. by increasing or decreasing land allocated to rice, or adjusting mineral fertiliser applications), such changes are not considered here. Farm households 5 and 6 are not taken into account in this scenario because rice is not produced.

The effect of changes in prices of rice varies among farm households, depending on the relative contribution of rice sales to total income. For farm household 1, growing only rice but depending for its income largely on off-farm employment, all productivity indices are modified but total income is hardly affected (Table 22). In contrast, the impact on productivity in the other farm households is much smaller, because their productivity does not depend on rice alone. Income effects are highest for farm household 4 since sale of rice is a major source of its income.

Table 22 Changes in overall performance (expressed as % change) for four farm households in Pujiang.

	Farm household 1					Farm household 2					Farm household 3					Farm household 4				
Price change (%) Indicators	-99	-50	25	75	125	-99	-50	25	75	125	-99	-50	25	75	125	-99	-50	25	75	125
Energy productivity	-39	-19	10	30	50	-8	-4	2	6	10	-10	-5	2	7	12	-22	-11	6	17	28
Land productivity	-99	-50	25	75	125	-11	-5	3	8	14	-10	-5	3	8	13	-25	-12	6	19	30
N productivity	-39	-20	10	30	49	-8	-4	2	6	10	-10	-5	2	7	12	-22	-11	5	17	28
Labour productivity	-39	-20	10	30	49	-8	-4	2	6	10	-10	-5	2	7	12	-22	-11	6	17	28
Cost-benefit ratio	-39	-19	10	30	50	-8	-4	2	6	10	-10	-5	2	7	12	-22	-11	6	17	28
Total on-farm income	-39	-20	10	30	49	-8	-4	2	6	10	-10	-5	2	7	12	-22	-11	6	17	28
Total income	-6	-3	1	4	7	-6	-3	1	4	7	-10	-5	2	7	12	-21	-11	5	16	27
Income diversity[1] (farm level)	-39	-16	5	13	21	-20	-7	4	7	11	-27	-10	4	10	15	-11	3	-3	-8	-14
Income diversity[2] (household)	-39	-16	6	18	25	-14	-5	2	5	8	-27	-10	4	10	15	-7	4	-2	-8	-14

[1] *Income diversity at farm level = - $\sum p_i \ln p_i$, where p_i quantify the relative importance (in monetary terms) of the production of the ith activity = (n_i/N). N is the on-farm income.*

[2] *Income diversity at household level includes off-farm employment as an income generating activity.*

Farm households with medium-sized land holdings depend largely on on-farm income generation. Here, the impact of a price change on productivity indices varies with the importance of rice production for total income. Contrasting effects are observed also for income diversity (Figure 32).

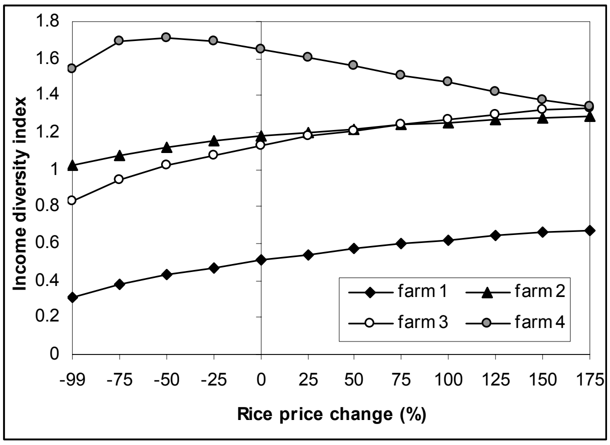

Figure 32 Effect of a change in the price of rice on the income diversity of different farm households in Pujiang, China.

Farm household 1, with the smallest land holding, has the least diversified income, which is reflected in a large effect on income diversity (Figure 33). When prices increase, rice contributes most to total income of farm household 4 and, therefore, income diversity decreases. Farm households 2 and 3 grow sugar-cane and fruits, which contribute more to total farm income at any price of rice. The effect on income diversity is proportional to the share of rice sold in total income.

Site-specific nutrient management

Site-specific nutrient management (SSNM) is a general concept for optimising the supply and demand of nutrients according to their variation in time and space (Dobermann *et al*., 2004). The concept is based on the projects 'Reversing Trends of Declining Productivity' (RTDP) and 'Reaching Toward Optimal Productivity' (RTOP) of IRRI's Irrigated Rice Research Consortium, which has been operational near Pujiang since 1997.

Within that project an SSNM technology has been developed aimed at applying NPK fertilisers on the basis of field and cropping-season specific conditions. The SSNM approach is based on three principles: (i) Emphasis on balanced nutrition using estimates of nutrients lost through crop removal; (ii) Application of fertiliser based on native soil fertility, and (iii) Improved timing of applications based on leaf colour at specific growing stages.

In SSNM, a basic N dressing is followed by three top dressings during different crop development stages, while under conventional management all fertilisers are supplied within the first 10 days after transplanting. In addition, SNNM involves abolishing the common practice of mid-season drainage, which causes large losses of nitrogen to the atmosphere (Wassmann *et al*., 2000). SSNM requires more labour but experimental evidence suggests that there is scope for improving yields while reducing N fertilisation significantly. On average, research has shown that the N rate could be reduced between 36% and 58% in Zhejiang province (Guanghuo *et al*, 2004). Thus, SSNM increases yields, farm profits and efficiency of nutrient use. The effect of improved nutrient management for the environment is expected to be positive since increases in productivity would reduce pressure on land and emissions of N may be reduced as well.

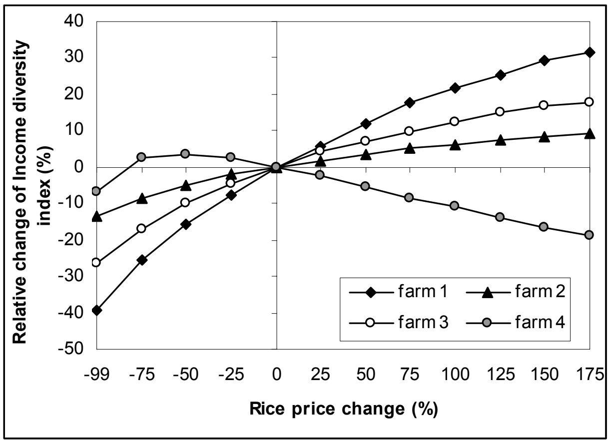

Figure 33 Relative effect of a change in the price of rice on the income diversity of different farm households in Pujiang, China.

For implementation of SSNM, in the case of Pujiang, an increase of 6.5% in rice yield was assumed for calculation of a target N uptake. Then nitrogen fertiliser applied and an assumed native soil nitrogen supply of 70 kg N ha^{-1} (estimated through omission plots at the SSNM project for the neighbouring site of Jinhua) were used to calculate the current Apparent Nitrogen Recovery (ANR):

ANR = [(Biomass N_f – Biomass N_o) / N fertiliser applied]

In which:

Biomass N_f = the N uptake of the targeted yield (6.5% higher than current yield)
Biomass N_o = the N uptake of rice under non-fertilised conditions (70 kg N ha^{-1})
N fertiliser = the nitrogen fertiliser rate.

The required nitrogen fertiliser is calculated on the basis of an ANR = 0.34 (the maximum achieved for SSNM plots at the Jinhua site). Current fertiliser use was corrected to this value by reducing the nitrogen rate of the most expensive N source.

The average number of fertiliser applications need to be increased from 2.7 to 3.8 times per season following SSNM principles. It takes about 6 h ha^{-1} to apply a dose of fertiliser. Plant density for SSNM (22 hills m^{-2}) is higher than in the conventional practice (19 hills m^{-2}), which implies extra seed and labour costs of around USD 25 ha^{-1}. Based on these assumptions, for two of the Pujiang farm households the potential effect of SSNM in rice on various performance indicators is shown.

Very small farm household 1

This farm household grows only rice, with a yield for single rice of 7.5 t ha^{-1} attained with 247 kg N ha^{-1}. In this scenario, rice yield increases to 8.0 t ha^{-1}, which can be achieved with 176 kg N ha^{-1}. Consequently, the nitrogen balance for the rice crop is reduced by 78 kg ha^{-1}. The carbon import increases slightly because of the 6% higher yield (Table 23). The energy input-output ratio improves by 20%, as more energy contained in the biomass is produced using less energy-demanding fertilisers. Productivity indices improve as a consequence of higher yield and reduced cost of production. Although there is an increase in labour costs to implement SSNM, it represents only about 1% of total labour costs, and is, therefore, negligible.

Table 23 Impact of SSNM on performance (expresses as % change) for the very small farm household 1 in Pujiang.

Component	Area ('000 m^2)	Partial N balance[1] %	C import %	Energy I-O ratio %	Energy productivity %	Labour productivity %	Land productivity %	Benefit-cost ratio %
Single rice	1.330	-56	4	-20	20	6	6	9

[1] Not considering losses through denitrification, leaching, volatilisation, etc.

Average farm household 4
The yield of single rice was 5.7 t ha^{-1} and the fertiliser use was 165 kg ha^{-1}. An increase of 6.5% in yield and an ANR = 0.34 can be obtained with 113 kg ha^{-1} of fertiliser N, which means a reduction of 33% in fertiliser use. Effects of the scenario are presented in Table 24.

Table 24 Impact of SSNM on performance (expressed as % change) for the average farm household 4 in Pujiang.

Component	Area ('000 m^2)	Partial N balance[1] %	C import %	Energy I-O ratio %	Energy productivity %	Labour productivity %)	Land productivity %	Benefit-cost ratio %
Single rice	3.170	-70	7	-40	76	6	6	16

[1] Not considering losses through denitrification, leaching, volatilisation, etc.

Though the effects are larger than in farm household 1, the positive effect of SSNM at plot level will have a low impact at household level since rice is one of several activities of this farm household. For example, bamboo and tea both receive about 280 kg N ha^{-1}, contributing to the positive N farm-household balance.

Impact of SSNM in rice on household performance

There is scope for improving the performance of rice crops through improved nutrient management (Table 25). However, important benefits at household level will be observed when the nutrient management of fruits and industrial crops is targeted as well, since farmers allocate only part of their land to rice production. Because fruits and industrial crops generate more income than rice, farmers tend to apply more inputs (both fertilisers and biocides) on these crops than on rice.

Table 25 Changes in overall performance (expressed as % change) for farm households 1 and 4 in Pujiang applying SSNM in rice.

Indicators	Farm household 1 (very small)	Farm household 4 (medium)
Variable production costs	<1	1
On-farm income (‘000 CNY)	2	1
Total farm income (‘000 CNY)	<1	1
Land productivity [CNY ha^{-1}]	6	2
Labour productivity (CNY $man\text{-}day^{-1}$)	2	1
N productivity [CNY kg N^{-1}]	10	9
Energy productivity (CNY MJ^{-1})	8	8
Benefit-cost ratio (CNY CNY^{-1})	3	<1
C import (tonne)	1	1
Partial N balance (kg)	-24	-18
Energy input-output ratio	-8	-11
Income diversity (farm level)	0	<-1
Income diversity (household)	2	<-1

5. Honduras

5.1 Introduction

The republic of Honduras in Central America is bounded to the north and east by the Caribbean Sea, to the south by Nicaragua, to the Southwest by the Pacific Ocean and El Salvador, and to the west by Guatemala. With an area of 112,492 km^2, Honduras is one of the largest countries in Central America. Approximately 4 million people, or 60% of the total population, live in rural areas. An estimated half of these people live in areas classified as hillsides.

The term 'hillsides' refers to areas where land management is significantly influenced by the presence of medium (12-30%) to steep (> 30%) slopes. In Honduras, hillsides account for some 85% of the total land area, with farming as the major economic activity. Poverty is also concentrated in the hillside areas, where 93% of the population is believed to live below the poverty line.

The majority of farm households are involved in the cultivation of the staple foods maize, beans and sorghum (Table 26). Cash crops such as coffee and sugar-cane are also grown. For the large-scale farms, the main activity is cattle ranching. Market access and off-farm employment opportunities are largely determined by the location. Jansen *et al*. (2003) show that small farms prevail in areas least favourable for agriculture, with lower market access, fewer roads and higher population density. Yet these farm households earn most of their income through off-farm employment, mainly as workers in large plantations. Livestock farm households are usually located in areas with good access to markets.

Table 26 Income generating activities of farm households in Honduras.

Crop activities	Animals	Other activities
Basic grains (maize, beans, sorghum)	Cattle	Renting in/out land
Coffee	Poultry	Renting in/out oxen
Sugar-cane	Pigs	Renting in/out labour
Pastures	Horses	Off-farm employment
Vegetables		

Basic grains are cropped in two seasons: 'Primera' (May to August) and 'Postrera' (August - December). In exceptional years, there is a third cropping season, called 'Apante' (December to February).

5.2 The multi-step approach

The analysis is based on the survey carried out by the project 'Rural Development Policies and Sustainable Land Use in the Hillsides of Honduras' of the International Food Policy Research

Institute (IFPRI) in cooperation with Wageningen University and Research Centre (WUR) and the National Program for Sustainable Rural Development (PRONADERS) of the Secretariat of Agriculture and Livestock (SAG) in Honduras. Research was carried out at three levels: the village or community level, the farm household level, and the individual plot level. The research covered 9 provinces and 19 counties, which were selected on the basis of agro-ecological conditions, dominant land use, population density, market access, and the presence of projects and programmes. A household survey, gathering information from 376 farm households, was carried out as part of the project.

Step i: developing a farm household typology

The farm household typology developed by Jansen *et al*. (2003) was used as a basis for this study. They defined six farm household types based on livelihood strategies. On the basis of a cluster analysis, six statistically different groups (clusters) were identified for the selected variables, which were farm size, level of education, livestock value, machinery value, share of annual crops, permanent crops and pasture, land-labour ratio and off-farm employment (Table 27). From each cluster, a random sample of 10% of the cases was selected; from this sample one farm household was selected to study resource flows and efficiencies. Clusters 4 and 6 were excluded from the study because differences with other clusters were considered not significant.

Cluster 1 represents 116 farm households. The group comprises grain farmers with small land holdings. They rent in most of the land and 60% and 14% of their income, respectively, is based on off-farm employment and transfers (remittances, government programmes and pensions). Cluster 2 represents 17 farm households. These farms have larger land holdings, more livestock and machinery than cluster 1, around 10% of their land is allocated to pastures; more than one-third is forest or fallow land. Off-farm income contributes less to total income than for Cluster 1. Cluster 3 is the largest group with 128 farm households. Land holdings are larger than for Cluster 2 and at least 50% of their income is from on-farm activities. Cluster 5 represents 56 farm households. They have significantly more income, land and a higher level of education than the other clusters. In general, this cluster contains medium-sized livestock farms, with more than half of the land allocated to pastures, while a number of the households crop coffee. One-third of the available labour is used in off-farm employment.

Table 27 Farm households selected for the case study Honduras.

No	Department	Municipality	Land holding (ha)	Crops	No. plots	Animals
1	Choluteca	El Corpus	0.6	Maize, beans, home garden	3	Chicken, bees
2	Copán	Santa Rita	3.9	Maize-beans, sugar-cane, home garden	5	Chicken, horse
3	Yoro	Yorito	9.9	Maize-beans, maize, coffee, vegetables	6	Chicken
4	Choluteca	El Corpus	23.1	Maize-sorghum, beans, sugar-cane, pastures	10	Cattle, horses, pigs, chicken

Step ii: quantification of resource flows

Energy flows were selected to show resource flows between household components and with the exterior. Off-farm employment is conceptualised as a component outside the farm household system, but there is an energy flow to the household component. The energy flow maps of the individual farm households are shown in step iv. All figures refer to annual flows, unless otherwise stated.

Step iii: calculation of indicators

In addition to the general description of and discussion on performance indicators of farm households systems in Chapter 2, specific information is provided here on the indicators used in the Honduras case study. More detailed are presented in Annex III.

Economic performance indicators are based on an exchange rate of HNL 1 = € 0.04. The costs for family labour are based on a location-and task-specific wage ranging from HNL 30 to 75 man-day^{-1}. Prices for products have been reported by farmers; otherwise those were extracted from the survey.

Soil carbon and nitrogen stocks of land-related components have not been estimated since relevant soil characteristics were not available in this case study. Farmers do not apply human or animal excreta to crops. Household organic waste is used to feed chickens. There is no recognition of value of livestock manure (Ordoñez, 2004) which is considered an outflow for the system as it is accumulated somewhere on the farm where it is subject to losses.

Partial N balance [kg N ha^{-1}]: Crop residues are usually not removed from the field in Honduras. Beans are generally poor nitrogen fixers due to sensitivity to a whole range of environmental effects. It was assumed that 50% of the nitrogen accumulated in the biomass of beans is from nitrogen fixation (Giller, 2001).

C import [tonne C ha^{-1}]: Carbon contained in coffee prunings is considered a gross input as it is not removed from the field. Cattle and horses are fed with on-farm resources such as fodder from pastures or vegetation from fallow land. Pigs are fed purchased concentrates. For calculation of feed requirements and manure production of pigs it is assumed that piglets of 20 kg live weight are purchased and sold when the animals reach a weight of 100 kg. A simple model was used to calculate feed requirements and nitrogen excretion of animals (Ketelaars and Van der Meer, unpublished).

Step iv: analysis and synthesis

Referring to input-output relationships of individual household components that have been quantified above, performance of farm households is analysed in three steps. First, productivity and environmental performance is evaluated (this section). Next, nitrogen management and integration are discussed in a separate section (5.3), after which general performance is evaluated in section 5.4.

Farm household 1: very small farm
This household cultivates 0.6 hectare. It does not own land but rather borrows it without payment of rent. The family has five members, one of whom is temporarily engaged in off-farm employment. On-farm income is generated through the cultivation of basic grains (bean and maize), poultry and bee-keeping (Figure 34). The maize yield is 2.9 tonne ha^{-1} and 0.5 tonne ha^{-1} for beans for the two growing seasons (*primera* and *postrera*). This system uses few external inputs, although some chemical fertilisers are applied preferentially to maize. Labour is hired in for the maize component. Farm animals comprise chickens and bees (bee hives). Chickens are consumed in the home and any honey produced is sold at local markets.

The farmer reported cultivating the following crops in the home garden: mango, bananas, nances (*Byrsonima crassifolia*), “mamón”, sweet peppers, and coriander (*Eryngium foetidum*). Unfortunately, inputs and outputs were not recorded in detail for the home garden. Though the annual amount of labour and total inputs invested are known, it was not possible to estimate the mass flows and, therefore, the partial nitrogen balance, carbon input and productivity indices were not calculated. The contribution of the home garden sales to total income was included and accounted for variable production costs. It is expected that the household members consume products from the home garden, and therefore the real contribution to on-farm income is actually larger. Literature suggests that products from home gardens are critical for coping with household energy requirements in off-season (Méndez *et al*., 2001). It is also likely that most of the household waste and manures are used in this component, thus modifying the farm household nitrogen and carbon balances.

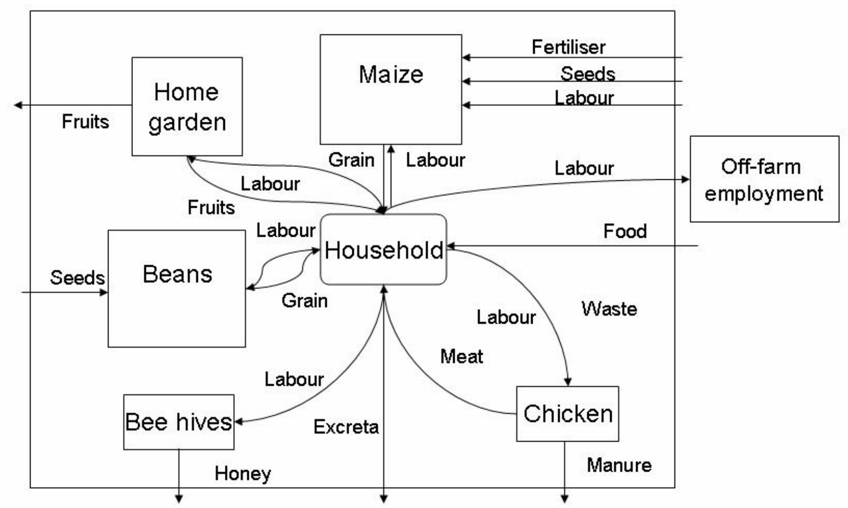

Figure 34 Energy flows for a very small farm household.

Although beans fix atmospheric nitrogen, their partial nitrogen balance is negative because the N harvest exceeds the contribution of the N fixation. Benefit-cost ratios of all activities are less than one, which suggests that costs are not compensated by returns (Table 28).

Table 28 Performance indicators of the very small farm household category in Honduras.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	C import (tonne ha^{-1})	Energy I-O ratio	Energy productivity (HNL MJ^{-1})	Labour productivity (HNL man-day^{-1})	Land productivity ('000 HNL ha^{-1})	Benefit-cost ratio
Maize	1.750	13	0.892	0.09	1.2	43	7.067	0.8
Beans	1.750	-2	0.108	0.23	3.1	80	6.852	0.7
Home garden	2.100							
Bee hives[3]	6 units	-0.01	0	0.22	17.3	29		0.6
Chicken[3]	30 units	1.3	0.131	4.2	0.07	13		0.3

[1] *Animals in units*

[2] *Not considering losses through denitrification, leaching, volatilisation, etc.*

[3] *Nitrogen balance and carbon import are expressed per animal component*

Farm household 2: small farm

The land holding of this farm household is 3.9 ha, a relatively large part (64%) of which is left fallow (Figure 35). All land is owned by the farmer. The farmer perceives his land as suitable for maize production. Probably not all land is cultivated because of labour scarcity. None of the household members is involved in off-farm employment and there is no hiring in of labour.

Maize and beans are intercropped on 1.0 hectare only in the first growing season (*primera*). Maize yields are 1.3 tonne ha^{-1}, while beans only produce 0.17 tonne ha^{-1}. Large application levels of mineral nitrogen (203 kg N ha^{-1}) yield positive partial nitrogen balances (Table 29). Crop residues are not removed from the field. Most of the production cost (63%) is related to family labour. The intercropping plot receives much more of inputs than the other on-farm components, but it realised a benefit-cost ratio of less than 1.

Sugar-cane is cultivated on 0.35 hectare; the harvested stalks are used to produce 'panela', blocks of solid brown sugar for human consumption. The sugar-cane yield has been estimated at 46.3 tonne fresh stalks ha^{-1} (0.13 tonne panela/ tonne cane). The negative nitrogen balance and relatively high energy and labour productivity indices are the result of the absence of fertilisers and limited use of labour. The residues of the cane milling process are assumed to be used as fuel for evaporating the cane juice. The sugar-cane crop and panela production could be seen as two separated components; the outputs of the former serve as inputs for the latter. In this way, the relative contribution of each activity to total income could be evaluated separately, while it also affects the calculation of the integration indices. Unfortunately, information available was not detailed enough to quantify indicators for the two separated components, i.e. labour allocation per activity and opportunity price of the sugar-cane stalks were missing.

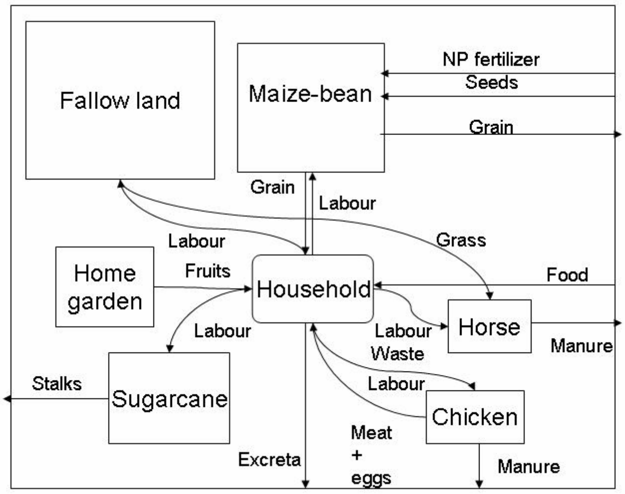

Figure 35. Energy flows for a small farm household.

Table 29 Performance indicators of the small farm household category in Honduras.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	C import (tonne ha^{-1})	Energy I-O ratio	Energy productivity (HNL MJ^{-1})	Labour productivity (HNL manday^{-1})	Land productivity ('000 HNL ha^{-1})	Benefit-cost ratio
Maize-beans	10.500	179	0.442	0.56	0.4	49	8.006	0.9
Sugarcane	3.500	-185	1.042	0.006	2.7	208	2.884	1.5
Fallow land	25.000	-20	0.716	0.005	0	0	0	0
Chicken[3]	20	1.5	0.191	3.5	0.64	177		5.1
Horse[3]		9.8	0.918	1.0	0.03	24		0.7

[1] Animals in units.

[2] Not considering losses through denitrification, leaching, volatilisation, etc.

[3] Nitrogen balance and carbon import are expressed per animal component.

The farmer reported having mango, oranges and coffee in his home garden but there was no information about outputs, which are all used for home consumption. Farm animals comprise chickens and a horse. Chickens are fed household organic waste and the household consumes all the produce (meat and eggs). The horse is used for transportation of harvested products within the farm and to the market. It was assumed that the horse is fed with grass collected from fallow land. Fallow land produces approximately 4 t dry matter ha^{-1} (Hugo van der Meer, personal communication). Fallow plots can be rented out for cattle grazing, in which case the grass produced has an opportunity cost. However, this farmer did not report grazing in his land and, therefore, no value was assigned to the production of the fallow land or to the grass grazed by the horse. Nevertheless, the benefit-cost ratio of the horse is less than 1 because its maintenance requires labour, while its productivity is low (under-utilised).

Farm household 3: medium size farm

The size of the land holding of this household is 9.9 ha, of which approximately 20% is borrowed without payment of rent. The farmer cultivates maize, beans, coffee and vegetables (cabbage and tomatoes). Most of the land is allocated to forest (55%) or left fallow (17%) (Figure 36).

There is controversy as to whether the forest and the fallow land can be considered as components of the farm household system. On the one hand, they compromise resources (land), but at present they do not contribute to household consumption. However, the forest represents both an asset to the farm household that could be converted into cash in the future and a carbon store that will be depleted when harvested, thus modifying nitrogen and energy balances as well. In this case, the definition of farm-household system component is time dependent, which has consequences for drawing conclusions about the economic and environmental performance of this household. It is possible to estimate indicators for the forest and fallow land component, although some information on species composition, standing biomass and potential productivity would be needed.

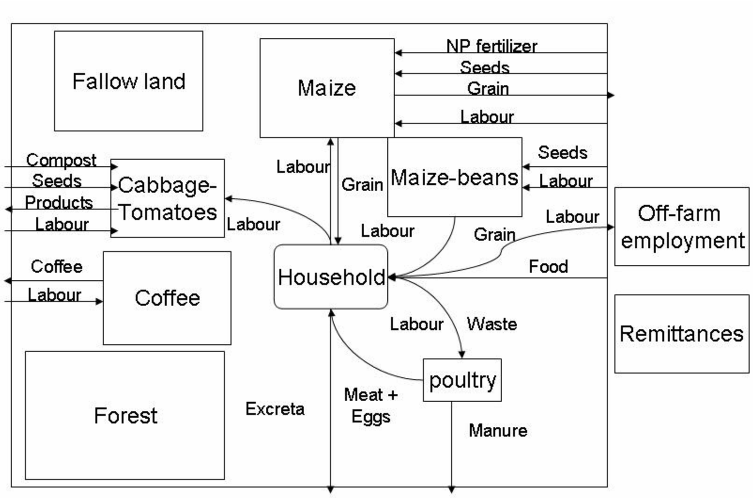

Figure 36 Energy flows for a medium size farm household.

The family comprises six members, one of which is involved in off-farm employment. Labour is hired in for maize and coffee production. The household also receives remittances from abroad, which account for 5% of the total gross income.

Maize and beans are intercropped; maize is also grown as monocrop but only in the first season (*primera*). The maize monocrop receives 84 kg N ha^{-1} and yields 2.6 tonne ha^{-1}. The intercrop, which receives only labour as input, has low maize (0.6 tonne ha^{-1}) and beans (0.5 tonne ha^{-1}) yields, negative nitrogen balances and high energy productivity (Table 30). Vegetable production consists of cabbage and tomatoes that are grown with high inputs on a relatively small area. Labour is the only input for coffee cultivation.

Table 30 Performance indicators of the medium size farm household category in Honduras.

Component	Area[1] ('000 m^2)	Partial N balance[2] (kg ha^{-1})	C import (tonne ha^{-1})	Energy I-O ratio	Energy productivity (HNL MJ^{-1})	Labour productivity (HNL man-day^{-1})	Land productivity ('000 HNL ha^{-1})	Benefit-cost ratio
Maize-beans	3.5	-14	0.311	0.06	3.1	46	4.467	1.3
Maize	14.0	46	0.113	0.12	1.1	88	8.571	1.8
Vegetables	0.5	88	0.923	6.4	0.26	90	19.900	1.9
Coffee	10.0	-6	0.031	0.05	12.9	59	7.440	2.0
Chickens[3]	20	1.7	0.103	2.6	0.20	29		1.0

[1] *Animals in units*

[2] *Nitrogen balance and carbon import are expressed per animal component.*

[3] *Not considering losses through denitrification, leaching, volatilisation, etc.*

Farm household 4: livestock farm

The land holding of this farm household is 23 ha, of which 70% is under production. There is no off-farm employment but the household receives an important contribution to total income through remittances. Most of the land under production is allocated to pasture (33%; Figure 37). Sorghum and beans are cultivated in the first season (*primera*) and beans are also cultivated in the second season (*postrera*). A plot is cultivated with sugar-cane for the production of panela. Sugar-cane yields 113 tonne ha^{-1}. Sorghum yields 1.3 tonne ha^{-1} and beans 0.8 tonne ha^{-1} in the first season and 0.2 tonne ha^{-1} in the second season. Crops are not fertilised and weeds are controlled with herbicides.

The household owns 20 cattle, 3 horses, 4 pigs and 22 chickens. The cattle herd consists of 2 oxen, 1 bull, 5 lactating cows, 3 dry cows, 4 heifers and 5 calves. Cattle graze during the day on farm pastures, while the horses graze the fallow land. At night, both are stalled in the household's barn. Pigs are fed with purchased feed and chickens consume organic waste from the household. Pastures are rented out if the household's cattle are not grazing them. Therefore, it is assumed that the opportunity cost of the feed for the household's cattle is equal to value of renting out pastures (286 HNL ha^{-1}).

Mango, chamote (sweet potatoes) and cassava are grown in the home garden. All are reported to be consumed by the household although no details are available about the amounts consumed. Most of the labour used on-farm is hired in, while family labour is only used for animal husbandry.

Although the bean crop fixes atmospheric nitrogen, the harvest of grain nitrogen exceeds that contribution and the partial nitrogen balance is slightly negative (Table 31). The differences in productivity indices between beans cultivated in the first and second season is due to the large difference in yields, since input use is similar for both crops. Nitrogen balances of all crop components are negative for this farm household, especially sugar-cane, which extracts large amount of nitrogen through the harvested stalks.

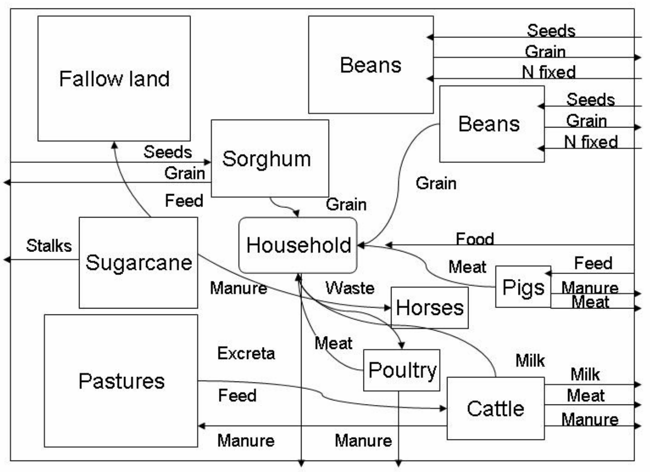

Figure 37 Energy flows for a livestock farm household.

The animal components and the household produce annually 228 kg of nitrogen excreta, which accumulates on-farm and is lost because the farmer does not re-utilise it for farming. This amount, if well managed, may help to reduce largely the negative farm-household partial-nitrogen balance.

Table 31 Performance indicators of the livestock farm household category in Honduras.

Component	Area[1] ('000 m²)	Partial N balance[2] (kg ha⁻¹)	C import (tonne ha⁻¹)	Energy I-O ratio	Energy productivity (HNL MJ⁻¹)	Labour productivity (HNL man-day⁻¹)	Land productivity ('000 HNL ha⁻¹)	Benefit-cost ratio
Beans-postrera	49.0	-2	0.042	0.14	4.2	73	2.237	2.0
Sorghum	14.0	-22	0.270	0.04	4.0	54	3.787	1.2
Beans-primera	14.0	-8	0.162	0.04	15.1	219	8.541	5.6
Sugar-cane	7.0	-454	2.554	0.002	10.1	234	13.036	3.2
Pastures	77.0	-23	0.067	0.13	0.05	29	0.286	0.3
Fallow land	70.0	-7	0.043	0.18	0.01	45	0.060	1.1
Chickens[3]	22	1.4	0.207	2.2	0.37	111		3.7
Pigs[3]	4	5.5	0.597	4.4	0.12	105		0.5
Horses[3]	3	17.1	2.754	1.8	0.01	11		0.2
Cattle[3]	20	-19.6[4]	13.224	2.2	0.18	381		4.5

1 Animals in units.
2 Not considering losses through denitrification, leaching, volatilisation, etc.
3 Nitrogen balance and carbon import are expressed per animal component.
4 A negative nitrogen balance means a reduction in the herd because of sale or death of animals.

The cattle component generates more than half of the gross on-farm income through animal products (milk, cheese, butter and meat), besides the value of the herd. Pigs and horses do not generate returns as they get feed and labour input, while benefits according the farmer are limited.

Step v: conclusions and recommendations

Maize is grown as monocrop (farm households 1 and 3) and in combination with beans (farm households 2 and 3). Differences in the performance of intercropped maize relate to the use of inputs and associated yields. Household 2 uses high nitrogen inputs, which results in highly positive nitrogen balances and maize yields twice as much as for household 3. However, the benefit-cost ratio is more favourable for household 3, as its costs of production are much lower than household 2, suggesting that the use of nitrogen fertiliser in household 2 does not pay off. Household 3 also performs better than household 1 for monocrop maize: as yields are similar, this better performance is mainly the result of reducing the costs of production.

Although beans fix nitrogen, all crops have negative nitrogen balances, since the nitrogen in the harvested beans exceeds the contribution of nitrogen fixation. No fertilisers are added to bean crops. The economic performance of the bean components is determined by the yield, which varies between farms and seasons. The price of beans is relatively high. Two farm households cultivate sugar-cane for the production of *panela*, which has a favourable market price. A limited amount of labour is the only input used and, therefore, nitrogen balances are strongly negative, energy input-output ratios are very low and energy productivity relatively high.

In general, chickens are fed with household waste. Differences in economic performance are due to the variable production (eggs and meat) between farm household, which is always used for home consumption.

5.3 Nitrogen management and integration

Integration indices were calculated for all farm households based on nitrogen flows. For the calculation, the same components as in the analyses of the household components described above were used. Integration indices were calculated on the basis of current nitrogen management.

Farm household 1: very small farm
Household 1 consumes all maize and beans produced on-farm, but it also purchases food (nitrogen) to fulfil household food needs (Figure 38). There are five components and limited recycling of nitrogen within the system.
Few external nitrogen inputs are purchased for farming, yet they represent 58% of the total nitrogen flow in the system (Table 32). Chickens are fed with household waste but manure and human excreta are not recycled and are, therefore, lost. Crop residues are left in the fields. The recycling index for this farm household is only 1.7%.

Opportunities exist for increasing nitrogen recycling. Purchased fertilisers could be replaced with animal manure and human excreta. The role of the home garden in nitrogen recycling is unknown. It is likely that this component represents a sink for organic residues and that the recycling index is higher than calculated.

Farm household 2: small farm
This farm household consumes part of the on-farm produce (maize, beans and chicken products) but also sells (grain, *panela*) produce, while it discards manure and human excreta. It imports large amounts of nitrogen through food and fertilisers purchased (Figure 39). There are six components

and limited recycling of nitrogen within the system. Total nitrogen inflow represents 93% of the total system nitrogen flow, which is largely explained by nitrogen imports.

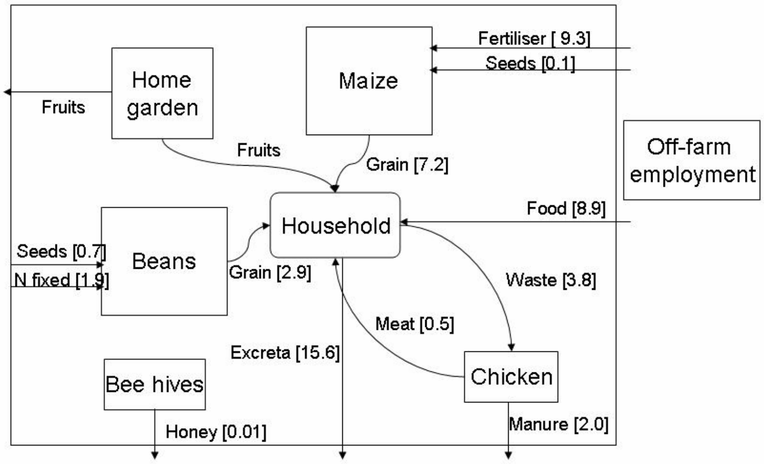

Figure 38 Nitrogen flows of the very small farm household category under current nutrient management. Values in brackets in kg N ha^{-1}.

Under current management, nitrogen recycling is minimal (Table 32). Recycling all animal manure and human excreta produced on-farm will marginally help to reduce dependency on nitrogen inputs.

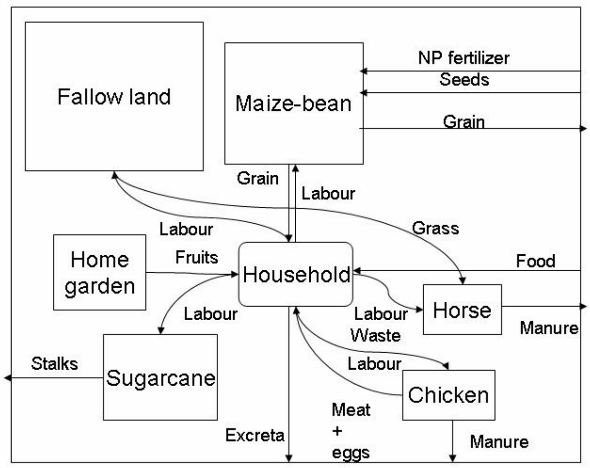

Figure 39 Nitrogen flows of the small farm household category under current nutrient management. Values in brackets in kg N ha^{-1}.

Farm household 3: medium size farm

Most of the grain produced on-farm is sold on the market, which represents an important nitrogen export from the system (Figure 40). The system consists of six components and shows limited recycling of nitrogen. Forest and fallow land components do not play a role in the nitrogen cycling. Little nitrogen is imported as food but considerable amounts of mineral nitrogen fertilisers are applied to maize. Animal manure and human excreta are not recycled. Only 0.4% of the total nitrogen flow is recycled in this farm household (Table 32).

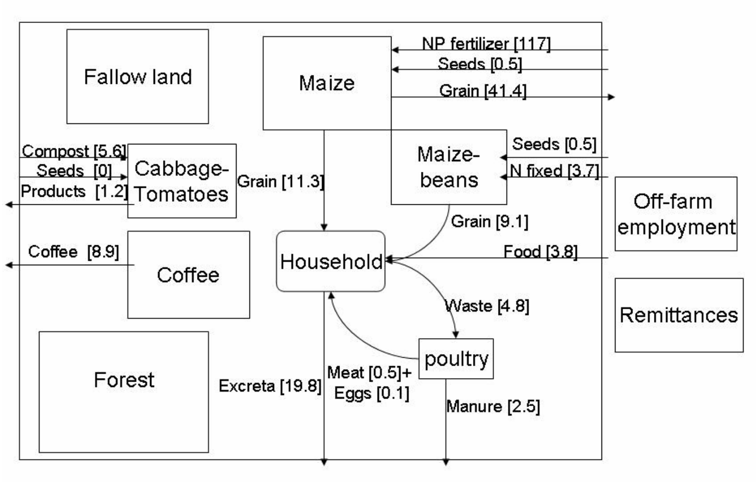

Figure 40 Nitrogen flows of the medium size farm household category under current nutrient management. Values in brackets in kg N ha^{-1}.

Farm household 4: livestock farm

Considerable amounts of nitrogen are exported through the sale of on-farm products, while nitrogen input is much less (Figure 41). There are 11 components and nitrogen recycling in the system is limited. There is no purchase of mineral nitrogen fertiliser and input of food nitrogen comprises a relatively low proportion (37%) of total household consumption.

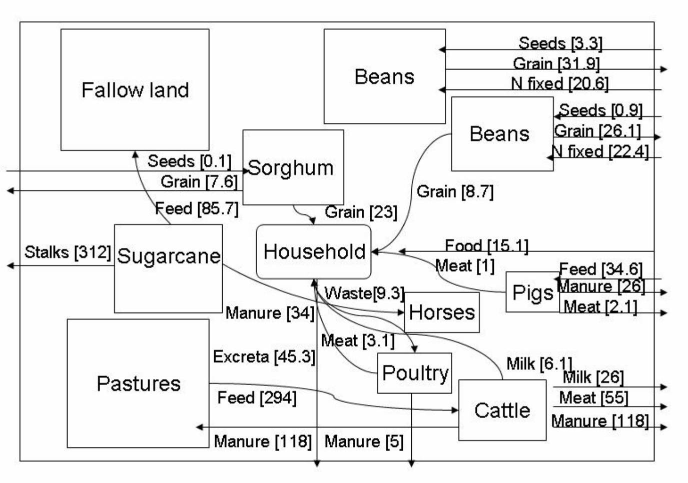

Figure 41 Nitrogen flows of the livestock farm household category under current nutrient management. Values in brackets in kg N ha^{-1}.

Because animals graze on-farm, a significant amount of manure is recycled through pastures and fallow land. The presence of cattle and the utilisation of on-farm resources as feed increase the nitrogen recycling index to 22.8%, considerably higher than for the other farm households, without livestock grazing on-farm (Table 32). There are more opportunities to increase the connectivity of components within this farm household. Manure collected in the stables could be applied to crops, producing a yield increase, and purchased feed for pigs could be substituted by fodder produced on-farm.

Table 32 Integration indices for three farm households in Honduras.

Farm	Scenario	Total N inflow	Total system N flow	Path length	Recycling index (%)
1	Actual recycling, all manure is lost	21	36	1.68	1.7
2	Actual recycling, all manure is lost	333	358	1.08	0.3
3	Actual recycling, all manure is lost	145	166	1.14	0.4
4	Actual recycling, manure is left in grasslands	720	1303	1.81	22.8

Re-utilisation of nitrogen in most of these farm household systems is extremely low, mainly due to poor management of available organic resources.

5.4 Performance of farm household systems

In general, accumulation of nitrogen is low and only farm household 4 shows very negative N balances, indicating soil depletion, mainly due to sugar-cane and pastures not receiving any external nitrogen and the sale (off-farm) of harvested crop products (Table 32). Middle-sized farms are more dependent on external energy inputs than either the very small or very large farms. Energy productivity varies between farms and is probably closely related to the relative importance of energy-input consuming activities to total income. Maize uses more external inputs, but animals consume more labour than the other on-farm activities. Land productivity decreases as farm size increases, because more land is left fallow or allocated to pastures or to forest. The larger the land holdings, the higher the labour productivity, benefit cost-ratio and on-farm gross income. Except for the very small farm, farm households are food self-sufficient.

In farm household 1, off-farm work contributes 63% of the household income. The produce of basic grains in this farm household is not sufficient to cope with household consumption. Approximately 35% of the maize and 50% of the beans consumed is met by purchasing grain. Household expenditure for food takes 61% of the total income. On-farm production and off-farm employment allow this household to meet physiological energy needs and there is still a cash surplus, which may be used to cover other needs. This is only possible because family labour is not valued; otherwise the farm household net income is negative. The energy and protein consumption of the household is above the average reported for Honduras (FAOSTAT, 2002). As long as off-farm employment is guaranteed, this household has food security. The lowest income diversity at farm level also indicates that this farm household may be most vulnerable to external shocks.

For farm household 2, off-farm employment makes no contribution to total farm income. Beans produced are used completely for household consumption, although maize production generates a surplus (30%), which is sold to the market. Energy of on-farm production is sufficient to meet household needs. Household expenditure on food represents 43% of the total income. The net income of this household is negative when the cost of family labour (87% of the variable production costs) is taken into account. The energy and protein consumption of the household is just above the average reported for Honduras.

Off-farm employment and remittances contribute 15% to the total gross income of farm household 3. Beans produced are used for household-consumption but 64% of maize produced is sold on the market, after household energy requirements are met. Household expenditure on food represents

23% of its total gross income. Net income is positive even when family labour is taken into account. The energy embodied in on-farm production is sufficient to meet the needs of the household.

Farm household 4 shows the most diversified income distribution, generating a large energy surplus on the farm. Most farm products are destined for the market. Household energy and nitrogen consumption are higher than the average for Honduras. Remittances represent 19% of its total gross income, while household expenditure on food is only 8%. The large numbers of animals on the farm contribute considerably to the feeding of the household and explain the high recycling index (Table 33).

Table 33 Comparison of performance indicators of four farm household systems in Honduras.

Indicators	Very small farm	Small farm	Medium size farm	Livestock farm
Area ('000 m^2)	5.6	39.0	99.0	259.0
Household members	5	7	6	13
Livestock	30 chickens, 6 bee-hives	20 chickens, 1 horse	20 chickens	20 cattle, 3 horses, 4 pigs, 22 chickens
Crops	maize, beans, home garden	maize-beans, sugar-cane, home garden, fallow land	maize-beans, maize, coffee, vegetables, forest, fallow land	sorghum, beans, sugar-cane, pastures, fallow land
Energy in home-grown crops (GJ)	9.083	57.346	59.655	207.293
Household energy requirements (GJ)	16.608	23.251	19.929	43.180
Energy balance (GJ)	-7.525	0.787	0.169	3.241
Total gross income ('000 HNL)	15.375	14.537	26.388	120.623
Total on-farm income ('000 HNL)	5.655	14.537	22.668	97.523
Cash generated by on-farm production ('000 HNL)	2.919	2.811	17.868	77.544
Total off-farm income ('000 HNL)	9.720	0	3.720	23.100
Share animals gross income	0.05	0.35	0.03	0.59
Household expenditure ('000 HNL)	9.400	6.239	6.292	9.789
Variable production costs ('000 HNL)	9.403	12.582	12.848	41.520
Net income ('000 HNL)	-3.429	-4.337	4.140	69.704
Land productivity ('000 HNL ha^{-1})	10.098	3.737	8.096 (2.290)*	4.222
Labour productivity (HNL $manday^{-1}$)	38	58	69	144
N productivity (HNL kg N^{-1})	560	68	179	492
Energy productivity (HNL MJ^{-1})	0.97	0.24	1.2	0.20
Benefit-cost ratio (HNL HNL^{-1})	0.6	1.2	1.8	2.3
N import (kg)	21	219	131	97
C import (tonne)	0.721	4.317	0.979	3.840
Partial N balance (kg)	3.2	86	54	-589
Energy input-output ratio	0.08	0.10	0.14	0.03
Income diversity (farm level)	0.92	1.05	1.10	1.54
Income diversity (household)	1.21	1.05	1.46	1.88
Recycling index (%)	1.7	0.3	0.4	22.8

* *Values between in parentheses calculations are made for the total land holdings, ignoring the potential contributions of the forest and fallow land.*

6. Perspectives for diversification

6.1 Introduction

This Chapter presents perspectives for the diversification of farm household systems in the three study areas. The focus is on diversification because it is seen as one of the most important strategies for increasing resilience, reducing poverty and to improving natural resource management (Dixon *et al*., 2001; Ellis and Allison, 2004; Barrett *et al*., 2001a, 2001b; Chapter 1). Effects of diversification strategies on household income and resource management are analysed for three areas, which each exhibit specific agro-ecological conditions and socio-economic settings. By identifying trends and relationships between performance indicators, a generic view can be established on the relation between diversification, income and resource use efficiency. In this way, more insight can be provided into the conditions and circumstances under which diversification proves to be a viable strategy.

6.2 Farm income

The key issue is whether diversification is an appropriate strategy to reduce poverty, i.e. whether diversified farm households are associated with higher incomes. As diversification serves to reduce risks, it is assumed to lead to more stable and, on average, higher household incomes (Barrett *et al*., 2001a). To test this hypothesis, the relationship between household income diversity and total gross farm-household income, including both off-farm and on-farm income components, is examined. In Teghane and Honduras, more income-diversified households are indeed associated with higher incomes (Figure 42). In contrast, in Pujiang more diversified households have lower total gross incomes as compared to specialised households.

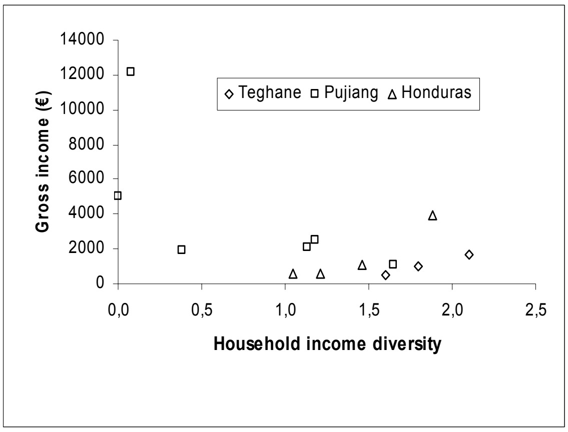

Figure 42 Relationship between total gross income of farm households and household income diversity in Pujiang, Teghane, and Honduras.

The effects of diversification in terms of food expenditure - as a proxy for improved household income - have also been assessed. If diversification leads to increased incomes, access to food is improved either directly (by improving home production) or indirectly (guaranteeing higher and more stable income and, hence, better access to food). Information on food expenditure is restricted to the Pujiang case. If the specialised farm household with highest gross income (Figure 42) is excluded, Pujiang households do indeed confirm this the relationship, i.e. elevated food expenditure (calculated from both home-grown and purchased consumables) goes together with increased income diversity (Figure 43).

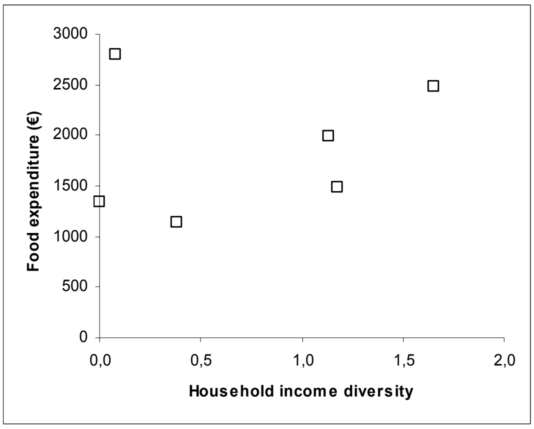

Figure 43 Relationship between household income diversity and household food expenditure in Pujiang.

6.3 Farm size

The positive relationship between total gross household income and (household) income diversification that has been found in Honduras and Teghane might be explained by differences in farm size. In general, a large degree of diversification is associated with small (poor) farm households, to reduce income risks (Ellis and Allison, 2004), even though larger (richer) farm households may be in a better position to diversify as their scale and assets allow them to undertake more (types of) activities (Barrett *et al*., 2001b). Such combined and conflicting effects may obscure the findings of Section 6.2. If diversification is restricted to large farms only (with ample assets), it will not be a viable strategy for small farm households with few assets (Hengsdijk *et al*., 2004).

For the analysis, farm (land holding) size was related to household income diversification (Figure 44), and farm size to total gross household income (Figure 45). Generally, more diversified farm households correlate positively with farm size, i.e. larger farms have more diversified income-generating sources. This does however not apply to Pujiang, where the smallest and largest farms show the lowest diversification. One should further note the difference in farm size between (large farms in) Honduras on the one hand and (smaller farms in) Pujiang and Teghane on the other hand.

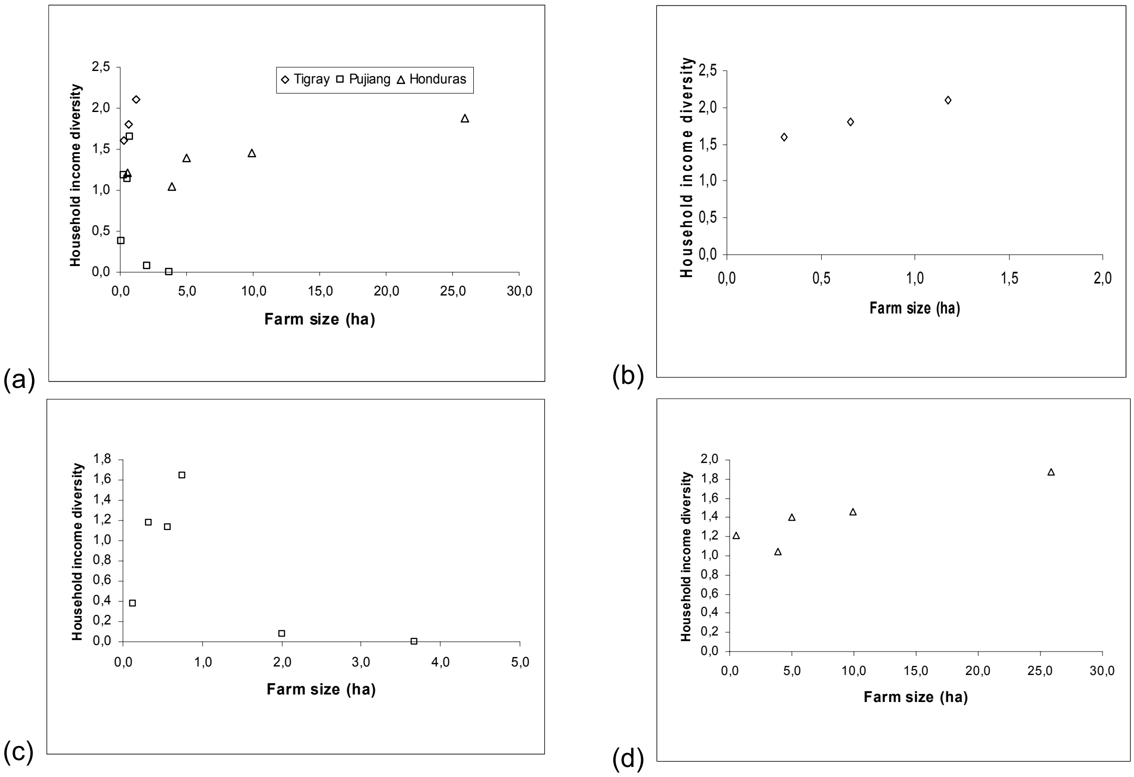

Figure 44 Relationship between household income diversity and farm size for all case study areas (a), Teghane (b), Pujiang (c), and Honduras (d)

The relationship between farm size and total gross household income shows a positive correlation in all cases, i.e. gross incomes tend to be higher for larger farms, although the two smallest households in Pujiang, which derive a major share of their income from off-farm employment, may have incomes slightly above what might be expected.

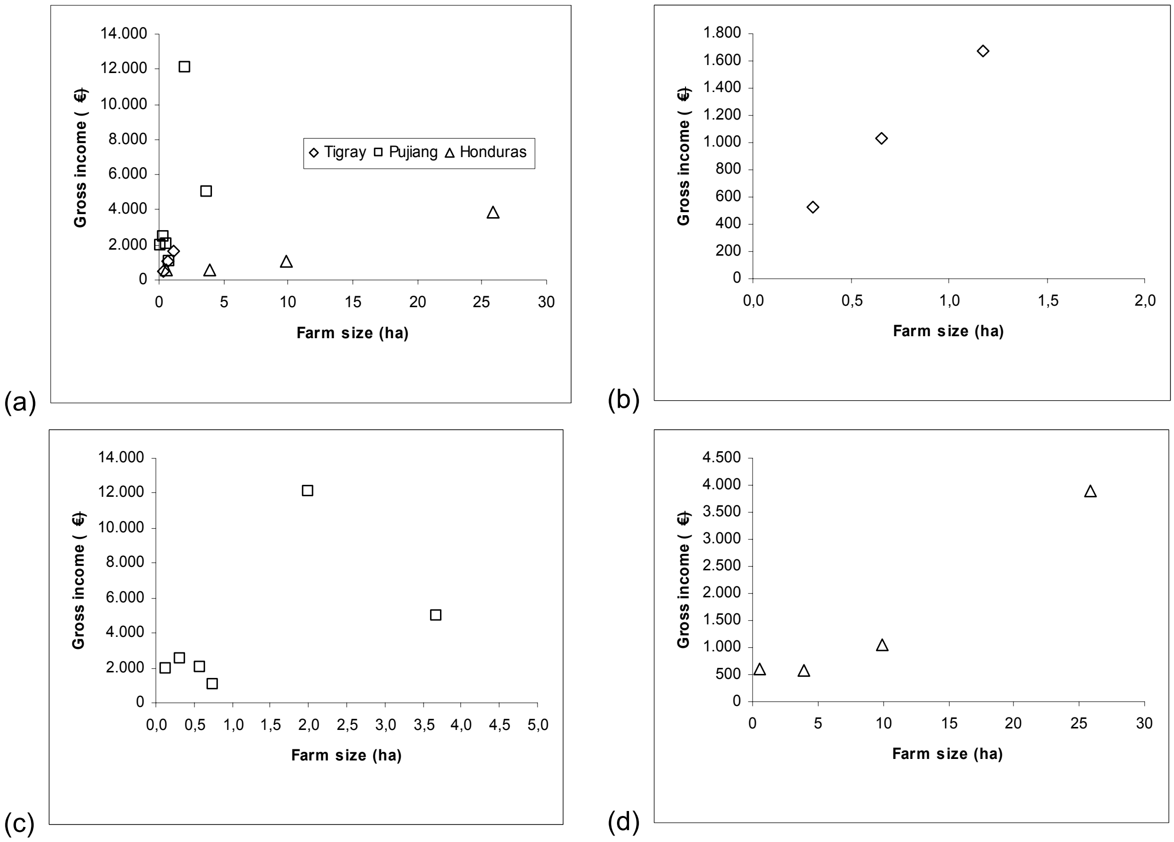

Figure 45 Relationship between farm size and total gross income of households for all case study areas (a), Teghane (b), Pujiang (c), and Honduras (d).

6.4 Land productivity

Diversification is expected to have a negative impact on factor productivity (Singh *et al*., 2002) due to the loss of economies of scale. Farmers need to pay attention to each of their activities, increasing total costs as each activity has its own specific transaction costs (training, facilities, relations with suppliers and retailers, market orientation, etc.). Hence, increased diversification, represented by increased income diversity, can lead to reduced factor productivity.

An analysis of the relationship between land productivity and household income diversity suggests a negative relationship in Puijang and Honduras (Figure 46). Land productivity in Pujiang is generally about 10 and 15 times as high as that in Teghane and Honduras, respectively. Note that land productivity does not include income from animal production. Two Pujiang farm households combine low diversity with low land productivity, being the smallest (mostly supported by off-farm income) and the largest (producing tea that is low priced), respectively.

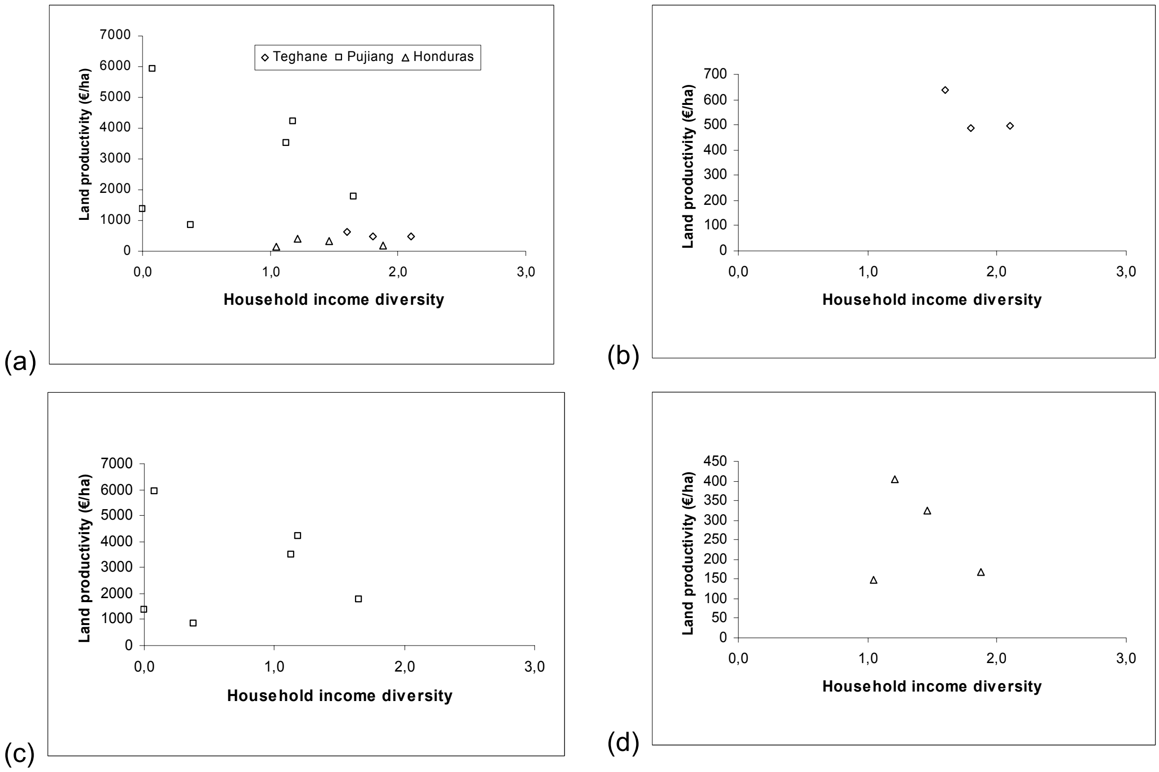

Figure 46 Relationship between land productivity and household income diversity for all case study areas (a), Teghane (b), Pujiang (c) and Honduras (d).

6.5 Labour productivity

The economics of diversification was further analysed by taking a look at its relation to labour productivity. All case studies show a positive relation between labour productivity and diversification (Figure 47). There is, thus, a distinct difference between land productivity, which tends to decrease on more diversified farms, and labour productivity, which shows, in contrast, a positive correlation with diversification. Combining Figure 44c and Figure 47c suggests that households with the largest land holding in Pujiang have the lowest labour productivity. Note the differences in labour productivity between the case study areas, the difference between Pujiang and Teghane being roughly being a factor of 10 to 20, with Honduras in the middle of this range.

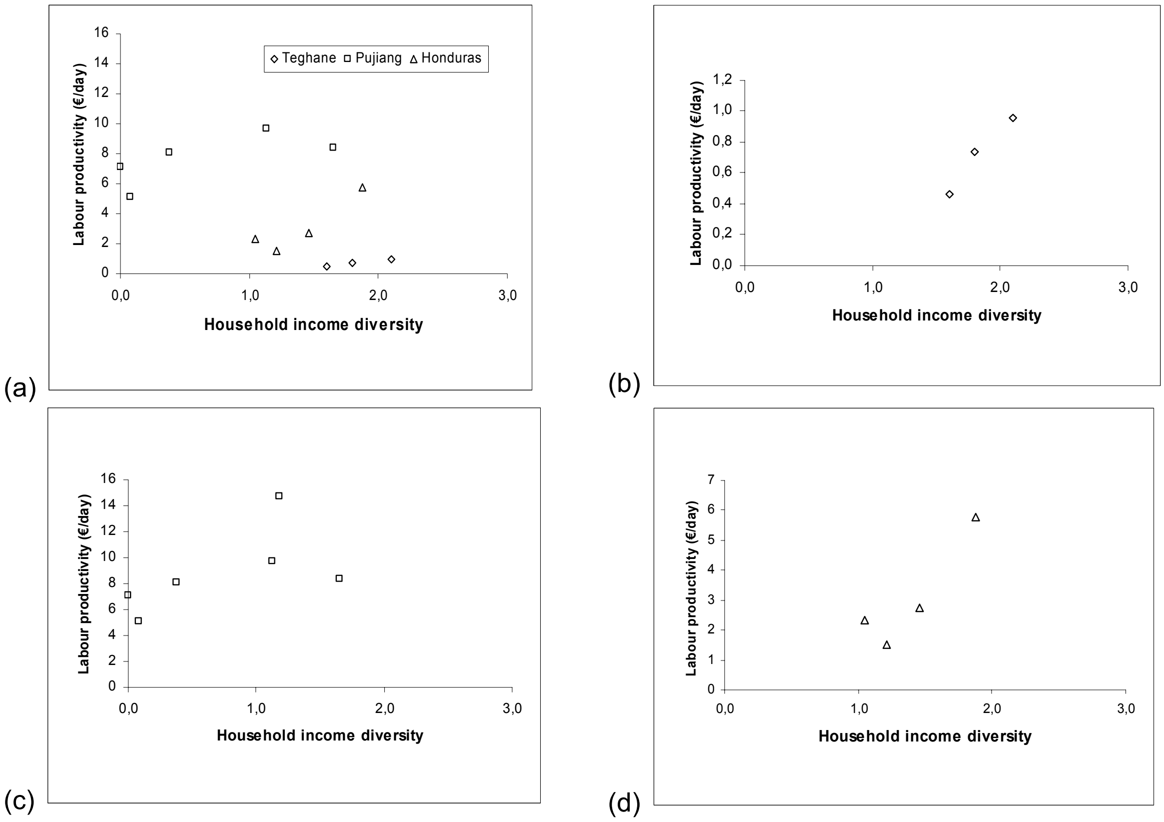

Figure 47 Relation between labour productivity and household income diversity for all case study areas (a), Teghane (b), Pujiang (c), and Honduras (d).

6.6 Nitrogen management

Moving from economic to environmental household performance, the focus is shifted to the relation between income diversification and nitrogen management, where the latter is approximated by the partial nitrogen balance[2] (as calculated in Chapters 3-5). In general, the partial nitrogen balance should not be extremely high or low if nitrogen management is to be classified as 'sustainable'. Since partial balances do not include losses caused by leaching, volatilization or denitrification, low balances indicate potential soil nitrogen depletion (as they would most likely become negative when such losses are accounted for). In contrast, extremely high balances indicate potentially large losses (the surplus by far exceeding crop uptake) or soil nitrogen accumulation, both of which are generally undesirable processes.

No clear relationship could be determined between household diversity and nitrogen balance for Pujiang and Teghane, whereas a negative relation may be executed in Honduras (Figure 48). There is, further, a clear difference in the magnitude of the nitrogen balance between the individual cases. Low to very low nitrogen balances in Honduras, for example, suggest soil nitrogen depletion, while positive balances in Teghane can be largely explained by the import of animal feed from common pastures, thus transferring soil depletion problems from farm to common grazing land. Two very high balances in Pujiang, finally, suggest potential pollution problems.

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[2] *Defined as the difference between measurable nitrogen inputs and outputs at household level.*

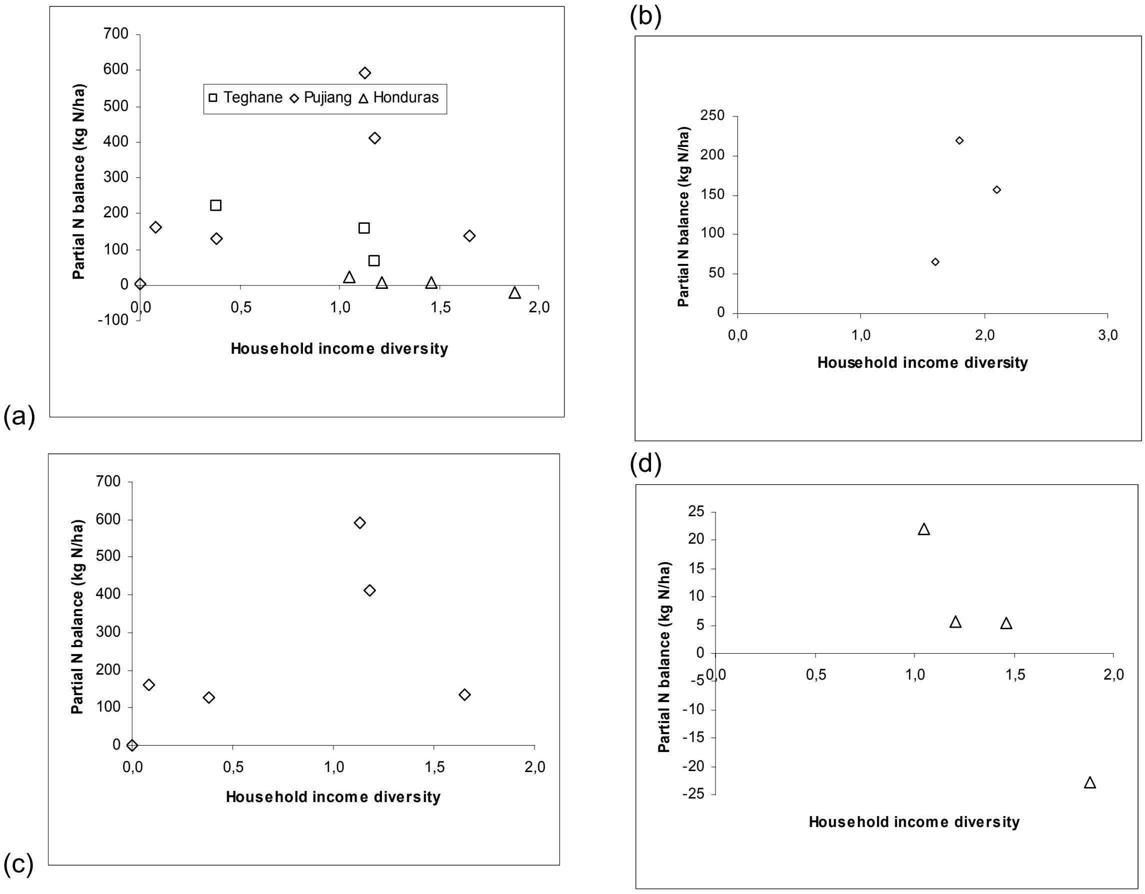

Figure 48 Relationship between nitrogen balance and household income diversity in all case study areas (a), Teghane (b), Pujiang (c) and Honduras (d).

6.7 Carbon management

Carbon management in this study is approximated by carbon import. Similar to the nitrogen balance, carbon imports should not be extremely high or low for the system to be labelled as 'sustainable'. Low carbon imports indicate soil carbon (organic matter) depletion, while high imports suggests a high dependency on external carbon resources and a build up of soil organic-matter stocks.

The relationship between carbon imports and household income diversity suggests an increase in carbon imports with increasing income diversity (Figure 49). In Teghane and Honduras, carbon import per unit of area exceeds imports in Pujiang, which is probably related to the former’s larger animal component and associated feed imports.

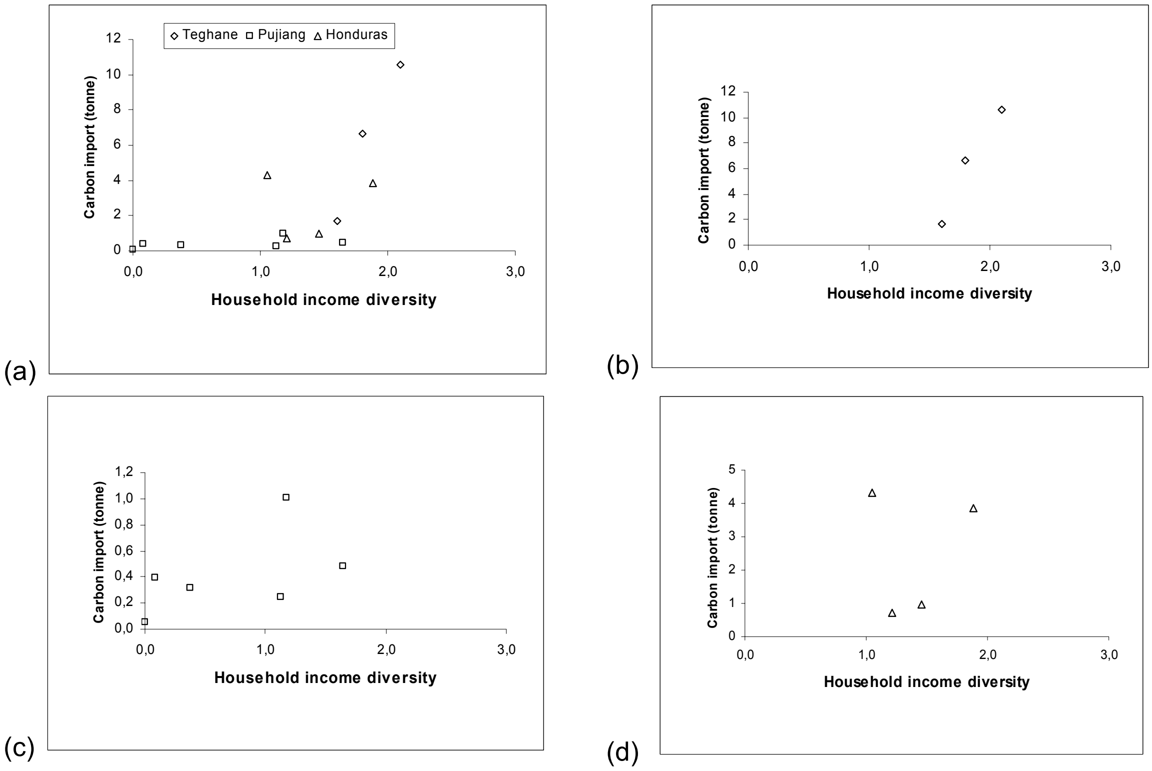

Figure 49 Relationship between carbon import and household income diversity in all case study areas (a), Teghane (b), Pujiang (c) and Honduras (d).

6.8 Recycling index

Diversification of farm household activities is not necessarily synonymous with integration, as different types of, for example, crop and animal production may co-exist independently on the farm. Integration will only be found if farm activities relate to each other, such as animals providing manure for cropping systems, while crop products can be included in animal feed. It already was mentioned that such interdependencies are less common than might be expected, and that improvement is essential. In this section, the relationship between household income diversity, on the one hand, and nitrogen recycling index (as an indicator of integration) on the other, is examined.

Available data are not sufficient to confirm a clear-cut relationship. In Pujiang, cycling is negligible in all cases (Chapter 3). Farm households there are less diversified than those in the other two study areas, while diversified farm households show little integration of their activities. The number of observations in Teghane (Figure 50a) and Honduras (Figure 50b) is too low to identify general trends between nitrogen cycling and diversification, leaving a general picture of low nitrogen cycling in all but one household in Honduras (a household with a large pasture and fallow area that provides feed for grazing cattle and allows the return of manure to the land for fertilisation).

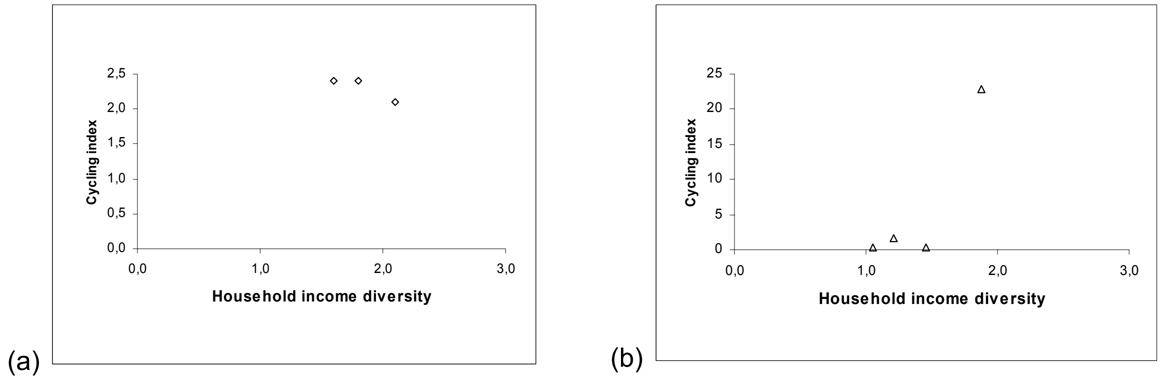

Figure 50 Relationship between household income diversity and recycling index in Teghane (a) and Honduras (b).

6.9 Summary

In this report, data were compiled and analysed on activities on farm households types on three different continents:

- crop production, including pulses, and animal production in Teghane, Ethiopia
- mixed animal-crop production with some off-farm employment and commercial crops in Honduras, and
- mixed, but hardly integrated, farm household systems that combining staple crops with commercial horticultural crops or off-farm employment in Pujiang, China.

The data reveal large differences in the way farm size relates to poverty, hunger and sustainable production under given economic and ecological conditions. In Teghane, the poor farm household with additional income from off-farm employment seems to be better off in terms of food availability than the average farm household. Poor households are also less likely to be affected by decreasing cereal prices. Production in this region depends on high nitrogen and carbon inputs originating from communal lands, which is expected to cause huge problems with soil nutrient depletion. The level of integration is low, but has scope for improvement, eventually leading to increased yields, income and food accessibility.

In Pujiang, information on food availability is limited. Highest incomes here are realised on the largest farms, differences between small and medium size farms being negligible. Declines in rice prices are likely to affect farm households which lack other sources of income, off-farm employment offering a buffer for some of the small and medium sized farms. Use of external inputs (mainly nitrogen), is high to very high, especially on medium sized farms, leading to low use efficiencies and high nitrogen losses. Intra-farm integration is virtually non-existent, all activities being linked to the outside world rather than to each other. There is, however, considerable scope for improvement, which may, in some cases, lead to reduced nitrogen inputs with approximately 25 to 35%.

Food deficiency in Honduras is found on the smallest farms where income, whether supported by off-farm employment or not, is low. The effects of price changes were not studied; most farm households, however, depend less on sales of primary farm products due to additional income generated by off-farm employment and/or remittances. Application levels of external nitrogen appear to be reasonable, with exception of the largest farm. This farm depends almost completely on manure, realising the highest Recycling index value of all farms included in the report. Integration levels on other farms are low.

Referring to diversification and integration, from the analysis in the current chapter it can be concluded that:

- Gross farm income is positively related to income diversification in Teghane and Honduras, but negatively so in Pujiang. However, food expenditure data suggest that more diversified farms in Pujiang are better-off.
- Income diversity increases with farm size as (latent) labour surpluses may be better utilized in more diverse farm activities. This indicates that there is insufficient use for available labour. Development of labour markets (and opportunities for off-farm employment) will increase opportunities for farmers in Teghane and Honduras, where small and less-diversified farms realise lower total incomes than larger and more diversified farm households, but not in Pujiang, where small farms realise higher gross incomes than middle-sized and more diversified farms.
- The favourable economics of diversification is also supported by higher labour productivity with increasing income diversity. Again the situation in Pujiang is different, where the lowest labour productivities are found in farm households that are the least and most diversified.
- Land productivity is negatively related to income diversity, which may indicate a loss of scale economies.
- Carbon import is positively correlated to diversification. In many occasions this is related to animal production on many diversified farm supported by either purchases of feed or grazing on communal land.
- Diversified farming systems are not necessarily equivalent to (fully) integrated farming systems. Data from the case studies showed no firm relationship between income diversity and nitrogen cycling, although a positive relation may be expected in Honduras. Under conditions prevailing in the case study areas, diversification, thus, does not automatically improve resource use efficiency within the farm household system, even though such a relationship might be expected, and often inherently is assumed.

7. Policy and institutional implications

7.1 Introduction

This report features an analytical analysis of case studies from three farming systems across the world – intensive lowland rice in East Asia, temperate mixed farming in the African mountains and maize-beans in Central America – which together account for more than one-fifth of the agricultural population of developing countries. While this demonstrates the utility of such analyses, the approach followed has some limitations. One, obviously, relates to the wider applicability of the results to areas and farm households outside the range of those currently included in the study. Such applicability has not been tested and therefore, formally, no firm conclusions on scaling up the implications of the study can be drawn in this respect.

The small number of case studies represents a further limitation of the study. The results do suggest, however, that a further expansion of the dataset and subsequent analyses would be worthwhile to evaluate and validate the insights derived from the case studies. Pending such an expansion, it is worthwhile to reflect on the possible implications of the findings for agricultural and rural sector strategies, institutions and policies. By using the lessons from the case studies as a basis and inferring relations between diversification and integration on the one hand and food production and economic and environmental performance on the other hand, insights from this study can be combined with more general knowledge on development issues in order to explore the potential implications of diversification and integration.

Ever-increasing demands are being placed on farm households against a background of globalisation and increasing competition in agricultural commodity markets. In addition, unfortunately, in many developing countries structural adjustment, cuts in fiscal deficits and downsizing of government have led to a dismantling of classical agricultural extension and research services. These constraints are especially acute for those living in complex, diverse and risk-prone environments.

From an economic perspective, there are parallels between the discussions on nutrient and energy flows, on-farm integration and transactions costs in the theory of the firm proposed by Coase (1937). According to Coase, firms internalise the transaction costs of acquiring resources and inputs and grow until internal transaction costs (of management and coordination) equal the transaction costs of external resource and input acquisition. In the case of recycling nutrients within production systems, a rational farm manager will choose nutrients from the lowest cost source, either on-farm or off-farm.

From a farm-household economic perspective, integration of production may lower the cost of purchasing some external inputs (e.g. saving on fertiliser), and to some extend increase factor productivity and farm and household income. Integration may further represent a risk-avoidance strategy if accessibility to external inputs is uncertain. From an enterprise perspective, recycling may lower costs or add value through the use of underutilised or undervalued by-products.

The discussion of the implications of the case study results for policies and institutional development in developing countries focuses on the first two of the five main agricultural development strategies, which are: intensification of existing patterns, diversification, farm business growth, increased off-farm income and migration (see Chapter 1 and Dixon *et al.*, 2001). The strategy that is chosen will depend on market conditions: stable labour markets, and input and output markets are prerequisites for intensification. In Pujiang small farmers can choose off-farm employment but in Teghane such an option does not exist. Intensification is also not an option in Teghane (high nitrogen inputs are already realised through the use of communal grazing land), therefore farmers there opt for diversification. Given the production-system focus of the current analysis, the emphasis is placed on intensification and diversification. Before discussing overarching policies that would have an impact across the board, policies and institutions required for implementing the remaining three main development strategies are briefly discussed: i.e. expansion, increasing off-farm income and withdrawal from agriculture.

Farm expansion and farm business growth is not an option for the vast majority of farmers, often because they lack land and/or production inputs. The requirements for the expansion of farm or herd size tend to be location specific. Interestingly, the largest farm in the Honduras case study is also most diverse, although the converse effect is more usually reported in the literature, i.e. small farmers are more diverse.

The notion of integrated off-farm employment merits some discussion. The literature generally demonstrates that off-farm income changes the character of farm household systems, often increasing diversification (Reardon and Stamoulis, 1997). The intensification of smallholder agriculture can also stimulate non-farm economic growth and the expansion of off-farm employment. The case studies demonstrate that small farms supported by off-farm employment can generate as much income as large farms. In Pujiang, for instance, the smallest farms make sufficient money from off-farm employment. In the near future, they might opt for an exit strategy. This is not the case in Teghane and, to a lesser extent, Honduras, where options for off-farm employment are much less promising.

Relevant policies and institutions to promote off-farm employment would foster flexible, often small, enterprises with varying through put depending on the season and labour availability. The major source of flexible employment for farmers may not be agro-processing, for which the peak demands for labour often fall at the same time as the crop harvest season when farmers are very busy in their own fields. Nevertheless, the usual raft of policies and institutions to foster small enterprise growth, flexible labour regulations and well functioning labour markets would tend to foster the growth of off-farm employment.

Exit from agriculture, or at least from a particular farming locality, is an important strategy, especially in low potential areas. However, as a strategy for the escape from poverty and for the sustainable development of remaining farms, migration is not strongly linked to the integration of production systems. In fact, in so far as re-cycling is relatively labour intensive and often associated with low labour: land ratios, migration may discourage integration by raising the opportunity cost of labour.

7.2 Polices and institutions for sustainable agriculture

The number of policy prescriptions for sustainable agriculture are legion (e.g., from FAO, UNEP, World Bank, CGIAR). One useful set is advanced by Pretty (1995) who proposes 25 areas for improvements in national strategies, and in policies for resources conserving technologies, building social capital and reforming professional approaches and methods. However, policy makers may wish to achieve particular types of production system integration, and for that reason the relevance and effectiveness of particular categories of policies in creating incentives for various types of integration are discussed in the following sections on intensification, diversification and increasing robustness of farm production and food availability.

7.2.1 Policies and institutions for integrated intensification of production systems

Intensification of existing production systems is one important pathway for farming system development, economic growth and poverty reduction, especially in high potential farming systems. Specialisation is a subset of, or a special case of, intensification in which the number of components is reduced. In the case of integrated production systems, few or no additional external inputs may be required for increased productivity if sufficient productivity gains can be derived from on-farm recycled inputs, e.g., manure from cattle, feed from crop by-products, compost, etc. Such integration productively utilises by-products, often termed wastes, with low or zero opportunity cost under conventional technology. The case studies focused mainly on nitrogen (N) and carbon (C) imports to crop production and biocides considered in energy analysis.

Policies for the development of produce market institutions which lower the transaction costs of input or produce marketing would, *ceteris paribus*, favour intensification in general. From an economic perspective, market development often improves the produce : input price ratio and thus encourages higher levels of input use. Obviously, there needs to be a demand for the increased market surplus arising from intensification as well as a capacity to handle the larger volumes of production along the post-harvest chain, while it should be noted that reality is more complex than such a simple characterisation. For example, farmers' participation in markets involves a complicated inter-locking system of acquisition of agricultural inputs and technical information extension, and production, packing, marketing and processing activities. In terms of their agricultural produce, farmers often have to overcome three major hurdles: sufficient volume to satisfy market demands, as well as continuity of production and of course quality.

To the degree that produce markets develop faster than input markets (i.e., asymmetric market development), on-farm recycling gains relative to the purchase of external inputs. Once recycling becomes more economically attractive than the purchase of external inputs, production systems will tend to become more integrated. This evolution can be accelerated by suitable 'enabling business environments' fostered by policies, regulations and institutional practices that are beyond the direct control of economic actors in the market-chain and notably small farmers. It is useful to distinguish in this respect between factors that relate to market demand i.e. prices, quantities, qualities and timeliness of supplies required by buyers; factors that bear on transformation activities i.e. costs of producing, processing, storing and moving produce, technologies (seeds, breeds, inputs, processing etc.); and factors that affect transactions activities i.e. costs of doing business (Hellin *et al.*, 2005).

In value (or market) chains based on produce from smallholder agriculture, transaction costs can easily outweigh the potential benefits of participation in the market - and thus increase the relative incentives for on-farm recycling. The costs of transactions along value chains in rural economies tend to be high due to diseconomies of dispersed low-yield production, inaccessible legal systems, unclear title to property, and low levels of trust generally. In contrast to more developed economies, transactions-cost-reducing institutions and structures (e.g. contract enforcement mechanisms, communications infrastructure, land registries, trading standards, organisations of producer collaboration) are very weak.

There has been a long tradition of agricultural development policies which favour external input use: the elimination of such subsidies, whether direct or indirect, on external inputs will stimulate use of other nutrient sources. In most African countries, however, availability of such sources is limited. Structural adjustment policies which eliminate input subsidies certainly reduce the use of such inputs, as has been observed in many African and central Asian countries during the late 1980s and 1990s. The reduction or elimination of fertiliser subsidies has led to a contraction of the demand for mineral fertiliser, but could, when it was combined with adequate incentives for production of market surplus such as in northern Nigeria in the late 1990s, increase the demand for alternative sources of crop nutrients such as animal manure thereby encouraging the spread of mixed crop-livestock farming. Similarly, the elimination of subsidised credit programmes, which were often tied to the provision of external inputs, may favour greater integration of production systems.

As said, however, availability of sufficient manure in many cases is not guaranteed, while large scale use of communal land for grazing further brings serious risks of nutrient depletion. It is therefore recommended that ecological and bio-physical conditions (determining factors like inherent soil fertility and regional nutrient availability) be included in policy analysis with respect to changes in nutrient availability or support programmes. Any changes not based on such information easily may lead to measures that turn out to be counter-productive both in economic and environmental terms. This is also the case for information on off-farm employment which can serve as an additional source of income, generating financial means for purchases of external inputs. The way in which policy changes will affect poor and food-deficient farm households will depend on specific combinations of economic and ecological conditions, requiring a quantified, integrated, systems analysis like the one developed and applied in this report.

7.2.2 Policies and institutions for integrated diversification

Diversification should not be confused with integration; the former refers to the increase in the number of farm components generally for augmenting farm income, reducing risk or lowering cost through integration, while the latter relates to improved interaction between farming activities in terms of exchange of inputs and (intermediate) products. Diversification may or may not be combined with integration. For example, a mixed crop-livestock farm may be diversified and integrated if substantial amounts of animal manure are used as fertiliser on crop lands; but a diversified farm with similar farm components would not be integrated if enterprise by-products do not find a use elsewhere on the farm, e.g., tractors or hoes are used instead of animal draft for cultivation, or inorganic fertiliser is purchased instead of manure for crop land. Diversification is not an option under all conditions. If bio-physical and socio-economic prerequisites are met, farmers may seek specialisation (see the largest farms in Pujiang); if not, farmers remain oriented to diversified production because of risk aversion or lack of market opportunities.

In Teghane and Honduras, higher labour productivity was observed on the more diversified farms. It also appears that a lack of integration (on these diversified farms) is associated with a lack of sustainability. This is related to risks of soil depletion on communal lands in Teghane (providing the necessary nitrogen and organic matter for livestock production of the farm households), high external nitrogen inputs in Pujiang (leading to high nitrogen losses) and potential soil depletion in Honduras. Scenario analyses in Teghane and Pujiang show that there is considerable potential for improved nitrogen management, allowing yield increases, higher incomes and, hence, increased food availability.

It is often considered that any one of a wide range of policies and institutions can be used to promote diversification; reality is, however, that rural development is littered with failed diversification programmes. In fact, 'winners' (or particular farm components to be promoted) can rarely be successfully identified *a priori*. The essence of many successful diversification programmes is the enrichment of meso-level institutions to provide production, generally market, incentives for new components at acceptable levels of risk; on other occasions new technology may shift incentives towards new farming activities. It should be noted that diversification generally places a larger burden on institutional development than does intensification.

In general, the policies and institutions which favour integration or on-farm recycling over the purchase of external inputs under processes of intensification will also apply in the case of diversification.

7.2.3 Farm households and global change

The findings of this study allow some general inferences to be made with respect to aspects of global change, poverty and food deficiency. Clearly, one should be careful making generalisations, specific combinations of economic and bio-physical conditions determining perspectives of different strategies for a given farm household, background and preferences of the household members co-determining the outcome. Results from the case studies can help to clarify this point. Data from Teghane and Pujiang, for example, show that smaller farms which can rely on additional income from off-farm employment may be better off in terms of income and food availability. Because of this, they may also be less vulnerable to changes in cereal prices compared to households with slightly larger farms that lack external sources of income, and rely on sales of cereals as almost the sole source of income that is needed to cover farm and household costs.

One should be equally careful with respect to the relationship that is often assumed between off-farm employment and intensification. While it has been found that income generated by off-farm employment may be helpful to acquire necessary external inputs needed for intensification (diversification hence being used to increase production levels; Barrett *et al*., 2001b), data in Teghane, Pujiang and Honduras show that poor farm households with off-farm employment have less diversified farm holdings and do not necessarily apply more external inputs (or realise higher yields), nor are they automatically less food deficient than farm households that lack this source of income.

Vulnerability to price changes in cereals already has been discussed above. It is beyond the scope of this report to reflect in detail on the potential effects of climate change on production or income of the farm households presented here. While climate models (GCMs) used to predict the effects of climate change indicate a northerly movement of thermal regions and of drought (such that the dry sub-tropical zones of Africa, Australia and South Asia extend further north, as will warm temperate zones north of the equator), they also predict an increase in the variability of precipitation, temperature and extreme events. Under such conditions, off-farm employment (if not based on agricultural work nearby) may increase the resilience of farm households to withstand such variability. On-farm integration of production activities, in so far as it leads to reduced dependency on external inputs while securing sufficient production, may reduce financial risks.

7.3 Implications for research

The research framework used in this study is essentially of a static and exploratory nature, mainly looking at flows and neglecting stocks which are of main importance for a better understanding of flow dynamics in a temporal scale. Further tuning of the methodology is required to incorporate dynamic (feedback) effects, based on a detailed assessment of the interactions between resource stocks, nutrient and income flows, and their impact on income. This will enable an analysis of the consequences of household diversification over longer time horizons. In addition, attention should be given to the scale issue. The outcomes of analysis (resource flows and balances) may be different at different scales revealing resource use inefficiencies and opportunities for interventions.

The analysis is further restricted by its focus on nitrogen and carbon, thus not including phosphorus or water. It would certainly add to the value of the assessment if an evaluation of water use (input, efficiency) could be included in the framework. Water is becoming increasingly scarce, and in the near future it is expected that its availability will determine both selection and output of agricultural production processes.

With most research on the organisation and performance of (diversified) farming systems focusing on disciplinary indicators (e.g. crop diversification (Papademetriou and Dent, 2001), crop-livestock interaction (McIntire *et al*., 1992) or off-farm employment (Reardon and Taylor, 1996)), progress can be realised with multi-criteria assessment of farm-household strategies that simultaneously address socio-economic and environmental performance. This may increase the understanding of the rationale of farm householders and their capability to withstand stochastic stress and idiosyncratic shocks (i.e. shocks that can be seriously reduced with a more diverse farm household activity portfolio). It is therefore recommended that more interdisciplinary studies are carried out, preferably combining quantified economic and environmental analysis of farm household performance under defined economic and agro-ecological conditions.

Promising area of research on the relationships between livelihood diversification and farming systems performance include the following:

- water use and its efficiency;
- possible ‘economies’ of scale in diversified farm household systems;
- interactions between stocks and annual (nutrient, water, energy) flows within diversified farm household systems (including cropping-livestock interactions), determining dynamic (long-term) effects of diversification and integration;
- prospects of diversification for integrated resource management, identifying activities that allow integration and improved resource use;
- effects of non-farm activities (e.g. wages and remittances) on economic and environmental performance of farm household systems;
- behavioural implications related to farm household systems (effect on farmers’ risk attitudes and their willingness to invest);
- consumption effects for farm household systems diversification;
- effects of diversification on management of common resources (game theory).

7.4 Summary

The improved availability of information is one of the basic pre-requisites for improved policies and institutions. Furthermore, action to improve the policies and institutions for the integration of production systems often depend on concerted lobbying, coordinated campaigns or advocacy. While the attention for farm household activities and its impact on access to food, poverty alienation, environmental performance and resilience to external shocks is increasing, there is a need for quantified, interdisciplinary analyses based on detailed farm household data.

Setting up such a study for multiple regions to cover a range of agro-ecological and economic conditions was beyond the scope of this study. The study aimed to develop a framework to evaluate farm household performance using existing data. It contributes to diversification literature by developing an integral and quantified approach and applying it to case studies from Africa, Asia and Latin America. Although the approach presented here has significant limitations, which are mainly linked to the fact that the analysis is static and does not represent effects of dynamic processes, it can be used to derive implications for research as well as policy interventions.

Major general results from the study include:

- Adapting the Shannon diversity index, the contribution of individual activities to the monetary value of total production has been quantified in an index to express the diversification level of farms or farm households (Chapter 2). The indices were applied to case studies in Teghane (Ethiopia, Chapter 3), Pujiang (China, Chapter 4) and Honduras (Chapter 5).
- Similarly, Finn’s flow analysis model was used to evaluate the level of integration of farm household systems with respect to nitrogen recycling (Chapter 2). The index was applied to case studies in Chapters 3 to 5.
- There is no clear relation between level of diversification and that of integration. Under conditions prevailing in the case study areas, diversification, thus, does not automatically improve resource use efficiency of the farm household even though such a relationship often is assumed (Chapters 3 to 5).
- Policy measures that favour diversification include the development of institutions that provide incentives for new farming activities at acceptable levels of risk, while, additionally, on some occasions new technologies may be needed to promote new farming activities. Especially important are policies that stimulate recycling of available nutrients.

More specific results related to the case studies are:

- Diversification levels showed considerable variation, highest values being found in Teghane and Honduras. With one exception (a mixed dairy farm in Honduras), integration levels were low (Teghane, most farm household types in Honduras) to non-existent (Pujiang).
- Diversification and integration levels were related to major farm household characteristics. Inferred relationships based on case study data indicate that diversification is positively correlated to farm size, food availability, farm household income, labour productivity and carbon input levels, but negatively with land productivity. No clear relation could be defined with respect to diversification and nitrogen management (Chapter 6).
- Scenario analyses indicate that there is ample scope for improvement of nitrogen management, increased integration leading to reduced nitrogen inputs, increased use efficiency, production and income.
- Recommendations for research include application of the methodology to other case studies to check its applicability under different conditions and using quantified data to study (i) relation between farm size and diversification, (ii) interactions between stocks and annual (e.g. nutrient)

flows, (iii) water use and its efficiency, (iv) prospects of diversification for integrated resource management, (v) effects of non-farm activities (e.g. wages) on economic and environmental performance, (vi) behavioural aspects of decision making, (vii) consumption effects of diversification and (viii) effects on common resources management (game theory).

It is concluded that quantification of economic and environmental performance of more or less diversified farm household systems yields relevant information for the evaluation of development strategies and potential policies, and that diversification offers important perspectives for poor and food deficit households such as the ones analysed in the case studies. Potential positive environmental impacts of farm level diversification however only can be attained if farming activities are sufficiently integrated. In practice, the level of integration of farm systems generally remains low.

References

Abdulai, A. and A. CroleRees, 2001. Determinants of income diversification amongst rural households in Southern Mali. Food Policy 26: 437-452.

Baird, D. and R.E. Ulanowicz, 1993. Comparative study on the trophic structure, cycling and ecosystem properties of four tidal estuaries. Marine Ecology Progress Series 99: 221-237.

Barrett, C.B., M. Bezuneh and A. Aboud, 2001a. Income diversification, poverty traps and policy shocks in Côte d'Ivoire and Kenya. Food Policy 26: 367-384.

Barrett, C.B., T. Reardon and B. Webb, 2001b. Nonfarm income diversification and household livelihood strategies in rural Africa: concepts, dynamics, and policy implications. Food Policy 26, 315-331.

Basanta, M.V., D. Douradi-Neto, K. Reichardt, O.O.S. Bacchi, J.C.M. Oliveira, P.C.O. Trivelin, L.C. Timm, T.T. Tominaga, V. Correchel, F.A.M. Cássaro, L.F. Pires and J.R. de Macedo, 2003. Management effects on nitrogen recovery in a sugarcane crop grown in Brazil. Geoderma 116: 235-248.

Bender, W.H. 1997. How much food will we need in the 21st century? Environment 39: 7-11.

Biederbeck, V.O., C.A. Campbell, K.E. Bowren, M. Schitzer and R.N. McIver, 1980. Effect of burning cereal straw on soil properties and grain yields in Saskatchewan. Soil Science Society of America Journal 44: 103-111.

Boserup, E. 1965. The conditions of agricultural growth: the economics of agrarian change under population pressure. Allen and Unwin, London, UK.

Carpenter, S., B. Walker, J.M. Anderies, and N. Abel, 2001. From metaphor to measurement: resilience of what to what? Ecosystems 4: 765-781.

Cavero, J., R.E. Plant, C. Shennan, J.R. Williams, J.R. Kiniry and V.W. Benson, 1998. Application of epic model to nitrogen cycling in irrigated processing tomatoes under different management systems. Agricultural Systems 56: 391-414.

Coase, R., 1937. The nature of the firm. Economica 4: 386-405.

Dalsgaard, J.P.T. and R.T. Oficial, 1997. A quantitative approach for assessing the productive performance and ecological contributions of smallholder farms. Agricultural Systems 55: 503-533.

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

De Ridder, N. and H. van Keulen, 1990. Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West-African semi-arid tropics (SAT). Fertilizer Research 26: 299-310.

Deininger, K. and P. Olinto, 2001. Rural nonfarm employment and income diversification in Columbia. World Development 29: 455-465.

Delgado, C. and A. Siamwalla, 1999. Rural economy and farm income diversification in developing countries. In: G. Peters, ed., Food security, diversification and resource management: refocusing the role of agriculture? Proceedings of the XIII International Conference of Agricultural Economists, Sacramento, California, August 10-16, 1997. Aldershot, UK: Dartmouth Publishing Company.

Dixon, J., J. Gulliver and D. Gibbon, 2001. Farming systems and poverty. Improving farmers' livelihoods in a changing world. Food and Agriculture Organization of the United Nations, Rome, and World Bank, Washington.

Dobermann A, C. Witt and D. Dawe (Eds.), 2004. Increasing productivity of intensive rice systems through site-specific nutrient management. Enfield, N.H. (USA) and Los Baños (Philippines): Science Publishers, Inc. and International Rice Research Institute (IRRI). 410 p.

Ellis, F., 2000. The determinants of rural livelihood diversification in developing countries. Journal of Economics 51: 289-302.

Ellis, F. and E. Allison, 2004. Livelihood diversification and natural resource access. Livelihood Support Programme (LSP) Working Paper 9. Rome: Food and Agriculture Organization of the United Nations.

FAO [Food and Agriculture Organization], 1997. The impact of HIV/AIDS on rural households/communities and the need for multisectoral prevention and mitigation strategies to combat the epidemic in rural areas. Prepared by E.G. Baier. Rome.

FAOSTATS, 2002. FAO Statistical Databases. Visited on-line 10/10/2004. http://faostat.fao.org/faostat.

Finn, J.T., 1976. Measures of ecosystem structure and function derived from analysis of flows. Journal of Theoretical Biology 56: 363-380.

Finn, J.T., 1980. Flow analysis of models of the Hubbard Brook ecosystem. Ecology 61: 562-571.

Fluck, R.C., 1979. Energy productivity: a measure of energy utilisation in agricultural systems. Agricultural Systems 4: 29-37.

Fores, E. and R.R. Christian, 1993. Network analysis of nitrogen cycling in temperate, wetland ricefields. Oikos 67: 299-308.

Fores, E., R.R. Christian, F.A. Comin and M. Menendez. 1994. Network analysis on nitrogen cycling in a coastal lagoon. Marine Ecology Progress Series 106: 283-290.

Giller, K.E., 2001. Nitrogen Fixation in Tropical Cropping Systems. 2nd. CAB International, Wallingford, 423 p.

Girmay Deffar, 1998. Non-wood forest products in Ethiopia. Data Collection and Analysis for Sustainable Forest Management in ACP Countries - Linking National and International Efforts. EC-FAO PARTNERSHIP PROGRAMME (1998-2000). Tropical forestry Budget line B7-6201/97-15/VIII/FORPROJECTGCP/INT/679/EC. http://www.fao.org/DOCREP/003/X6690E/X6690E00.htm#TopOfPage. Visited 11/05/2004.

Guanghuo, W., Q. Sun, R. Fu, X. Huang, X. Ding, J. Wu, Y. He, A. Dobermann and C. Wit, 2004. Site-specific nutrient management in irrigated rice systems of Zhejiang province, China. In: Dobermann, A, Witt, C, Dawe, D, editors. Increasing productivity of intensive rice systems through site-specific nutrient management. Enfield, N.H. (USA) and Los Baños (Philippines): Science Publishers, Inc. and International Rice Research Institute (IRRI). p. 243-263.

Halsnaes, K. and J. Verhagen, 2005. Development based climate change adaptation and mitigation. Conceptual issues and lessons learned in studies in developing countries. Accepted by Mitigation and Adaptation Strategies for Global Change.

Hellin, J., A. Griffith and M. Albu, 2005. Mapping the market: market-literacy for agricultural research and policy to tackle rural poverty in Africa. In: Proceedings of the International Seminar: Beyond agriculture: making markets work for the poor. London, 28 February-1 March 2005.

Hengsdijk, H., M. van den Berg, R. Roetter, J. Wolf, W. Guanghuo, N.X. Lai, N.T. Cuong and H. van Keulen, 2004. Consequences of technologies and production diversification for the economic and environmental performance of rice-based farming systems in East and South-east Asia. Paper for the World Rice Conference 4-7 November 2004 in Tokyo and Tsukuba, Japan.

Hinrichsen, U. and F. Wulff. 1998. Biogeochemical and physical controls of nitrogen fluxes in a highly dynamic marine ecosystem: Model and network flow analysis of the Baltic Sea. Ecological Modelling 109: 165-191.

Holling, C.S., 1973. Resilience and stability of ecological systems. Annual Review of Ecology and Systematics 4: 1-23.

IMF [International Monetary Fund] and World Bank, 2005. Global monitoring report 2005. Millennium goals: from consensus to momentum.

Inglese, P., G. Barbera and T. La Mantia, 1999. Seasonal reproductive and vegetative growth patterns and resource allocation during cactus pear fruit growth. Horticultural Sciences 34: 69-72.

IPCC [International Panel on Climate Change], 2001. Climate change 2001: The scientific basis. Contribution of working group I to the Third Assessment Report of the International Panel on Climate Change. Hougthon, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Dai, X., Maskell, K. and C.A. Johnson (Eds.). Cambridge: Cambridge University Press.

IRMLA, 2002. Systems Research for Integrated Resource Management and Land Use in E and SE Asia. First Annual Scientific Report, Alterra, Wageningen, The Netherlands: 19-28. (http://www.alterra-research.nl/pls/portal30/docs/FOLDER/IRMLA/IRMLA/p_mainpage.htm).

Jansen, H.G.P., A. Damon, J. Pender, W. Wielemaker and R. Schipper, 2003. Policies for sustainable development in the hillsides of Honduras: a quantitative livelihoods approach. Paper for the international workshop on 'Reconciling Rural Poverty Reduction and Resource Conservation: Identifying Relationships and Remedies', Cornell University, May 2-3, 2003. IFPRI, Washington, DC, USA, Development Economics Group, Wageningen University, Wageningen, The Netherlands, Agricultural Economics Institute (LEI Ltd), The Hague, The Netherlands.

Jianyun Ruan, Xun Wu and R. Härdter, 1997. The interaction between soil water regime and potassium availability on the growth of tea. Communications in Soil Science and Plant Analysis, 28: 89-98.

Kamphuis, B., A. Jongbloed and H. van Keulen, 2004. Agriculture and water in Shunyi, Beijing municipality. Results of a Rapid Diagnostic Appraisal. Resource management options in the Greater Beijing Area.

Kolenbrander G.J., 1974. Efficiency of organic matter manure in increasing soil organic matter content. In: Transactions of the 10th Congress of the International Society of Soil Science, Vol II pp 129-136, Moscow.

Kung, J.K.S., 2002. Off-farm labour markets and the emergence of land rental markets in rural China. Journal of Comparative Economics, 30: 395-414.

Leach, G., 1976. Energy and Food production. IPC Business Press. Guildford.

Lefroy, R.D., W. Chaitep and G.J. Blair, 1994. Release of sulphur from rice residues under flooded and non-flooded soil conditions. Australian Journal of Agricultural Research 45: 657-667.

Lockeretz, W., 1980. Energy inputs for nitrogen, phosphorus, and potash fertilisers. In: D. Pimentel (ed.) Handbook of energy utilisation in agriculture. CRC Press, Boca Raton (Florida) USA: 23-24.

López-Bellido, R.J., L. López-Bellido, F.J. López-Bellido and J. E. Castillo, 2003. Faba Bean (Vicia faba L.) Response to Tillage and Soil Residual Nitrogen in a Continuous Rotation with Wheat (Triticum aestivum L.) under Rainfed Mediterranean Conditions. Agronomy Journal 95:1253-1261

Magurran, A.E., 1988. Ecological diversity and its measurement. Cambridge University Press, Cambridge, UK: 145-149.

McIntire, J., D. Bourzat and P. Pingali, 1992. Crop-livestock interaction in Sub-Saharan Africa. Regional and Sectoral Studies series. Washington: World Bank.

Méndez, V.E., 2001. Interdisciplinary analysis of homegardens in Nicaragua: micro-zonation, plant use and socioeconomic importance. Agroforestry Systems 51: 85-96.

Mulder, H., 2003. A household analysis on income and nutrient management in Tigray, Ethiopia. A quantitative and qualitative analysis using the Nutrient Monitoring toot, NUTMON. IFPRI-WUR project 'Policies for Sustainable Land management in the Ethiopian Highlands', Wageningen, The Netherlands, Working paper 5: 63 p.

Norman, D.W., F.D. Worman, J.D. Siebert and E. Modiakgotla, 1995. The farming systems approach to development and appropriate technology generation. FAO Farm System Management Series 10, Rome, Italy.

Okike, I., M.A. Jabbar, V. Manyong, J.W. Smith, J.A. Akinwumi and S.K. Ehui, 2001. Agricultural intensification and efficiency in the West African savannahs: evidence from northern Nigeria. Working paper 33. Nairobi: International Livestock Research Institute, Ibadan: International Institute of Tropical Agriculture and University of Ibadan.

Ordoñez Barragan, J., 2004. Main factors influencing maize production in the Quesungal agroforestry system in Southern Honduras: An exploratory study. MSc Thesis. Wageningen University, Wageningen, The Netherlands: 100 p.

Pacini, C., A. Wossink, G. Giesen, C. Vazzana and R. Huirne, 2003. Evaluation of sustainability of organic, integrated and conventional farming systems: a farm and field-scale analysis. Agriculture Ecosystems and Environment 95: 273-288.

Papademetriou, M.K. and F.J. Dent (Eds.), 2001. Crop diversification in the Asia-Pacific region. Papers presented at the Expert Consultation held in Bangkok, Thailand, 4 to 6 July, 2000. RAP Publication 2001/03. Bangkok: Regional Office for Asia and the Pacific.

PIMEA, 2005. ‘Policies for sustainable land management in the East African highlands (PIMEA)’ (www.north-south.nl/index.php/item/352).

Pingali, P.L., 2001. Environmental consequences of agricultural commercialization in Asia. Environmental Development Economics 6: 483-502.

Pingali, P., Y. Bigot and H.P. Binswanger, 1987. Agricultural mechanisation and the evolution of farming systems in sub-Saharan Africa. World Bank and Johns Hopkins University Press, Baltimore, MD, USA. 216 pp.

Pretty, J., 1995. Participatory learning for sustainable agriculture. World Development 23, 1247-1263.

Reardon, T. and K. Stamoulis, 1997. Relating agro-industrialization, intermediate cities and farm-nonfarm linkages: concepts, hypotheses and Latin American examples. Invited paper presented at the FAO International Conference, Interrelacion rural-urbana y desarollo descentralizado. Taxco, Mexico, 9-11 April.

Reardon, T. and J.E. Taylor, 1996. Agroclimatic shock, income inequality, and poverty: evidence from Burkina Faso. World Development 24, 901-914.

Reardon, T., E. Crawford and V. Kelly, 1994. Links between nonfarm income and farm investment in African households adding the capital market perspective. American Journal of Agricultural Economics 76: 1172-1176.

Reardon, T., C. Barrett, V. Kelly and K. Savadogo, 1999. Policy reforms and sustainable agricultural intensification in Africa. Development Policy Review 17: 375-395.

Rothuis, A.J., D.K. Nhan, C.J.J. Richter and F. Ollevier, 1998. Rice with fish culture in the semi-deep waters of the Mekong Delta, Vietnam: a socio-economic survey. Aquaculture Research 29, 47-57.

Rozelle, S.J., J. Huang and L. Zhang, 2002. Emerging markets, evolving institutions, and the new opportunities for growth in China's rural economy. China Economics Review 13: 345-353.

Ruthenberg, H., 1980. Farming systems in the tropics (3rd ed.). Clarendon Press, Oxford, UK. 424 pp.

Sinebo, W., R. Gretzmacher and A. Edelbauer, 2004. Genotypic variation for nitrogen use efficiency in Ethiopian barley. Field Crops Research 85: 43-60.

Singh, V.K., B.B. Sharma and B.S. Dwividi, 2002. The impact of diversification in rice-wheat cropping systems on crop productivity and soil fertility. Journal of Agricultural Science 139: 405-412.

Soltani, A., S. Galeshi, M.R. Attarbashi and A.H. Taheri, 2004. Comparison of two methods for estimating parameters of harvest index increase during seed growth. Field Crops Research 89: 369-378.

Strauss, M., 2000. Human waste (excreta and wastewater) reuse. Contribution to: ETC/SIDA Bibliography on Urban Agriculture. EAWAG/SANDEC, Duebendorf, Switzerland, 31 p.

Suttie, J.M., 2000. Hay and Straw Conservation - For Small-Scale Farming and Pastoral Conditions. FAO Plant Production and Protection Series 29.

Uhl, C. and P. Murphy, 1981. A comparison of production and energy values between slash and burn agriculture and secondary succession in the upper Rio Negro region of the Amazon basin. Biotropica 14: 249-254.2.

UN [United Nations], 2000. United Nations Millennium declaration. United Nations A/RES/55/2.

UN [United Nations], 2005. United Nations Millennium Project 2005. Investing in development: a practical plan to achieve the Millennium Development Goals. New York.

USDA, Nutrient Data Laboratory, 2004. National Nutrient Database for Standard Reference, release 16. http://www.nal.usda.gov/fnic/foodcomp/search/ visited 13/05/2004.

Van den Bosch, H., A. de Jager and J. Vlaming, 1998a. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): II. Tool development. Agriculture Ecosystems and Environment 71: 49-62.

Van den Bosch, H., J.N. Gitari, V.N. Ogaro, S. Maobe and J. Vlaming, 1998b. Monitoring nutrient flows and economic performance in African farming systems (NUTMON): III. Monitoring nutrient flows and balances in three districts in Kenya. Agriculture Ecosystems and Environment 71: 63-80.

Vlaming, J., H. van den Bosch, M.S. van Wijk, A. de Jaeger, A. Bannink and H. van Keulen, 2001. Monitoring nutrient flows and economic performance in tropical farming systems (NUTMON). Manual for the NUTMON-toolbox. Alterra, Green World Research, Agricultural Economics Research Institute, LEI. Wageningen, The Netherlands: 180 p.

Wassmann, R., R.S. Lantin, H.-U. Neue (Eds), 2000. Methane emissions from major rice ecosystems in Asia. Developments in Plant and Soil Sciences, Vol. 91. Dordrecht (The Netherlands): Kluwer Academic Publishers. 394 p.

Whipple, S.J. and B.C. Patten, 1993. The problem of nontrophic processes in trophic ecology: Toward a network unfolding solution. Journal of Theoretical Biology 163: 393-411.

Wiggins, S., 2002. Smallholder farming in Africa. In: D. Belshaw and I. Livingstone (eds.), Renewing development in Sub-Saharan Africa: Policy, performance and prospects. London: UK, Routledge.

Annex I.
Calculation of integration indices

A.1.1 Mathematical description

Integration indicators are described in mathematical terms using a system comprising two components (H1 and H2) for which all outflows are recorded (Figure A 1). The following elements are defined:

H_K: component k;
X_k: change in nitrogen stock of component k;
Y_{Ok}: outflow from component k outside the system;
Z_{kO}: inflow from outside to component k;
f_{kj}: internal flow from component H_j to component H_k,

where X_k denotes negative stock changes from component k (i.e. all nitrogen released from stock and brought into the system in the given period of time). In principle, Y_{Ok} can depict any outgoing nitrogen flow. In the current study, however, nitrogen losses (e.g. resulting from leaching or ammonia volatilisation) are not included, and $Y_{Ok\,f}$ mainly refers to sales or trade of farm products.

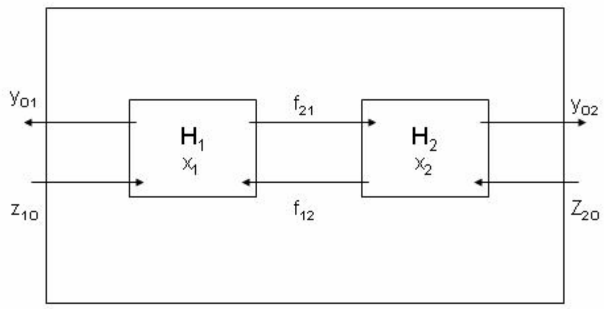

Figure A 1 Diagram representing a system with 2 components. Definition of symbols: see text.

Calculation of the indicators:

Throughflow $T_k = \sum f_{kj} + z_{ko} - \sum (x_k)_-$

Total system throughflow $TST = \sum T_k$

Total inflow/outflow $TIN = \sum z_{io} - \sum (x_k)$, $TOUT = \sum y_{oj} + \sum (x_k)_+$

Path length $PL = TST / TIN = TST / TOUT$

Where $\sum (x_k)_-$ denotes the sum of negative stock changes for all components (i.e. all nitrogen released from stocks and brought into the system in the given period of time), while $\sum (x_k)_+$ refers to positive stock changes (nitrogen accumulation).

A.1.2 System components and flows analysis: an example

A simple farm household system is considered, consisting of 4 components, e.g. a farm household with a crop, livestock, manure management and household component. Figure A 2 presents an overview of the system, depicting components by boxes and flows by arrows (values along arrows represent flows in kg of nitrogen).

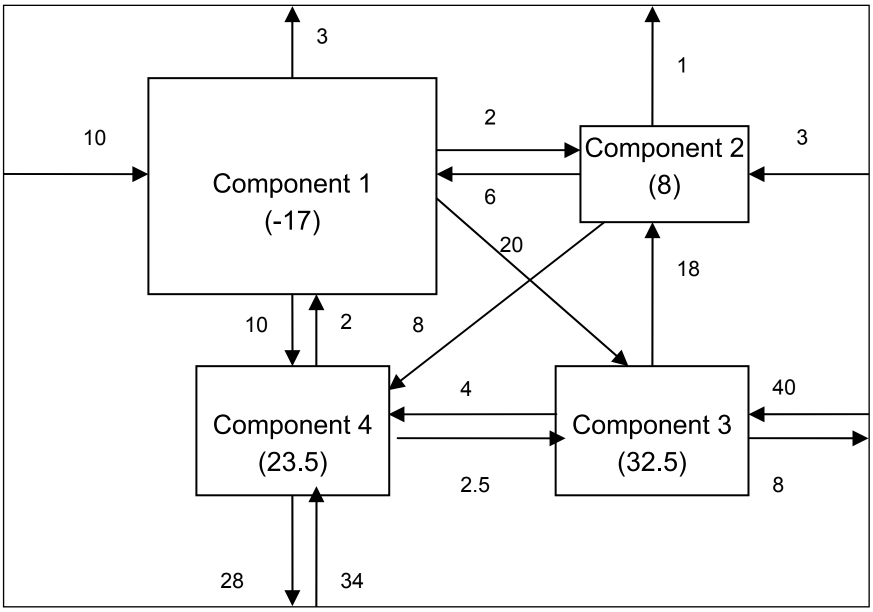

Figure A 2 Flow diagram of virtual farm household showing nitrogen flows and changes in nitrogen stocks.

Calculation of flows is given in Table A 1

Table A 1 Nitrogen flows of the farm household system depicted in Figure A 2.

From: To:	Component 1	Component 2	Component 3	Component 4	Inflows (z_{io})	$X_{k(-)}$	$T_{k(i)}$
Component 1	0	6	0	2	10	17	35.0
Component 2	2	0	18	0	3	0	23.0
Component 3	20	0	0	2.5	40	0	62.5
Component 4	10	8	4	0	34	0	56.0
Ouflows (y_{oj})	3	1	8	28	0	0	40.0
$X_{k(+)}$	0	8	32.5	23.5	0	0	0
$T_{k(j)}$	35.0	23.0	62.5	56.0	87		176.5

Calculation of indicators yields:

Throughflow	T_1	=	$\sum f_{kj} + z_{ko} - \sum (x_k)_-$
		=	$\sum (2 + 6) + 10 - \sum (-17)$
		=	35
	T_2	=	$\sum (2+18) + 3 - \sum (0)$
		=	23
	T_3	=	$\sum (20+2.5) +40 - \sum (0)$
		=	62.5
	T_4	=	$\sum (10+8+4+0) + 34 - \sum (0)$
		=	56
Total system throughflow	TST	=	$\sum T_k$
		=	$\sum (T_1 +T_2 + T_3 +T_4)$
		=	$\sum (35 + 23 + 62.5 + 56)$
		=	176.5
Total inflow	TIN	=	$\sum z_{io} – \sum (x_k)$
		=	$\sum (10 + 3 + 40 + 34) - \sum (-17)$
		=	104
Total outflow	TOUT	=	$\sum y_{oj} + \sum (x_k)_+$
		=	$\sum (3 + 1 + 8 + 28) + \sum (0 + 8 + 32.5 + 23.5)$
		=	104
Pathlength	PL	=	TST / TIN
		=	176.5 / 104
		=	1.7

The flow matrix N^{**} is calculated as $N^{**} = [\, I – Q^{**}]^{-1}$, where I is the identity matrix and Q^{**} is a matrix that contains the fractions q^{**}_{ij}, in which each flow f_{ij} is expressed as a fraction of the total flow entering a component H_k. Then Q** is:

0	0.26	0	0.04
0.06	0	0.29	0
0.57	0	0	0.04
0.29	0.35	0.06	0

and N** is:

1.079	0.296	0.088	0.042
0.245	1.072	0.310	0.023
0.636	0.190	1.059	0.070
0.434	0.470	0.200	1.024

Cycling efficiency (RE) of each component is calculated by examining the diagonals of the matrix N^{**}, the diagonal element n^{**}_{kk} represents the amount of flow in H_k generated by a unit of flow starting in H_k.

$RE = (n^{**}_{kk} – 1)/ n^{**}_{kk}$

$TST_c = \sum RE_k T_k$

$$TST_c \quad \sum \begin{pmatrix} 0.074 \\ 0.067 \\ 0.056 \\ 0.024 \end{pmatrix} \quad X \quad \begin{pmatrix} 35.0 \\ 23.0 \\ 62.5 \\ 56.0 \end{pmatrix}$$

The recycling index is the fraction of total system throughflow that is cycled. The cycled portion is:

$$\begin{aligned} CI &= TST_c/TST \\ &= 8.95 \end{aligned}$$

Thus total external inputs amount to 87 kg N, and system outputs to 40 kg N. Total inflow consists of the external inputs plus changes in components stocks. A unit of nitrogen on average flows through 1.5 components (path length) while less than 9% of the total throughflow is recycled.

Annex II.

Assumptions used in the case study on Teghane

Livestock feed consumption was not reported by farmers during their interviews. Instead, calculated feed consumption was calculated with the livestock model of NUTMON Toolbox (Vlaming *et al.*, 2001). The basic assumptions made are that the data on direct feeding is provided by the farmer and the remainder to meet feed requirement comes from grazing outside the farm, on common grasslands. It was also assumed that, on the whole, animals do not lose weight during the period of analysis (one year). Manure N excretion was calculated as a fraction of feed N intake (80%). The total manure N was partitioned between farm and communal grazing land by using a fixed grazing factor of 0.5. On the farm, only faeces are recycled, which contain 50% of the total manure N. Fixed conversion factors for dry matter (DM) and N contents were used. All types of fresh manure are assumed to have 35% DM content and 2% N on a DM basis as they become mixed in the stable. Part of the manure excreted on grazing land is collected by children while herding. These are considered inputs of manure to the farm stable/heap component.

Chickens yield 1.5 kg of meat, sheep produce 10 kg of meat and cattle 110 kg (Suttie, 2000). Donkeys and mules consume farm resources and are rented out for salt transport, which provides off-farm income (Girmay Tesfay, personal communication). Labour days have 8 hours. Labour allocation to livestock: animals were expressed as Tropical Livestock Units (TLU; cattle: 1; sheep: 0.11; chicken 0.01). Labour allocation was further weighted using time household members were present on the farm. Barley stover is calculated assuming a HI of 0.31 (Sinebo *et al*., 2004). Faba bean crop residues are calculated assuming a HI of 0.60 (López Bellido *et al*., 2003). To calculate wheat stover production a HI of 0.4 (Soltani *et al*., 2004) was used. Honey yields are assumed to be 5.5 kg honey per hive (Girmay Deffar, 1998).

The household was considered a component with inflows (grains and animal products) and outflows (human excreta, household waste). It was assumed that household waste represents 20% of the grain destined for home consumption. A fixed conversion factor of 85% was used to allocate N intake in excreta. Excreta N was partitioned between urine and faeces on a ratio 2.3: 1 (Strauss, 2000).

Table A 2 Conversion factors

Product	Source	References
Dry matter (%) crop products	NUTMON database	Vlaming et al. (2001)
Dry matter (%) manure	NUTMON database	Vlaming et al. (2001)
N (%) crop products	NUTMON database	Vlaming et al. (2001)
N (%) milk, eggs, meat	USDA database	USDA, Nutrient Data Laboratory (2004)
N (%) manure, soils	Survey	Laboratory analyses
C (%) all products		De Ridder and Van Keulen (1990)
C (%) soils	Survey	Laboratory analyses
Energy in grains	USDA database	USDA, Nutrient Data Laboratory (2004)
Energy needs for labour		Uhl and Murphy (1981)
Energy in manure and human excreta	Phyllis database	Energy Research Centre of the Netherlands
Energy in fertilisers		Lockeretz (1980)
Energy for animal traction		Leach (1976)
Energy needs for humans		Bender, (1997)
Energy in animal products	USDA database	USDA, Nutrient Data Laboratory (2004)

Annex III.

Assumptions used in the case study on Honduras

Production of human excreta was calculated as a fixed daily amount per household member (Strauss, 2000). Faeces production is calculated to be 0.25 kg (20% DM and 5.5% N) and urine production 1.2 kg (5% DM and 16% N). Conversion factors further are similar to those of the Teghane case study.