Disentangling poverty and biodiversity in the context of rural development: A case study for Pujiang county, China

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Abstract

Both, poverty reduction and preservation of biodiversity are high on the global agenda on sustainable development. The relationships between poverty, biodiversity of ecosystems and agricultural development are complex and poorly understood. In this paper we present an integrated framework for analysis of agricultural development and natural resource management options at ecosystem level. We use Pujiang county, in Zhejiang province, China as a case study area to perform the analysis. A regional Linear Programming (LP) model is applied maximizing regional economic surplus given product and labour market conditions in Pujiang. We use the model to determine the consequences of four so-called poverty reduction strategies, i.e. (i) intensification of production, (ii) diversification towards livestock production, (iii) land expansion, and (iv) an exit from agriculture, for a set of regional poverty and biodiversity indicators. Diversification seems the most promising poverty reduction strategy, but requires an efficient use of animal manure in cropping systems to avoid environmental problems.

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Improved nutrient management in cropping systems is effective in reducing the regional nitrogen surplus but less effective in increasing per capita income. The exit strategy is beneficial for reducing poverty and achieving biodiversity goals, but may have important social consequences which are not addressed in this study. Further reduction of rural poverty is hampered by labour constraints during the harvesting period in high value crops such as vegetables and fruits, which calls for research and development in the field of agricultural mechanization.

Keywords: Diversification; Intensification; Environment; LP; Sustainability; Ecosystem approach.

1. Introduction

Both, poverty reduction and preservation of biodiversity are high on the global agenda on sustainable development after adoption of the Millennium Declaration by the General Assembly of the United Nations (UN, 2000). This declaration resulted in formulation of eight Millennium Development Goals (MDG's): a set of goals and targets to guide international policies. The most important cross-cutting MDG's are poverty alleviation and securing environmental sustainability, both of which, in developing countries, are strongly linked to agricultural development and the conservation of biodiversity at the ecosystem level. The relationships between poverty, biodiversity of ecosystems and agricultural development are complex and poorly understood. Poverty can force people to deplete or pollute natural resources, resulting in destruction of the ecosystems on which they rely for food and income generation. Conversely, degraded ecosystems may be an underlying reason for poverty as poor natural resource qualities prevent implementation of viable livelihood strategies. A considerable body of scientific evidence points to the world-wide degradation of ecosystems and the decline in ecosystem services as a cause of many of the most pressing issues we face today, including hunger and poverty, rural-urban migration, health problems, and water scarcity. Hence, the loss of biodiversity and declining ecosystem services affect all aspects of human life. The combination of goals and targets as set by the MDG's pinpoints to the need for an integrated analysis of agricultural development options to improve insight in the complex relationships between poverty and biodiversity objectives. Such an analysis may reveal existence of important trade-offs between both objectives and, hence, contribute to well thought-out policy decisions.

In this paper, we present an integrated analysis of agricultural development and natural resource management options at ecosystem level in relation to a set of poverty and biodiversity indicators. We use Pujiang county, in Zhejiang province, China as a case study area to perform the analysis. Pujiang county is characterized as a lowland rice-based ecosystem facing moderate prevalence of poverty (Dixon et al., 2001). In general, rice-based ecosystems are being challenged by the simultaneous demands for increased productivity, contribution to poverty alleviation and reduced environmental impact. Diversification of agricultural production, for example by including vegetable and livestock production is considered one of the means to increase farmers' income and improve food security (Hossain, 1998). However, consequences of wide-scale introduction of vegetables and livestock for the ecosystem are unknown, but may result in pollution (Pingali, 2001). Technological innovations, such as site-specific nutrient management (Dobermann et al., 2004) may improve simultaneously productivity and environmental performance of these rice-based ecosystems, but their effects on agricultural development still have to be fostered.

The aim of this study is to identify the scope for rural development in Pujiang on the basis of four possible poverty reduction strategies (Dixon et al., 2001): (a) intensification of agricultural production, (b) diversification of agricultural production, (c) expansion of land area, and (d) a departure from agriculture. In different scenarios, we explore the consequences of these strategies for poverty and biodiversity indicators in Pujiang, including quantification of trade-offs between both. The analysis contributes to transparency in the debate on poverty alleviation and biodiversity preservation in relation to the opportunities and limitations for agricultural development. Hence, the study is an illustration of how regional (micro) studies may link to the international (macro) agenda on poverty and biodiversity. The methodology applied in this study is based on Bouman et al. (1998) and Roetter et al. (2004) and has been further developed within the project 'Integrated Resource Management and Land Use Analysis (IRMLA)'.

In Section 2, the study area, the applied methodology and its components, and the poverty and biodiversity indicators selected for this study are described. In Section 3, the different scenarios are described, followed by a description of their results in Section 4. In Section 5, we discuss the results and draw general conclusions.

2. Methods and materials

2.1. Study area

Pujiang county (119°79’ E, 29°31' N), covering about 89,000 ha, is located in the centre of Zhejiang province, about 100 km SW of the provincial capital and Metropolis Hangzhou (Fig. 1). It is located in the subtropical climate zone, with mean annual temperature of 16 °C and annual rainfall ranging between 1100 and 1900 mm. The altitude of Pujiang varies between 30 and 1000 m asl. Its total population is 380,000, of which about 112,000 are employed in agriculture (ZSB, 2001). Farmers, traditionally focusing on rice cultivation, are increasingly diversifying their production portfolio with vegetables, fruits, ornamentals and animals, supported by the local government with technical and financial programmes. Moreover, the number of part-time farmers in Pujiang has increased, because of the ample availability of off-farm employment opportunities in the nearby industrialized zone around Hangzhou.

In Pujiang, about 28,300 ha is suitable for agriculture, of which 23,200 ha currently is cultivated. About 50,800 ha is covered by permanent forests, bamboo or natural vegetation, mainly located in the higher altitude zones, while about 9,600 ha consists of stony soils and urban areas. Despite their recent decline, single and double rice cropping systems are still the predominant agricultural land use activities in Pujiang. About 50% of the cultivated area consists of rice or rice-vegetable systems on fertile soils, mainly in the

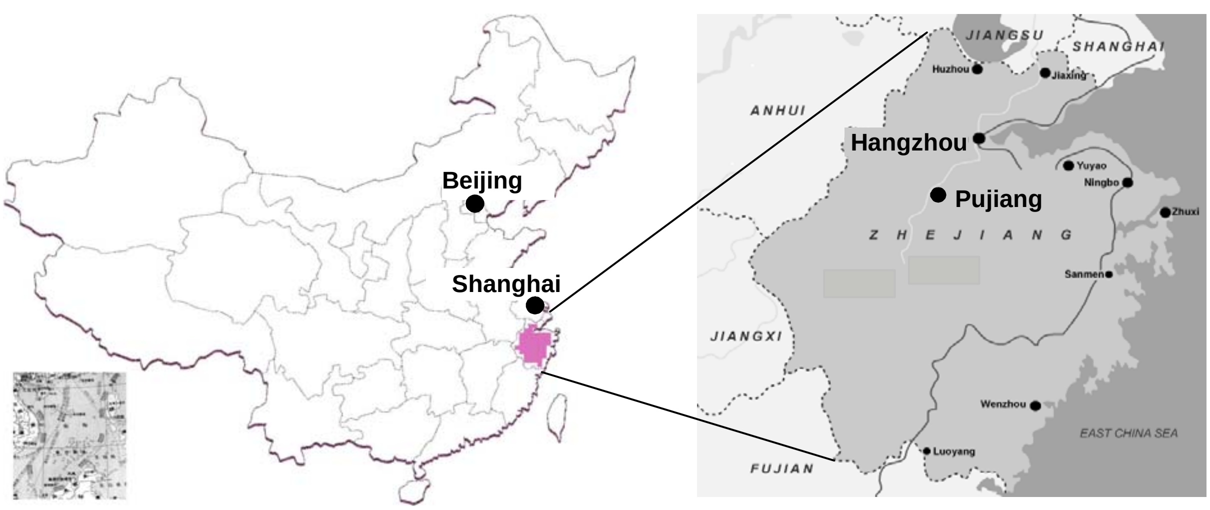

Fig. 1. Pujiang county, Zhejiang province, P.R. China.

lowlands, while vegetable systems and fruits are mainly located on less fertile soils in the uplands. Expansion of agriculture is only possible in the upland area up to a maximum of 5,100 ha. The remainder of the county is not suitable for agriculture due to steep slopes, or is under sustainably managed forest, bamboo and natural vegetation with a semi-protected status.

Environmental problems in Pujiang are associated with the high use of chemical inputs in agriculture, such as nitrogen fertilizers and biocides. Especially in vegetable crops, average nitrogen use is very high, i.e. 743 kg N ha^{-1}, compared to 300 kg in double rice systems and 150 in single rice systems. In general, only 25 and 35% of the applied nitrogen is taken up by rice and vegetables, respectively, suggesting agriculture as a major source of nitrogen pollution of ground- and surface water in Pujiang county. The limited information on biocide use in Pujiang suggests that that the situation is not much different from that in other parts of China where environmental pollution and occupational health problems associated with biocide use are major concerns (Hui et al., 2003).

Though systematic information on agricultural incomes in Pujiang is not available, net returns from a single rice system, in combination with the average farm (0.4 ha) and family size (4 persons), gives a rough indication of the magnitude of agricultural returns for families. Based on 2001 survey data, average net returns from single rice, i.e. income from production minus non-labour costs, amount to about 6,500 CNY[†] ha^{-1}.

2.2. Methodological framework

The applied methodology consists of three main components (Fig. 2): (i) a bio-economic Linear Programming (LP) model, (ii) two expert systems designed to quantify inputs and outputs for a large number of cropping and animal production systems, each characterized by a specific technology, and (iii) a Geographic Information System (GIS) to store and manage spatially explicit input data and to create maps from LP output.

In the following the main components of the framework are briefly described.

2.2.1. GIS

A GIS (using ARCVIEW) is used to store, geo-reference and manipulate regional resource data. Digital maps at scale 1:50,000 were available for current land use, soil characteristics, topography and administrative boundaries. Based on the land use map, first a distinction was made between agricultural and non-agricultural land. Current

[†] 1 US$ ~ 8.25 CNY (2004)

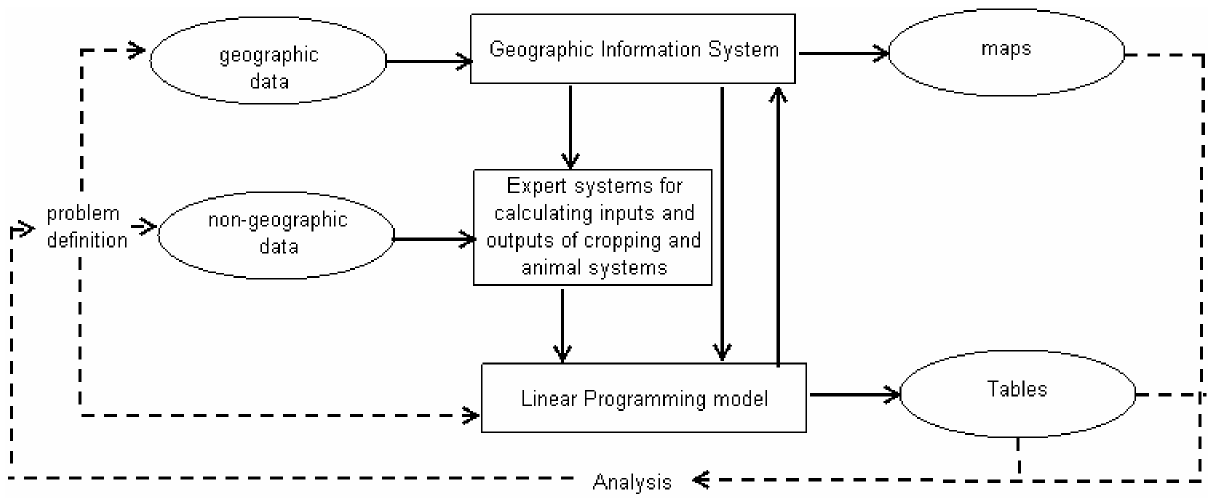

Fig. 2. Structure of the applied framework based on Bouman et al. (1998). Boxes are models or tools, blank names are activities, drawn lines are data flows, and dotted lines information flows.

agricultural land includes irrigated and rainfed crop land, pastures and natural vegetation consisting of shrubs. The remaining land use classes, comprising forests, water ways and urban areas are not suitable for agriculture. Second, major soil types and their characteristics were extracted from the soil map. Third, based on the digital elevation map (DEM), four altitude zones and four slope classes were identified. The altitude zones consist of areas between 30 and 150 m asl, between 150 and 300 m, between 300 and 600 m and above 600 m, while the slope classes are less than 6 degrees, 6 to 15 degrees, 16 to 25 degrees, and more than 25 degrees. The altitude zone above 600 m and the slope class exceeding 25 degrees were considered not suitable for agriculture because of the risk of erosion. Subsequently, accessibility zones were mapped representing zones of 1 km around towns and major villages, considered suitable for agriculture. It is assumed that outside these zones, access and transport limit agricultural development in the largely rough terrain of Pujiang. For calculation purposes, all the maps were stored in a grid format. Using the map calculation function of ARCVIEW, the map overlay with land use, soil types, elevation zones, slope classes and accessibility zones resulted in nine land units potentially suitable for agriculture, which can be grouped roughly in fertile and less fertile soils (Table 1). Finally, the overlay with the administrative map resulted in the area of suitable land units per township.

Table 1. Characteristics of the nine land units in Pujiang county which are suitable for agriculture.

Land unit description	Code	Area (ha)	Soil classification	Fertility status	Crop suitability [1]	Indigenous N supply (kg N ha^{-1} yr^{-1})
Alluvial plain, loamy paddy soil	APL	2397	Typic eduoaquepts	Fertile	Rice, non-rice crops, grapes, woody ornamentals	70
Alluvial plain, gleyed loamy paddy soil	APGL	162	Typic eduoaquepts	Fertile	Rice	70
Colluvial plain, clayey paddy soil	ADPC	7286	Typic plinthaqualfts	Fertile	Rice, non-rice crops, grapes, woody ornamentals	80
Colluvial valley, clayey paddy soil	ADC	3557	Typic plinthaqualfts	Fertile	Rice, non-rice crops, grapes, woody ornamentals	80
Alluvial flats, loamy paddy soil	AFL	357	Typic eduoaquepts	Fertile	Rice, non-rice crops, grapes, woody ornamentals	60
Hillock, clayey red soil	HRC	2013	Hapludults	Less Fertile	Non-rice crops, perennials	50
Hillock, loamy rock soil	HRL	5005	Plinthudults	Less Fertile	Non-rice crops, perennials (no tea)	60
Terrace, loamy rock soil	TRL	2484	Eutrochepts	Less Fertile	Non-rice crops, perennials (no tea)	60
Gentle sloping land, clayey red soils	GSC	5100	Hapludults	Less Fertile	Non-rice crops	50

[1] Non-rice crops include arable crops such as vegetables, soybean and sugarcane; perennial crops include fruits, tea and woody ornamentals (see Table 2).

2.2.2. Expert systems: Inputs and outputs of production systems

For quantification of inputs and outputs of production systems two expert tools were developed, one for animal systems and one for cropping systems, called TechnoGIN (Ponsioen et al., 2003, 2005). TechnoGIN calculates, on the basis of soil, crop and technology characteristics, relevant inputs and outputs of all specified cropping systems, such as yield, crop residue production, nutrient and biocide use, labour and machinery requirements (Hengsdijk and Van Ittersum, 2002). Most inputs and outputs are expressed both in physical and economic terms. Input-output coefficients for current cropping systems are quantified on the basis of interpretation of survey data for representative cropping systems. TechnoGIN also allows generation of information that is often not available from surveys, such as nutrient emissions to the environment and a biocide index (BI). The latter is defined as total active ingredients in the applied biocides times their toxicity (derived from the classification of the World Health Organization) times their persistence in the soil.

TechnoGIN has been calibrated for conditions in Pujiang on the basis of an extensive survey carried out in 2003, covering over 100 farm households, and comprising the input and output data for over 200 individual plots. In addition to single and double rice systems, in TechnoGIN input-output coefficients are calculated for rice-based cropping systems, non-rice systems and perennials (Table 2).

On the basis of a survey under livestock farmers, we estimated input-output coefficients for dairy cows, ducks, broilers, layers, rabbits and fattening pigs. The expert system

Table 2. Cropping systems for Pujiang incorporated in TechnoGIN.

Rice-based systems	Non-rice systems	Perennial systems
Single rice	Sugarcane	Oranges
Double rice	Celery-leafy vegetables-garden radish	Grapes
Rotations of rice with:	Celery-chilli (red pepper)-garden radish	Pears
Cabbage	Soybean-sweet potato	Plums
Rapeseed	Potato-corn	Jujube
Green manure	Double sorghum	Tea
Pasture	Wheat-soybean (or sweet potato)	Woody ornamentals
Sorghum		
Water melon		
Sweet corn		
Leafy vegetables		

for deriving input and outputs of systems is based on feed-quality specific conversion ratios for specific types of animals (EC, 1999). Based on total nitrogen intake of animals and the nitrogen incorporated in body tissue and economic product (such as eggs), their nitrogen excretion is estimated. For dairy cows, a slightly different approach was followed based on Hengsdijk et al. (1996). We simplified their approach by ignoring herd structure, and calculated energy requirements for maintenance and live weight gain of a single mature cow, starting from a pre-defined milk production level. Subsequently, these energy requirements were converted into feed requirements of a specified quality in terms of nitrogen content. Part of the feed requirements of dairy cows needs to be covered by roughage, while the remainder may be covered by concentrate feeds, as for the other animals.

In the LP model, animal and cropping systems are analysed in an integrated way by allowing crops or crop residues to be used as feed resources for animals and applying manure nitrogen to cropping systems. Labour required for transport and distribution of manure in the field is taken into account.

2.2.3. Linear Programming model

The LP model for Pujiang is a regional agricultural sector model that maximizes regional economic surplus subject to a set of constraints. The LP model selects from the range of alternative land use options generated with the expert systems, those land use activities that contribute most to the regional surplus, taking into account the set of boundary conditions and restrictions. The latter refer to available areas of land with well-defined soil qualities, available labour force, required degree of self-sufficiency in rice, available agricultural technologies, and market prices. Land availability is specified for nine land units with different production potentials (Subsection 2.2.1; Table 1). Agricultural production depends on the regional available labour force, as it is assumed that agricultural labour from outside Pujiang is not available. Labour balances are computed per decade of days (10–11 days) to account for periods of peak labour demands, and are key constraints in our analyses. Optional constraints in the model relate to the use of nitrogen manure from the animal sector in the crop sector, which will affect regional income, nitrogen and labour balances, and resource use efficiency.

By varying the restrictions and boundary conditions, consequences for and trade-offs between poverty and biodiversity indicators are quantified. In the following, a set of coherent objectives, restrictions and boundary conditions is called a scenario.

2.3. Rural poverty and biodiversity indicators

To characterize rural poverty we use two indicators. First, per capita income of the agricultural population, defined as the regional economic surplus divided by the available agricultural labour force. The regional economic surplus is defined as the sum for all commodities of the regional production minus non-labour costs, as calculated in each scenario. Second, the ratio between the active labour force and the total available agricultural labour force in Pujiang, as a proxy for the number of people that can be employed in agriculture in each scenario. A small ratio means a large underemployment of the agricultural labour force and, thus, indicates latent rural poverty and calls for creation of employment opportunities outside agriculture.

The biodiversity indicators used in this study closely relate to the set of indicators proposed by the Convention of Biological Diversity to assess progress towards the achievement of biodiversity goals in 2010 (CBD, 2004). Services provided by biodiversity in support of local human well-being, here, are approximated with land productivity. The calculated average nitrogen surplus per unit agricultural area and the Biocide Index per unit agricultural area are indicators for the threats to biodiversity and ecosystem integrity, respectively (CBD, 2004). Nitrogen surplus is the difference between the amount of nitrogen applied and the nitrogen removed from the field in crop products. When manure nitrogen is not applied to cropping systems, the ‘unused’ manure nitrogen is added to the nitrogen surplus. The decrease in biological diversity in ecosystems is also characterized by the ratio between the area under agriculture and that under forest in each scenario.

In addition to these poverty and biodiversity indicators, we show indicators related to the regional use of land and other natural resources.

3. Scenarios

FAO proposes five main strategies to reduce hunger and poverty and to improve the livelihoods of farm households (Dixon et al., 2001): (i) intensification of existing production systems, i.e. increasing factor productivity through greater use of external inputs per unit area or per animal, (ii) diversification of production and processing, i.e. the allocation of production resources among different income-generating activities, (iii) expansion of land holding or herd size, (iv) increasing off-farm income, both agricultural and non-agricultural, and (v) complete exit from the agricultural sector. Quantitative information on the impact of these strategies on poverty alleviation and biodiversity protection in Pujiang, including their possible trade-offs, is required to identify feasible and acceptable rural development options. Here, we have defined four scenarios, in addition to a reference scenario representing the current situation that is used as a benchmark for the results of the other scenarios. The four scenarios refer to the first three poverty reduction strategies, while the fourth scenario combines the last two poverty reduction strategies. The strategies to increase off-farm income and to exit from agriculture are to a certain extent related as both depend on the generation of employment opportunities outside the agricultural sector. In each scenario we will analyse the effects of the strategy on both poverty and biodiversity indicators (Subsection 2.2.3). In the following, the scenarios are further described.

Table 3. Number of animals currently present in Pujiang expressed in animal places.

Animal type	Animal places[1]
Dairy	2500
Broilers	16000
Hens	80000
Ducks	20000
Rabbits	60000
Slaughter pigs	70000

[1] The number of animals is expressed per animal place to account for differences in the length of production cycles among animals. For example, a production cycle of a broiler with 40 days implies 9.1 cycles per year. One animal place in this example represents 9.1 production cycles and thus 9.1 broilers per year.

3.1. Reference

This scenario serves for validation of the regional model, and its results are the basis for assessment of the effects of the other scenarios. It represents the current situation in Pujiang, in which most farmers on the alluvial and generally fertile soils cultivate double rice, single rice, vegetable-rice and vegetable systems, while on the less fertile soils, perennials and annual crops as soybean, sorghum and sweet potato dominate (see also Subsection 2.2.2). Input and output coefficients of the land use systems have been derived from the systems currently practiced in Pujiang. The current agricultural area in Pujiang is set as resource constraint in the model, i.e. 13,800 ha of fertile soils and 9,500 ha of less fertile soils and the number of animals (dairy cows, fattening pigs, broilers, layers, ducks and rabbits) to the numbers currently present (Table 3). The other constraints are the available agricultural labour force, and the rice required for achieving regional self-sufficiency (100 Mln kg) which is an important local policy objective (based on stakeholder meetings and an annual food demand of 250 kg rice per capita). The roughage required by dairy animals has to be produced within Pujiang, while other feedstuffs may be imported against market prices. In this and the other scenarios we maximize regional economic surplus of Pujiang.

3.2. Intensification

In this scenario, the available land use systems are identical to those in the reference scenario, however using new technologies. These technologies aim at increasing crop, animal and labour productivity and reducing fertilizer use through (i) the use of hybrid rice varieties in early rice, (ii) introduction of mechanized field preparation in rice and vegetable production, (iii) direct seeding of rice, and mechanized harvesting operations in rice, (iv) site-specific nutrient management (SSNM), and (v) feeding high quality feed resulting in more favourable feed conversion ratios of animals. The use of hybrids in early rice systems is associated with 15% higher yields, higher nutrient inputs and higher costs for seeds (16 versus 1.2 CNY kg^{-1} seed) (Wang et al., 2004). Labour requirements of mechanized field preparation and harvesting are on average 10% and 1%, respectively of those in the reference scenario. Costs for mechanization are based on prevailing rental fees for machinery in Pujiang. Direct seeding results in a yield reduction of 10%, but requires 95% less labour than transplanting, without additional costs as no machinery is required. In SSNM, NPK fertilizer doses are based on field and cropping-season specific conditions, requiring more labour, but increasing nitrogen recoveries (Dobermann et al., 2004). SSNM in rice cultivation has been developed and tested for conditions in Pujiang, but has not yet been widely adopted (Wang et al., 2004). Here, the nitrogen recoveries in flooded rice, conservatively, increase from 25 to 37.5%, and in non-flooded crops from 35 to 52.5%. Access to better feed resources improves feed conversion ratios and thus production levels of animals on average with 10%. For dairy animals production levels increase much more, as current levels (1500 kg milk animal^{-1} yr^{-1}) are very low due to a poorly developed dairy sector in Pujiang. Milk production levels of 4500 kg animal^{-1} yr^{-1}, have been reported for other parts of China (Nanging, 1991). As in the base scenario, we assume that animal manure is not used in the cropping systems.

3.3. Diversification

Driven by economic reforms and the ensuing increase in living standards, the consumption of animal products in China has more than doubled since the 1980s (Rae, 1998) and is expected to increase further (Ma et al., 2004), providing opportunities for expansion of the livestock sector. In this scenario we analyse the consequences of a further diversification of the agricultural sector in Pujiang in the direction of animal production. We increase the current number of animals in steps of 50% up to 400% and analyse the impact on poverty and biodiversity indicators.

In the previous two scenarios, animal manure was not used in cropping systems, corresponding to current average manure management in Pujiang, as its transport and distribution in the field are costly and the use of fertilizers is economically more attractive. Hence, manure nitrogen contributes significantly to the regional nitrogen surplus and adversely affects the environmental impact. In principle, animal manure should not be considered a waste but as a suitable resource to meet the nutrient requirements of cropping systems. Here, we analyse two alternatives in which manure is (i) used as a nutrient resource in cropping systems (scenario D2) and (ii) considered a waste that contributes to the nitrogen surplus as in the previous scenarios (scenario D1). Since application of manure in cropping systems generally results in higher nitrogen losses to the environment, here, these losses are assumed 25% higher than from fertilizer nitrogen. The obligation to use manure in cropping systems will affect poverty indicators, as the costs for fertilizers will be reduced, and biodiversity indicators as the regional nitrogen surplus will decrease. The other model settings in this scenario are similar to those in the intensification scenario.

3.4. Agricultural land expansion

Currently, all fertile soils in Pujiang are being cultivated, but there is still scope for agricultural expansion on the less fertile soils. With increasing liberalization of land policies and considering the suitability of these soils for growing fruits and vegetables, pressure to use these soils for agricultural purposes is likely to increase. In this scenario, we analyse the consequences for regional poverty and biodiversity indicators when the area of less fertile soils available for agriculture increases with 5,100 ha, which is 22% of the agricultural area in the reference situation. We use the same animal population and settings as in the intensification scenario.

3.5. Exit from agriculture

Pujiang is in the vicinity of the triangle formed by the mega-cities Shanghai, Nanjing and Hangzhou, where off-farm employment opportunities are amply available, as illustrated by the number of people working outside Pujiang that more than doubled from 1999 to 2000 from 18,200 to 38,000 (ZSB, 2001). In this scenario, we analyse the effect of a decreasing agricultural labour force for rural poverty and biodiversity indicators. We decrease the available agricultural labour force in steps of 5% to analyse the consequences for the selection of land use systems and the regional self-sufficiency in rice production. We use the same animal population and model settings as in the intensification scenario.

4. Results

4.1. Reference

Detailed comparison of the results of the reference scenario with the current situation in Pujiang is cumbersome, as regional statistics are ambiguous and conflicting. Here, we assess the results with some of the scattered information available. In general, cropping systems are selected in the reference scenario that currently dominates in Pujiang: Rice and vegetable systems on the fertile alluvial soils mainly in the lowlands and fruit trees on the less fertile sandy soils mainly in the uplands (Table 4). The area under woody ornamentals appears to be overestimated, which is an indication for the high profitability of this activity. In recent years, the production of woody ornamentals has gained strong momentum, as output markets were favourable and the required production skills could be rapidly acquired. Labour shortages during peak periods limit further diversification towards profitable but labour-demanding activities, such as vegetables, woody ornamentals and fruits. Average land productivity (62,250 CNY ha^{-1}) is 9 times higher than that of a single rice crop (Section 2.1), but the value is not unrealistic, as it includes the economic surplus from more profitable land use activities such as fruits, vegetables and animal husbandry (Table 3). Van de Berg et al. (this volume) calculated an average land productivity of 54,580 CNY ha^{-1} for a mixed vegetable-rice farm in Pujiang. Average income in this scenario is about 13.000 CNY per capita, which compares well with the annual wages of unskilled labour in China (about 11,000 CNY per capita).

Table 4. Results (in units per year) of the reference, intensification, diversification, land expansion and exit scenarios.

Indicator	Unit	Reference	Intensification	Diversification		Land expansion	Exit
				D1	D2		
Labour income	CNY $pers^{-1}$	12,850	13,610	15,920	16,050	14,772	15,540
Land productivity	CNY ha^{-1}	62,250	65,920	77,110	77,720	58,716	60,180
Share active agri cultural population	%	32	32	35	63	33	35
N surplus	kg N ha^{-1}	425	296	412	237	251	283
Biocide index	-	756	758	747	747	632	664
Ratio agricultural area per forest area	-	0.46	0.46	0.46	0.46	0.56	0.46
Land use:							
Rice	ha	6,805	6,804	6,521	6,521	6,701	6,660
Vegetables	ha	3,745	3,745	3,584	3,584	3,685	2,896
Rice-vegetables	ha	3,309	3,210	3,654	3,653	3,373	3,436
Fruits	ha	8,107	8,107	8,162	8,162	13,183	9,146
Woody ornamentals	ha	1,395	1,395	1,340	1,340	1,396	1,105
Animal population	%	100	100	200	200	100	100
Labour force	%	100	100	100	100	100	80
Share unused manure in N surplus	%	22	39	57	0	38	41
Cropping intensity	%	1.75	1.75			1.62	
Mechanized activities	%	0	5	11	11	12	15

The LP model uses fixed market prices, irrespective of the supply of agricultural products, i.e. it does not account for market disequilibria. In general, one would expect prices of agricultural products to be influenced by their supply, as the demand in Pujiang is limited. Despite this omission, results are remarkably consistent with the information available for the current situation in Pujiang.

4.2. Intensification

Land use allocation in this scenario is not different from the reference scenario (Table 4). However, land use activities with improved nutrient recoveries are selected resulting in a reduction in nitrogen surplus of 130 kg N ha^{-1} compared to the reference situation, caused by lower nitrogen inputs in cropping systems. The manure nitrogen surplus increased by about 20% due to increased feed intake with a higher nitrogen content and the associated higher animal productivity. Land use activities with mechanized field operations are selected on 34% of the area under the rice-vegetable systems in this scenario, but not for other systems. These labour-saving activities are sufficiently remunerative and contribute to solving the labour constraints that limit a further increase in economic returns. Labour bottlenecks in this scenario are associated with harvesting of vegetables and fruits, and operations in woody ornamentals for which no mechanized alternatives were defined. Although the costs of production in cropping activities are lower than in the reference scenario, the major share of the 6% increase in per capita income and land productivity is derived from higher returns from livestock activities.

4.3. Diversification

First, Table 4 shows the scenario results for D1 and D2 when the number of animals in Pujiang is doubled. In scenario D1, manure is not used in cropping systems, while in scenario D2 it contributes to the nutrient requirements of cropping systems. The slightly higher per capita income and land productivity in D2 compared to D1 is a consequence of the lower costs for fertilizers, while manure is available at no costs and only requires labour for transport and distribution in the field. Manure application in cropping systems increases the participation in the active agricultural labour force (from 35 to 63%), indicating the labour-intensity of transport and distribution of manure. Concurrently, it results in a much lower nitrogen surplus in scenario D2 than in D1 and in the previous scenarios, as witnessed by the share of unused manure in the nitrogen surplus. In scenario D1 the opposite trend is observed, i.e. the share of unused manure in the regional nitrogen surplus increases to 57% due to the larger number of manure producing animals.

Second, in Fig. 3 we show the consequences of a stepwise increase in the number of animals in both scenarios for per capita income and nitrogen surplus. Per capita income hardly differs between both scenarios and increases linearly with the growth in number of animals. At first, the nitrogen surplus in D1 increases only slowly compared to D2 as all animal manure is applied in cropping systems. At a tripling of the animal population, nitrogen in manure exceeds the nitrogen requirements of cropping systems. All animal manure produced beyond this point contributes directly to the nitrogen surplus and the curves for D1 and D2 run parallelly. As most animal feed is imported, land use allocation and associated nitrogen requirements of cropping systems are only slightly affected by the increasing number of animals.

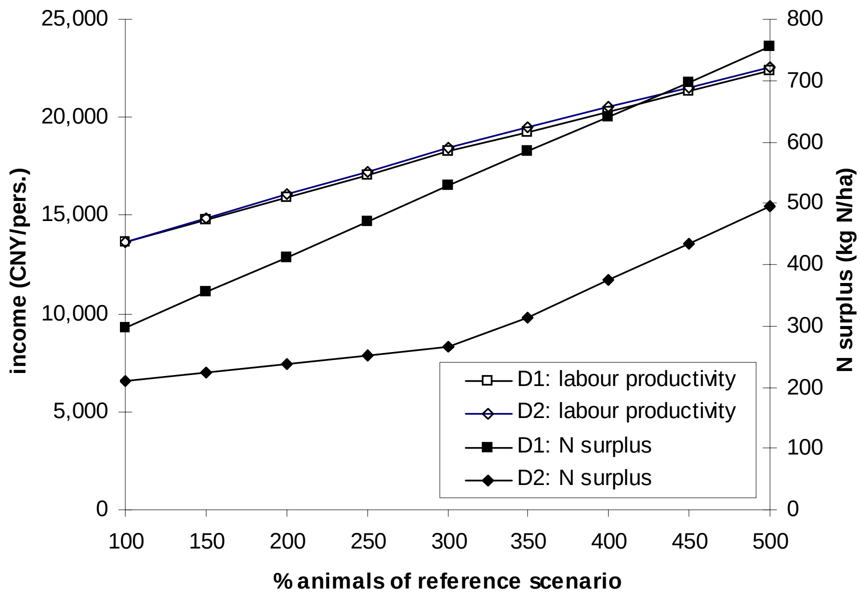

Fig. 3. Income and N surplus in scenarios D1 and D2 with an increasing number of animals in Pujiang (100% animals is reference scenario).

4.4. Agricultural land expansion

The less fertile soils coming available in the land expansion scenario are only used for fruit production (Table 4), the most profitable and least labour-demanding activity. Although average land productivity is 11% lower than in the intensification scenario, per capita income is 8% higher. Expansion of agricultural land use has a favourable effect on the nitrogen surplus, mainly because the animal manure surplus is 'diluted' over a larger area. Similarly, economic returns from livestock are 'diluted' resulting in lower land productivity. In this scenario, the agricultural area becomes almost half of the forest area in Pujiang. Most likely, fruit production in this scenario exceeds the local demand which may have a negative effect on the market prices for fruits (Section 4.1). As a consequence, both per capita income and land productivity would in reality be lower than calculated. Hence, this scenario suggests that a 22% increase in the agricultural area does decrease land productivity, while possible gains in income are much lower than the relative area expansion.

4.6. Exit from agriculture

We show in Table 4 the consequences of a 20% reduction in the agricultural labour force of Pujiang. Total regional economic surplus decreases less than the agricultural labour force, so that overall per capita income is 14% higher than in the intensification scenario. In contrast, land productivity is about 9% lower, due to the change from vegetable production to the less labour-demanding, but also less profitable fruit production. Despite the fact that the modelled land use changes to less-labour demanding land use systems, mechanized activities are selected only for the rice-vegetable systems. Remarkably, the participation of the active agricultural population is not markedly different from that in the intensification scenario: Labour constraints during peak periods prevent a larger participation of the available labour force in Pujiang.

In Fig. 4, we show the consequences of a stepwise reduction in the agricultural labour force for per capita income and the area with mechanized rice and rice-vegetable systems. It helps us to identify at which level of labour scarcity mechanized land use options have

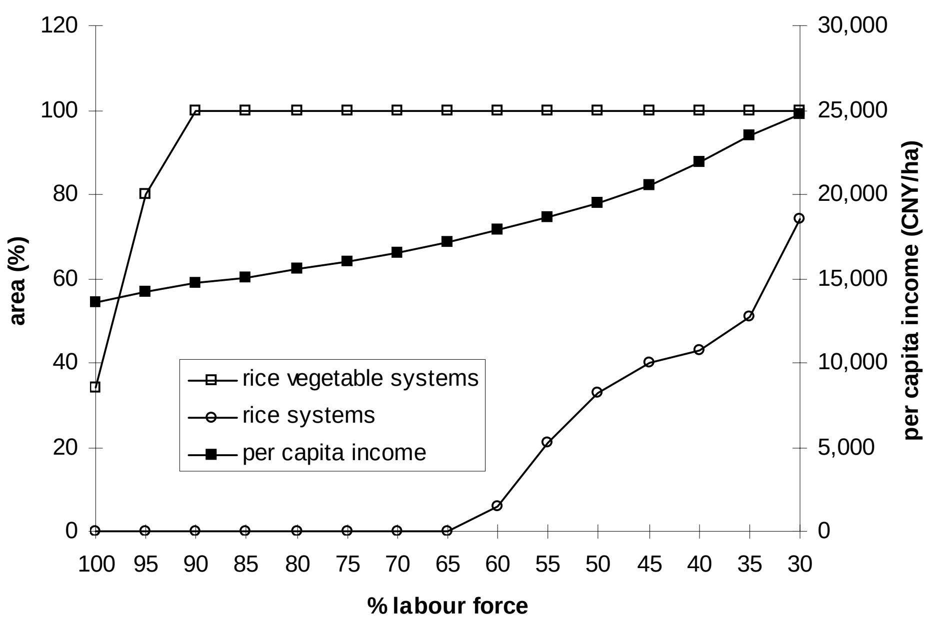

Fig. 4. Per capita income and the area of mechanized rice and rice-vegetable systems as percentage of the total cultivate area with rice and rice-vegetable systems, respectively. On the X-axis the reduction in available labour force expressed as percentage of the current available agricultural labour force in Pujiang.

a comparative advantage and it shows the consequences for per capita income in agriculture. In the previous scenarios, mechanized land use options were only selected in rice-vegetable systems and to a limited extent. Per capita income increases almost linearly with decreasing labour force at a rate of 750 CNY pers^{-1} for each 5% reduction in labour force. It becomes economically interesting to mechanize all rice-vegetable systems when the current available agricultural labour force in Pujiang is reduced with 10%. Mechanization of double rice systems is only attractive when the current labour force is reduced with 40%. From this point, the area with mechanized rice systems increases steadily to 75% of the rice area at 30% of the current labour force.

5. Discussion and conclusions

Location-specific socio-economic conditions, such as access to labour and product markets, and biophysical conditions, determine the potentials for and constraints to diversification, adoption of technological innovations and productivity increase in rice-based cropping systems. Furthermore, in many parts of E and SE Asia the current production structure, i.e. small land holdings with high labour/land ratios, limits the choice portfolio of farmers for applying new farming activities and technologies (Dixon et al., 2001). In studies at the farm household level such constraints at the micro level can be analysed, for example, in combination with the effects of off-farm employment opportunities (Hengsdijk et al., 2004; Van den Berg et al., this volume). Here, we have explored the consequences of four major poverty reduction strategies at the regional level for a number of poverty and biodiversity indicators.

Diversification towards animal husbandry seems the most promising poverty reduction strategy in terms of per capita income. However, to avoid environmental problems (N-surplus) that might interfere with biodiversity goals, manure should be applied efficiently in cropping systems. In that respect, the scope for expansion of animal husbandry seems limited in Pujiang, as the cropping systems can accommodate only a restricted quantity of manure nitrogen, and manure produced in excess of that level negatively affects the biodiversity indicators. It is remarkably that the N surplus in the reference scenario and in D1 is identical, despite a doubling of the number of animals in the last scenario. The increased N surplus due to more animals in D1 is completely compensated by the more efficient nutrient utilization in the cropping systems through site specific nutrient management. This illustrates the impact of improved nutrient management in cropping systems and the derived environmental benefits, as also is shown in the intensification scenario. In contrast, economic effects of the analysed intensification alternatives seem limited which may hamper their adoption by farmers.

Incorporation of manure in cropping systems is very labour-demanding and thus significantly increases regional labour participation, although it may be questioned whether this would represent ‘gainful’ employment. More important is its favourable effect on the N surplus. The share of manure nitrogen in the N surplus ranges from 20 to 60% across scenarios and when animal husbandry further expands and/or intensifies policy measures and new technologies should be designed to guarantee application of manure in cropping systems in an efficient way to avoid environmental problems.

The exit strategy contributes to a reduction in rural poverty, but this scenario is only realistic under sufficient availability of non-agricultural employment opportunities. For Pujiang, located near industrialized zones and given the impressive economic growth in China, this would seem a feasible development from an economic point of view. However, in the present situation in China such a development may have serious social consequences. For most rural inhabitants, land serves as an old-age insurance, and they will therefore be reluctant to give up their land rights.

Underemployment in the agricultural sector is difficult to tackle within the current structure, as certain peak periods (beside possible market constraints) prevent further expansion of labour-demanding crops (vegetables and woody ornamentals) and thus a larger participation of the available labour force in the regional production. This can only be solved through import of temporary labourers from outside Pujiang or the mechanization of operations in these peak periods, such as harvesting of vegetables and fruits. Machinery for this type of operations is under-developed, hence research and development is required to alleviate the labour constraint and further increase labour and land productivity.

Here, we have used regional income per capita as the major indicator to characterize rural poverty in Pujiang. However, considerable variation in income between different types of farming systems exist (Van den Berg et al., this volume). Heterogeneity in farming systems may be captured in the applied LP-framework through the incorporation of different matrices each representing different farm types with specific assets (Schipper et al., 1995). The discussion on appropriate indicators to monitor biodiversity loss has not been settled, which largely stems from the complex and multi-dimensional nature of biodiversity (Balmford et al., 2005). We used a partial set of the biodiversity indicators proposed by the CBD for assessing progress in achieving biodiversity goals in 2010. The used indicators illustrate some of the trade-offs at stake between poverty and biodiversity objectives in Pujiang. Therefore, the applied framework may support the implementation of the so-called ‘ecosystem approach’ as adopted by the CBD (CBD, 2000). This ecosystem approach aims at the integrated management of land, water and living resources to promote the conservation and sustainable use in an equitable way. This study showed the consequences of well-defined strategies and their consequences for resource use in Pujiang, and thus contributes to disentangling the complex relationships between poverty, biodiversity and rural development.

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