Exploring options for agricultural development

A case study in China

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Exploring options for agricultural development

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Jiayou Zhong

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- with summaries in English and Dutch -

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To

My father Zhong Guifu
My mother Xiao Chengxiu
My wife Fuhong
My daughter Zhong Xie

Tzu-chang asked Master K'ung about Goodness. Master K'ung said, 'He who could put the Five into practice everywhere under Heaven would be Good.' Tzu-chang begged to hear what these were. The Master said, 'Courtesy, breadth, good faith, diligence and clemency. He who is courteous is not scorned, he who is broad wins the multitude, he who is of good faith is trusted by the people, he who is diligent succeeds in all he undertakes, he who is clement can get service from the people.'

Confucius (551 BC-479 BC) (Translated by Arthur Waley). The Analects. Foreign Language Teaching and Research Press, Beijing, China (1998), pp. 229-231.

Abstract

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China's agriculture faces a series of challenges, *i.e.* guaranteeing national food security, increasing farmer's income and reducing the adverse effects on environment and human health associated with the use of fertilizers and biocides. At the same time, the availability of resources (*e.g.* agricultural land) decreases. The objective of this study is to operationalize a methodology to assess the effectiveness of new crop and livestock technologies in attaining rural development goals, using Jiangxi Province as a case study area.

Cropping and livestock systems, quantified in terms of inputs and outputs, are used as the smallest unit of analysis in this study. The new, also referred to as alternative, cropping systems comprise cultivation of Super Rice varieties and introduction of site-specific nutrient management (SSNM), integrated pest management (IPM) and mechanization in rice production. In alternative livestock systems, improved animal breeds, chemical treatment of crop residues and improved management in animal husbandry are adopted. A regional land use model, based on linear programming techniques, is used to assess the contribution of these alternative cropping and livestock systems to rural development goals. The results indicate that adoption of Super Rice varieties is most effective in attaining national grain security, while integration of Super Rice with improved beef cattle fattening systems is most effective in increasing income. Competition between livestock and rice production is limited, since high quality feed can be produced in rotation with rice without requiring additional rice land, and on non-rice land. Both, SSNM and IPM are most effective in reducing adverse environmental and human health effects, but hardly improve economic returns. Mechanization of rice production strongly reduces labour requirements in agriculture, leads to higher returns to labour and provides opportunities to work off-farm. When both, alternative crop and livestock systems are adopted concurrently, the goals of grain security, increasing rural income and reducing environmental pollution can be realized simultaneously. Results of this study contribute to the formulation of agricultural policies and a research agenda aiming at stimulating rural development in China.

Keywords: Linear programming; Land use model; Technology assessment

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1 General introduction

1.1 Background and rationale

One of many challenges faced by China is to guarantee grain security for the large and growing population, while the availability of resources, such as agricultural land, water and labour, decreases (Huang and Rozelle, 1998; Heilig 1999; HBPRST, 2004; Lichtenberg and Ding, 2008). In addition, the rapid economic development and the associated increase in living standards result in increasing demands for more luxurious and diverse food products that, at the same time, meet food safety standards. Especially, the demand for animal products, such as goat and sheep meat, beef and milk, increases rapidly (Verburg and Van Keulen, 1999; Zhu *et al*., 1999; Brown *et al*., 2002; Nin *et al*., 2004; Fuller *et al*., 2006), while the efficiency of resource use (especially of land and water) for food production is much lower in animal production than in crop production (Steinfeld *et al*., 2006).

Rice is the most important crop, as it remains the staple food for the majority of China's population, despite changing consumption patterns (Ling, 2004; Xie, 2004; Cheng, 2005). However, economic returns of rice are much lower than those of many other crops (Figure 1.1), which makes rice production less attractive to farmers (Li, 2005a). To guarantee sufficient supply of rice at national level, the profitability of rice production at farm level should be improved (Li, 2003; Cheng, 2005).

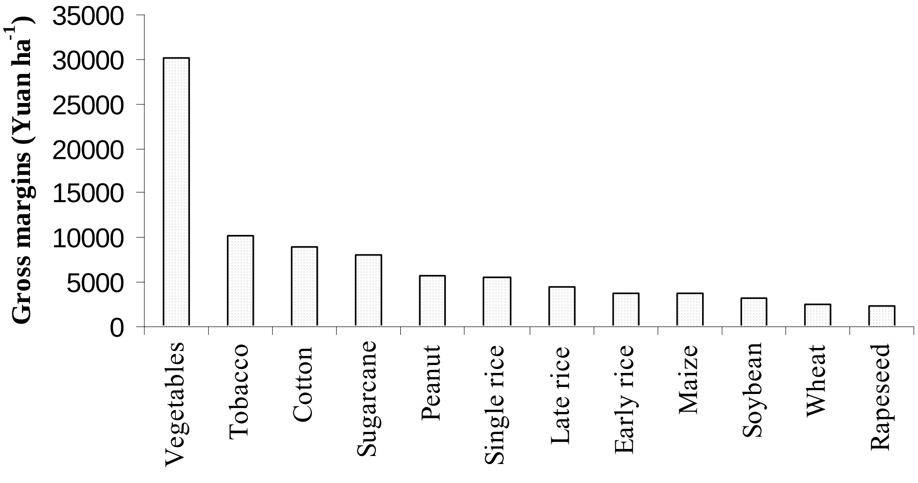


Figure 1.1 Gross margins (value of production minus costs of non-labour inputs) of some major crops in China (averages for the period 2000-2005) (Data source: NDRC, 2006).
Note: The data on vegetables is the mean value of seven vegetables: cucumber, tomato, eggplant, Chinese white cabbage, sweet pepper, Chinese cabbage and potato.

China's self-sufficiency in rice since the 1980s would not have been possible without the use of chemical fertilizers and biocides. The use of these inputs is increasingly associated with environmental pollution and human health risks, causing growing public concern (Wang *et al*., 1996; Widawsky *et al*., 1998; Zhu and Chen, 2002; Wei *et al*., 2007). Moreover, intensive use of fertilizers and biocides increases production costs, while insect pests and diseases may develop resistance against biocides under continuous high biocide input levels (Huang *et al*., 2001; Huang, 2003a; Shen, 2003; Zhang *et al*., 2003; Peng *et al*., 2006). Loss of N and P from farmland is one of the major sources of eutrophication of rivers and lakes (Bao *et al*., 2006; Gao *et al*., 2006a, b; Ji *et al*., 2007). Gaseous N losses from rice fields are associated with greenhouse-gas induced climate change (Pathak and Wassmann, 2007). In addition, biodiversity in rice ecosystems is threatened as a result of heavy application of agrochemicals (Li *et al*., 1999; Ling *et al*., 2001; Xiang *et al*., 2006).

Against this background, China's agriculture faces a series of interrelated and partly conflicting challenges, *i.e.* to increase grain production, to increase income of farmers and to reduce the adverse environmental effects of high application rates of fertilizer and biocides. Obviously, among others, new agricultural technologies can play an important role in realization of these goals (Huang and Rozelle, 1996).

After a short period of grain shortage in 2003, the Chinese government introduced a number of measures to stimulate grain production, such as a tax reduction and subsidies on seeds and the purchase and use of agricultural machinery (CCCPC and SCC, 2004, 2005; Gale *et al*., 2005). Policy priority was given to the development of technologies leading to increased input use efficiency, such as breeding of improved animal breeds and crop varieties, new nutrient management and integrated pest management (CCCPC and SCC, 2006). Policy considers development and adoption of new agricultural technologies essential to realize the multiple rural development goals as much as possible.

To support technology selection and priority setting, ex-ante assessment of the impact of adoption of promising agricultural technologies on achievement of development goals is required. Such an assessment provides valuable information for the formulation of agricultural policies and a research agenda. In this study, a methodology is developed to assess the effectiveness of new crop and livestock technologies in attaining rural development goals, using Jiangxi Province in China as a case study area.

1.2 Description of the case study area

Jiangxi Province (113˚34'-118˚28' E, 24˚29'-30˚04' N) (Figure 1.2) is selected as case study area, because it is agriculture-oriented and one of the major rice producing areas in China (CCJPH, 1999; Liu and Wei, 1999; JXPPG, 2000). Although located in the Southeast of China, not far from the country's centre of economic growth (*i.e.* Shanghai, Nanjing, Hangzhou and Guangzhou), Jiangxi is one of China's poorest provinces (Heerink *et al*., 2007).

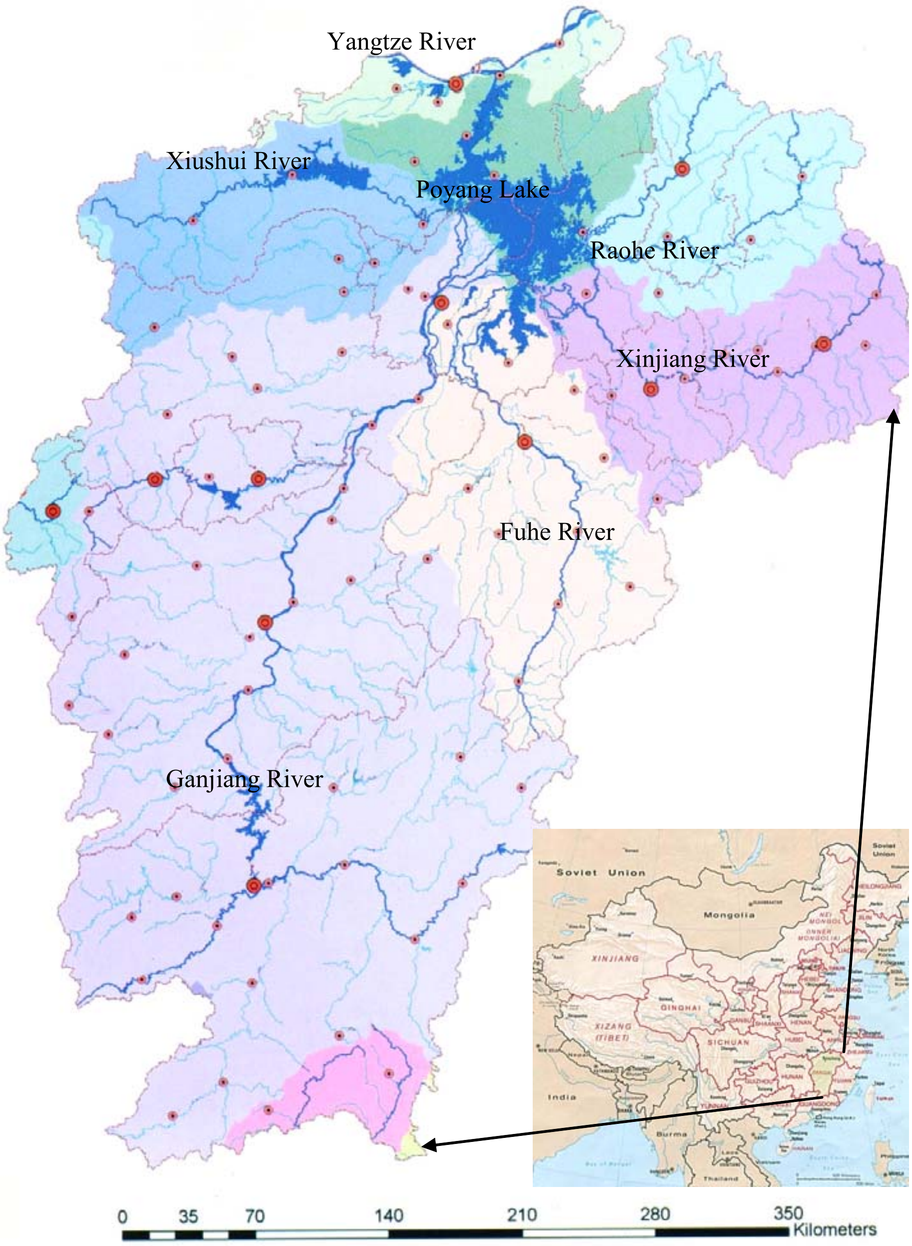


Figure 1.2 Location of Jiangxi Province in the People's Republic of China and major river basins in Jiangxi Province.
Note: The map of the People's Republic of China was downloaded from: http://www.cemrc.nmsu.edu/images/events/china_admin_91.jpg.

Jiangxi has a typical humid subtropical climate, which is favourable for year-round cultivation of a range of crops (Huang, 1994; Xiao, 2001; Chen *et al.*, 2002). Average annual temperature is 18 ºC with a clear peak of mean daily temperatures above 25 ºC from June to August (Figure 1.3a). Average annual sunshine duration is 1700 hours (Figure 1.3b). Average annual rainfall is 1600 mm, with a distinct wet period from March to June. From July to September, potential evapotranspiration exceeds rainfall (Figure 1.3c). Available irrigation water resources per unit of cultivated land are twice as high as the national average (Xu, 2001; Yu and Xu, 2001).

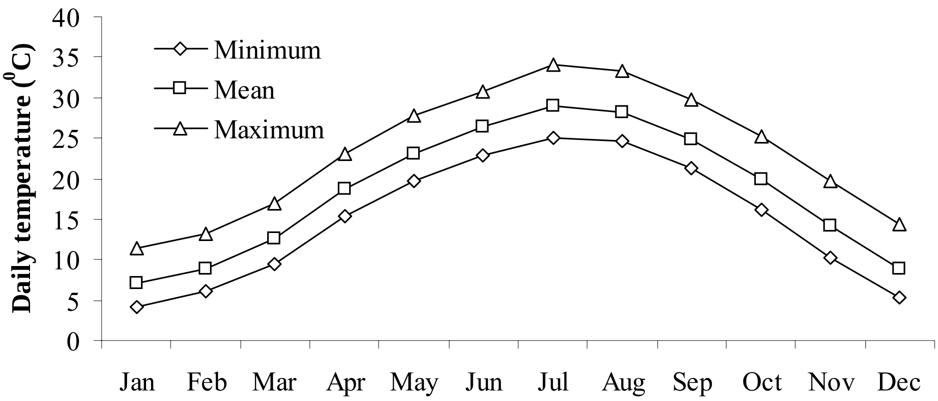


Figure 1.3a Mean daily minimum, mean and maximum temperatures during 1984–2003 (averages for three sites: Huichang in Southern Jiangxi (115˚48' E, 25˚36' N), Taihe in Central Jiangxi (114˚55' E, 26˚48' N) and Fengxin in Northern Jiangxi (115˚23' E, 28˚42' N)).

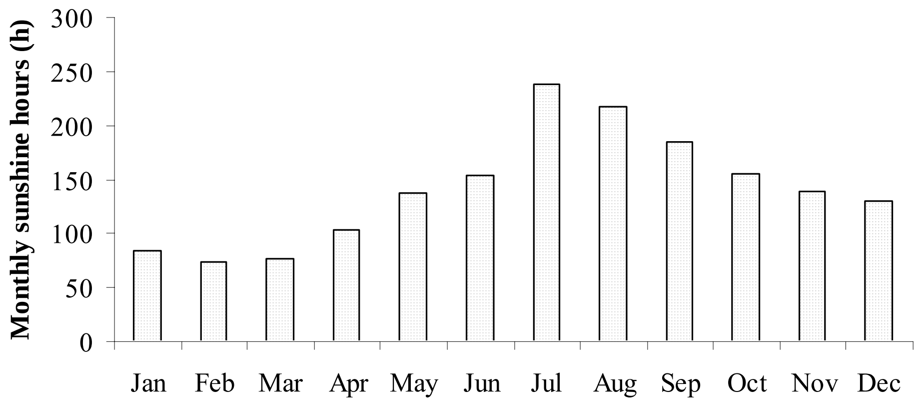


Figure 1.3b Mean monthly sunshine hours during 1984–2003 (average for three sites: Huichang in Southern Jiangxi (115˚48' E, 25˚36' N), Taihe in Central Jiangxi (114˚55' E, 26˚48' N) and Fengxin in Northern Jiangxi (115˚23' E, 28˚42' N) (Data sources of Figures 1.3a and 1.3b: Huichang County Meteorological station, Taihe County Meteorological station and Fengxin County Meteorological station).

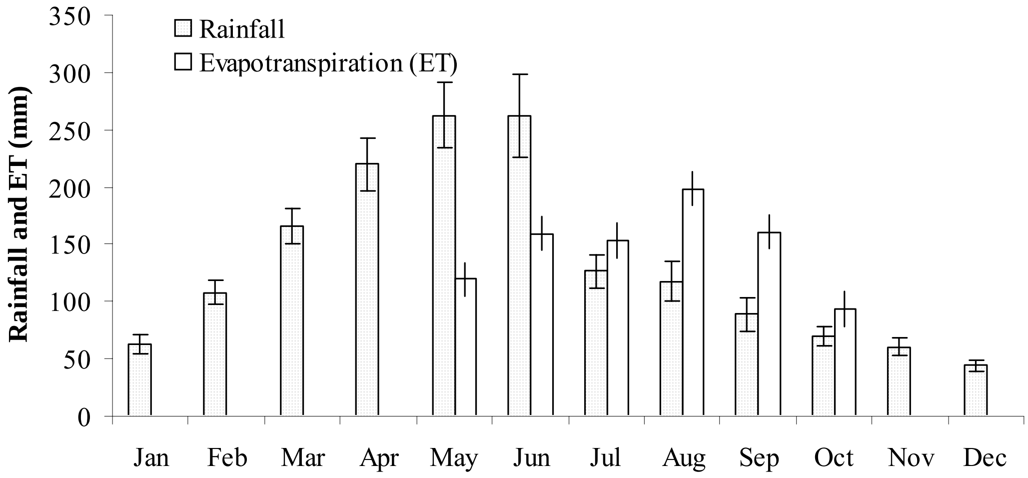


Figure 1.3c Mean monthly rainfall and potential evapotranspiration (mm) during the rice growing season during 1949-1990 (averages for 12 representative stations across Jiangxi Province) (Data source: Department of Water Resources of Jiangxi Province).
Note: Bars represent the variation among the 12 stations.

The total area of Jiangxi is 16.7 Mha of which 10% is lakes, 12% plains, 42% low hills (100-500 m) and 36% mountains (500-2000 m). About 60% of the province is covered with forest (Lin and Xu, 2001). The total area cultivated to crops ranges between 2.1 and 3.1 Mha, as reported by different sources. This does not include orchards, tea gardens and mulberry fields (Xu, 2001; JPRST, 2004; JXSB, 2006). Of the cultivated land, 80% is suitable for rice, so-called 'rice land' and the remainder is referred to as 'non-rice land'. The proportion of rice land in total cultivated land is one of the highest in China (Huang, 2000a, b).

Currently, agricultural production accounts for 30% of GDP (gross domestic product) of Jiangxi Province. Crop and animal husbandry account for 45 and 30% of agricultural GDP, respectively, the remainder originating from other sub-sectors such as fisheries and forestry (JXSB, 2006). As in the remainder of China, the demand for meat, eggs and milk is growing fast. The growth rate of animal production, particularly dairy and beef, is much higher than that of crop production.

Among all crops, rice is most important in terms of both area (about 55% of the total crop area) and production (more than 95% of the grain production). Despite the importance of rice in production and land use, income from rice production is often only about 20% of farmers' total household income (Wang and Shi, 2005). To increase their income, farmers are increasingly diversifying their production portfolio with vegetables, fruits and animals. Despite this trend, the traditional double rice system is still the predominant agricultural system.

1.3 Challenges faced by agriculture in Jiangxi

In general, the agricultural sector in Jiangxi faces challenges similar to those elsewhere in China. Even after the implementation of favourable polices to stimulate grain production (CCCPC and SCC, 2004), income from rice production still lags behind income from other commodities, while Jiangxi Province is obliged to contribute rice to attain the national objective of self-sufficiency in rice (CCJPH, 1999; JXPPG, 2000). The traditional double rice system with its tight cropping calendar has continuously been intensified through increasing inputs of chemical fertilizers and biocides to maintain and further increase yields. One of the consequences has been increased concerns for the environment and human health at local and provincial level (CCHPPJ, 2001; JXAAS, 2001; Ye *et al*., 2001; Liu and Dai, 2003; Li *et al*., 2004). Given the prevailing climate conditions and irrigation systems in Jiangxi, the scope for further intensification of the cropping system or expansion of the total area of cultivated land is limited (Zhou, 2000; Huang, 2000a, c). Parallelly, the area of cultivated land has been decreasing since 1990 with about 17,000 ha per year. Areas with the highest production potentials are most strongly affected by urbanization. Reclamation of land with lower production potentials cannot compensate the loss of more fertile land (JXSB, 1991, 2006; Li and Lin, 1999; Xu, 2001; Wang *et al*., 2003a).

Therefore, increased agricultural production must be realized mainly through increasing crop yields per unit of land. At the same time, the adverse effects of chemical fertilizers and biocides on the environment and human health, associated with agricultural intensification during the past 20 years, need to be addressed. In the livestock sector, the efficiency of conversion of plant material into animal products needs to be improved. Thus, the performance of current cropping and livestock production systems needs to be improved through adoption of innovative technologies, based on the latest developments in plant and animal sciences. However, technology changes may mitigate, but also aggravate land use conflicts, while they may reduce, but also increase adverse environmental effects (Stoorvogel and Antle, 2001).

Another recent development is the rapid expansion of more remunerative employment opportunities outside agriculture in the nearby developed coastal zones (De Brauw *et al*., 2002). Income per capita in agriculture is only about one-third of that of urban labour (Ianchovichina and Martin, 2003). Migration of rural labour has already resulted in agricultural labour shortages in some regions (Yang, 2004).

Especially the migration of young and educated rural workers has significant negative effects on agricultural production, as that hampers adoption of innovative, labour-intensive and knowledge-intensive management systems.

1.4 Objectives of study

The overall objective of this study is to identify the effectiveness of new crop and livestock production technologies in attaining rural development goals in Jiangxi. Specific objectives are:

1. To characterize the dominant rice-based agro-ecosystems in Jiangxi and to assess the agronomic, socio-economic and environmental performance of current and alternative rice-based agro-ecosystems.
2. To operationalize a methodology for assessing the effectiveness of innovative crop and livestock technologies in attaining rural development goals.
3. To identify potential synergies and conflicts among the various development goals.
4. To identify knowledge gaps and research priorities to further assess alternative cropping and livestock systems in practice.

1.5 Outline of the thesis

Chapter 2 characterizes rice-based agro-ecosystems in Jiangxi and analyses the challenges they face. Current rice-based agro-ecosystems are classified and their management described and analyzed. A SWOT (strengths, weaknesses, opportunities and threats) analysis is performed to identify research and development (R&D) requirements. A specific rice-based agro-ecosystem, the integrated rice-duck (IRD) system, is described in Chapter 3. Based on data collected in Jiangxi, its economic and environmental performance is assessed. Inputs and outputs of current and alternative cropping systems are quantified in Chapter 4. The following technological innovations are considered in the alternative cropping systems: Super Rice varieties, site-specific nutrient management (SSNM), integrated pest management (IPM) and mechanization of rice production. Input-output relations of current and alternative cropping systems are illustrated. In Chapter 5, the current livestock sector in Jiangxi is described and the method to derive input-output relations of current and alternative dairy, beef cattle fattening and goat fattening systems is presented and illustrated. Chapter 6 integrates information from Chapter 4 and Chapter 5 into a regional model for land use analysis, using linear programming techniques. This model is used to assess the effectiveness of new crop and livestock technologies in attaining rural development goals. Finally, Chapter 7 comprises a general discussion and summarizes the major conclusions of this thesis.

2 Rice-based agro-ecosystems in Jiangxi Province: Developments and challenges

Abstract

Guaranteeing national security in rice and increasing rural income are key goals in China's policy agenda. Rice-based agro-ecosystems in China's rice belt provide over 60% of the national rice production. Economic developments in China stimulate agricultural diversification towards vegetables and animal products, contributing to the goal of increasing income, but reducing rice production. Considering the importance of the rice belt for China's food production, relatively little information is available on the biophysical and socio-economic characteristics of rice-based agro-ecosystems in this area. In this chapter, Jiangxi Province is selected as a case study area to characterize and analyze current rice-based agro-ecosystems. Focus is on the rice component, which is the common denominator of these systems, while the characterization unlocks and integrates Chinese literature. First, the natural resource base and agricultural land use in Jiangxi are characterized. Then, current rice-based agro-ecosystems are classified and features of their crop management described and analyzed. The policy recommendations and research agenda aiming at improving the performance of these rice-based systems are identified on the basis of major biophysical and socio-economic constraints to rice production. It is concluded that despite the continuing trend of diversification towards non-rice crops, Jiangxi Province will remain an important contributor to realizing the national objectives in terms of rice.

Keywords: China; Resource management; Crop management; Rural development

2.1 Introduction

China's very large population that needs to be fed continues to grow, while available land and water resources are declining. The question whether China can feed itself in the future is heavily debated (Huang and Rozelle, 1998; Heilig, 1999). Rice (*Oryza sativa* L.) is, in terms of area cultivated, China's most important cereal crop, supplying about 40% of China's grain production (Cheng, 2005). More than 60% of China's rice production originates from the so-called 'rice belt', comprising nine provinces along the Yangtze River, *i.e.* Sichuan, Chongqing, Guizhou, Hubei, Hunan, Jiangxi, Anhui, Zhejiang and Jiangsu.

Considering the importance of the rice belt for China's food production, it is essential to clearly understand the biophysical and socio-economic characteristics of its rice-based agro-ecosystems in order to be able to effectively respond to pressures these systems are facing. Rice-based agro-ecosystems are production-oriented systems in which rice is part of the rotation. These systems may consist of one or two rice crops per year, but also of rice in combination with one or two other crops (Huang, 1994; Zhou, 2000; Luo and Peng, 2003). Focus in this chapter is on the rice component, which is the common denominator of these systems, while the characterization hinges heavily on unlocking and integrating Chinese literature, which is difficult to access for an international audience. Here, the rice-based agro-ecosystems in Jiangxi Province (Figure 1.2), which is typical for the rice belt and one of the major rice producing areas in China, are characterized. Cultivation of rice began in Jiangxi 7000 to 8000 BC, which is the earliest record of rice cultivation in the world (Zhao, 1998; Chen, 2002). Since the West Han Dynasty (206 BC-25 AD), Jiangxi has been one of the major rice producing areas in China, especially after introduction of double rice (DR) systems in the Tang Dynasty (618-907 AD) (CCJPH, 1999; Liu and Wei, 1999; Chen, 2002). The area of cultivated land in Jiangxi is only 2.3% of that in China, but the rice area and rice production account for 10% of those in China as a result of the intensive DR systems practiced. The high level of inputs of chemical fertilizers and biocides in these systems and the associated environmental pollution are increasingly debated (Li *et al.*, 1998; JXAAS, 2001; Liu and Dai, 2003; Li *et al.*, 2004).

Although the sown area of rice accounted for about 55% of the total crop area in Jiangxi, the associated earnings accounted for only 20% of total household income (Wang and Shi, 2005). Growing demand for other commodities such as vegetables and animal products within Jiangxi and from Jiangxi's neighboring and economically more prosperous provinces favours diversification towards more profitable products. Although the demand for food increases and market chain prospects are favourable in Jiangxi, the area of arable land decreases due to urbanization and industrialization by about 17,000 ha per year (Wang *et al.*, 2003a). In addition, the plan of converting 0.67 Mha of arable land into forests and pastures is implemented as part of a national soil conservation program (JPRST, 2004). The agricultural labour force in Jiangxi declines, because part of the rural population, especially the young and better educated, migrates to urban centers.

Against this background of fast and unprecedented economic developments, presenting severe challenges to the rice belt of China, the rice-based agro-ecosystems in Jiangxi are characterized from a biophysical and socio-economic point of view, and the current developments and challenges faced by these systems are described.

Strengths, weaknesses and major threats of current systems are identified, and opportunities to improve current systems are explored.

This chapter is organized as follows: First, the natural resource base and agricultural land use in Jiangxi is described in Section 2.2. Second, current rice-based agro-ecosystems are characterized and analyzed in Section 2.3. Then, crop management is analyzed in Section 2.4. On the basis of these analyses, a SWOT (strengths, weaknesses, opportunities and threats) analysis is performed in Section 2.5. Last, conclusions are presented in Section 2.6.

2.2 Natural resource base and agricultural land use in Jiangxi

2.2.1 Climate

Jiangxi Province (113˚34'-118˚28' E, 24˚29'-30˚04' N) is a typical humid subtropical region. Annual average temperature is 18 ºC, with a distinct peak with mean daily temperatures above 25 ºC from June to August (Figure 2.1a). Except for a few mountainous areas, climate conditions allow growing three crops per year. The number of days with a mean daily temperature higher than 10 ºC varies between 236 and 274, and accumulated temperature in this period is between 5044 and 6339 ºC, for a base temperature of 10 ºC. Two rice crops per year can be grown when accumulated temperature ranges between 4500-7000 ºC, while single rice (SR) can be grown with only 2000-4500 ºC (CNRRI, 1989). Average annual rainfall is 1600 mm, with a distinct wet period from March to June (Figure 2.1b). Total days with rainfall vary between 138 and 182. From July to September, potential evapotranspiration exceeds rainfall (Figure 2.1b).

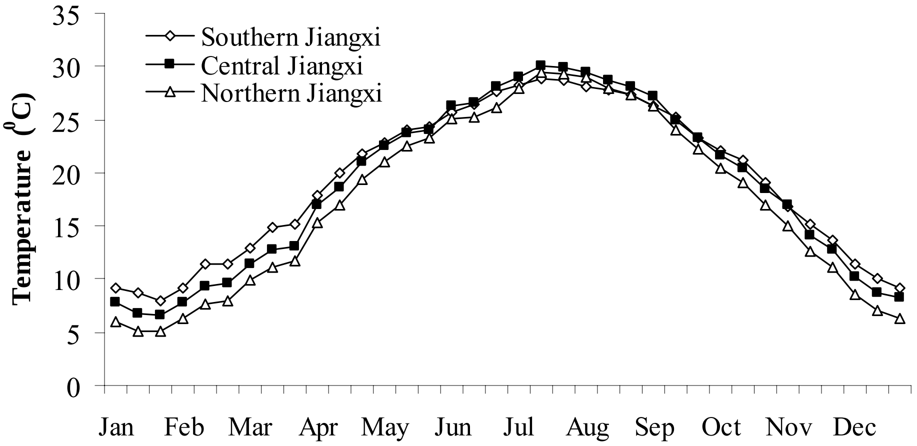


Figure 2.1a Mean daily temperature during 1984-2003 in Huichang in Southern Jiangxi (115˚48' E, 25˚36' N), Taihe in Central Jiangxi (114˚55' E, 26˚48' N) and Fengxin in Northern Jiangxi (115˚23' E, 28˚42' N) (Data sources: Huichang County Meteorological station, Taihe County Meteorological station and Fengxin County Meteorological station).

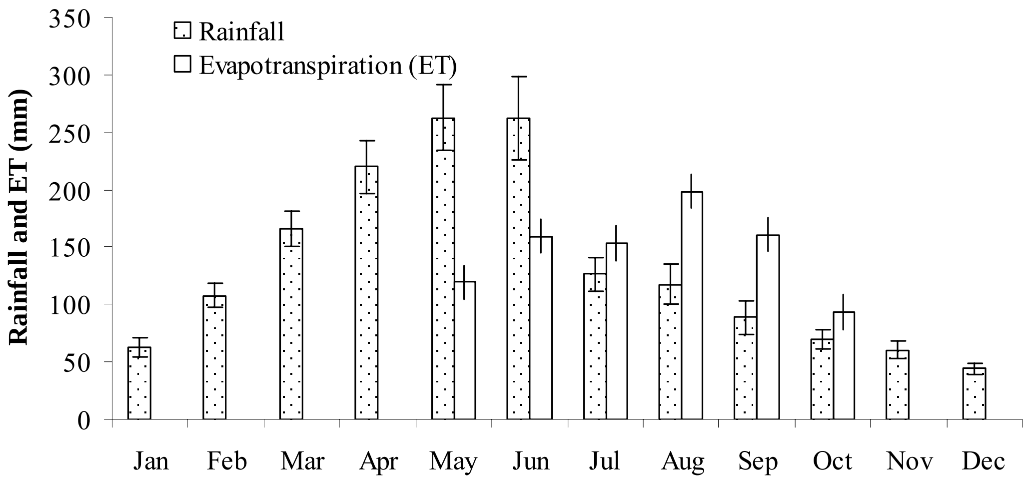


Figure 2.1b Mean monthly rainfall and potential evapotranspiration (mm) during the rice growing season during 1949-1990 (averages for 12 representative stations across Jiangxi Province) (Data source: Department of Water Resources of Jiangxi).

Note: Bars represent the variation among the 12 stations.

2.2.2 Water resources

The total area of Jiangxi is 16.7 Mha of which 10% is surface water. Five major rivers originate in Jiangxi, *i.e.* Ganjiang, Fuhe, Xinjing, Xiuhe and Raohe and flow into Poyang Lake in Northern Jiangxi, the largest freshwater lake in China with an area of about 5100 km^2 (Figure 1.2). The Yangtze River forms the northern border of Jiangxi. As a consequence of ample rainfall, surface water resources are abundant in Jiangxi, *i.e.* on average 140 Gm^3 (G = Giga = 10^9) per year, while annually an additional 32 Gm^3 of groundwater is available. Of the total available freshwater resources, about 20 Gm^3 is used, of which about 65% for irrigation. Total storage capacity of reservoirs in Jiangxi is only 17.5 Gm^3, limiting the area that can be irrigated (Yu and Xu, 2001). In addition, most irrigation facilities urgently need to be renovated and modernized as the majority was constructed in the 1960s and 1970s and poor maintenance negatively affects their performance.

Especially from May to June, large parts of Jiangxi are prone to floods, frequently damaging agricultural production. On the other hand, droughts happened from late July to September may limit rice production due to the unfavourable distribution of rainfall. Typically, floods and droughts may happen in the same year. During the years 1949 to 1990, average losses in rice production caused by floods and droughts were estimated at 18 and 6%, respectively (Huang, 2000d, 2001).

2.2.3 Soil resources

The Chinese soil classification system is different from the widely used FAO-UNESCO soil classification system (DLMJP, 1991a, b; Maclean *et al.*, 2002). As the soil resources in Jiangxi have not been classified according to the FAO-UNESCO system, in this study, the Chinese classification system in used, in which ‘rice land’ refers to land with bunds and a hard pan used for growing both rice and non-rice crops. The ‘non-rice land’ has no bunds and not a hard pan, and is used to grow non-rice crops only (DLMJP, 1991a, b; Xu, 2001). The area of cultivated land of Jiangxi is about 2.3 Mha, consisting of 1.9 Mha rice land and 0.4 Mha of non-rice land.

Table 2.1 Area (Mha) and major characteristics of seven rice land units in Jiangxi Province.

Land unit	Area	Location[a]	Fertility[b]	Irrigation conditions[c]	Drainage level	Particle size distribution (%)			BD[d] (g cm^{-3})	OC[e] (g kg^{-1})	TN[f]	AN[g]	AP[h]	AK[i]	pH[j]
						Clay	Silt	Sand							
LU1	0.43	P. Plain	Very high	Reliable	Well	23.7	41.0	35.3	1.1	1.9	1.8	156	47	89	5.2
LU2	0.41	A. Plain	Very high	Reliable	Well	20.0	43.8	36.2	1.0	1.9	1.8	141	33	68	5.6
LU3	0.04	P. Plain	Medium	Reliable	Poorly	28.1	41.8	30.1	1.1	1.7	1.7	149	36	71	5.1
LU4	0.38	Hilly	High	Reliable	Well	24.1	45.9	30.0	1.2	1.7	1.7	139	35	69	4.9
LU5	0.39	H & M	Medium	Unreliable	Well	20.9	37.0	42.1	1.1	1.6	1.6	129	24	82	5.4
LU6	0.06	H & M	Low	Rainfed	Poorly	19.4	29.9	50.7	1.1	0.7	1.3	114	14	52	4.8
LU7	0.19	H & M	Low	Rainfed	Excessive	11.8	20.7	67.4	1.4	1.5	1.5	81	12	41	5.0

[a] P. Plain = Poyang Lake Plain; A. Plain = Alluvial plain along rivers; H = hilly area; M = mountainous area. In hilly areas, more than 40% of the area ranges between 100 and 500 m, and less than 40% is above 500 m. In mountainous areas, more than 40% of the area is above 500 m, and less than 40% ranges between 100 and 500 m.

[b] Based on DLMJP (1991a, b).

[c] Availability and reliability of irrigation water.

[d] Bulk density.

[e] Organic carbon.

[f] Total nitrogen (g kg^{-1}).

[g] Alkali-hydrolysable nitrogen (mg kg^{-1}).

[h] 0.5 M $NaHCO_3$ extractable P (Olsen-P) (mg kg^{-1}).

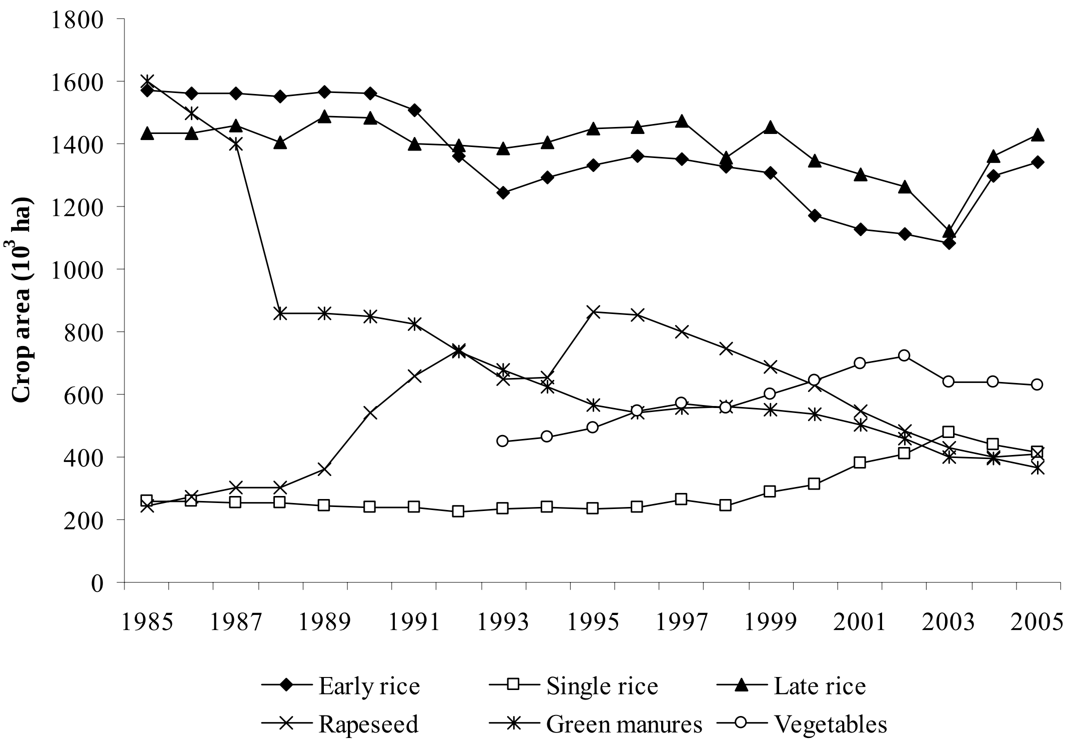
[i] 1 N NH_4-acetate extractable K (mg kg^{-1}).

[j] Soil pH (H_2O, 1:1).

Rice land is further sub-divided into seven land units on the basis of the following criteria (Table 2.1): geographical location, availability of irrigation water, drainage condition, soil texture, bulk density, soil organic carbon content, nutrient content and soil pH (DLMJP, 1991a, b; Xu, 2001). A land unit (LU) is defined as a physical area of land that is uniform in its characteristics and qualities (Hengsdijk and Van Ittersum, 2002). Land unit 1 (LU1) and land unit 2 (LU2) are the most fertile land rice lands and mainly differ in geographical location. LU1 is in the Poyang Lake Plain in Northern Jiangxi and LU2 in the alluvial plains along the rivers. Both land units are suitable for most crops and they allow growing three crops per year of which two rice crops. Major land use types in the LU1 and LU2 include early rice (ER)-late rice (LR)-rapeseed (*Brassica spp.*), ER-LR- Chinese milk vetch (*Astragalus sinicus* L.), ER-LR-Italian ryegrass (*Lolium multiflorum* Lam.) and ER-LR-potato (*Solanum tuberosum* L.). Here, the land use type is defined as a crop sequence of one, two or three crop types within one year (Van Ittersum and Rabbinge, 1997). About 0.04 Mha irrigated rice land in the plains (Land unit 3) is less fertile and poorly drained due to its position in the toposequence. These poorly drained soils are major production areas for single rice (SR) and aquatic vegetables, such as lotus root (*Nelumbo nucifera* Gaertn.), taro (*Colocasia esculenta* (L.) Schott.) and common arrowhead (*Sagittaria sagittifolia* L.). Four other land units are located in the hilly and mountainous areas. There is 0.38 Mha of rice land in hilly areas (Land unit 4) with relatively high soil fertility and a reliable irrigation water supply allowing cultivation of three crops per year. Typical land use types in land unit 4 are similar to those in LU1 and LU2 but with lower yields. In the hilly and mountainous areas, another 0.39 Mha of rice land (Land unit 5) is characterized by low soil fertility and less reliable irrigation supply. Often two crops per year can be grown. Typical land use types include ER-LR, ER-sweet potato (*Ipomoea batatas* (L.) Lam.), ER-soybean (*Glyine max* (L.) Merr.), ER-maize (*Zea mays* L.), ER-sorghum (*Sorghum bicolor* (L.) Moench) and SR-green manure(s). There is 0.06 Mha of water-logged rice land (Land unit 6) and 0.19 Mha of rainfed rice land (Land unit 7) in remote and poorly accessible hilly and mountainous areas. Soils prone to water-logging are characterized by surplus water throughout the year and due to their location on the northern side of the hills, radiation and temperature are lower than in the plains. In addition, soil fertility is extremely low (Table 2.1) and Fe toxicity may occur. Single rice is the dominant crop in soils prone to water-logging. Soil fertility of rainfed rice land is often low and soil texture is unfavourable due mainly to high contents of sand. Low water availability limits the production possibilities to one crop per year.

2.2.4 Agricultural land use

Predominant land use types during the 1970s and 1980s were ER in combination with LR, followed by green manure(s) or rapeseed (Huang, 1994, 2000a, b). In the last two decades, the area of green manures has decreased (Figure 2.2a) due to the availability of cheap chemical fertilizers. The area of rapeseed has decreased since 1995 (Figure 2.2a) due to low economic returns (Table 2.2). In contrast, the area with vegetables has increased considerably to meet growing market demands (Figure 2.2a). Since vegetable production is often more profitable than rice production, vegetables are part of most current rice-based systems. However, the area of vegetables is restricted because major vegetables (Table 2.2), such as watermelon (*Citrullus vulgaris* Schrad.), red pepper (*Capsicum annuum* L.), eggplant (*Solanum melongena* L.) and tomato (*Lycopersicon esculentum* Mill.), are only grown once every four years to avoid build-up of soil-born diseases. Other major high value crops in Jiangxi include cotton (*Gossypium hirsutum* L.) and tobacco (*Nicotiana tabacum* L.) (Figure 2.2b).



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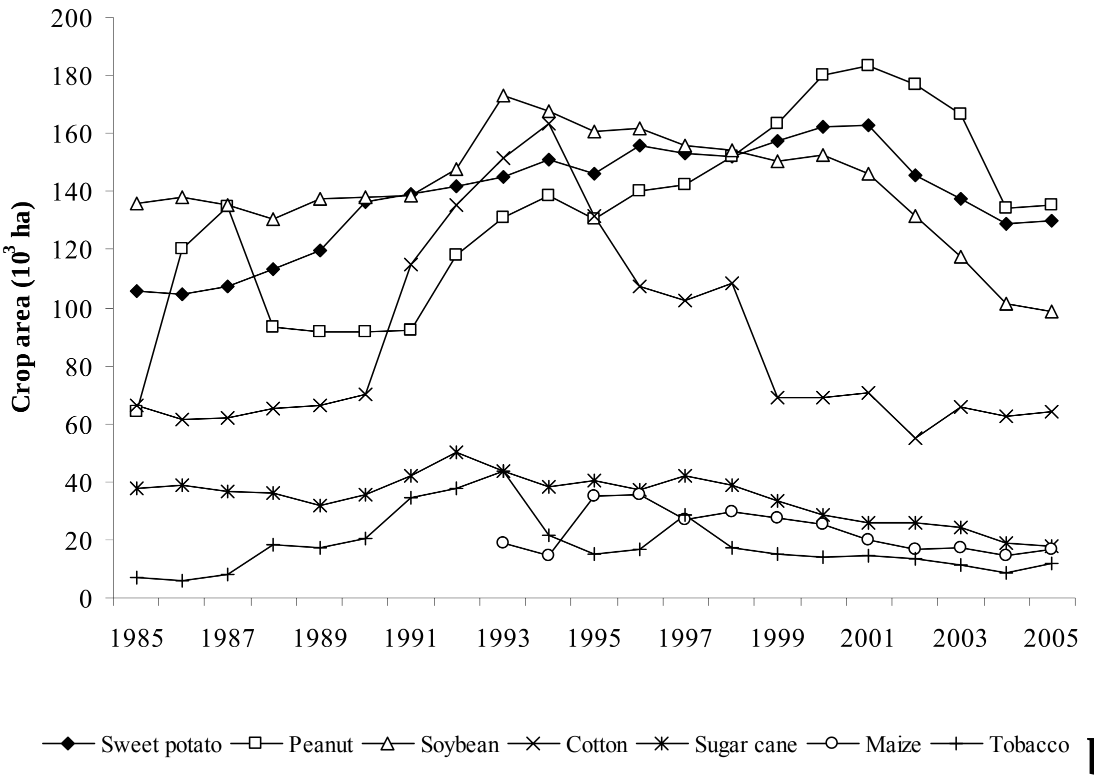


Figure 2.2 Dynamics of areas under major crops in Jiangxi during 1985-2005 (Data sources: 1985-1987, Department of Agriculture of Jiangxi Province; 1988-2005, Jiangxi Provincial Statistics Bureau, Jiangxi Statistical Yearbook, issues 1989 to 2006. China Statistics Press, Beijing, China).

Table 2.2 Gross margins (production value minus costs of non-labour inputs) and returns to labour of some major non-rice crops in Jiangxi before (2003) and after (2005) the implementation of favourable rural policies (Data sources: Department of Agriculture of Jiangxi Province; NDRC, 2004, 2006).

	Gross margins (Yuan ha^{-1})		Returns to labour (Yuan d^{-1})	
	2003	2005	2003	2005
Early rice	2559	5553	21	47
Late rice	3915	5421	27	43
Single rice	3588	6536	26	46
Vegetables[a]	27492	35456	45	51
Cotton	13505	20370	33	38
Tobacco	9207	10173	14	18
Peanut	6246	7529	44	55
Soybean	3333	5984	33	31
Rapeseed	2898	2273	32	24

[a] Averages of cucumber, tomato and Chinese cabbage.

2.3 Characterizing rice-based agro-ecosystems

2.3.1 Classification of rice-based agro-ecosystems

Rice-based agro-ecosystems can be classified into four types: (i) ER-LR followed by a non-rice crop or fallow, (ii) LR preceded by a non-rice crop and followed by a non-rice crop or fallow, (iii) ER followed by one or two non-rice crops, and (iv) single rice followed by a non-rice crop or fallow. Figure 2.3 shows the typical configuration of these systems. The first two systems are predominant in the plains and in the irrigated land in the hilly areas. ER systems are mainly practiced in the hilly and mountainous areas with poor irrigation facilities. SR systems predominate in the poorly drained rice land in the plains and the water-logged rice land in the hilly and mountainous areas (DLMJP, 1991a, b; Huang, 1994; Luo and Peng, 2003).

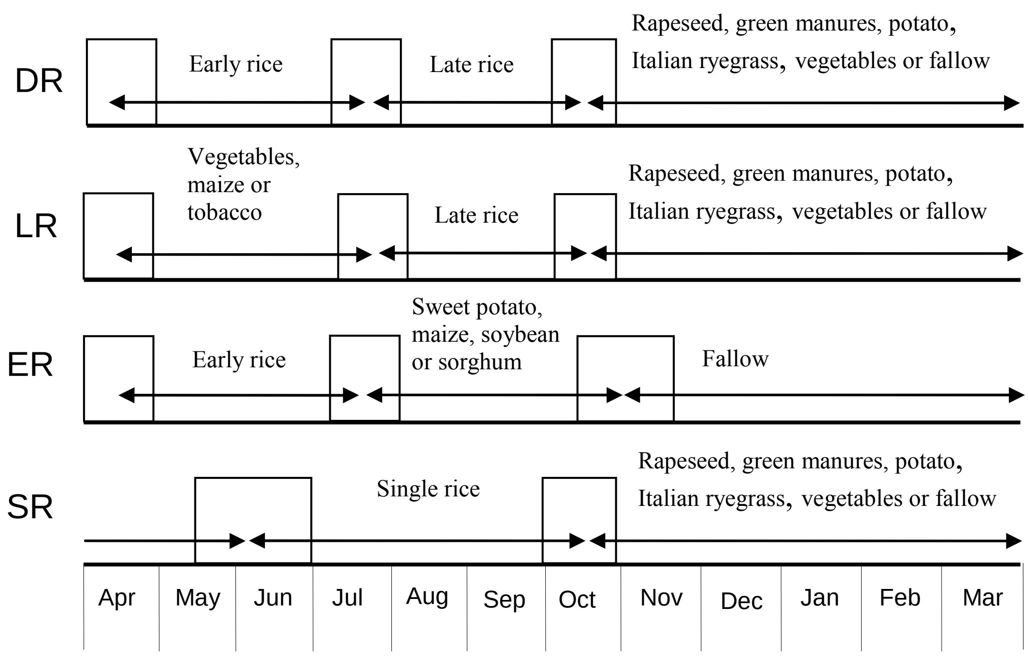


Figure 2.3 Classification of rice-based agro-ecosystems and their configuration through the year.
Note: DR = double rice, LR =late rice, ER = early rice, SR = single rice.

2.3.2 Productivity of rice

Average rice yields in Jiangxi increased from 2.0 Mg ha^{-1} in the 1950s to 2.8 Mg ha^{-1} in the mid-1970s mainly due to adoption of modern semi-dwarf high-yielding rice varieties (Huang, 1994; 2000a), and subsequently continued to increase even faster to about 5.4 Mg ha^{-1} in 1997 (Figure 2.4) mainly due to the adoption of hybrid rice varieties and use of chemical fertilizers. The proportion of the rice area with hybrid rice increased from 20% in 1978 to 70% in 1997, while concurrently annual fertilizer N input increased from less than 100 kg N ha^{-1} to nearly 300 kg N ha^{-1}. Especially the yield increase in LR has been spectacular in the 1980s (Figure 2.4) thanks to the availability of suitable LR hybrid rice varieties. In 1996, LR yields reached a record high of 5.6 Mg ha^{-1}. Till the late 1980s, yields of ER and SR were similar but SR yields increased much faster in the early 1990s (Figure 2.4), following release of suitable hybrid rice varieties. Suitable ER hybrid rice varieties were released ten years later and currently about 80% of the ER area consists of hybrid rice varieties (Wang, 2005). The adoption of ER hybrid rice varieties is based mainly on their lower seed rates, requiring smaller seedbeds and lower labour requirements for transplanting, as well as their higher yields.

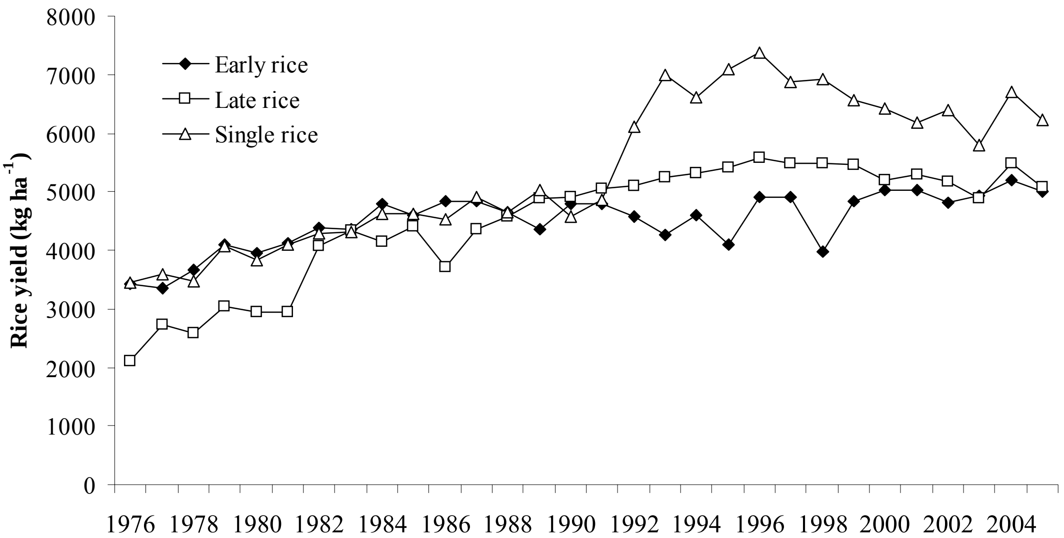


Figure 2.4 Development of average yields in early, late and single rice in Jiangxi Province during 1976-2005 (Data sources: 1976-1987, Department of Agriculture of Jiangxi Province; 1988-2005, Jiangxi Statistical Yearbook, issues 1989 to 2006, China Statistics Press, Beijing, China).

Agro-ecological conditions strongly affect attainable rice yields, as illustrated in Figure 2.5 with farm survey data from 2001 to 2004 of DR systems. Yields of ER and LR in the irrigated plains (Nanchang County in the Poyang Lake Plain and Nancheng County in the alluvial plain of the Fuhe River) are similar at 6 Mg ha^{-1}. Yields in the irrigated hilly areas (Taihe County with reliable irrigation water supply) are about 5 Mg ha^{-1} for both ER and LR. In the mountainous rainfed area (Taihe County with unreliable water supply) yields are about 3.7 Mg ha^{-1} for both ER and LR (Figure 2.5). The somewhat lower yield for LR in the mountainous areas is likely associated with the greater variability in water availability. This would suggest that there is scope for yield increase if irrigation water availability could be increased. In the plains there may also be scope for yield increase, as in demonstration plots and by the best farmers yields of about 7.5 Mg ha^{-1} are attained for both ER and LR. In the hilly areas, the yield gap in ER between best farmers and demonstration trials is relatively wide, *i.e.* 5.8 and 7.6 Mg ha^{-1}, respectively, due to poor farm management such as unbalanced fertilization, untimely control of insect pests and diseases and flood irrigation.

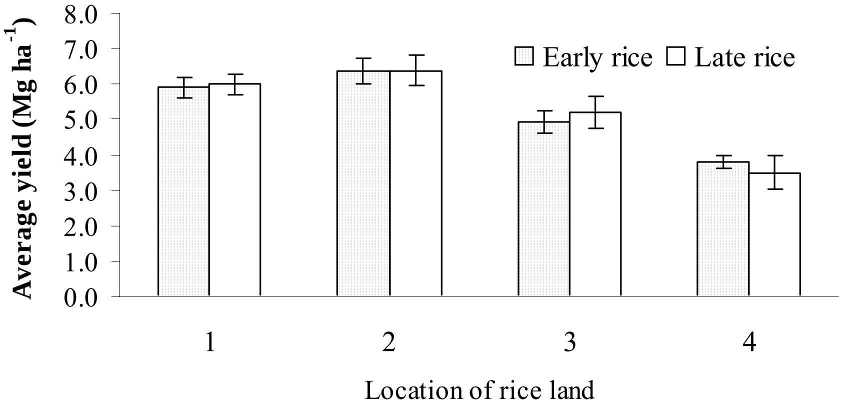


Figure 2.5 Average rice yields (including standard deviation) in different locations of Jiangxi during 2001-2004 (Data sources: Nanchang County Rural Survey Team, Nancheng County Rural Survey Team and Taihe County Rural Survey Team).

1: Rice land in Poyang Lake plain with good irrigation facilities and high soil fertility.

2: Rice land in alluvial plain with good irrigation facilities and high soil fertility

3: Rice land in hilly area with good irrigation facilities and medium soil fertility.

4: Rice land in mountainous area with poor irrigation facilities and low soil fertility.

Yields attained under experimental conditions, however, do not necessarily reflect the potential yield of rice as determined by prevailing radiation and temperature. Here, a simple method (Timsina and Connor, 2001) is used to quantify the yield gap between attainable yields and potential yields on the basis of the interception of radiation during the grain filling periods of ER and LR. I use a radiation use efficiency of 1.5 g dry matter MJ^{-1} short wave radiation and average daily solar radiation of 17.5 and 16.5 MJ^{-1} m^{-2} (24-year average for Shanggao County Meteorological Station (114°55' E, 28°14' N, altitude 69 m)) during the grain filling stage for ER and LR, respectively. The length of the grain filling period for ER and LR is 25-35 and 30-45 days, respectively, resulting in potential yields for ER between 8.5 and 11.0 Mg ha^{-1}, and for LR between 9.5 and 14.0 Mg ha^{-1}. Current highest recorded ER yield in Jiangxi is 10.6 Mg ha^{-1} (Cai, 2005).

2.3.3 Economics of rice production

2.3.3.1 Macro developments

Rice production in China reached a record high of 201 Tg (teragram, 10^{12} g) in 1997, and subsequently declined for 6 consecutive years due to decreasing prices of rice. The producer price of ER declined from 1300 Yuan Mg^{-1} in 1997 to 700 in 2000, and then partly recovered to 960 Yuan Mg^{-1} in 2002[1]. The price of LR declined gradually from 1440 Yuan Mg^{-1} in 1997 to 1020 in 2002. Consequently, at national scale, both, sown area and average rice yield decreased from 31.8 Mha and 6.3 Mg ha^{-1} in 1997 to 26.5 Mha and 6.1 Mg ha^{-1} in 2003 (NBSC, 2006). Lower yields were mainly the result of reduced use of inputs such as fertilizers and labour (Li, 2005a). Total rice production in 2003 was only 161 Tg. China's grain stocks in 2003 were at the lowest level since 1974, which resulted in a rapid and unusual increase in rice prices (Li, 2003). In order to safeguard national grain security, the Chinese government stimulated rice production through the implementation of various policy measures in 2004, including a guaranteed minimum price for rice, tax reductions, and subsidies for seeds and machinery (CCCPC and SCC, 2004; Gale *et al*., 2005). The area of rice in China increased by 7.1% to 28.4 Mha in 2004, while production increased by 11.5% to 179 Tg. In 2005, area and production increased further to 28.8 Mha and 181 Tg (NBSC, 2006). However, it is estimated that China's annual rice requirement is 185 to 190 Tg (Cheng, 2005), which suggests that the 2005 production still did not satisfy market demand.

Rice production in Jiangxi showed similar fluctuations in sown area and yield. Rice production declined from 16.6 Tg in 1996 to 13.6 Tg in 2003, associated with a reduction in sown area from 3.1 to 2.7 Mha, and in yield from 5.4 to 5.0 Mg ha^{-1}. In 2004, rice area and production recovered to 3.4 Mha and 17.1 Tg, respectively, while in 2005 they reached record highs of 3.6 Mha and 17.5 Tg, respectively (JXSB, 1997, 2004, 2005, 2006).

2.3.3.2 Farm household economics

A salient characteristic of rice-based farming systems in Jiangxi is the small size of the land holdings, which determines to a large extent the economic performance at micro-level. Average farm size in Jiangxi decreased from 0.5 ha in 1990 to 0.4 ha in 2000 associated with an increase in the number of rural households and a decrease in total

[1] 1 US dollar = 8.27 Yuan (1997), 1 US dollar = 8.11 Yuan (2004).

area of cultivated land. Farm size is relatively uniform across Jiangxi, *i.e.* 29% of the households cultivate less than 0.2 ha, 59% between 0.2 and 0.4 ha, 10% between 0.6 and 1.0 ha, and only 2% more than 1.0 ha (Li *et al.*, 1999). An average rice-based farming system comprises 80% rice land, while the remainder is non-rice land (Huang, 2000b, c).

A cost-benefit analysis of the rice components in DR and SR systems is conducted here, using farm survey data provided by the Department of Agriculture of Jiangxi Province. The surveyed farms were representative for the different rice-based agro-ecosystems across the province. The results show that fertilizers represented the largest cost component, accounting for about 35% of the total non-labour costs in 2003 and up to about 45% in 2004 and 2005 (Table 2.3). Costs for biocides were in general higher for LR and SR, due to higher pest and disease pressure (Sub-section 2.4.4). Gross margins, *i.e.* the value of production minus the costs of non-labour inputs, of ER in 2003 were 2559 Yuan ha^{-1} compared to 3915 Yuan ha^{-1} in LR and 3588 in SR, due to lower yield and lower price in ER. As a consequence of the price policy at macro level (Sub-section 2.3.3.1), profitability of rice production increased considerably in 2004 with gross margins in ER, LR and SR of 5943, 6632 and 7780 Yuan ha^{-1}, respectively (Table 2.3). Although taxes were lower in 2004, total costs of non-labour inputs did not decrease because of the higher costs of seed, fertilizers and biocides. Hence, the higher profitability in 2004 was mainly the result of the higher prices for rice, *i.e.* 54, 27 and 39% for ER, LR and SR, respectively. Higher yields, mainly the result of favourable weather conditions (Gale *et al*., 2005) and light pest and disease pressure, also contributed to the higher profits that stimulated farmers to further expand the area of rice in 2005. However, in that year, profitability of rice production was significantly lower, due to a combination of lower prices and lower yields. Guaranteed minimum prices for ER, LR and SR were maintained at the level of 2004 with 1400, 1440 and 1440 Yuan Mg^{-1}, respectively. In practice, average farm gate prices for ER and LR attained values of 1384 and 1424 Yuan Mg^{-1}, while it just reached the minimum price for SR. Lower yields in 2005 (Figure 2.4) were mainly the result of unfavourable weather conditions and heavy pest and disease pressure. Although the agricultural tax was completely abolished in 2005, total costs of non-labour inputs remained almost the same, because costs for biocides increased considerably, to control an outbreak of planthoppers (Sub-section 2.4.4).

Table 2.3 Cost-benefit analysis of double rice (DR) and single rice (SR) production in 2003, 2004 and 2005 (unless stated otherwise, in Yuan ha^{-1}) (Data source: Department of Agriculture of Jiangxi Province).

	2003			2004			2005		
	DR		SR[c]	DR		SR[f]	DR		SR[i]
	ER[a]	LR[b]		ER[d]	LR[e]		ER[g]	LR[h]	
Seed	211	173	229	209	176	227	239	213	268
Fertilizers	1025	917	1155	1200	1113	1211	1301	1218	1380
Biocides	179	209	375	211	308	324	261	518	502
Irrigation	72	172	264	69	108	110	82	117	115
Machines and traction	435	513	389	459	526	631	538	545	605
Taxes	454	448	669	256	260	368	0	0	0
Other costs	394	280	366	353	237	295	313	212	242
Total costs	2769	2712	3447	2756	2727	3165	2734	2823	3111
Yield (kg ha^{-1})	5684	5395	6396	6030	5998	7147	5988	5787	6697
Price (Yuan Mg^{-1})	937	1228	1100	1443	1560	1531	1384	1424	1440
Gross income	5328	6626	7034	8700	9359	10946	8286	8243	9647
Gross margins	2559	3915	3588	5943	6632	7780	5553	5421	6536
Labour input (d ha^{-1})	125	145	136	129	126	146	119	126	142
Returns to labour (Yuan d^{-1})	21	27	26	46	53	54	47	43	46
Costs per Mg rice (Yuan Mg^{-1})	487	503	539	457	455	443	457	488	465
Labour productivity (kg d^{-1})	46	37	47	47	48	49	50	46	47
Share of costs (%):									
Seed	7.6	6.4	6.6	7.6	6.4	7.2	8.7	7.5	8.6
Fertilizers	37.0	33.8	33.5	43.5	40.8	38.3	47.6	43.2	44.4
Biocides	6.5	7.7	10.9	7.6	11.3	10.2	9.6	18.3	16.1
Irrigation	2.6	6.3	7.7	2.5	3.9	3.5	3.0	4.1	3.7
Machines and traction	15.7	18.9	11.3	16.7	19.3	19.9	19.7	19.3	19.4
Taxes	16.2	16.5	19.4	9.3	9.5	11.6	0	0	0
Other non-labour costs	14.2	10.3	10.6	12.8	8.7	9.3	11.4	7.5	7.8

[a] 90 households in 6 counties; [b] 90 households in 6 counties; [c] 20 households in 2 counties; [d] 150 households in 10 counties; [e] 153 households in 11 counties; [f] 142 households in 11 counties; [g] 155 households in 10 counties; [h] 195 households in 13 counties; [i] 185 households in 13 counties.
Note 1: ER = early rice, LR = late rice, SR = single rice; Note 2: 1 US dollar = 8.27 Yuan (2003), 1 US dollar = 8.11 Yuan (2004), 1 US dollar = 8.05 Yuan (2005).

2.4 Crop management

In order to increase rice production, rice cultivation should become more remunerative, which could be achieved through increased efficiency in terms of resource use, while sustainability considerations and consumer concerns call for more environmentally friendly cultivation methods. Given the large variability in yield gaps among areas in Jiangxi, among farmers and among current yields and the biophysical production potential (Sub-section 2.3.2), specific attention should be paid to management of the rice production system.

2.4.1 Methods of crop establishment

Three crop establishment methods are used in Jiangxi: transplanting, broadcasting of seedlings and direct seeding. Despite its high labour requirements, transplanting of seedlings is still the most widely used method. Major reason is that it allows extension of the growing season for rice and winter crops due to the shorter field period of rice. Seedlings of ER are often 20 to 35 days old and LR seedlings vary in age from 15 to 50 days, thus expanding the entire growing period for rice crops with 35 to 85 days and for winter (non-rice) crops with 20 to 35 days. Therefore, long-duration ER and LR varieties can be grown, resulting in higher yields, while winter crops can be harvested timely before transplanting of ER. Transplanting ensures a uniform plant stand and gives the crop a head start over emerging weeds. In addition, planting density can be adapted to rice variety and soil fertility. The percentage of productive tillers is much higher than in other crop establishment methods, contributing to higher yield (Ling, 1997, 2000).

Broadcasting of seedlings was popular as a labour-saving technique mainly for ER, as crop growth is faster than with transplanted seedlings (Zheng and Tu, 1999). For broadcasting, seedlings are raised in plastic trays, and at the 3 to 5-leaf stage are manually removed from the trays and broadcasted (Ten Berge *et al.*, 2000). A major disadvantage of this method is that the seedlings produce many non-productive tillers, resulting in lower yields than with transplanted seedlings, while weed control requires more effort (Huang *et al.*, 1999). Moreover, the rice crop established by broadcasting of seedlings often is more susceptible to planthoppers (Liu *et al.*, 2002) and rice sheath blight (Zhang and Qian, 2000) and grain quality is supposedly lower due to the uneven maturation of early and late tillers (Ling, 1997). In addition, broadcasting of seedlings is more expensive due to the costs for substrate and plastic trays (Chen, 1998).

Direct seeding of rice was also introduced as a labour-saving technique (Zhang and Zhu, 1995), but is currently used by few farmers. In addition to the disadvantages mentioned for the broadcasting of seedlings, a problem of direct seeding is that more labour is required for field preparation (Wang and Luo, 2002). In intensive rice-based agro-ecosystems, scheduling of crop sequences is very tight and direct seeding of rice extends the field period too much (Cao *et al*., 2001). In addition, direct seeded ER is susceptible to damage by low temperatures in spring and by heavy rainfall washing away the seeds (Jing *et al*., 2001).

2.4.2 Water management

The predominant irrigation management practices include conventional flood irrigation and intermittent irrigation, also called alternate wet and dry irrigation, which allows producing the same amount of rice with less water, and (Belder *et al*., 2004). Intermittent irrigation is especially important in LR as during its growing period potential evapotranspiration exceeds rainfall (Figure 2.1b), while the supply of irrigation water may be limited. Intermittent irrigation may reduce some rice pests and diseases, such as planthoppers, rice sheath blight, rice false smut and rice blast (Sub-section 2.4.4). However, implementation of intermittent irrigation is difficult due to the fragmentation of land holdings and small plots, requiring more labour for water management. The current water policies in China provide little incentives for farmers to adopt water-saving technologies, as irrigation fees are based on area irrigated and not on the amount of water used (Jin and Young, 2001). Frequently, a combination of flood and intermittent irrigation is practiced. After transplanting, a relatively deep water layer is introduced, and maintained till the late tillering stage. Subsequently, so-called mid-season drainage is performed at a variety-specific stage, depending on the number of tillers produced. Mid-season drainage improves physical and chemical soil conditions, stimulates root growth, reduces the number of non-productive tillers, and enhances resistance to lodging, and insect pests and diseases (Zhang *et al*., 2003). When the second leaf from the top emerges, the field is irrigated again (Ling, 2000). Alternate wet and dry irrigation is adopted after the heading stage, while fields are drained 5-7 (for ER) or 7-10 days (for LR) before maturity. Continuous flooding is still most widely practiced in rice lands where irrigation water supply is not reliable, as water is stored on the field for periods with low rainfall, while on land vulnerable to water-logging, drainage problems leave no other options.

2.4.3 Nutrient management

Before the 1980s, major nutrient sources were farm yard compost and green manures such as Chinese milk vetch, common vetch (*Vicia sativa* L.), hairy vetch (*Vicia villosa* Roth.) and radish (*Raphanus sativus* L.). The largest area of green manures was that of Chinese milk vetch, which averaged 1.3 Mha during the 1960s and 1970s, with fresh yields up to 22.5 Mg ha^{-1} (Huang, 1994, 2000a, b). Over the years, the share of organic nutrient sources has decreased, as in other parts of China, due to the availability of cheap and easy-to-apply chemical fertilizers (Ellis and Wang, 1997; Heerink *et al*., 2007). Moreover, organic manures are preferentially used in the more profitable production of vegetables, fruits and tea. Current use of manure in ER and LR averages 4.5 and 1.5 Mg ha^{-1}, respectively, compared to 18, 45 and 30 Mg ha^{-1} in open field vegetable, protected vegetable and orange production, respectively (JXAAS, 2001; Li *et al*., 2004). Reduced use of organic manure in rice production is associated with increased incidence and severity of pests and diseases such as planthoppers, rice false smut and rice blast (CCHPPJ, 2001). Total use of chemical nitrogen fertilizers increased rapidly from 31 kg N ha^{-1} in 1976 to a record high of 293 kg N ha^{-1} in 1997, then gradually declined and stabilized at about 250 kg N ha^{-1} (Figure 2.6). In 2004, N input increased again to 286 kg N ha^{-1}, as a consequence of the favourable agricultural policies (Sub-section 2.3.3.1). Developments in the use of P and K fertilizers were similar, reaching 173 kg P_2O_5 ha^{-1} and 151 kg K_2O ha^{-1} in 2004.

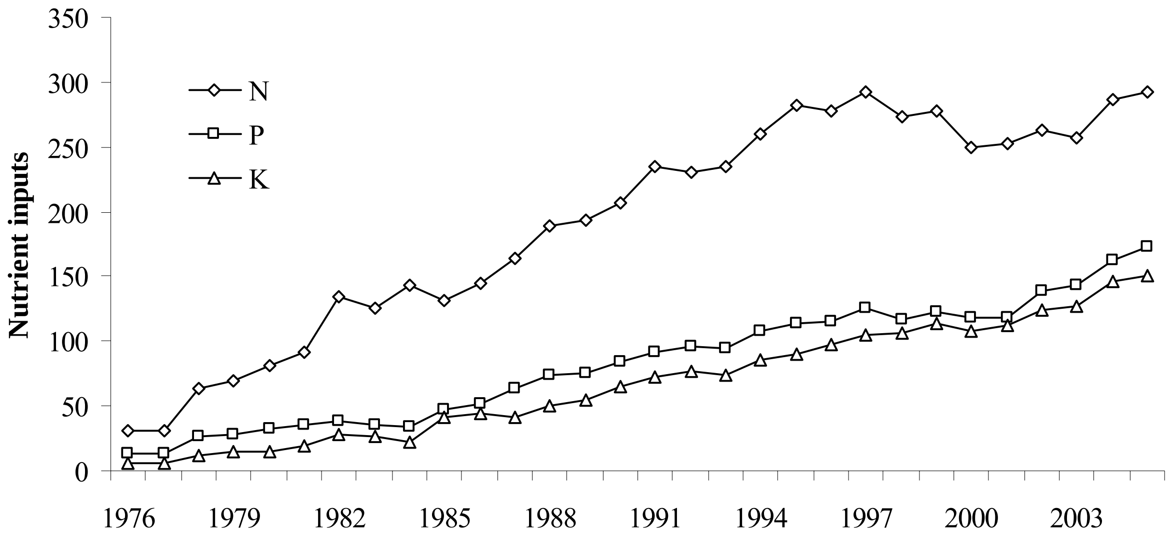


Figure 2.6 Inputs of chemical fertilizer N (kg N ha^{-1}), P (kg P_2O_5 ha^{-1}) and K (kg K_2O ha^{-1}) in Jiangxi during 1976-2005 (Data sources: 1976-1987, Department of Agriculture of Jiangxi Province; 1988-2005, Jiangxi Statistical Yearbook, issues 1989 to 2006, China Statistics Press, Beijing, China)

Most P fertilizer is applied as a basal dressing during puddling of rice land, while most farmers apply varying proportions of N and K fertilizers in two splits during puddling and tillering. Application of N and K after panicle initiation is rare, despite its positive effect on yield (Jiang, 1996; Jiang and Hong, 1996).

One of the major problems in nutrient management of rice-based agro-ecosystem is the unbalanced use of N, P and K. Generally, N and P are applied in excess of crop needs, while K application is too low to meet crop demand (Ye *et al*., 1999, 2001; Li *et al*., 2003c). This unbalanced supply of N and K increases the susceptibility of the rice crop to pests and diseases such as rice gall midge, planthoppers, rice sheath blight, rice false smut and rice blast (Sub-section 2.4.4.3). The imbalance in nutrient inputs is reflected in the long-term changes in soil nutrient stocks in Jiangxi: between 1981 and 1997 total soil N increased by 16%, alkali-hydrolysable N by 8% and Olsen-P by 120%, while exchangeable K declined by 17% (Ye *et al*., 1999). Declining yields in rice-based agro-ecosystems have been related to declining soil-K stocks (Dobermann *et al*., 1998; Li *et al*., 2003c; Zeng *et al*., 2005). High N and P inputs increase production costs, but may also increase the risk of environmental pollution (Liu and Dai, 2003; Li *et al*., 2004; Xiao *et al*., 2005). Yet, nutrient inputs vary widely across Jiangxi, *i.e.* more fertilizers are used in the fertile plains than in the hilly and mountainous areas (Ye *et al*., 2001). P deficiency still exists in parts of the hilly and mountainous areas, in addition to K deficiency, which is especially serious in mountainous areas, for instance in Xingguo County, where exchangeable K declined from 75 mg kg^{-1} in 1981 to 49 mg kg^{-1} in 1997 (Ye and Liu, 2000; JXAAS, 2001).

2.4.4 Pest management

2.4.4.1 Control methods of insect pests and diseases

Prevailing rice insect pests and diseases in Jiangxi are shown in Table 2.4. Application of biocides is the conventional way to their control. Generally, in ER, biocides are applied twice, and in LR and SR 3 to 5 times per season due to the higher insect pest and disease pressure later in the season (Table 2.5). Frequently, 2 to 4 different types of insecticides and fungicides are mixed in one application. Alternative control methods (e.g. insect-traps) were used in the 1960s and 1970s (CCHPPJ, 2001), but currently hardly anymore, mainly due to the collapse of agricultural extension systems. During the 1980s and 1990s, integrated pest management (IPM) was introduced in Jiangxi (JXPPS, 1991a, b, c; CCHPPJ, 2001), but adoption was slow, due mainly to shortage of financial and institutional support. Mixed planting of different rice varieties was introduced in the early 1990s to control rice blast (Mao *et al*. 1991; Luo and Gan, 1994). Recently, these alternatives have received renewed attention, because of increasing resistance of insects to insecticides and the growing concern about negative environmental and health effects of biocide use (Zhu *et al*., 2000, 2003; Leng *et al*., 2001; Liu *et al*., 2003).

Table 2.4 Major rice insect pests and diseases in Jiangxi (Data source: CCHPPJ, 2001).

Insect pests and diseases
Insect pests:
Striped stem borer (*Chilo suppressalis* (Walker))
Yellow stem borer (*Tryporyza incertulas* (Walker))
Pink stem borer (*Sesamia inferens* (Walker))
Rice leaffolder (*Cnaphalocrocis medinalis* (Guenee))
Brown planthopper (*Nilaparvata lugens* (Stal))
Whitebacked planthopper (*Sogatella furcifera* (Horvath))
Rice gall midge (*Pachydiplosis oryzae* (Wood-Mason))
Rice locust (*Oryzae chinensis* (Thunberg))
Rice armyworms (*Leucania separate* (Walker) and *Leucania lorgi* (Duponchel))
Rice thrips (*Stenchaetothrips biformis* (Bagnall))
Diseases:
Sheath blight (*Thanatephorus cucumeris* (Frank) Donk)
Rice blast (*Pyricularia oryzae* Cavara)
Bacterial leaf blight (*Xanthomonas oryzae* pv. *oryzae* (Ishiyama) Swings *et al*.)
Bacterial leaf streak (*Xanthomonas oryzae* pv. *oryzicola* (Fang *et al*.) Swings *et al*.)
False smut (*Ustilaginoidea virens* (Cooke) Takah)

2.4.4.2 Yield losses caused by insect pests and diseases: summary of experiments and farm surveys

Since the 1980s, pest control experiments have been conducted by Jiangxi Provincial Plant Protection Station to study relationships between rice yields and pests. Treatments included application of biocides according to insect pest and disease development forecasts, and controls without biocides (Tables 2.5 and 2.6). Results show that in the absence of biocide application, average yield losses in LR are 55% higher than in ER, while also the variation in yield loss is much higher. In both, ER and LR, yield losses in the control treatment seem to increase over time. Yield losses caused by individual insect pests and diseases indicate that temporal and spatial variability in severity of infestation is high (Table 2.7). The results of farm surveys are shown in Table 2.5.

Table 2.5 Biocide use (g active ingredient ha^{-1}), frequency of application and costs of biocides (Yuan ha^{-1}) in pest control experiments and farm surveys (Data sources: Mr. Shu Chang at Jiangxi Provincial Plant Protection Station, Mr. Zhao Xianfeng at Shanggao County Agricultural Bureau and Mr. Wu Guanghua at Nancheng County Rural Survey).

Source	Year	Location	Rice	Insecticide	Fungicide	Frequency[a]	Costs
Experiment	2002	Shanggao	ER	1110	488	2	178
Experiment	2003	Shanggao	ER	1155	450	3	230
Experiment	2004	Shanggao	ER	765	285	2	162
Experiment	2005	Shanggao	ER	1485	585	4	308
Experiment	2005	Taihe	ER	593	487	3	425
Experiment	2002	Shanggao	LR	1110	150	2	120
Experiment	2003	Shanggao	LR	1103	263	3	203
Experiment	2004	Shanggao	LR	960	413	3	275
Experiment	2004	Yugan	LR	1365	150	3	147
Experiment	2005	Shanggao	LR	5474	1563	6	893
Experiment	2005	Yugan	LR	5430	113	5	338
Farm survey	2003	Nancheng[b]	ER	1514	240	2	293
Farm survey	2004	Shanggao[c]	ER	915	82	2	119
Farm survey	2004	Shanggao[d]	LR	1746	194	3	245
Farm survey	2004	Shanggao[e]	SR	1692	271	4	277

[a] In each application, usually both insecticide and fungicide are applied; [b] Rice yield is 6450 kg ha^{-1}; [c] Rice yield is 5891 kg ha^{-1}; [d] Rice yield is 6793 kg ha^{-1}; [e] Rice yield is 6756 kg ha^{-1}.

Note: ER = early rice, LR = late rice, SR = single rice.

2.4.4.3 Development of insect pests and diseases

The area infested with rice insect pests and diseases increased considerably since the late 1990s. Among all insect pests, striped stem borer, yellow stem borer, brown planthopper and whitebacked planthopper increased especially fast in recent years (Figure 2.7). Initially, rice gall midge occurred only in Southern Jiangxi, but it spread very fast throughout Jiangxi since the 1990s (Zhang and Yan, 2002; Xu *et al*., 2003). Rice sheath blight infestation is most widespread, while the area infested with rice blast increased rapidly since 1999 (Figure 2.7). Rice false smut, which became a major disease after the 1980s, causes yield losses, and in addition, reduces the quality of rice due to the toxin contained in the pathogen (*Ustilaginoidea virens* (Cooke) Takah) (Liu *et al*., 1998; Chen *et al*., 2000; Huang and Yu, 2002, 2003).

Table 2.6 Yields (kg ha^{-1}) and yield losses caused by rice insect pests and diseases without biocide application in Jiangxi: summary of experiments (Data sources: Mr. Shu Chang at Jiangxi Provincial Plant Protection Station, Mr. Zhao Xianfeng at Shanggao County Agricultural Bureau, CCHPPJ, 2001; Xu, 2003).

Year	Early rice			Late rice		
	Yield with biocide	Yield without biocide	Yield loss (%)	Yield with biocide	Yield without biocide	Yield loss (%)
1980[a]	4790	4550	5.0	3790	2737	27.8
1981[a]	4636	3678	20.6	3843	2920	24.0
1982[a]	5584	4267	23.6	5144	3325	35.4
1989[b]	5321	4302	19.1	6888	5121	25.7
1990[c]	6614	5678	14.2	4874	2506	48.6
1995[d]	7313	5457	25.4	6554	4478	31.7
1996[e]	4950	3633	26.6	7621	6528	14.3
2002[f]	7223	5810	19.6	6840	4890	28.5
2003[g]	6908	3968	42.6	6795	4680	31.1
2004[h]	7411	5781	22.0	6518	1713	73.7
2005[i]	6344	3591	43.4	6836	1790	73.8
Average	6099	4610	21.9	5973	3699	34.1
CV (%)	17.6	19.6	43.8	22.2	41.6	48.2

[a] Average of 7 locations across the whole province; [b] Late rice: average of two locations in 1995; [c] Late rice: year 1996; [d] Late rice: year 2002 in Yugan; [e] Late rice: year 2002 in Shanggao; [f] Late rice: year 2003 in Shanggao; [g] Late rice: year 2004 in Yugan; [h] Early rice and late rice: year 2004 in Shanggao; [i] Early rice: average of two locations (Taihe and Shanggao), late rice: average of two locations (Yugan and Shanggao).

The increased incidence of insect pests and diseases may be related to the fact that currently about 80% of the rice area is planted with hybrid rice varieties. These hybrid rice varieties are characterized by larger leaf areas and have higher chlorophyll contents than inbred varieties, which make them more susceptible to insect pests, such as rice stem borers, rice planthoppers and rice gall midge, and to diseases, such as rice sheath blight (CCHPPJ, 2001; Liu *et al*., 1999) and rice false smut (Wu *et al*., 2000; Yang, 2003).

The area of SR has increased in the last two decades (Figure 2.2a). SR bridges the period between ER and LR when the absence of rice can serve as a break for pests and diseases (Qin *et al*., 2005). Shortening the field period reduces the time for pests and diseases to infest crops and to proliferate (Grist and Lever, 1969). Expansion of the SR area resulted in a continuous food supply, thus favouring reproduction of some major insects, such as stem borers, planthoppers and rice gall midge (CCHPPJ, 2001; Lei and Lu, 2003).

Table 2.7 Yield losses in early rice (ER) and late rice (LR) caused by different rice insect pests and diseases determined in field experiments (Data sources: Mr. Shu Chang at Jiangxi Provincial Plant Protection Station, Mr. Zhao Xianfeng at Shanggao County Agricultural Bureau and Mr. Xu Shanzhong at Taihe County Agricultural Bureau).

Location (year)	Yield with biocides (kg ha^{-1})	Loss by Plant-hoppers[a] (%)	Loss by stem borers[b] (%)	Loss by leaf-folder (%)	Loss by sheath blight (%)	Loss by rice blast[c] (%)
Early rice:						
Shanggao (2002)	7223	4.8	4.4	6.3	9.6	
Shanggao (2003)	6908	11.3	21.0	7.8	6.2	
Shanggao (2004)	7411	6.8	12.8	3.6	11.4	
Shanggao (2005)	7740	36.0	25.4	8.3	26.7	
Taihe (2005)	4947	10.0	3.6	5.1	9.8	13.2
Average	6846	13.8	13.5	6.5	12.8	13.2
CV (%)	16.1	72.2	32.6	91.8	63.0	
Late rice:						
Taihe (2002)	6554	5.0	12.6	4.8	5.7	
Shanggao (2002)	7621	6.2	7.6	6.0	9.1	
Shanggao (2003)	6840	13.6	15.8	11.8	14.5	
Shanggao (2004)	6518	29.9	13.5	10.7	21.2	4.1
Yugan (2004)	6795	11.1	1.6	20.5	5.0	
Shanggao (2005)	6834	79.0	17.4	18.5	37.2	20.8
Yugan (2005)	6838	47.0	38.6	41.5	15.7	
Average	6857	27.4	15.3	16.2	15.5	12.5
CV (%)	5.3	75.7	77.4	99.5	72.3	94.5

[a] Including brown planthopper and whitebacked planthopper; [b] Including striped stem borer, yellow stem borer and pink stem borer; [c] Rice blast for early rice and bacterial leaf streak for late rice.

Current overuse of fertilizer N is closely related to outbreaks of planthopper, rice sheath blight, rice false smut and rice blast, as high N contents make crops more susceptible to pest and disease infestations (Ding *et al*., 1998; Yang and Liao, 2001; Chen *et al*., 2004; He *et al*., 2005).

Intermittent irrigation could reduce disease incidence of rice sheath blight, rice false smut and rice blast (Fan *et al*., 1993; Ruo *et al*., 2000; Huang and Yu, 2003; Liu *et al*., 2004; Zhang, 2005), but many farmers use alternately conventional flooding and intermittent irrigation (Sub-section 2.4.2). Long-term flood irrigation is conducive for occurrence of some insect pests, for instance rice gall midge (Xu *et al*., 2003; He, 2004).

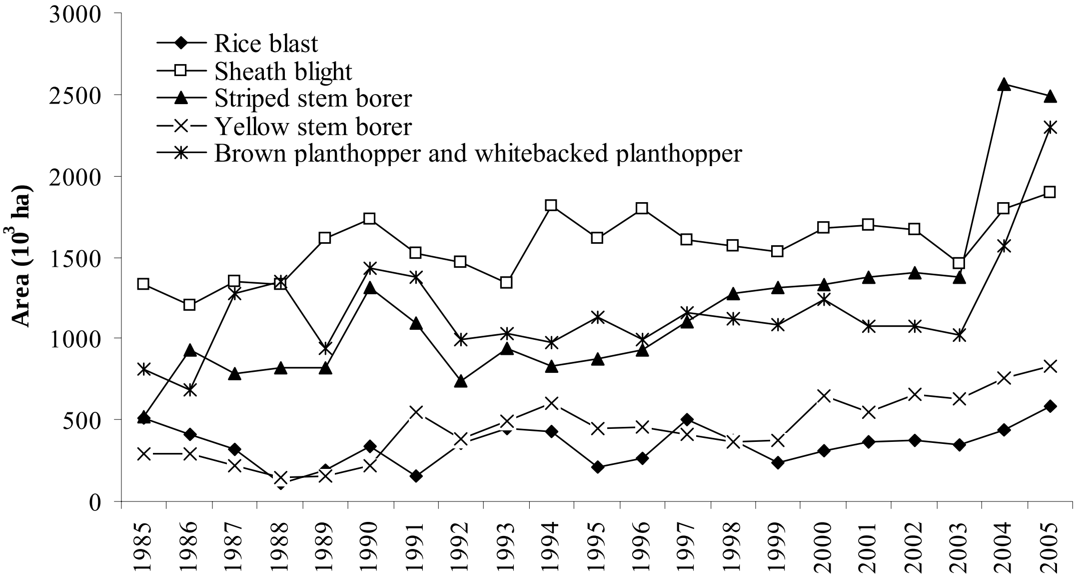


Figure 2.7 Total area infested with rice blast, sheath blight, striped stem borer, yellow stem borer, brown planthopper and whitebacked planthopper during 1985-2005 in Jiangxi (Data source: Jiangxi Provincial Plant Protection Station)

Some insect pests may accelerate infestation of certain disease. For example, honeydew excreted by planthopper provides nutrients for rice sheath blight that can also more easily invade the rice plant through the lesions made by planthopper (Qi *et al*., 1991). Similarly, lesions of stem borer accelerate infestations of rice false smut and rice blast (Jiang *et al*., 2005). Moreover, triazophos, an important insecticide against stem borers, can stimulate oviposition of planthopper and shorten the length of the nymph stage, promoting multiplication of planthopper (Yi *et al*., 1995).

Various phytosanitary methods used before the 1980s were effective in controlling insect pests and diseases. Soil tillage operations after harvest of LR and clearing of bunds, ditches and irrigation canals from weeds can reduce habitats for over-wintering insect larvae such as stem borers and rice gall midge. Land preparation in spring may kill sclerotia of diseases such as rice sheath blight and rice false smut and thus reduce infestation significantly (CCHPPJ, 2001; Huang and Yu, 2002). Phytosanitary measures, however, are neglected mainly due to shortage of labour and the low profitability of rice production.

Accurate forecasts of pest development and information on how to control pests are often unavailable, because of the weak agricultural extension systems. In addition, the young and educated part of the rural population migrates to cities, making introduction of knowledge-intensive crop management systems difficult. Both developments contribute to inappropriate application of biocides and increased and accelerated resistance of insects and diseases to biocides.

2.5 Strengths, weaknesses, opportunities and threats

Here, an analysis of the strengths, weaknesses, opportunities and threats of rice-based eco-agro ecosystems in Jiangxi is performed, as a basis for identification of possible interventions by policy and the research community.

2.5.1 Strengths

Jiangxi is blessed with a high-quality natural resource base and a favourable cultural and socio-economic environment to grow rice (CCJPH, 1999; Liu and Wei, 1999; Huang, 2000a; JXPPG, 2000). First, temperature allows cultivation of two rice crops per year in most parts of Jiangxi. Although potential evapotranspiration exceeds rainfall during part of the year, surface water for irrigation purposes is abundantly available. Second, 80% of the cultivated land is rice land, the highest percentage in China (Huang, 2000b, c). About half of the rice land is located in the fertile plains, thus providing suitable soils to produce high rice yields (Xu, 2001). Third, Jiangxi has more than 2000 years of tradition in intensive and meticulous rice-based farming, thus a rich experience in rice cultivation has accumulated (CCJPH, 1999). Last, Jiangxi's geographical location, close to China's coastal provinces, provides access to new and wealthy markets allowing to diversify and to improve the income position of rice-based farmers.

2.5.2 Weaknesses

Although average weather conditions are favourable for growing rice and other crops, extreme summer rainfall and associated floods frequently damage ER and SR, and also LR nurseries. Only costly flood control measures, such as constructing water conservation facilities could prevent such disasters. In the plains, irrigation water supply is relatively reliable. However, irrigation infrastructure is less developed in large parts of the hilly and mountainous areas of Jiangxi. Currently, less than a quarter of the available water resources are used for irrigation, due to insufficient water conservation facilities. In addition, large tracks of irrigation infrastructure in the plains are poorly maintained, hampering reliable water supply to rice farmers. The soils susceptible to water-logging are characterized by low soil fertility and inadequate drainage conditions, hampering mid-season drainage and, thus limiting yields.

Part of the hilly areas may be suitable from a biophysical point of view for growing vegetables and other non-rice crops. However, poor infrastructure hampers transport, especially important for perishable products (e.g. vegetables). The plains have better access to markets, but their irrigation infrastructure is rather rigid and their design is less suitable for flexible and accurate water management needed for non-rice crops such as vegetables. Rice can be flooded for several days or even weeks, while most vegetables need to be watered regularly at short intervals and do not stand flooded conditions for prolonged periods.

2.5.3 Opportunities

Experimental data and yield estimates based on prevailing solar radiation indicate unexploited potentials for yield increase. In addition, productivity strongly varies, *i.e.* differing between the plains and hilly areas, as well as among farmers producing under similar socio-economic and environmental conditions. Further study is required to identify the causes for these differences, which may be related to nutrient, water and pest management.

The increased use of chemical fertilizers was one of the major factors underlying the strong increases in rice yields in China from the 1970s to the 1990s. The recent stagnation in rice yields calls for a more location-specific and balanced supply of nutrients to the crop. Experiences in China and elsewhere in Asia with site-specific nutrient management techniques have shown substantial potentials for yield increase and reduced fertilizer costs (Dobermann *et al*., 2002; Witt *et al*., 2002; Wang *et al*., 2004b; Hu *et al*., 2007; Pampolino *et al*., 2007; Wang *et al*., 2007).

Although alternate wet and dry irrigation practices can be implemented in the plains, it is almost impossible in most of the hilly and mountainous areas due to lack of sound irrigation infrastructure. Parts of the rice lands in the hilly areas are highly fertile, as those in the plains, but the rice yields are generally much lower, for instance, due to lack of reliable irrigation and drainage facilities. It is often difficult to timely drain the surplus water for ER, while no enough water is available for LR. Improvement of irrigation and drainage infrastructure could greatly increase the yield potentials. Moreover, some more remunerative crops such as vegetables can be grown if reliable irrigation water supply is available from late July to September. Currently, only one crop can be grown in the poorly drained rice land in the plains and water-logged rice land in the hilly and mountainous areas. Experience in Jiangxi has shown that the productivity of these lands can be greatly increased if sound irrigation and drainage systems are constructed. Through such methods as drainage and application of organic manures, three crops can be grown in the current poorly drained rice lands in the plains, while two or even three crops can be grown in the current water-logged rice land in the hilly and mountainous areas (JXAAS, 2001).

Increased incidence and severity of insect pests and diseases are the major threat to rice-based agro-ecosystems (Sub-section 2.4.4). Experiments and demonstrations with IPM in Jiangxi in the 1980s and 1990s have shown that adoption of IPM could simultaneously increase yield and reduce the use of biocides. However, IPM was not adopted mainly due to lack of technical and financial support from the government (CCHPPJ, 2001). Hence, technically feasible options to manage pests and diseases in an economically viable and environmentally friendly way are available, but until now these potentials have not been fully utilized. Attention, however, should be paid to the risks involved in adoption of IPM.

The process of mechanization of rice production in Jiangxi was relatively slow before 2003. To stimulate rice production, substantial outlays in subsidies have been made towards purchase and use of agricultural machinery in rice production since 2004 (Sub-section 2.3.3.1). Currently, 60% of all land preparation and 31% of all harvesting operations are mechanized, however only 1% of all transplanting operations. With the increasing mechanization, labour requirements in rice production continue to decrease, which at least partly compensates for the negative effects of migration of rural labour to cities on labour availability.

2.5.4 Threats

Securing national grain supply and raising rural income are key goals of China's policy agenda. However, these two goals may conflict because rice typically provides low returns and diversification, for example, towards vegetables is generally more profitable (Van den Berg *et al.*, 2007). Hence, despite recent successful efforts of the Chinese government to stimulate rice production, probably other incentives are required to maintain rice production at the current high level, when considering the results of the cost-benefit analysis for rice production in 2005 as shown in Table 2.3. So, on the one hand, low economic returns of rice production remain a threat for rice-based farmers. On the other hand, many market chains for non-rice products have not (yet) fully developed and these are, therefore, susceptible to strong price fluctuations, presenting a risk to farmers.

Diversification towards vegetables and other non-rice crops will result in higher labour demands due to higher labour requirements for land preparation, crop supervision and harvesting (Pingali, 2004). However, the on-going unprecedented rural migration to urban centers reduces rural labour availability, especially of the young and better educated (Yang, 2004; Hengsdijk et al., 2007). Another threat, closely associated with diversification, is the high input use, particularly the fertilizer N and biocides in various non-rice crops such as vegetables and cotton, presenting high risks for environmental pollution (JXAAS, 2001). Besides, traditionally rice is grown in mountainous areas on terraces, protecting the soils against erosion. Introduction of non-rice crops, such as vegetables, in such areas may increase the risk of soil erosion (Ling, 2004).

The increased use of chemical fertilizers and dissemination of hybrid rice varieties have played key roles in increasing rice yields. However, widespread overuse of N and P increases production costs and contributes to environmental pollution (Liu and Dai, 2003; Li *et al.*, 2004). Most of the current hybrid rice varieties are more susceptible to major rice insect pests and diseases than conventional rice varieties, which has led to increased use of biocides. This also increases production costs, and increases the risks for environmental pollution and occupational health problems. Options should be identified to adopt balanced fertilization practices and curtail the use of biocides.

An overarching role in addressing weaknesses and threats of rice-based agro-ecosystems in Jiangxi and in realizing the potentials offered by the opportunities is for agricultural research and extension that, in close collaboration with other stakeholders, should provide information and assistance in identification of options and design of production activities that lead to their improved performance. Due to the declining government support, agricultural extension services have been severely curtailed. For example, the collapse of the agricultural extension services in the 1980s was one of the reasons for the failed large-scale adoption of promising IPM techniques. Introduction of knowledge-intensive technologies, such as SSNM and IPM, also will require well-organized and robust extension services. Financial support of such services by the local or central government is a prerequisite for successful introduction and adoption of such technologies.

2.6 Conclusions

Diversification of rice-based agro-ecosystems in Jiangxi is challenging the double rice cropping systems. This development certainly offers opportunities, but also important risks that are addressed in this chapter. Policy development is required to properly address the identified issues.

Despite the trend towards diversification, Jiangxi Province will remain an important contributor to realizing national objectives of grain security in the near future. Many of the smallholder farmers will continue to grow rice for home consumption in the foreseeable future, as the era of food shortages is still not forgotten. In addition, many non-rice crops need to be grown in rotation and rice is a suitable inter-crop for this purpose. Main challenge will be to allow rice-based farmers to generate a parity income, while simultaneously management practices need to be further optimized, reducing costs and avoiding adverse environmental effects. Appropriate agricultural polices and a targeted research agenda should address these two aspects, allowing sustainable development of rice-based agro-ecosystems in Jiangxi.

3 Assessment of the integrated rice-duck system in China

Abstract

In integrated rice-duck (IRD) systems, ducks are kept in the rice field during part of the growing season, feeding on organisms such as snails and insects. IRD systems are recommended to Asian rice-based farmers as an option to produce rice in an environmentally friendly way and to increase income. In this chapter, the economic and environmental performance of IRD systems is assessed. Data from IRD systems in Jiangxi Province in China are used and compared with data from conventional rice (CR) systems and semi-intensive duck (SID) systems. Gross margins of rice production in IRD systems vary between early, late and single rice systems but in general differ less than 10% from CR systems. Savings in fertilizer nutrients in IRD systems is modest. Ducks are able to control some rice pests, which results in reduced biocide use in IRD systems compared to CR systems. However, reliance on ducks for pest control is risky since ducks are less able to control severe pest outbreaks. Little knowledge exists about the consequences of roaming ducks preying on natural enemies of rice pests. The economic performance of duck production in IRD systems is much poorer than that in SID systems, but IRD systems are less polluting. Resource constraints at farm level (land and labour) most likely constrain farmers to adopt IRD systems at large scale. IRD systems could become economically more interesting if products would be eligible for premium prices.

Keywords: Rice-based systems; Duck production; Pests; Economic and environmental assessment

3.1 Introduction

Realization of China's security in rice is mainly based on a combination of cultivation of high-yielding rice varieties, extensive use of irrigation facilities, and intensive use of chemical fertilizers and biocides. Chinese rice farmers apply about 50% of all biocides currently used in arable crops excluding vegetables and fruits in China (Huang *et al*., 2001). Fertilizer nitrogen use in rice averages 170 kg N ha^{-1}, but reaches levels as high as 300 kg N ha^{-1} per season in some places (Wang *et al*., 2003c). Although the use of agrochemicals such as fertilizers and biocides has resulted in dramatic gains in productivity, production costs of rice have increased correspondingly. Moreover, the use of agrochemicals has caused environmental pollution, and occupational and public health problems (Li *et al*., 1998; Shi *et al*., 2000; Xing and Yan, 2002; Ge *et al*., 2003).

In response to these developments, alternatives have been explored aiming at producing rice in a more environmentally friendly and economically viable way, for instance in the integrated rice-duck (IRD) system. In IRD systems, ducks are kept in the rice field during part of the growing season, feeding on organisms in rice field such as weeds, fish, frogs, snails and on potentially harmful insects for rice. This would reduce the need for biocides in IRD systems, while inputs of duck excreta reduce the need for chemical fertilizers (Su, 2001; Bui *et al*., 2002; Yang and Dai, 2002; Zhang *et al*., 2002; Xu and Yu, 2003; Zhu *et al*., 2004a, b). In addition, selling ducks adds to the income of rice farmers (Jiang *et al*., 2003). Hence, IRD systems appear to be technically feasible, economically viable and environmentally friendly systems to produce rice and ducks in an integrated way (Huang, 2003a; Shen 2003; Quan *et al*., 2005). However, much lower rice yields in IRD systems than in conventional rice (CR) systems have also been reported (Zhu *et al*., 2001; Wang *et al*., 2003b), as well as risks for serious yield losses due to pests and diseases, that are not well controlled by ducks (Shen and Tang, 2004).

Therefore, an integrated assessment of IRD systems is of interest. The objective of this paper is to asses the economic and environmental consequences of IRD systems. The approach followed is that rice production in IRD systems is compared with that of CR systems, and duck production in IRD systems with that of semi-intensive duck (SID) systems, taking into account their interaction in IRD systems. SID systems are specialized farms in which ducks are fattened in pens, mainly using concentrate feed (Yang and Wu, 1994; Yue, 1999).

IRD systems have been introduced in many other Asian countries including Japan, South Korea, Vietnam, the Philippines, Indonesia, Bangladesh, Malaysia and Myanmar (Zhen *et al*., 2004). The assessment focuses on IRD systems in China, and more specifically in Jiangxi Province, and is based on recently collected information and on Chinese literature not easily accessible for an international audience. First, the data collection and major characteristics of IRD and SID systems are described. Subsequently, the economic and environmental performance of IRD farms is assessed. The discussion and conclusions are presented in the last section.

3.2 Data collection

Data were collected from IRD demonstration farms and SID farms in Jiangxi Province, one of the major rice and duck producing areas in China. The IRD demonstration farms have been supported by the Department of Agriculture of Jiangxi Province (DAJX) in 2003 and 2004. Participating farmers obtained technical assistance and subsidies for rice seed, nylon nets, ducklings and feed supplements from DAJX. The data on management, input use and economic returns of five demonstration farms were collected in 2004. Some general characteristics of these farms are shown in Table 3.1.

Table 3.1 Major characteristics of five integrated rice-duck (IRD) demonstration farms with early, late and single rice.

Characteristics	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5
Early rice integrated rice-duck (ER-IRD) system:					
Area of rice land (ha)	3.80	1.07	0.89	0.84	0.67
Duck density (head ha^{-1})	183	94	112	119	150
Age of duckling[a] (d)	20	20	20	20	20
Field period of ducks (d)	52	52	52	52	52
Costs of concentrates[b]	4.34	7.02	7.26	6.84	6.90
Rice yield (kg ha^{-1})	5499	4921	6045	6577	6052
Duck live weight (kg $duck^{-1}$)	0.97	1.17	1.16	1.19	1.18
Late rice integrated rice-duck (LR-IRD) system:					
Area of rice land (ha)	5.13	1.20	1.07	1.11	0.73
Duck density (head ha^{-1})	127	167	187	136	205
Age of duckling (d)	25	25	25	25	25
Field period of ducks (d)	61	61	61	61	61
Costs of concentrates	4.15	5.13	5.15	5.15	4.85
Rice yield (kg ha^{-1})	7472	6813	6234	5873	6807
Duck live weight (kg $duck^{-1}$)	1.25	1.30	1.31	1.32	1.31
Single rice integrated rice-duck (SR-IRD) system:					
Area of rice land (ha)	1.87	2.93	2.33	1.96	2.6
Duck density (head ha^{-1})	161	170	171	153	135
Age of duckling (d)	25	25	25	25	25
Field period of ducks (d)	56	56	56	56	56
Costs of concentrates	5.91	5.97	6.26	6.57	6.84
Rice yield (kg ha^{-1})	6150	6482	6431	6938	6491
Duck live weight (kg $duck^{-1}$)	1.11	1.08	1.12	1.12	1.04

[a] Age of duckling released into the rice field (d).
[b] Costs of concentrates (Yuan) per kg liveweight gain of duck.

Rice land of the surveyed IRD farms is relatively homogenous, of medium fertility and with reliable supply of irrigation water. Selected farmers were experienced rice and duck producers, realizing high rice and duck production. They were capable of keeping detailed and accurate records of their management.

Farmers practiced the IRD systems according to the technical specifications and under the guidance of extension personnel who also were responsible for collecting daily management information. Ducks in the surveyed SID farms were fattened in about 9 weeks during autumn of 2004. In both, IRD and SID systems the same duck breed, 'Maya', and the same type of feed supplements (nutritionally complete rations) were used.

Biocides were applied timely to avoid yield loss. Chemical fertilizers were applied to realize a target yield, taking into account indigenous soil fertility and expected nutrient supply from duck excreta. Data on integrated rice and duck production have been collected for double rice (DR) and single rice (SR) systems. The DR system consists of early rice (ER) transplanted in April and harvested in July, followed by late rice (LR), transplanted in July shortly after harvest of ER and harvested in October. SR is transplanted in early June and harvested in early October.

In addition to the survey data from the IRD and SID farms, results of pest control experiments are used. These experiments were conducted during 2002-2005 in plots located in the close vicinity of the surveyed IRD farms. Treatments included application of insecticides and fungicides according to insect pest and disease development forecasts, and controls without biocides. The experimental results are also used to illustrate the frequency and severity of insect pests and diseases and the associated yield losses.

Finally, field observations and informal discussions with farmers, technicians, local officials and private entrepreneurs in Jiangxi and in other provinces such as Zhejiang and Hunan contributed to the knowledge base on IDR systems.

3.3 Description of IRD systems and SID systems

3.3.1 Integrated rice-duck (IRD) systems

IRD systems are based on the traditional herding of ducks in rice fields that can be traced back to the sixteenth century (Zhang, 1993). These systems declined in importance in the 1980s when higher profits could be realized in SID systems (Ran *et al*., 1993; CCJPH, 1999). At that time, the household contract responsibility system was implemented, giving rice farmers the possibility to deny herders access to their rice fields. In addition, the increased use of biocides in rice systems negatively affected the health and production of ducks (CCHPPJ, 2001).

In IRD systems, rice fields are fenced with nylon nets or low-voltage wire to prevent ducks from escaping (Shen, 2003). One to two weeks after transplanting of rice seedlings, 100 to 450 one- to four-week old ducklings per ha are released into the field, where they stay continuously. A pen is available to shelter ducks during adverse weather conditions, mid-season drainage of the rice field and application of biocides. Ducks depend for their feed on weeds, insects, snails, fish and frogs, *etc*., while often feed supplements are provided. The ducks reach their sale weight after 50 to 60 days, before the milking stage of the rice crop.

To avoid damage to rice plants by trampling, planting density of rice is less than 20 hills m^2 in IRD systems compared to between 15 and 36 hills m^2 in CR systems (Xu and Jian, 2004). Hence, rice varieties used in IRD systems should have large panicles to attain yields similar to those in CR systems (Li *et al*., 2003a; Wang and Shi, 2005). In CR systems, predominantly alternate wet and dry irrigation is practiced (Ling, 2000; Zhang *et al*., 2003). In IRD systems, a water layer of more than 3 cm is generally maintained during the entire growing season, except for a midseason drainage period of one week. The permanent water layer is required to create attractive conditions for potential feed sources of the ducks and to suppress weeds (Gan *et al*., 2003; Zhang *et al*., 2003).

Duck breeds suitable to be fattened in IRD systems should preferably have the following characteristics: (i) small body size, (ii) strong roaming ability to prey on insects and other feed sources, and (iii) high tolerance to extreme weather conditions such as heavy rains, high temperature and low temperature (Li *et al*., 2003a; Shi *et al*., 2003a, b; Shen and Tang, 2004). A great majority of duck breeds used in IRD systems are dual-purpose breeds, for instance, Maya is one of the most popular duck breeds in China used for egg and meat production. In most IRD systems, it is mainly used for meat production.

3.3.2 Semi-intensive duck (SID) systems

Currently, most ducks sold at the market in China are produced in SID systems. Such systems were introduced in the late 1980s when commercially produced feed supplements and veterinary products became readily available. SID farms are specialized in fattening 1000 to 2000 ducks per production cycle on concentrate feed. Ducks are kept in small fenced areas including a pond, while at night they are kept in a pen. They reach their sale weight in 7 to 9 weeks, allowing completion of four to six production cycles per year (Liu and Wei, 1999; CCHPPJ, 1999; Yue, 1999). SID systems differ from intensive duck systems that fatten ducks in well insulated and ventilated housing systems. A few of such intensive duck systems are currently operational in China, but not yet in Jiangxi.

3.4 Economic assessment of IRD systems

3.4.1 Rice production

In general, yield differences between IRD and CR systems were small (Table 3.2). Yields of ER in IRD systems were 2% higher than in CR systems, but LR and SR in IRD systems produced 3 and 5% less than in CR systems, respectively (Table 3.2). A reason for this difference may be that pest pressure in LR and SR was higher than in ER (Sub-section 3.5.2), while application of biocides is a more reliable pest control method than ducks under such conditions.

Table 3.2 Input costs, returns and other economic characteristics of rice production in integrated rice-duck (IRD) and conventional rice (CR) systems.

Items	Early rice		Late rice		Single rice	
	IRD	CR	IRD	CR	IRD	CR
Fertilizers (Yuan ha^{-1})	944	1084	1011	1221	975	1063
Biocides (Yuan ha^{-1})	92	126	177	248	288	303
Labour input[a] (d ha^{-1})	62	54	59	60	66	64
Other costs[b] (Yuan ha^{-1})	2753	2593	2566	2531	3564	3595
Total costs (Yuan ha^{-1})	3789	3803	3754	4000	4826	4960
Yield (kg ha^{-1})	5819	5702	6640	6846	6499	6818
Price (Yuan kg^{-1})	1.44	1.44	1.56	1.56	1.56	1.56
Total returns (Yuan ha^{-1})	8379	8211	10358	10680	10138	10637
Gross margins (Yuan ha^{-1})	4591	4408	6604	6680	5312	5676
Return to labour (Yuan d^{-1})	74	82	113	112	80	89
Costs (Yuan Mg^{-1} grain)	651	667	565	584	743	728
Labour productivity (kg d^{-1})	94	106	113	114	98	106
Share of cost items in rice production of IRD and CR systems (%):						
Fertilizers	24.9	28.5	26.9	30.5	20.2	21.4
Biocides	2.4	3.3	4.7	6.2	6.0	6.1
Other costs	72.7	68.2	68.4	63.3	73.8	72.5

[a] Including labour used to repair bunds. Labour used in the duck production component is shown in Table 3.3.
[b] Other costs include taxes and costs of seed, machines, animal traction, irrigation water and implements.

Total costs of non-labour inputs of IRD systems were lower than of CR systems because of lower costs for fertilizers (8 to 17%) and biocides (5 to 29%). Gross margins (production value minus costs of non-labour inputs) of ER in IRD systems were 4% higher than in CR systems, but those of LR and SR were 1 and 6% lower, respectively.

Labour input for rice production was somewhat higher in IRD systems, except for LR, because field bunds in IRD systems had to be reinforced. Net returns per labour-day in LR in both, IRD and CR systems were about 112 Yuan, while those in ER and SR in IRD systems were 74 and 80 Yuan, about 11 and 10% lower than in CR systems, respectively (Table 3.2).

3.4.2 Duck production

The economic performance of an average production cycle in SID systems is compared to one production cycle of ducks in each, ER, LR and SR of IRD systems (Table 3.3).

The length of the production cycle of ducks in ER, LR and SR of IRD systems exceeds that in SID systems by 10, 24 and 19 days, respectively, while their average final live weight was between 23 and 35% lower, thus their average daily weight gain in ER, LR and SR of IRD systems was 41, 44 and 50% lower, respectively.

Consumed feed supplements per kg liveweight gain were 4.63, 3.15, 4.50 and 3.55 kg for ducks in ER, LR, SR and SID systems, respectively, *i.e.* feed conversion ratios of ducks in ER and SR in IRD systems were much lower than in SID systems, while that in LR was higher. However, feed conversion ratios in IRD systems cannot be compared to that of SID systems, because ducks also eat feeds available in the rice field. The reason for the differences in feed conversion ratios among the three IRD systems remains unknown.

As a result of the less favourable feed conversion ratios in IRD systems, total costs of non-labour inputs per kg liveweight gain of ducks in the ER, LR and SR system of IRD systems were 39, 4 and 29% higher than in SID systems. Hence, despite the fact that ducks in IRD systems fed on organisms in the rice fields, the costs of supplements per kg liveweight gain were higher in the ER and SR systems, and only slightly lower in the LR system, than in SID systems. As a result, profitability of duck production in IRD systems was much lower than in SID systems, both per kg live weight (79, 29 and 67% lower in ER, LR and SR, respectively) and per unit labour input (88, 65 and 71% lower in ER, LR and SR, respectively). Net returns to labour were 6.5, 18.4, 15.2 and 52.2 Yuan d^{-1} in ER, LR, SR and SID systems, respectively. Hence, income of duck production in IRD systems in most of the surveyed demonstration farms was insufficient to generate an average agricultural wage rate of 30 Yuan per day, because the number of ducks was too small. In order to generate this wage rate, more than 400 ducks are required in LR and about 1000 in ER. Given a duck density of 150 ducks ha^{-1}, at least 2.8 ha of LR is required and 6.7 ha for ER. So, possible ways to improve income from the duck component in IRD systems may include increasing the feed conversion ration of ducks, the duck density and land holding size.

Table 3.3 Costs and other economic characteristics of duck production in integrated rice-duck (IRD) and semi-intensive duck (SID) systems.

	ER-IRD	LR-IRD	SR-IRD	SID
Area of rice land (ha)	1.45	1.85	2.34	
Number of ducklings	219	270	370	1080
Cost of ducklings (Yuan)	328	405	555	1740
Duckling density (head ha^{-1})	151	146	158	
Total number of collected ducks	188	232	367	958
Number of collected ducks per ha	130	126	157	
Total live weight of collected ducks (kg)	200	299	401	1615
Price of sold duck (Yuan kg^{-1})	11	11	11	11
Value of production (Yuan)	2198	3284	4449	17769
Total costs of non-labour inputs (Yuan)	1861	2160	3596	11286
Gross margins per farm (Yuan)	337	1124	853	6483
Mortality rate of ducklings (%)	4.8	9.2	1.0	11.1
Feed conversion ratio[a] (kg kg^{-1})	4.63	3.15	4.50	3.55
Costs of concentrates[b] (Yuan kg^{-1})	6.47	4.89	6.31	5.5
Costs of medicines[c]	82.59	156.33	184.87	197.14
Costs of pen and fence[d] (Yuan kg^{-1})	1.97	1.06	1.12	0.22
Total fattening period[e] (d)	72	86	81	62
Average liveweight of collected duck (kg)	1.14	1.3	1.09	1.69
Average daily weight gain (g d^{-1})	15.8	15.1	13.5	27.1
Total costs per kg liveweight gain (Yuan)	9.70	7.29	9.02	7.00
Returns to labour[f] (Yuan d^{-1})	6.5	18.4	15.2	52.2
Gross margins per duck (Yuan)	1.44	4.81	2.30	6.77

[a] Consumed concentrates (kg) per kg liveweight gain.
[b] Costs of concentrates per kg liveweight gain.
[c] Costs of medicines per 1000 kg liveweight gain.
[d] Costs of pen and fence per kg liveweight gain.
[e] Total fattening period includes period before and in the rice field.
[f] Labour inputs in duck production in IRD systems.
Note: ER = early rice, LR = late rice, SR = single rice.

3.5 Environmental assessment of IRD systems

3.5.1 Nutrient cycling

One of the assumed benefits of IRD systems is that part of the crop nutrient requirements is supplied by duck excreta, thus reducing fertilizer requirements. To test this hypothesis, the macro-nutrient supply (N, P and K) in excreta to the rice system is estimated. Then, the associated yield response is estimated using a fixed agronomic N-use efficiency (AEN), in kg grain yield increase per kg N applied (Dobermann *et al.*, 2002).

Nutrient contents of duck excreta vary widely depending on factors, such as duck breed and nutrient content of the feed. Duck density in current IRD systems ranges from 100 to 450 ducks ha^{-1}. Fresh excreta production per duck during the field period averages 10 kg, with N concentrations varying between 4.7 and 10 g N kg^{-1}, P concentrations between 2.2 and 14 g P kg^{-1}, and K concentrations between 3.1 and 6.2 g K kg^{-1} (CNATE, 1999; Huang 2003; Wang *et al.*, 2004a). Hence, the supply of N, P and K by 100 ducks ha^{-1} varies between 4.7 and 10.0 kg N ha^{-1}, 2.2 and 14.0 kg P ha^{-1}, and 3.1 and 6.2 kg K ha^{-1}, respectively, and by 450 ducks ha^{-1}, between 21.2 and 45.0 kg N ha^{-1}, 16.2 and 63.0 kg P ha^{-1}, and 14.0 and 27.9 kg K ha^{-1}, respectively. Part of the excreted N is in organic form, and will not be available during the growing season. A working coefficient of total N in the duck excreta of 70% may be assumed (Ir. H.G. van der Meer, Plant Research International, pers. com.). AEN in farmers' fields is often in the range of 15 to 25 kg kg^{-1}. An AEN of 25 kg kg^{-1} is attainable under good crop management in seasons with favourable weather conditions and 15 kg kg^{-1} in situations where existing fertilizer N management practices are very inefficient (IRRI, 2007). Thus, 45 kg N ha^{-1} in duck excreta N, combined with an AEN of 25 kg kg^{-1}, could potentially increase rice yield 788 kg ha^{-1}, while the combination of 4.7 kg N ha^{-1} in duck excreta with an AEN of 15 kg kg^{-1} gives a yield response of 50 kg ha^{-1}.

Nutrient supply from duck excreta in the surveyed IRD farms can be estimated from the difference in fertilizer application between the IRD systems and CR systems , as the difference of rice yields between the IRD systems and CR systems are very small (Sub-section 3.4.1; Table 3.4). N fertilizer savings varied between 9.7 and 24 kg N ha^{-1}, savings of P fertilizer between 1.4 and 2.6 kg P ha^{-1}, and saving of K fertilizer between 6.8 and 13.8 kg K ha^{-1}. N and K savings are somewhat high and P savings somewhat low compared to the calculated contribution from the duck excreta in the IRD farms, but of the same order of magnitude.

Table 3.4 Nutrient inputs, agronomic N-use efficiency (AEN) and yields in early rice, late rice and single rice in the integrated rice-duck (IRD) and conventional rice (CR) systems in Jiangxi in 2004.

	Early rice		Late rice		Single rice	
	IRD	CR	IRD	CR	IRD	CR
N (kg N ha^{-1})	128.0	151.9	130.6	153.2	130.4	140.1
P (kg P ha^{-1})	24.2	25.6	24.3	26.6	24.7	27.3
K (kg K ha^{-1})	76.6	90.4	99.4	106.2	95.1	105.3
AEN[a] (kg kg^{-1})		19.5		18.9		20.5
Yield (kg ha^{-1})	5819	5702	6640	6846	6499	6818

[a] AEN in IRD systems can not be calculated because the amount of N in duck excreta is unknown.

3.5.2 Pest suppression

Predation by ducks may significantly reduce the number of some insect species in rice field such as planthoppers, green leafhoppers, locusts, and that of others, such as rice stem borers, rice leaffolders, plant weevils, leaf beetles, armyworms, and skipper butterflies to some extent, while there are indications that ducks may alleviate the yield-reducing effect of some diseases (*e.g.* rice sheath blight), but the control mechanism is poorly understood (Ran, 1991; CCHPPJ, 2001; Feng *et al.*, 2001; Li *et al.*, 2004; Jiang *et al.*, 2004; Yang *et al.*, 2004; Yu *et al.*, 2004; Huang *et al.*, 2005). Therefore, the presence of ducks may reduce the biocide requirements in rice cultivation.

In IRD systems, biocide application was lower (in terms of active ingredients by 35% in ER, 18% in LR and 11% in SR) than in CR systems (Table 3.5), with the strongest reduction in insecticides. In CR systems, contrary to the ER-IRD system, a second biocide application was necessary, aimed at controlling rice planthopper, rice sheath blight and rice leaffolder. This suggests a positive effect of ducks on the control of pests, because yields in the IRD systems were not significantly lower than in the CR systems (Sub-section 3.4.1). The pest-controlling effect of ducks in LR and SR is relatively smaller than in ER (Table 3.5). The frequency of biocide application in LR and SR in IRD and CR systems was the same, although the dose was somewhat lower in IRD systems.

Results of the pest control experiments showed greater yield reduction caused by insect pests and diseases in LR than in ER (Table 3.6). Results of farm surveys by DPJX in Jiangxi during 2003-2005 showed average costs of biocides in ER, LR and SR of 217, 345 and 400 Yuan ha^{-1}, respectively, suggesting increasing severity and frequency of pest and disease attacks in this order (Chapter 2). Savings in biocide use in IRD systems decrease in the order of ER, LR and SR, which suggests that the capability of roaming ducks to control rice insect pests and diseases decreases with increasing pest pressure.

Table 3.5 Biocide inputs in integrated rice-duck (IRD) systems and conventional rice (CR) systems in Jiangxi in 2004 (a.i. = active ingredient).

	Early rice		Late rice		Single rice	
	IRD	CR	IRD	CR	IRD	CR
Insecticides (g a.i ha^{-1})	561	829	1247	1565	1531	1767
Fungicides (g a.i. ha^{-1})	41	101	188	192	311	309

Table 3.6 Yield losses in early rice and late rice caused by insect pests and diseases in experimental plots with and without biocide application in the period 2002-2005 (Data source: Mr. Zhao Xianfeng at Shanggao County Agricultural Bureau).

	Yield with biocides[a] (kg ha^{-1})	Loss by stem borers[b] (%)	Loss by plant-hoppers (%)	Loss by leaf-folder (%)	Loss by sheath blight (%)	Loss by bacterial leaf streak (%)	Yield loss without biocides[c] (%)
Early rice:							
2002	7223	4.4	4.8	6.3	9.6		19.6
2003	6908	21.0	11.3	7.8	6.2		42.6
2004	7411	12.8	6.8	3.6	11.4		22.0
2005	7740	25.4	36.0	8.3	26.7		47.9
Average	7320	15.9	14.8	6.5	13.5		33.0
CV%	4.8	58.3	98.0	32.9	67.5		43.4
Late rice:							
2002	7621	7.6	6.2	6.0	9.1		14.3
2003	6840	15.8	13.6	11.8	14.5		28.5
2004	6518	13.5	29.9	10.7	21.2	4.1	73.7
2005	6834	17.4	79.0	18.5	37.2	20.8	98.9
Average	6953	13.6	32.2	11.8	20.5	12.5	53.9
CV (%)	6.8	31.4	101.7	43.5	59.6	94.5	72.9

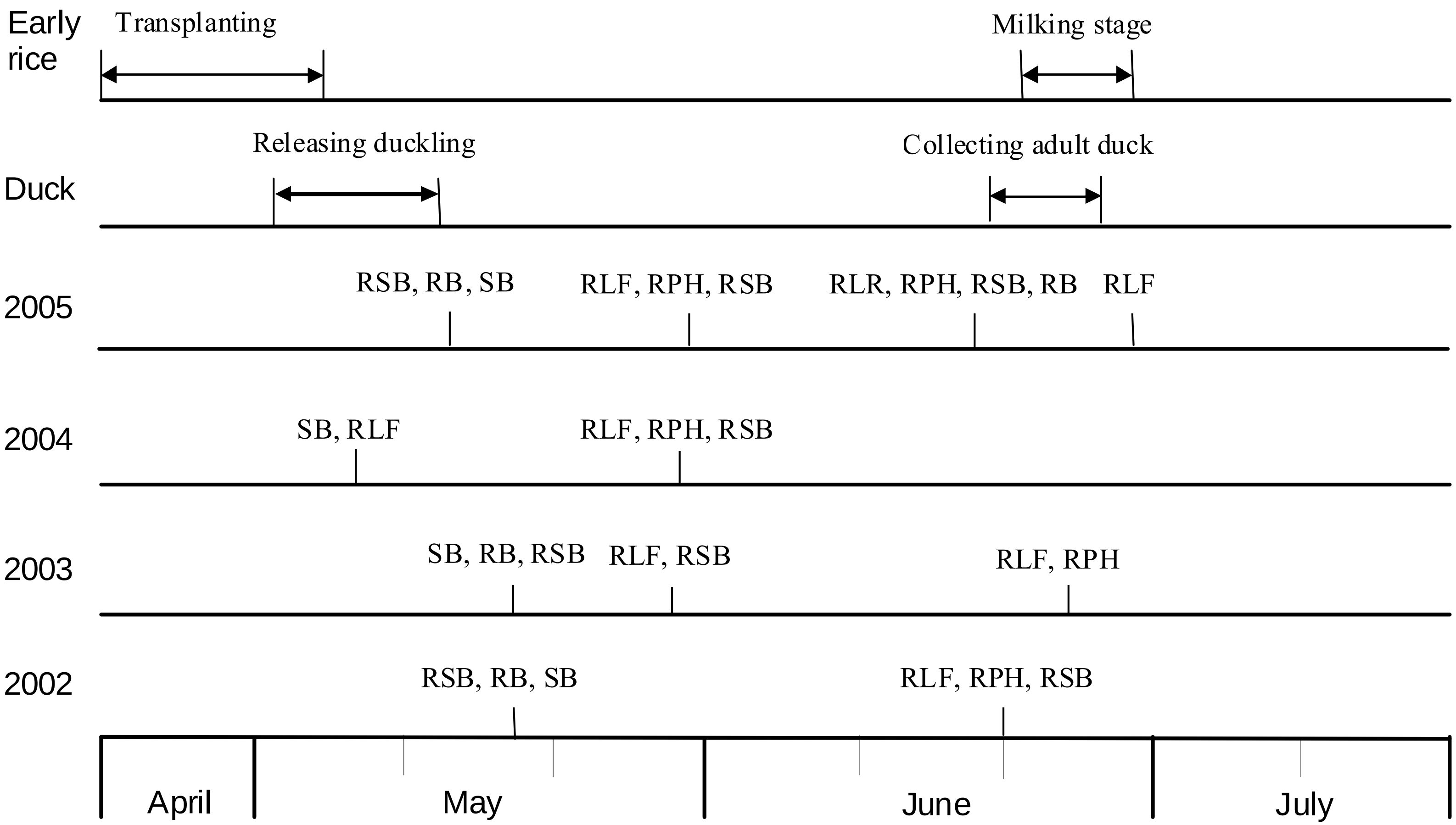
[a] Yield of plots with timely application of biocides according to the pest pressure.
[b] Stem borers were not controlled, while other pests and diseases were controlled using biocides according to pest pressure. Similar treatments for rice planthoppers, leaffolder, sheath blight and bacterial leaf streak (next columns). The bacterial leaf streak did not occur in early rice. In 2002 and 2003, the bacterial leaf steak did not occur in late rice.
[c] Total yield loss in plots without biocide application.

Severity and frequency of attacks by rice insect pests and diseases vary considerably among years (Table 3.6; Figures 3.1a and 3.1b). Without biocide application, yield losses caused by insect pests and diseases during 2002-2005 would have varied between 20 and 48% in ER, and between 14 and 99% in LR. Ducks have no effect on some major rice insect pests and diseases such as rice thrips, rice blast and bacterial leaf streak and only a moderate effect on rice leaffolder, stem borer and sheath blight. In addition, pests and diseases occurring later than the milking stage of rice always have to be controlled by other means. For example, in 2005, in both ER and LR various insect pests such as rice leaffolder and planthopper occurred after the milking stage (Figures 3.1a and 3.1b). In short, heavy reliance on ducks to control pests and diseases is very risky. Therefore, in the surveyed IRD systems still biocides were used.

3.5.3 Natural enemies

Ducks in IRD systems are a double-edged sword with respect to the control of rice pests and diseases. In addition to pests, they also prey on natural pest predators such as spiders and frogs (Li *et al*., 2003b; Wang *et al*., 2003b). Studies have shown that populations of spiders belonging to the families of *Lycosidae* (wolf spiders), *Salticidae* (jumping spiders) and *Araneidae* (araneid spiders) that can prey on a wide range of insect pests, strongly decreased in IRD systems (Tong, 2002; Zhu *et al*., 2004a, b), *i.e.* by 49 and 23% in ER and LR, respectively, while spiders are the most important natural enemies of rice leaffolder and planthopper (CNPPS, 1991). Of the total number of planthoppers preyed by natural enemies, 80 to 90% are preyed by the wolf spider (*Pirata subpiraticus* Boes. et Str.) (She *et al*., 2004). In addition, various frog species, such as spotless tree toad (*Hyla arborea immaculate* Boettger) and guenther's frog (*Hylarana guentheri* Boulenger), consumed by ducks, are predators of rice insect pests. Most frogs lay eggs between May and June (Fei, 1999), the main field period of ducks, making frog eggs and young frogs an easy prey (Zhu *et al*., 2004a, b).

Among the insects preyed by spiders and frogs, some can damage the crop directly, and some are vectors of rice virus diseases. The role of natural enemies in controlling rice pests and diseases is still poorly understood, but fostering of natural enemies is an important element in integrated pest management (Heinrichs, 1994; Barrion and Litsinger, 1995). More research is needed on the relationships among ducks, natural enemies and the presence of pests.


Early rice
Transplanting
Milking stage
Duck
Releasing duckling
Collecting adult duck
2005
RSB, RB, SB
RLF, RPH, RSB
RLR, RPH, RSB, RB
RLF
2004
SB, RLF
RLF, RPH, RSB
2003
SB, RB, RSB
RLF, RSB
RLF, RPH
2002
RSB, RB, SB
RLF, RPH, RSB
April
May
June
July

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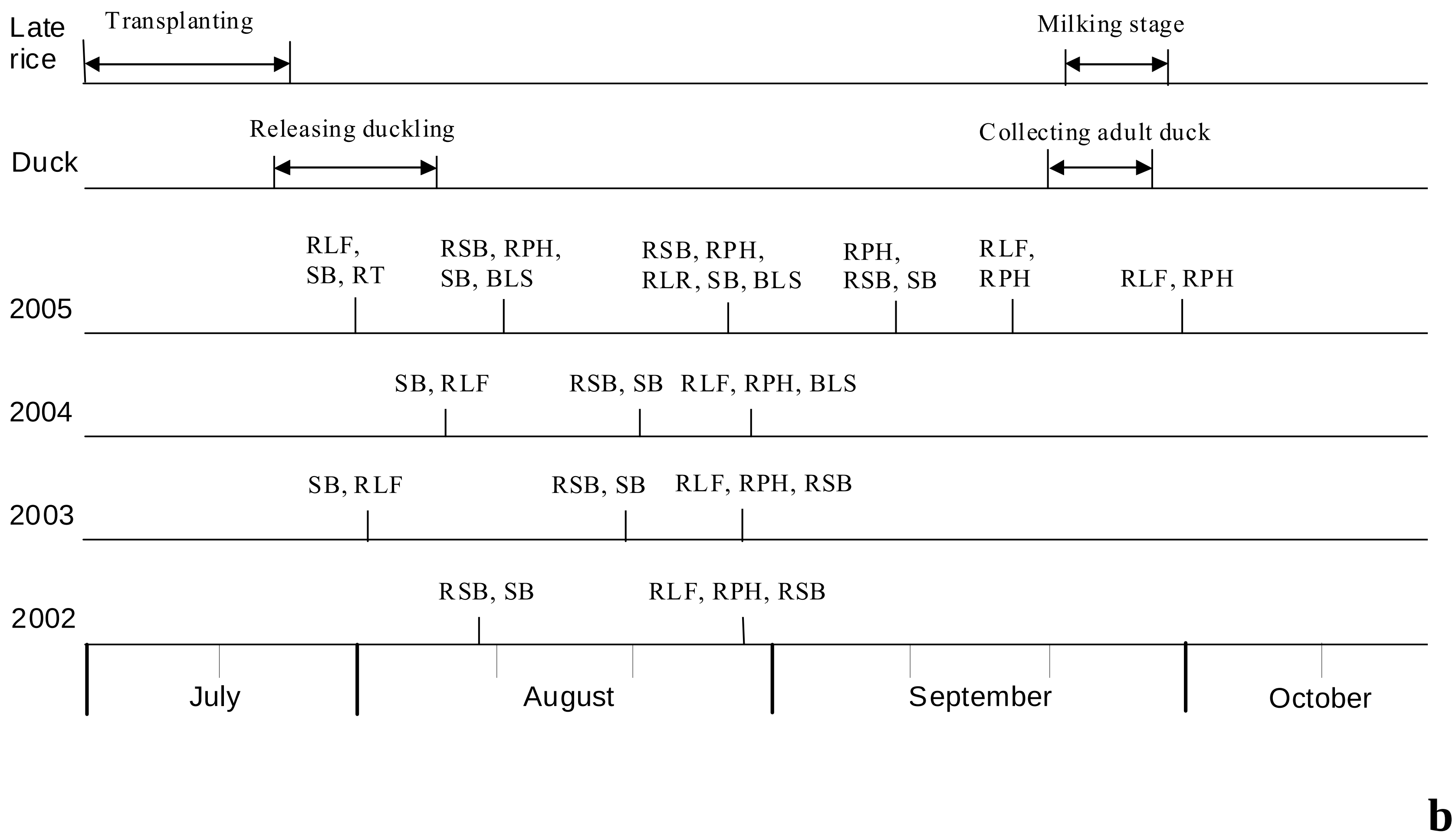


Figure 3.1 *Date and target rice insect pests and diseases of biocide applications for early rice (a) and late rice (b) in pest control experiments from 2002 to 2005 (Data source: Mr. Zhao Xianfeng at Shanggao County Agricultural Bureau).*
Note: SB = rice stem borers, RLF = rice leaffolder, RPH = rice planthoppers, RT = rice thrips, RSB = rice sheath blight, RB = rice blast, BLS = rice bacterial leaf streak.

3.6 Discussion and conclusions

Results of IRD farms have demonstrated that integration of ducks into rice systems can lead to reduced inputs of fertilizers and biocides, while gross margins of the rice component in IRD systems are similar to those in CR systems. If rice produced in IRD systems would be eligible for a so-called ‘green rice’[2] premium, gross margins would clearly exceed those of CR systems. Widely reported higher economic returns of rice from IRD systems are the result of a premium price for rice and reduced costs of fertilizers and biocides (Chen, 2003; Liu and Wang, 2004; Zhen *et al*., 2004).

Nutrient supply in excreta of ducks varies greatly depending on factors such as duck density and composition of the consumed feeds. However, in general, nutrient supply to the rice crop by ducks in IRD systems is limited. Isobe *et al*. (2005) reported that the amount of nitrogen supplied from the feces of duck is a minor part of nitrogen taken up by rice. Hence, reported high savings on fertilizers, even complete abolishment of fertilizer use in IRD systems, may not be sustainable.

Lower biocide use may entail high risks for IRD farmers for three major reasons. First, ducks have a decisive controlling effect on only a few insect pests and a moderate effect on some others. Secondly, ducks are in the field only about two months, and pests may occur outside that period, which may lead to substantial yield loss without biocide application. Finally, the highly unpredictable occurrence of pests and diseases in rice crops adds to the risk. Even the well-controlled pests by ducks under mild infestation may impose a yield reducing risk under a severe pest outbreak. Many IRD farmers are not prepared to accept that risk, despite the premium price they may receive for certified rice. An additional constraint is that the procedure for certification is time-consuming, expensive, and often requires that many farmers in the area participate.

Although the profitability of duck production in IRD systems is much lower than in SID systems, the duck component may generate extra income for IRD farmers. However, whether duck production in IRD systems is economically viable depends mainly on the scale of production. In general, one fulltime hired labourer is required to tend ducks, even if the flock is small, and flock size is constrained by the size of the holding of smallholders. Agricultural landholdings in China have an average size of only 0.53 ha (Tan, 2005). Leasing additional land to create the minimum area required for an economically viable production unit increases costs and is difficult, since most farmers do not want to give up their land.

[2] In China, ‘green rice’ is a certification scheme for rice produced according to such well-defined standards as Environmental technical terms for green food production (NY/T391-2000), Pesticide application guideline for green food production (NY/T393-2000), Fertilizer application guideline for green food production (NY/T394-2000). Green rice can be sold at a premium price.

The low profitability of duck production in IRD systems is mainly the result of low feed conversion ratios and high fixed costs (pen and fence). Meat-type duck breeds, such as Peking Duck and Cherry Valley Duck, have more favourable feed conversion ratios than the currently used native breed Maya (Lai and Huang, 2001), but they are unsuitable for IRD systems due to their large body size (Su, 2001), poor adaptation to field conditions and low resistance to diseases (Shi *et al*., 2003a). New duck breeds, for instance hybrid ducks with promising characteristics for IRD systems (Xiong *et al*., 2003a), could increase their profitability, but they need further evaluation.

Although SID farms produce duck meat more efficiently, the associated pollution of air (through emission of NH_3) and water (surface water through run-off and groundwater through leaching) from duck excreta causes increasing concern (DAJX, 2006). Until now, pollution problems in SID systems have not been studied in-depth, and policy measures aimed at abatement of pollution problems are lacking. Environmental problems in IRD systems are considerable less, because most of the nutrients from excreta are taken up by the rice crop.

Summarizing, IRD systems provide an environmentally friendly way of producing ducks, especially when compared to current SID systems in China, but their feed conversion efficiency is appreciably lower. The potential benefits of duck production for smallholder rice farmers may have been overestimated, since resource limitations at farm level (land and labour) may constrain farmers to adopt IRD systems. Only, when products of IRD systems would be eligible for certification and receive higher prices, could such systems offer a viable economic option to smallholder farmers.

4 Quantification of input-output relations of cropping systems using TechnoGIN

Abstract

In this chapter, inputs and outputs of current and alternative cropping systems in Jiangxi have been quantified. For both, current and alternative cropping systems, 45 land use types have been identified consisting of combinations of 38 crop types. Alternative systems comprise Super Rice varieties and innovative production techniques including site-specific nutrient management (SSNM), integrated pest management (IPM) and mechanization of rice production. Inputs and outputs of current systems are quantified in an input-oriented way, *i.e.* most inputs and outputs are based on observed data from farm surveys, experiments and expert knowledge, while outputs that have not been measured in practice, such as N loss and biocide index, have been generated using TechnoGIN, a technical coefficient generator. Inputs and outputs of alternative cropping systems are quantified in a target-oriented way, *e.g.* crop yields are fixed and inputs and other outputs are calculated using databases and generic calculation rules of TechnoGIN. Input-output relationships of various current and alternative cropping systems in Jiangxi are illustrated. The generated input-output relationships are suitable for incorporation in a regional linear programming model to assess the effectiveness of current and alternative cropping systems in attaining rural development goals.

Keywords: Current cropping systems; Alternative cropping systems; Technical coefficients; Linear programming model

4.1 Introduction

To attain a variety of rural development goals in a situation with decreasing availability of resources such as land and labour, alternative and innovative cropping systems need to be developed and tested (Hengsdijk and Van Ittersum, 2002; Lu *et al.*, 2003). Alternative cropping systems consist of agricultural systems that are new or not widely practiced in the region under study and may include, for example, new crops, new high-yielding and disease-resistant or otherwise superior varieties or new crop management practices. New cropping systems can be designed and engineered based on knowledge of the underlying physical processes of plant production, technical insights and relevant objectives (Hengsdijk and Van Ittersum, 2002). Quantification of such alternative cropping systems in terms of inputs and outputs and incorporation in a regional linear programming (LP) model in combination with current cropping systems allows simultaneous analysis of their contribution to the realization of rural development goals (Chapter 6).

In this chapter, the generation of input-output coefficients is described for current and alternative cropping systems incorporated in the LP model for Jiangxi Province to assess their effectiveness in attaining rural development goals. Section 4.2 describes the identification of current and alternative cropping systems. Section 4.3 presents the method to quantify input-output relations of current and alternative cropping systems. In Section 4.4, examples of input-output relations of current and alternative cropping systems are presented. Finally, the discussion and conclusions are presented in Section 4.5.

4.2 Identification of current and alternative cropping systems

4.2.1 Concepts

In this study, the cropping system is used as the unit of analysis. A cropping system is a combination of a land unit (LU), land use type (LUT) and production technique. The cropping system defined here is similar to the land use system defined by Hengsdijk *et al.* (2000), Hengsdijk and Van Ittersum (2002) and Ponsioen *et al.* (2006). A land unit is defined as a physical area of land that is uniform in its characteristics and qualities (Hengsdijk and Van Ittersum, 2002). A land use type is defined as a crop sequence of one, two or three crop types within one year. Crop types are defined on the basis of variety and growing period, *i.e.* short and long duration rice varieties and crops grown in different periods of the year. For example, rice is classified into six crop types (Appendix I). The production technique refers to the complete set of inputs used to realize a pre-defined target yield (Van Ittersum and Rabbinge, 1997).

4.2.2 Design criteria of cropping systems

This section describes in more detail the characteristics of the LUs, LUTs and production techniques (Table 4.1) identified for Jiangxi. Sub-section 4.2.2.1 describes the land units, Sub-section 4.2.2.2 the LUTs and Sub-section 4.2.2.3 the production techniques. Priority is given to techniques that are included in the national research agenda.

Table 4.1 Design criteria and their variants as implemented for current and alternative cropping systems in Jiangxi Province (see Table 4.2 for definition of Land Units).

Design criterion	Current	Alternative
Land unit	Rice-land: LU1, LU2, LU3, LU4, LU5, LU6, LU7. Non-rice land: LU8, LU9, LU10, LU11.	Same as current cropping systems
Land use type	[a]ER-LR-rapeseed, ER-LR-potato, ER-LR-Chinese milk vetch, ER-LR-Italian ryegrass, celery-Chinese white cabbage-radish, celery-red pepper-radish, ERL-LRL, tobacco-LR, early sweet maize-LR, early silage maize-LR, watermelon-LR, Chinese white cabbage-LR, red pepper-LR, eggplant-LR, tomato-LR, cucumber-LR, ER-sweet potato, ER-sorghum, ER-soybean, ER-late maize, ER-late silage maize, Chinese cabbage-late SR, late SR-single Chinese milk vetch, late SR-rapeseed, late SR-single potato, late SR-single Italian ryegrass, early silage maize-late silage maize, early SR, late SR, sweet potato, early maize, sorghum, soybean, groundnut, cotton, watermelon, tobacco, sugarcane, single rapeseed, early silage maize, late silage maize, single Italian ryegrass, dwarf elephant grass, hybrid elephant grass, Chinese kudzu.	Similar to current land use types, but using Super Rice variety
Production technique	Observed production techniques	[b]SSNM, IPM and high mechanization level in rice production

[a] ER = early rice, LR = late rice, ERL = early rice long, LRL = late rice long, SR = single rice.
[b] SSNM = site-specific nutrient management, IPM = integrated pest management.
Note 1: The growth duration of 'early rice long' is about 15 days longer, and its yield is 10% higher than that of early rice. Inputs of biocides and fertilizers are also 10% higher. Similarly, the yield of 'late rice long' is 10% higher than that of late rice.
Note 2: Late single rice is not suitable for LU6 and LU7 due to mainly climate limitations (i.e. temperature and radiation) and unavailability of irrigation water (for LU7) while early single rice is suitable to all rice land (Appendices I and II).
Note 3: Chinese kudzu as forage crop is harvested several times during the growing season, while the root cannot be harvested.

4.2.2.1 Land units

On the basis of the Chinese soil classification system, cultivated land in Jiangxi (Figure 4.1) is classified into rice land and non-rice land. Typically, rice land has a hard pan below the cultivated layer to reduce percolation, and bunds to maintain a standing water layer on the field. Both are lacking in non-rice land. Rice land can be used for cultivation of either rice or non-rice crops, while non-rice land is only suitable for growing non-rice crops (DLMJP, 1991a, b; Huang, 2000a, b, c; Xu, 2001). Rice land, totaling 1.9 Mha, is sub-divided into seven LUs, and non-rice land, totaling 0.4 Mha, into four LUs. These eleven LUs are distinguished on the basis of the following criteria (Table 4.2): geographical location, availability of irrigation water, drainage condition, slope (for non-rice land), soil texture, bulk density, soil organic carbon content, nutrient content and soil pH (DLMJP, 1991a, b; Xu, 2001).

Land unit 1 (LU1) and land unit 2 (LU2) are the most fertile land units, in different geographical locations. LU1 is located in the Poyang Lake Plain in Northern Jiangxi and LU2 in the alluvial plains along the rivers. Both land units are suitable for most crops and allow LUTs with three crops per year. Typical LUTs are early rice (ER), followed by late rice (LR) and a non-rice crop (*e.g.* rapeseed, Chinese milk vetch, potato or Italian ryegrass). Land unit 3 (LU3) is also located in the Poyang Lake Plain, but consists of poorly drained soils, only suitable for single rice (SR) and aquatic vegetables, such as lotus root, taro and common arrowhead. Land unit 4 (LU4) is mainly located in the hilly areas, with low soil fertility as the main yield-limiting factor. In the hilly and mountainous areas land unit 5 (LU5), land unit 6 (LU6) and land unit 7 (LU7) prevail. Since in LU5 supply of irrigation water from late July to September is unreliable, typical LUTs consists of ER followed by a non-rice crop (*e.g.* sweet potato, soybean, maize or sorghum), or SR in rotation with a non-rice crop (*e.g.* Italian ryegrass, rapeseed, potato or Chinese milk vetch). In valleys of the hilly and mountainous areas, LU6 dominates, with high groundwater tables, resulting in water-logging during a major part of the year. Since soil pH is very low and the mountains restrict sunshine hours, yields of SR are low. Organic matter and nutrient contents in the rainfed high-lying terraces (LU7) are low. Soil texture is unfavourable due to high contents of sand (Table 4.2). Generally, fertility of LU7 is low and only one crop per year can be grown, mainly due to the shortage of water in autumn.

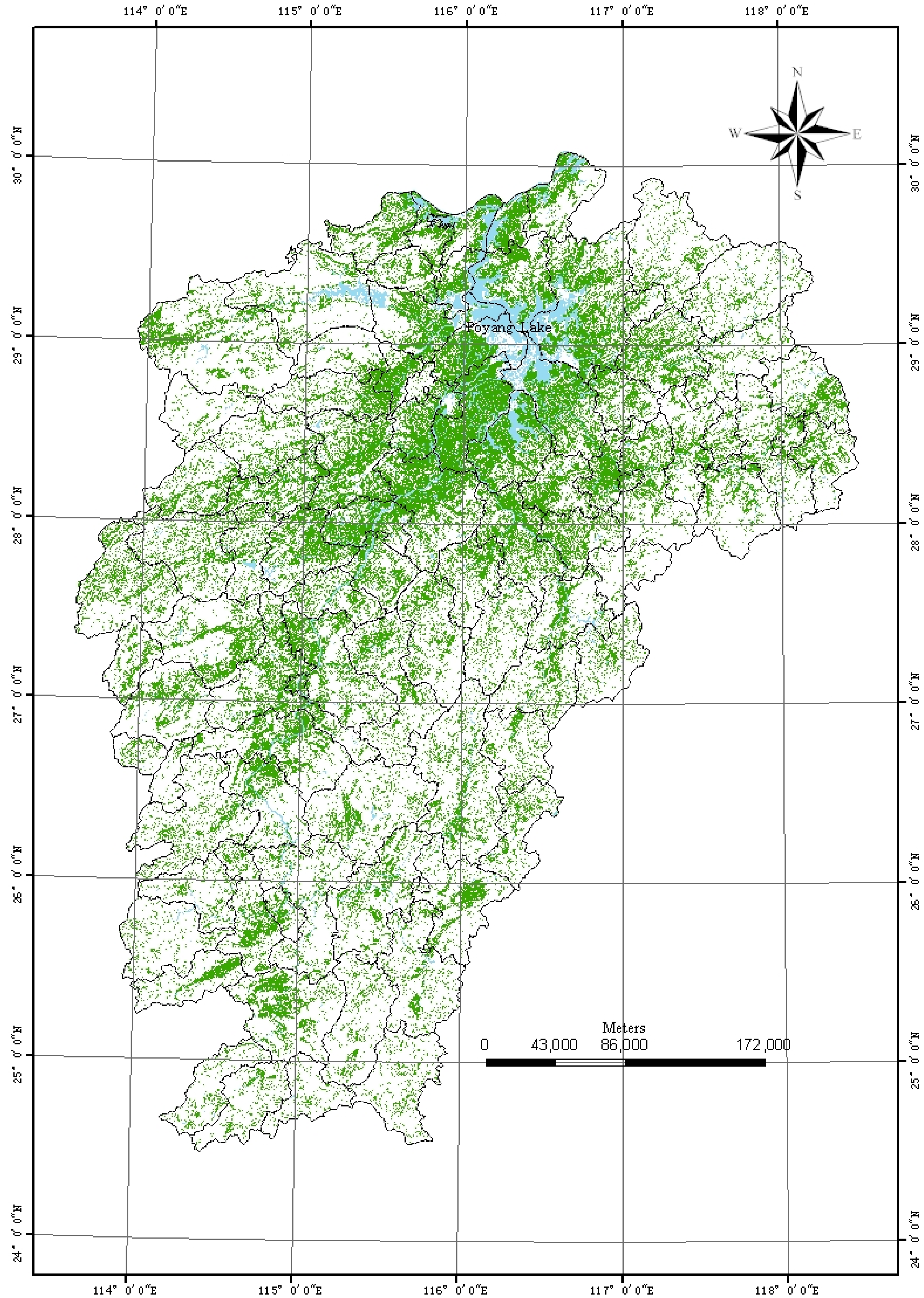


Figure 4.1 Cultivated land in Jiangxi.

Table 4.2 Area (Mha) and major characteristics of eleven land units in Jiangxi Province.

Land unit	Area	Location[a]	Fertility[b]	Irrigation conditions[c]	Drainage level	Slope[d] (˚)	Particle size distribution(%) Clay	Silt	Sand	BD[e] (g cm^{-3})	OC[f] (g kg^{-1})	TN[g]	AN[h]	AP[i]	AK[j]	pH[k]
LU1	0.43	P. Plain	Very high	Reliable	Well		23.7	41.0	35.3	1.1	1.9	1.8	156	47	89	5.2
LU2	0.41	A. Plain	Very high	Reliable	Well		20.0	43.8	36.2	1.0	1.9	1.8	141	33	68	5.6
LU3	0.04	P. Plain	Medium	Reliable	Poorly		28.1	41.8	30.1	1.1	1.7	1.7	149	36	71	5.1
LU4	0.38	Hilly	High	Reliable	Well		24.1	45.9	30.0	1.2	1.7	1.7	139	35	69	4.9
LU5	0.39	H & M	Medium	Unreliable	Well		20.9	37.0	42.1	1.1	1.6	1.6	129	24	82	5.4
LU6	0.06	H & M	Low	Rainfed	Poorly		19.4	29.9	50.7	1.1	0.7	1.3	114	14	52	4.8
LU7	0.19	H & M	Low	Rainfed	Excessive		11.8	20.7	67.4	1.4	1.5	1.5	81	12	41	5.0
LU8	0.10	Plain	High	Unreliable	Well	<5.0	18.7	42.4	38.9	1.3	1.4	1.1	87	13	83	5.6
LU9	0.12	Hilly	Medium	Rainfed	Well	5.0-8.0	29.1	36.1	34.8	1.2	1.1	1.0	85	9	96	5.6
LU10	0.08	H & M	Low	Rainfed	Imperfect	5.0-15.0	31.3	44.0	24.7	1.3	0.9	0.9	94	7	74	6.0
LU11	0.10	H & M	Very low	Rainfed	Excessive	8.0-15.0	21.6	20.0	58.4	1.3	0.5	0.6	50	13	51	5.7

[a] P. Plain = Poyang Lake Plain, A. Plain = Alluvial plain along rivers, H = hilly area, M = mountainous area. In hilly areas, more than 40% of the area ranges between 100 and 500 m, and less than 40% is above 500 m. In mountainous areas, more than 40% of the area is above 500 m, and less than 40% ranges between 100 and 500 m.

[b] Based on DLMJP (1991a, b).

[c] Availability and reliability of irrigation water.

[d] Only applicable to non-rice land.

[e] Bulk density.

[f] Organic carbon.

[g] Total nitrogen (g kg^{-1}).

[h] Alkali-hydrolysable nitrogen (mg kg^{-1}).

[I] 0.5 M $NaHCO_3$ extractable P (Olsen-P) (mg kg^{-1}).

[j] 1 N NH_4-acetate extractable K (mg kg^{-1}).

[k] Soil pH (H_2O, 1:1).

The only non-rice land with access to irrigation water (although unreliable during autumn) is land unit 8 (LU8) in the Poyang Lake Plain and the alluvial plains along the major rivers. Consequently, a wide range of non-rice crops, such as cotton, groundnut, soybean, watermelon, maize, rapeseed, potato, sweet potato, green manures and forage crops, can be grown. Land unit 9 (LU9) is located in the hilly area. Crops suitable for LU9 are similar to those for LU8, but their yields are lower. Traditionally, most of the cotton in Jiangxi is grown on LU8 and LU9. In the hilly and mountainous areas, land unit 10 (LU10) and land unit 11 (LU11) predominate. Although their physical properties differ widely, *i.e.* LU10 is imperfectly drained and LU11 excessively drained, both face soil erosion problems. Both, LU10 and LU11 are inaccessible to machines due to lack of infrastructure. Major crops grown include watermelon, rapeseed, sweet potato, groundnut and forage crops. However, yields are much lower than on LU8 and LU9, due to mainly lower soil fertility and water shortage.

4.2.2.2 Land use types

For both, current and alternative cropping systems, 45 LUTs (Appendix II) have been specified, consisting of combinations of 38 crop types (Appendix I). All major current crop types and LUTs in Jiangxi (Huang, 2000a; Luo and Peng, 2003) are included and combined into triple, double or single cropping systems. Among the 38 crop types, three perennial forage crops are included: dwarf elephant grass (*Pennisetum purpureum* Schum cv. Mott), Guimu No. 1 hybrid elephant grass ((*Pennisetum americium* × *Pennisetum purpureum* Schum cv. Mott) × *Pennisetum purpureum* Schum cv. Mott) and Chinese kudzu (*Pueraria edulis* Pamp.). The suitability of LUTs for specific land units is based on current cropping patterns and on expert knowledge for specific LUT/LU combinations that are not yet common in Jiangxi (Appendix II).

In alternative LUTs, current rice varieties are replaced by Super Rice varieties with higher yield potential. Since security of grain supply remains one of the major objectives in China, both in policy and research, priority is given to the development of new rice varieties and improved management to increase rice yields and profitability. The Super Rice Project, started in 1996, aims at breeding of ‘super’ high-yielding rice varieties by combining an ideal plant architecture and heterosis of F1 hybrids between *indica* and *japonica* subspecies (Wang *et al*., 2005). The objective is to increase current rice yield with 15 and 30% in 2010 and 2030, respectively (Min *et al*., 2002; Xie, 2004; Cheng, 2005; Li, 2005b, c). The first Super Rice variety, a two-line hybrid rice, named Liangyoupeijiu, was demonstrated in 1999 with average yield of 9 Mg ha^{-1} (Zhou *et al*., 2003). Since then, over 20 Super Rice varieties, including three-line hybrid rice varieties, two-line hybrid rice varieties and conventional rice varieties, have been demonstrated successfully across the country (Min *et al.*, 2002; Xie, 2004; Cheng, 2005). In 2006, a three-line hybrid rice variety named Xingan 688, the first Super Rice variety bred in Jiangxi, was successfully demonstrated (JAU, 2007). In this chapter, yield potentials of Super Rice varieties are assumed to exceed those of current rice varieties by 30%.

4.2.2.3 Production techniques

Production techniques in current cropping systems are described based on information from practice, *i.e.* surveys, experiments, expert knowledge, *et cetera*. Alternative production techniques considered in this study include site-specific nutrient management (SSNM), integrated pest management (IPM) and mechanized rice production.

Site-specific nutrient management (SSNM)

SSNM is a production technique aiming at synchronizing nutrient availability with the needs of the growing rice crop (Dobermann *et al.*, 2002; IRRI, 2007), through dynamic field-specific management of fertilizer N, P, and K. The crop's requirements for fertilizer N, P and K are determined from the gap between crop nutrient demand to realize a well-defined yield and nutrient supply from indigenous sources. Application and management of nutrients are dynamically adjusted to location- and season-specific crop needs. Target yields and yields from nutrient omission plots are directly used in a simplified manner to estimate fertilizer N, P and K requirements (Dobermann *et al.*, 2004; IRRI, 2007).

Total fertilizer N requirements (FN, kg N ha^{-1}) are derived from the anticipated crop response to fertilizer N application, defined as the difference between target yield (Ytarget, kg ha^{-1}) and N-limited yield (Y0N, kg ha^{-1}) (Pampolino *et al.*, 2007; IRRI, 2007):

$$FN = \frac{(Ytarget - Y0N)}{AEN}$$

Where: AEN is the agronomic efficiency of applied N (kg grain per kg N applied).

AEN in farmers' fields is often in the range of 15 to 25 kg kg^{-1}. An AEN of 25 is attainable under good crop management in seasons with favourable weather conditions and 20 with good crop management in seasons with less favourable weather conditions, such as rainy seasons with lower solar radiation, and 15 in situations where existing fertilizer N management practices are very inefficient (IRRI, 2007). N-limited yield is determined in N-omission plots with ample supply of P and K.

P and K fertilizer requirements in SSNM are determined similarly to those for N. P-limited yield is determined in a P-omission plot, and fertilizer P requirements are derived from the difference between target yield and P-limited yield. Depending on P-limited yield and target yield, 10 to 20 kg P_2O_5 is required per Mg grain production.The crop's need for fertilizer K is also based on the difference between target yield and K-limited yield. In general, 30 kg K_2O is required per Mg grain production (IRRI, 2007).

SSNM can increase N use efficiencies and increase rice yields (Wang *et al.*, 2001, 2003; Dobermann *et al.*, 2004), and reduce N_2O emission (Pampolino *et al.*, 2007). Recent studies indicate that SSNM can maintain rice yields under farmers' conditions with significantly less fertilizer N and that most farmers are willing to adopt SSNM (Hu *et al.*, 2007; Wang *et al.*, 2007). Currently, SSNM is not practiced in Jiangxi, but the adoption may lead to improved nutrient use efficiency and reduced N loss to the environment.

Integrated pest management (IPM)

Concerns about human health and environmental effects associated with biocide use have motivated the development of IPM programs around the world (Cuyno *et al.*, 2001). IPM aims at reducing pest damage to tolerable levels, using biological and cultivation methods, genetically resistant hosts, and, when appropriate, chemical methods, especially those that are selective and do not contribute to environmental contamination and human health problems (Zalom, 1993).

Principles of IPM in rice, cotton, sugarcane, tobacco and vegetables were developed, tested and demonstrated in Jiangxi during the 1980s and 1990s (CCHPPJ, 2001). IPM in rice production comprised the use of disease-resistant varieties, hygienic measures such as clearing of bunds, ditches and irrigation canals from weeds, catching insects with light-traps, balanced fertilization, alternate wet and dry irrigation, growing host plants (*e.g.* soybean) of natural enemies on bunds and the use of more appropriate biocide application techniques (Huang and Zhang, 1990; JXPPS, 1991a, b, c; CCHPPJ, 2001). Results of demonstrations showed that savings of 40% on insecticides and 20% on fungicides were attainable, but that more labour was required for crop management (CCHPPJ, 2001). In cotton, major IPM measures included varieties with high resistance to insects and diseases, hygienic measures similar to those used in rice, treatment of seed with biocides, intercropping of cotton with maize and control of insects through light-traps (Zhang, 1990; CCHPPJ, 2001). Results of demonstrations have shown that savings of 30% on insecticides and 20% on fungicides are possible (CCHPPJ, 2001).

Mechanization of rice production

To improve labour productivity, the Chinese government subsidizes the purchase and use of machinery for rice production since 2004 (CCCPC and SCC, 2004). Currently, about 60% of the land preparation in Jiangxi's rice area, 30% of the harvesting and 1% of the transplanting is mechanized. To address the issue of increased mechanization, the alternative production technique in rice production assumes mechanization of 100% of land preparation and harvesting, and for transplanting 75% of ER and 50% of LR. The use of machinery is expressed in monetary terms, using rental prices (Table 4.3). Labour requirements are specified for land preparation (*e.g.* maintenance of bunds, ploughing, puddling and leveling), crop establishment (*e.g.* raising seedlings and transplanting), crop management (*e.g.* application of fertilizers and biocides) and harvesting. Mechanized operations are not considered for LU3 and LU6, because of their inaccessibility for machinery.

Table 4.3 *Machine rent (Yuan ha^{-1}) and labour requirements for land preparation (d ha^{-1}), crop establishment (d ha^{-1}), crop management (d ha^{-1}) and harvesting (d Mg^{-1}) in rice production.*

	Land preparation	Crop establishment	Crop Management[a]	Harvesting
Labour requirements without machines:				
Early rice	40	40	30	6.5
Late rice	40	40	45	6.5
Single rice	40	40	45	6.5
Labour requirements with machines:				
Early rice	3.2	0.8	30	2.0
Late rice	3.2	0.8	45	2.0
Single rice	3.8	0.8	45	2.0
Machine rent:				
Early rice	600	450		750
Late rice	600	600		600
Single rice	675	600		525

[a] No machines are used in crop management.

4.2.3 Current and alternative cropping systems

For current practice, 243 cropping systems have been identified, taking into account observed LU-LUT combinations (Appendix II), of which 108 rice-based systems including one or two rice crop types.

Three types of alternative cropping systems are distinguished: (i) cropping systems based on Super Rice varieties; (ii) cropping systems based on individual production techniques, *i.e.* SSNM and IPM for both rice and non-rice crops, and cropping systems with mechanized field operations in rice; and (iii) cropping systems combining Super Rice varieties and the alternative production techniques.

4.3 Quantification of inputs and outputs of cropping systems

TechnoGIN (Ponsioen *et al*., 2006), a technical coefficient generator, has been used to generate technical coefficients for both current and alternative cropping systems, although in a different way. This expert tool integrates systems analytical knowledge, expert knowledge and agronomic data, enabling the assessment of inputs and outputs of cropping systems and the evaluation of their resource use efficiency. The term 'technical coefficients' refers to inputs and outputs of a cropping system. For each cropping system, a unique combination of inputs results in a unique combination of outputs (Hengsdijk *et al*., 2000). In this study, inputs of cropping systems include seed, biocides, fertilizer, agricultural plastic, labour requirements, requirements for animal traction, machinery requirements, implements and irrigation water. Outputs are crop yields, crop residues, N losses and a biocide index (BIOI). The BIOI takes into account the active ingredients used, their degree of toxicity as well as their persistence in the environment (Jansen *et al*., 1995; Hengsdijk *et al*., 2000; Schipper *et al*., 2000).

All outputs are expressed in physical terms, and yields also in monetary terms. Inputs of seeds, biocides, fertilizers and animal traction are expressed in both physical and monetary terms. Other inputs are expressed in monetary terms only. Gross margins of a cropping system are defined as the value of crop products minus the costs of non-labour inputs.

4.3.1 Current cropping systems

For quantification of inputs and outputs of current systems, TechnoGIN has been used in an input-oriented way, *i.e.* most inputs and outputs are based on observed data from farm surveys and experiments (Table 4.4), and outputs that have not been measured in practice, such as N losses and BIOI, have been generated using TechnoGIN. The majority of the data on crop yields (Appendix I), fertilizer use (Appendix III), biocide use (Appendix IV), input of seed, labour, animal traction, irrigation water and costs of non-labour inputs (Appendix V) have been derived from farm surveys between 2000 and 2005 in Jiangxi. Some data of vegetables have been derived from farm surveys in Pujiang, Zhejiang Province, characterized by comparable environmental conditions. Prices refer to 2005. Inputs and outputs for the three perennial forage crops represent average annual values (Tawang *et al.*, 2000), based on a life cycle of 5 years.

4.3.2 Alternative cropping systems

For alternative cropping systems, TechnoGIN has been used in a target-oriented way. For example, crop yields are fixed and inputs and other outputs are calculated using its databases and generic calculation rules. In alternative cropping systems with Super Rice varieties, yields are 30% higher than in current systems, and associated nutrient and biocide requirements increase proportionally with yield. Labour requirements are identical to those in current systems, except for harvesting, where labour requirements depend on yield.

In alternative cropping systems applying SSNM, fertilizer NPK requirements for rice are based on the recommendations for SSNM in Jiangxi (Table 4.5). On the basis of yields in N, P and K-omission plots in long-term soil fertility experiments in five land units in Jiangxi and an AEN of 25 kg kg^{-1}, nutrient requirements for realization of specific target yields have been estimated (Table 4.5). For estimation of the P requirements, it is assumed that 10 to 20 kg P_2O_5, depending on indigenous P-supply and target yield, is required per Mg grain production. For estimation of the K requirements, it is assumed that 30 kg K_2O is required per Mg grain production. It is assumed that less than 1 Mg ha^{-1} rice straw is returned to the soil, since most of the rice straw is either harvested to feed cattle or is burned. We have assumed that the SSNM concept could also be applied to non-rice crops. However, as no data from nutrient omission plots were available, the NPK requirements of non-rice crops under SSNM have been derived from the relative difference in NPK inputs between current practice and SSNM in rice production. Rice is not grown in the non-rice land units, so for the crops in non-rice land units LU8, LU9, LU10 and LU11, the data from LU1, LU4, LU5 and LU7 have been used, respectively. For both, rice and non-rice crops, 20% more labour is required for crop management to account for the split application of fertilizers and crop monitoring (Laborte, 2006).

Table 4.4 Location-specific information and data sources used to quantify inputs and outputs of cropping systems in Jiangxi.

Type of data	Method and period of data collection		Institution
	Method	Period	
Input and outputs of crop production	Farm surveys	2000-2005	Department of Agriculture of Jiangxi Province (DAJP)
Yields of some non-rice crops	Farm surveys and statistics	2003-2005	Jiangxi Provincial Statistic Bureau (JXSB)
Rice yields	Farm surveys	2001-2004	Jiangxi Provincial Rural Survey Team of JXSB
Land use	Land survey	2000	Department of Land and Resources of Jiangxi Province
Inputs and outputs of crops[a]	Farm surveys	2003-2005	National Development and Reform Commission (NDRC)
Long-term experimental soil data	Experiments	1984-2004	Jiangxi Provincial Soil and Fertilizer Station of DAJP
Soils	Experiments	2002-2004	Jiangxi Provincial Soil and Fertilizer Station of DAJP
Biocide use	Experiments and farm surveys	2003-2005	Jiangxi Provincial Plant Protection Station of DAJP
Inputs and outputs of forage crops	Experiments	2000-2005	Jiangxi Animal Husbandry Technology Extension Station
Land use	Land survey	1996-2000	Jiangxi Agricultural University (JAU)
Long-term experimental soil data	Experiments	1984-2004	College of Land Resources of JAU
Inputs and outputs of forage crops	Experiments and farm surveys	2001-2004	Feed Research Institute of JAU
Inputs and outputs of crop production	Farm surveys	2001	Jiangxi Academy of Agricultural Sciences (JXAAS)
Inputs and outputs of crop production	Farm surveys	2001	Agro-economic Research Institute of JXAAS
Long-term experimental soil data	Experiments	1984-2004	Soil and Fertilizer Research Institute of JXAAS
Soil data	Experiments	1998	Soil and Fertilizer Research Institute of JXAAS
Machine use	Farm surveys	2004	Agro-engineering Research Institute of JXAAS
Inputs and outputs of non-rice crops	Experiments	2001-2004	Upland Crop Research Institute of JXAAS
Inputs and outputs of forage crops	Experiments	2001-2004	Animal Husbandry and Veterinary Research Institute of JXAAS
Long-term experimental soil data	Experiments	1984-2003	Jiangxi Provincial Red Soil Research Institute
Inputs and outputs of nor-rice crops	Farm surveys in Pujiang	2000	Zhejiang University
Weather data		1984-2003	Huichang County Meteorological station in Southern Jiangxi
Weather data		1984-2003	Taihe County Meteorological station in Central Jiangxi
Weather data		1984-2003	Fengxin County Meteorological station in Northern Jiangxi

[a] Data of inputs and outputs of crops are published (NDRC, 2004, 2005, 2006).

For alternative cropping systems applying IPM, only biocide inputs and labour requirements have been modified. In rice, insecticide and fungicide requirements have been set to 40 and 20% lower, respectively, than in current systems. In non-rice crops, insecticide and fungicide requirements are set to 30 and 20% lower, respectively, than in current systems. Crop yields under IPM are identical to those in current systems, but labour requirements for crop management are 20% higher, due to the extra labour for hygienic measures and crop monitoring.

In the calculation of inputs and outputs for alternative mechanized rice systems, only the labour requirements and the costs of machines in rice have been modified (Table 4.3).

Table 4.5 Recommended fertilizer doses for N (kg N ha^{-1}), P (kg P_2O_5 ha^{-1}) and K (kg K_2O ha^{-1}) for rice in alternative cropping systems based on principles of site-specific nutrient management (SSNM) and yields in nutrient omission plots of long-term soil fertility experiments in Jiangxi.

Land unit	Nutrient[a]	Yield of omission plot (Mg ha^{-1})	Target yield (Mg ha^{-1})					
			4	5	6	7	8[b]	9[c]
Land unit 1	N	4	0	40	80	120	160	200
	P	5	0	20	30	40	60	80
	K	4	30	60	90	120	150	180
Land unit 2	N	3	40	80	120	160	200	240
	P	4	15	25	40	60	80	100
	K	4	30	60	90	120	150	180
Land unit 4	N	3	40	80	120	160	200	240
	P	3	20	40	60	80	100	120
	K	3	45	75	105	135	165	195
Land unit 5	N	2.5	60	100	140	180	220	
	P	2.5	30	50	70	90	110	
	K	3	45	75	105	135	165	
Land unit 7	N	2	80	120	160	200		
	P	2	40	60	80	100		
	K	2	60	90	120	150		

[a] Omitted nutrient in omission plot.
[b] Yields of 8 Mg ha^{-1} or higher are not feasible on LU7.
[c] Yields of 9 Mg ha^{-1} are not feasible on LU5 and LU7.

4.3.3 Comparison of farm survey results and data generated by TechnoGIN

In the comparison of farm survey data with those generated by TechnoGIN, results of early rice, late rice, single rice, rapeseed and cotton are analyzed using 2003-2005 farm survey data provided by the Department of Agriculture of Jiangxi Province. Results generated by TechnoGIN are shown for the fertile LU1 (LU8 for cotton) and less fertile LU5 (LU 9 for cotton). Average prices of 2005 are used in TechnoGIN to calculate the monetary value of crop inputs and outputs.

Since the farm survey data are averages collected on different land units, direct comparison with TechnoGIN results is not possible. The crop yields generated with TechnoGIN and from farm surveys are illustrated in Figure 4.2a. After implementation of favourable agricultural policies in 2004, aiming at stimulating grain production (Chapter 2), economic returns of rice substantially increased (Figure 4.2b: 2004 and 2005 vs. 2003). The economic returns for rice, calculated in TechnoGIN, are based on 2005 prices and can therefore not be compared to the observed 2003 data. Also for the non-rice crops such as rapeseed and cotton, the generated results are comparable to the data from the farm surveys, with the exception of the costs of non-labour inputs (Figure 4.2c) and labour requirements (Figure 4.2d) for cotton. One of the reasons is that the prices of agricultural inputs and cotton fluctuate in the course of the year. Average prices, as used in TechnoGIN, may deviate from the actual prices faced by farmers. In general, TechnoGIN satisfactorily reproduces the observed data.

4.4 Illustration of inputs and outputs of cropping systems

For illustrative purposes, some rice-based and non-rice based cropping systems are selected to show the generated input-output relations. The rice-based systems include LUTs of ER long-LR long-fallow (RRF), ER-LR-rapeseed (RRO), ER-LR-Italian ryegrass (RRG), eggplant-LR (EGR), ER-sweet potato (RST) and late single rice-single potato (RSP) on the fertile LU1 and the less fertile LU5. The non-rice based systems include LUTs of cotton (COT) and dwarf elephant grass (ELE) on the fertile LU8 and the less fertile LU9. For the forage crops such as Italian ryegrass and dwarf elephant grass, used as animal feed, the costs of non-labour inputs per Mg of fresh fodder are calculated. The purpose is to compare the costs of forage production in current cropping systems with those in alternative cropping systems.

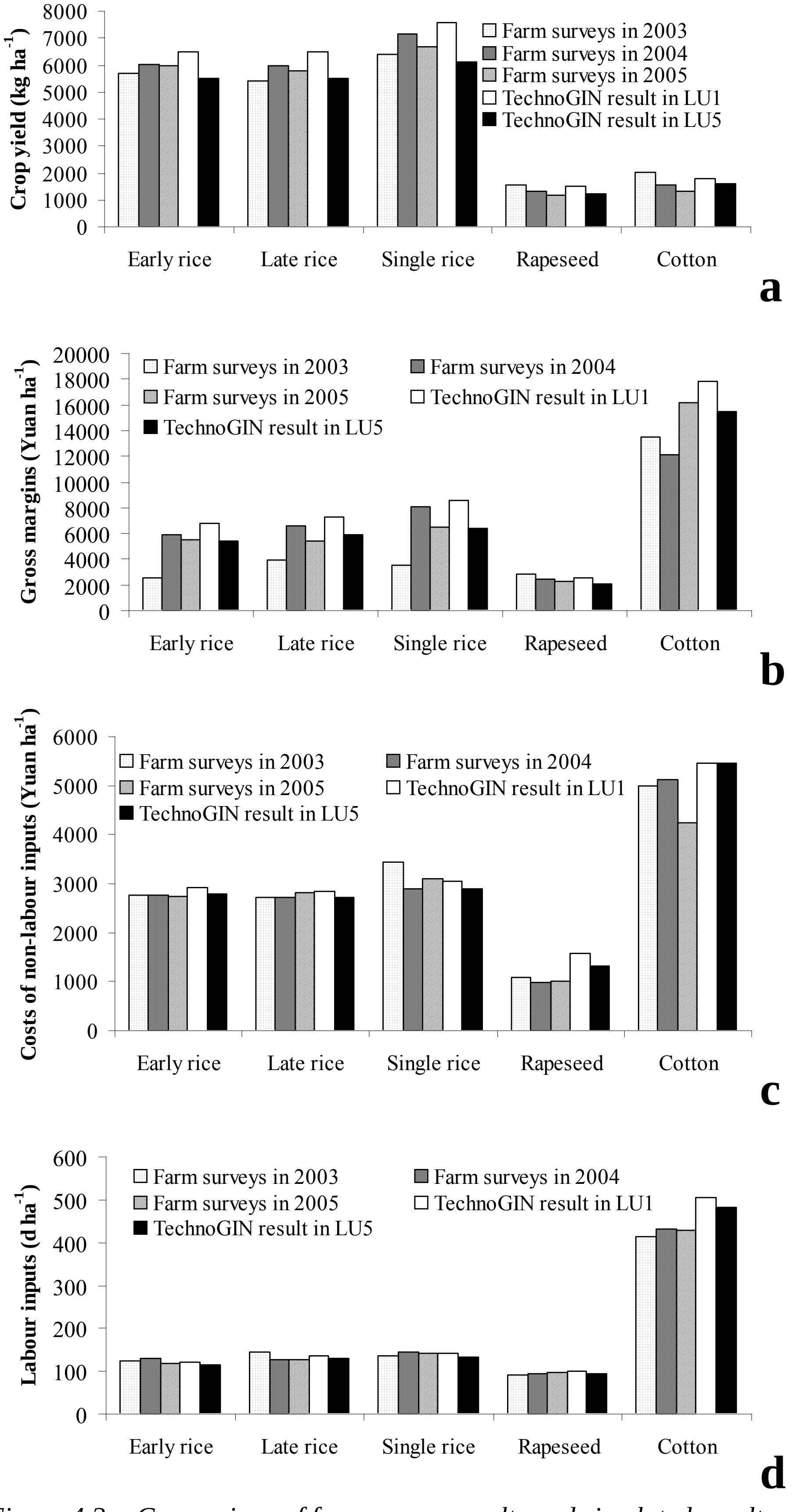


Figure 4.2 *Comparison of farm survey results and simulated results: crop yields (a), gross margins (b), costs of non-labour inputs (c) and labour inputs (d) of early rice, late rice, single rice, rapeseed and cotton.*

4.4.1 Current cropping systems

Gross margins of rice-based systems including vegetables (*e.g.* eggplant-LR) are about twice as high as those of rice-based systems without vegetables (*e.g.* ER long-LR long-fallow), which is associated with a much higher BIOI and high N loss (Table 4.6). N loss from RRG is also very high as a result of the large amounts of fertilizer N applied to Italian ryegrass, which is cut 3 times during the growing season, each time followed by fertilizer N application.

Gross margins of cotton are high (Table 4.7), but the biocide use of 11.9 kg a.i. ha^{-1} is also very high compared to rice and many non-rice crops use (Appendix IV). The adverse effect of biocide use in cotton on the environment and human health is a major concern in China (Huang *et al.*, 2003; Pemsl and Waibel, 2007). N loss of dwarf elephant grass is higher than that of almost all other crops except for vegetables, while its BIOI is lowest. This implies that expansion of elephant grass may contribute to increasing N pollution, but may reduce the negative effect on environment and human health associated with biocide use. The production costs per Mg of fresh weight for dwarf elephant grass (Table 4.7) are given for comparison with those of alternative cropping systems (Subsection 4.4.6).

4.4.2 Alternative cropping systems with Super Rice varieties

Both, land and labour productivity of rice production strongly increase following adoption of Super Rice varieties, even with current nutrient and pest management practices (Table 4.8). Gross margins of double rice are appreciably higher than those of cotton (Table 4.7) and its environmental performance is much better, *i.e.* biocide use (11.9 vs. 6.0 kg a.i. ha^{-1}) and BIOI (889 vs. 291 ha^{-1}) are much lower. Moreover, the returns to labour of rice are much higher. Therefore, adoption of Super Rice would strengthen the competitiveness of rice production for resources such as land and labour.

Table 4.6 Crop yield (Mg ha^{-1}), N use (kg N ha^{-1}), P use (kg P_2O_5 ha^{-1}), K use (kg K_2O ha^{-1}), biocide use (kg a.i. ha^{-1}), N loss (kg N ha^{-1}), biocide index (ha^{-1}), labour requirements (d ha^{-1}), costs of non-labour inputs (Yuan ha^{-1}) and gross margins (Yuan ha^{-1}) of some current rice-based cropping systems

Land unit	Land use type	Crop yield			NPK use			Biocide use[a]			N loss	BIOI[b]	Labour	Costs[c]	Gross margins[d]
		1st	2nd	3rd	N	P_2O_5	K_2O	Insecticide	Fungicide	Herbicide					
LU1	ERL-LRL[e]-fallow	7.2	7.2		352	114	240	1.6	2.6	0.2	231	226	265	6041	15991
	ER-LR[f]-rapeseed	6.5	6.5	1.5	395	142	286	2.1	3.4	1.1	224	335	357	7333	16697
	ER-LR-Italian ryegrass	6.5	6.5	60[g]	685	177	441	1.8	4.0	1.3	412	397	437	10486	12686
	Eggplant-LR	48	6.5		610	205	254	5.0	13.0	0.6	437	898	795	12245	31495
	ER-sweet potato	6.5	23		305	84	169	1.3	0.9	1.0	213	174	265	4575	13050
	LSR[h]-single potato	7.6	21		285	103	193	1.8	2.4	0.6	189	302	329	8598	15198
LU5	ERL-LRL-fallow	6.1	6.1		330	99	198	1.6	2.6	0.2	249	218	253	5830	12683
	ER-LR-rapeseed	5.5	5.5	1.2	345	113	225	2.1	3.4	1.1	221	330	341	6809	13375
	ER-LR-Italian ryegrass	5.5	5.5	49[g]	665	163	403	1.9	4.0	1.3	425	392	416	10238	9272
	Eggplant-LR	39	5.5		600	200	235	5.0	13.0	0.6	429	895	717	12121	23759
	ER-sweet potato	5.5	18		295	75	150	1.3	0.9	1.0	202	170	249	4450	10178
	LSR-single potato	6.1	17		270	103	168	1.8	2.4	0.6	194	289	308	8416	10517

[a] Active ingredient (a.i.) applied.
[b] Biocide index per ha of land.
[c] Costs of non-labour inputs (Yuan ha^{-1}).
[d] Gross margins are value of production minus costs of non-labour inputs (Yuan ha^{-1}). The economic returns from the forage crops are not included.
[e] ERL = early rice long, LRL = late rice long.
[f] ER = early rice, LR = late rice.
[g] Total yield (fresh weight) of three cuts.
[h] LSR = late single rice.

Table 4.7 Crop yield (Mg ha^{-1}), N use (kg N ha^{-1}), P use (kg P_2O_5 ha^{-1}), K use (kg K_2O ha^{-1}), biocide use (kg a.i. ha^{-1}), N loss (kg N ha^{-1}), biocide index (ha^{-1}), labour requirements (d ha^{-1}), costs of non-labour inputs (Yuan ha^{-1}) and gross margins (Yuan ha^{-1}) of some current non-rice based cropping systems.

Land unit	Land use type	Crop yield	NPK use			Biocide use[a]			N loss	BIOI[b]	Labour	Costs[c]	Gross margins[d]
			N	P_2O_5	K_2O	Insecticide	Fungicide	Herbicide					
LU8	Cotton	1.8	325	130	250	8.6	2.4	0.9	237	889	505	5446	17837
	Dwarf elephant grass	120[e]	451	102	268	0.5	1.8	0.5	289	133	260	5451	45
LU9	Cotton	1.6	325	130	250	8.6	2.4	0.9	235	889	481	5446	15482
	Dwarf elephant grass	108[e]	451	102	268	0.5	1.8	0.5	304	133	248	5451	51

[a] Active ingredient (a.i.) applied.
[b] Biocide index per ha of land.
[c] Costs of non-labour inputs (Yuan ha^{-1}).
[d] Gross margins of cotton (Yuan ha^{-1}) and costs of non-labour inputs per Mg dwarf elephant grass (Yuan Mg^{-1}).
[e] Total yield (fresh weight) of five cuts.

Table 4.8 Crop yield (Mg ha^{-1}), N use (kg N ha^{-1}), P use (kg P_2O_5 ha^{-1}), K use (kg K_2O ha^{-1}), biocide use (kg a.i. ha^{-1}), N loss (kg N ha^{-1}), biocide index (ha^{-1}), labour requirements (d ha^{-1}), costs of non-labour inputs (Yuan ha^{-1}) and gross margins (Yuan ha^{-1}) of some alternative rice-based cropping systems with Super Rice varieties (see Table 4.6 for abbreviations and notes).

Land unit	Land use type	Crop yield 1st	2nd	3rd	NPK use N	P_2O_5	K_2O	Biocide use[a] Insecticide	Fungicide	Herbicide	N loss	BIOI[b]	Labour	Costs[c]	Gross margins[d]
LU1	ERL-LRL[e]-fallow	9.4	9.4		458	148	312	2.2	3.6	0.2	236	291	287	6877	21887
	ER-LR[f]-rapeseed	8.5	8.5	1.5	491	173	351	2.6	4.2	1.1	240	401	377	8136	21861
	ER-LR-Italian ryegrass	8.5	8.5	60[g]	781	208	506	2.5	4.8	1.3	446	463	457	11210	17929
	Eggplant-LR	48	8.5		658	219	287	5.3	13.4	0.6	442	936	805	12616	34166
	ER-sweet potato	8.5	23		353	101	202	1.5	1.2	1.0	207	203	275	4941	15609
	LSR[h]-single potato	9.9	21		335	121	228	2.1	3.0	0.6	205	349	340	8966	18319
LU5	ERL-LRL-fallow	7.9	7.9		429	129	257	2.2	3.6	0.2	278	293	271	6595	17472
	ER-LR-rapeseed	7.2	7.2	1.2	435	140	279	2.6	4.2	1.1	250	394	358	7520	17713
	ER-LR-Italian ryegrass	7.2	7.2	49[g]	755	190	457	2.5	4.8	1.3	456	456	433	10858	13701
	Eggplant-LR	39	7.2		645	212	262	5.3	13.4	0.6	452	930	725	12437	26017
	ER-sweet potato	7.2	18		340	90	177	1.5	1.2	1.0	221	200	258	4767	12337
	LSR-single potato	7.9	17		315	121	195	2.1	3.0	0.6	207	334	317	8789	12944

4.4.3 Alternative cropping systems with SSNM

The impacts of SSNM on both, rice and non-rice crops, are presented here. For a given (target) yield level, fertilizer N requirements in the cropping systems applying SSNM are considerably lower than in those with conventional N management (Figures 4.3 and 4.4a). Generally, more N can be saved in the fertile LU1 and LU8. Using SSNM practices, P requirements in the fertile LU1 and LU8 are lower than under current management, but higher in the less fertile LU5 and LU9 (Figures 4.3 and 4.4b). K requirements using SSNM are higher than under current K management in almost all land units (Figures 4.3 and 4.4c). These results suggest that N is oversupplied and K is undersupplied in the current situation in Jiangxi. For P, the picture is more differentiated, as it is oversupplied in the more fertile land units in the plains, but undersupplied in the hilly and mountainous areas (Ye *et al*., 1999; Ye and Liu, 2000; JXAAS, 2001). The widespread K-deficiency in Jiangxi is one of the major constraints for increasing crop yields (Ye *et al*., 2001; Li *et al*., 2003c; Zeng *et al*., 2005).

N losses can be reduced substantially using SSNM for all crops, especially vegetable and forage crops (Figures 4.3 and 4.5). Since in general more P and specifically more K are needed using SSNM, savings on fertilizer costs are small. Gross margins of cropping systems with SSNM are similar to those with current nutrient management, but more labour is needed (Figure 4.3), so that labour productivity is lower.

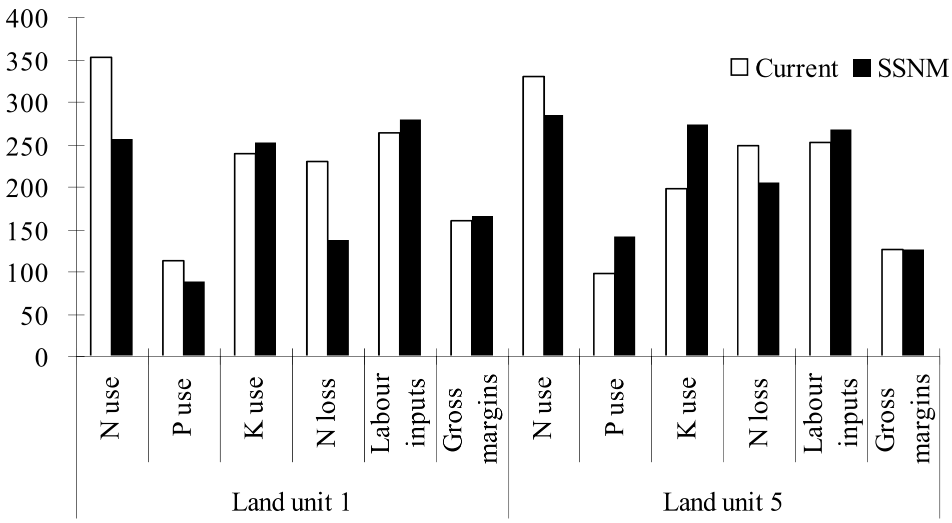


Figure 4.3 Comparison of fertilizer N use (kg N ha^{-1}), fertilizer P use (kg P_2O_5 ha^{-1}), fertilizer K use (kg K_2O ha^{-1}), N loss (kg N ha^{-1}), labour requirements (d ha^{-1}) and gross margins (10^2 Yuan ha^{-1}) between current nutrient management and site-specific nutrient management (SSNM) for land use type of early rice long-late rice long-fallow (RRF) on land unit 1 and land unit 5.

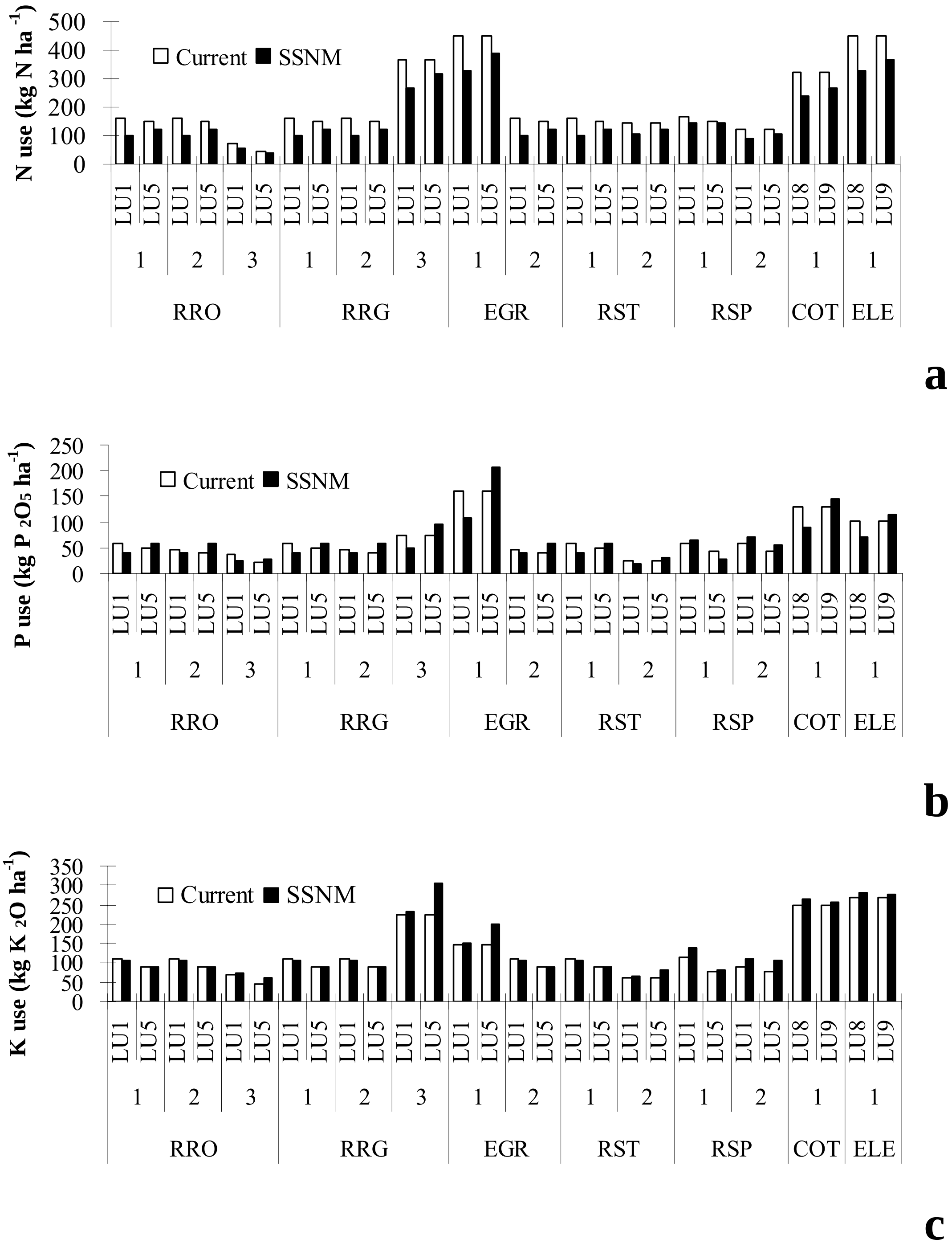


Figure 4.4 *Fertilizer requirements for N (a), P (b) and K (c) per crop in different cropping systems with current practice and site-specific nutrient management (SSNM). Note: Early rice-late rice-rapeseed (RRO), early rice-late rice-Italian ryegrass (RRG), eggplant-late rice (EGR), early rice-sweet potato (RST) and late single rice-single potato (RSP) on land unit 1 (LU1) and land unit 5 (LU5); cotton (COT) and dwarf elephant grass (ELE) on land unit 8 (LU8) and land unit 9 (LU9). In the figures, '1' on the X-axis refers to the first crop, '2' to the second crop and '3' to the third crop of land use types.*

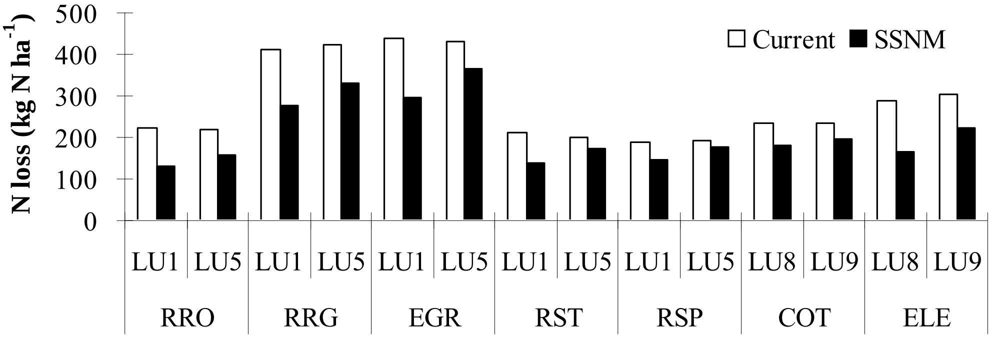


Figure 4.5 Calculated (TechnoGIN) N loss with current practice and site-specific nutrient management (SSNM) in early rice-late rice-rapeseed (RRO), early rice-late rice-Italian ryegrass (RRG), eggplant-late rice (EGR), early rice-sweet potato (RST) and late single rice-single potato (RSP) on land unit 1 (LU1) and land unit 5 (LU5); cotton (COT) and dwarf elephant grass (ELE) on land unit 8 (LU8) and land unit 9 (LU9).

4.4.4 Alternative cropping systems with IPM

The land use type RRF on LU1 has been selected to illustrate the difference between current pest management and IPM in rice production. Insecticide and fungicide use can be reduced significantly under IPM (Figure 4.6), which is also reflected in the biocide index (Figure 4.7). However, more labour is needed for crop management (Figure 4.7). Although savings on biocide use are possible, gross margins of alternative cropping systems are only slightly higher than those of current systems (Figure 4.7), because biocides represent 7 to 18% of the total costs of non-labour inputs (Chapter 2).

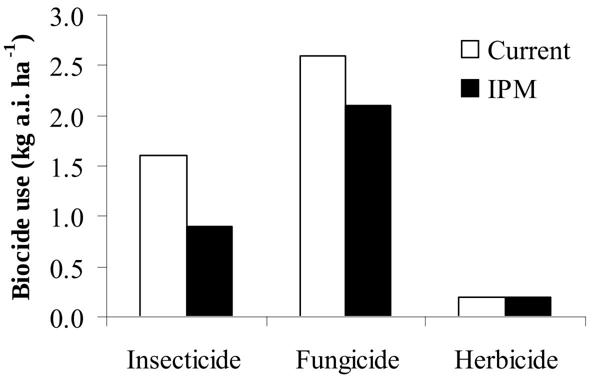


Figure 4.6 Insecticide, fungicide and herbicide use under current practice and integrated pest management (IPM) in early rice long-late rice long-fallow (RRF) on land unit 1.

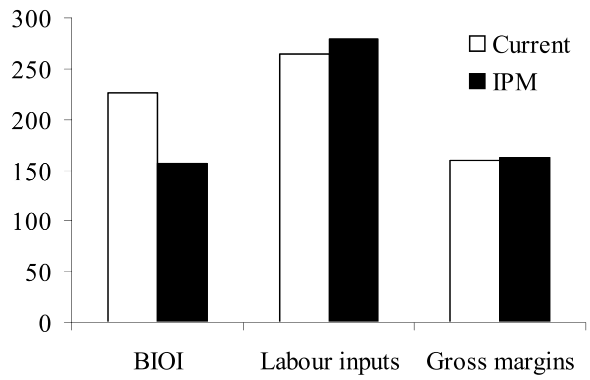


Figure 4.7 *Biocide index (BIOI) (ha^{-1}), labour inputs (d ha^{-1}) and gross margins (10^2 Yuan ha^{-1}) under current practice and integrated pest management (IPM) in early rice long-late rice long-fallow (RRF) on land unit 1.*

Five LUTs on LU1 have been selected to illustrate the impact of IPM on rice and non-rice crops in the rice-based cropping systems and two LUTs on LU8 to illustrate the impact on crops in non-rice based cropping systems. With adoption of IPM, the biocide index in the cropping systems with vegetables and cotton is much lower than under current practice (Figure 4.8a), with similar economic consequences (Figure 4.8b). The result shows that the BIOI of dwarf elephant grass is much lower than that of other LUTs under both current practice and IPM (Figure 4.8a).

4.4.5 Mechanized rice systems

In mechanized rice systems, labour requirements are substantially lower (Table 4.9), particularly in April, July and October, the months with the highest labour peaks (Figure 4.9). The returns to labour are much higher. However, gross margins are lower due to the costs of machines (Table 4.9).

Table 4.9 *Labour requirements (d ha^{-1}), costs of non-labour inputs (Yuan ha^{-1}), gross margins (Yuan ha^{-1}) and returns to labour (Yuan d^{-1}) in early rice long-late rice long-fallow (RRF) under current and mechanized rice systems on land unit 1 and land unit 5.*

Land unit	Rice system	Labour	Costs	Gross margins	Returns to labour
Land unit 1	Current	265	6041	15991	60
	Mechanized	141	7629	14403	102
Land unit 5	Current	253	5830	12683	50
	Mechanized	136	7444	11069	81

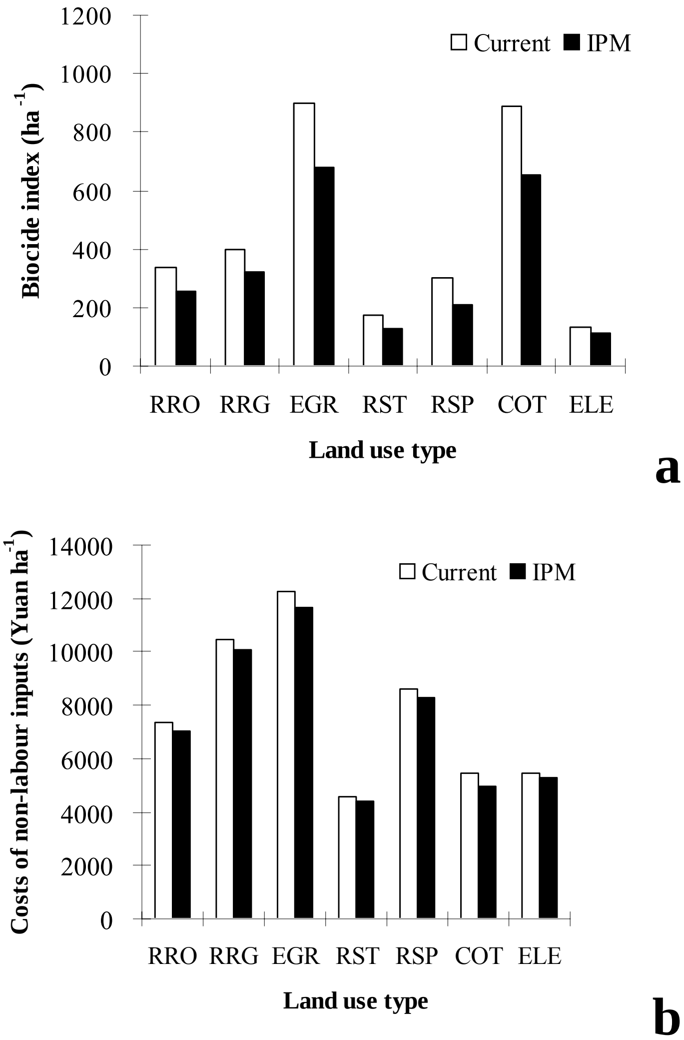


Figure 4.8 *Calculated (TechnoGIN) biocide index (a) and costs of non-labour inputs (b) under current practice and integrated pest management (IPM) in early rice-late rice-rapeseed (RRO), early rice-late rice-Italian ryegrass (RRG), eggplant-late rice (EGR), early rice-sweet potato (RST) and late single rice-single potato (RSP) on land unit 1; and cotton (COT) and dwarf elephant grass (ELE) on land unit 8.*

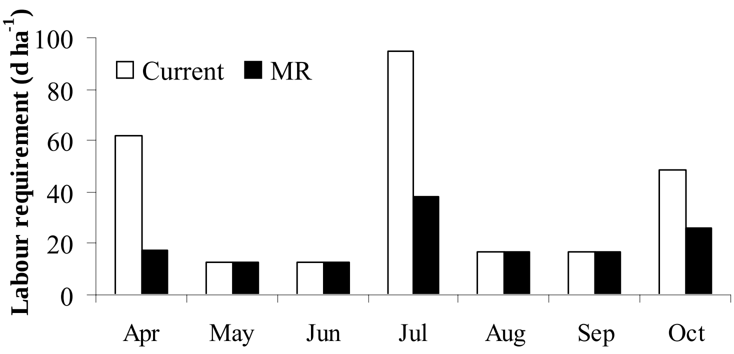


Figure 4.9 *Monthly labour requirements of early rice long-late rice long-fallow (RRF) on land unit 1 for current and mechanized rice systems (MR).*

4.4.6 Alternative cropping systems with Super Rice varieties and alternative production techniques

When the current rice varieties are replaced by Super Rice varieties, a high mechanization level is applied in rice production and both SSNM and IPM are adopted in all crops, both rice and non-rice crops can be produced in a more environmentally friendly way without sacrificing economic viability (Tables 4.10 and 4.11). Rice yields are higher, while N losses and biocide indices are lower. Also for non-rice crops with high inputs of fertilizers and biocides (*e.g.* vegetables), N loss and biocide indices can be reduced substantially.

4.5 Discussion and conclusions

The quality of input-output relations generated for both current and alternative cropping systems is strongly dependent on the quality of the input data. Most of the farm surveys and experiments from which data were used, were carried out in recent years by provincial research institutions, universities and government organizations (Table 4.4), giving confidence that the data used are representative for the current situation. The information collected on inputs and outputs comprises both physical and monetary values, which facilitated integration in and comparison with results generated by TechnoGIN. Comparison of simulated results and farm survey results shows that the technical coefficient generator TechnoGIN satisfactorily reproduces the input information, which gives confidence in the relevance of the characteristics that have been derived from the input data. The quality of the input data to TechnoGIN is acceptable given that it is a static model, hampering to capture temporal variability in data, and that many of the observed data are not spatially explicit.

TechnoGIN was principally developed to generate input-output relations of cropping systems for incorporation in LP models (Ponsioen *et al.*, 2006), but it also can serve as an analysis tool for assessing the performance of alternative cropping systems, characterized by different crops and/or different production techniques. Results show that both, land and labour productivity could be increased significantly with the adoption of Super Rice varieties. However, most of currently available Super Rice varieties are only suitable for single rice systems. Super Rice varieties with short growth durations suitable for double rice systems are still scarce. Currently, large amounts of biocides are used in rice, which not only increases production costs but also causes public health problems (Huang *et al.*, 2001). The use of fertilizer N in rice is also high, with an average N application rate of 180 kg N ha^{-1}. In the major rice-

Table 4.10 Crop yield (Mg ha^{-1}), N use (kg N ha^{-1}), P use (kg P_2O_5 ha^{-1}), K use (kg K_2O ha^{-1}), biocide use (kg a.i. ha^{-1}), N loss (kg N ha^{-1}), biocide index (ha^{-1}), labour requirements (d ha^{-1}), costs of non-labour inputs (Yuan ha^{-1}) and gross margins (Yuan ha^{-1}) of some rice-based alternative cropping systems with adoption of Super Rice varieties and alternative production techniques (see Table 4.6 for abbreviations and notes).

Land unit	Land use type	Crop yield			NPK use			Biocide use[a]			N loss	BIOI[b]	Labour	Costs[c]	Gross margins[d]
		1st	2nd	3rd	N	P_2O_5	K_2O	Insecticide	Fungicide	Herbicide					
LU1	ERL-LRL[e]-fallow	9.4	9.4		429	174	382	1.3	2.9	0.2	215	200	174	8549	20215
	ER-LR[f]-rapeseed	8.5	8.5	1.5	411	164	399	1.9	3.4	1.1	202	290	278	9324	20673
	ER-LR-Italian ryegrass	8.5	8.5	60[g]	621	188	561	1.7	3.8	1.3	351	359	368	12091	17048
	Eggplant-LR	48	8.5		505	178	316	3.9	10.6	0.6	332	696	822	12212	34570
	ER-sweet potato	8.5	23		284	86	227	1.1	1.0	1.0	161	147	235	5522	15028
	LSR[h]-single potato	9.9	21		323	127	288	1.4	2.3	0.6	192	229	295	9617	17668
LU5	ERL-LRL-fallow	7.9	7.9		430	215	322	1.3	2.9	0.2	279	201	168	8501	15566
	ER-LR-rapeseed	7.2	7.2	1.2	411	215	341	1.8	3.3	1.1	230	286	267	9386	15846
	ER-LR-Italian ryegrass	7.2	7.2	54[g]	686	280	586	1.5	3.7	1.3	405	354	357	12773	12060
	Eggplant-LR	39	7.2		573	300	339	3.9	10.6	0.6	402	692	747	12955	25499
	ER-sweet potato	7.2	18		311	125	222	1.1	1.0	1.0	204	145	222	5775	11329
	LSR-single potato	7.9	17		321	164	270	1.4	2.3	0.6	218	220	278	9695	12038

Table 4.11 Crop yield (Mg ha^{-1}), N use (kg N ha^{-1}), P use (kg P_2O_5 ha^{-1}), K use (kg K_2O ha^{-1}), biocide use (kg a.i. ha^{-1}), N loss (kg N ha^{-1}), biocide index (ha^{-1}), labour requirements (d ha^{-1}), costs of non-labour inputs (Yuan ha^{-1}) and gross margins (Yuan ha^{-1}) of non-rice based alternative cropping systems with adoption of alternative production techniques (see Table 4.7 for abbreviations and notes).

Land unit	Land use type	Crop Yield	NPK use			Biocide use[a]			N loss	BIOI[b]	Labour	Costs[c]	Gross margins[d]
			N	P_2O_5	K_2O	Insecticide	Fungicide	Herbicide					
LU8	Cotton	1.8	236	89	263	6.0	2.0	0.9	170	655	574	4460	18822
	Dwarf elephant grass	120[e]	328	70	281	0.3	1.4	0.5	166	112	308	4766	40
LU9	Cotton	1.6	266	146	257	6.0	2.0	0.9	226	655	550	4760	16168
	Dwarf elephant grass	108	369	115	275	0.3	1.4	0.5	222	112	296	5044	47

producing areas, where high-yielding varieties prevail, N application rates of 270-300 kg N ha^{-1} are not uncommon (Wang *et al*., 2003c; Zhang *et al*., 2003). Concurrent adoption of site-specific nutrient management (SSNM) and integrated pest management (IPM) could contribute to mitigation of such problems.

Adoption of SSNM could result in strongly reduced N losses. However, total fertilizer costs are hardly affected, as generally more K fertilizers are required with SSNM in Jiangxi. This is the result of the current low and deficient K application rates in rice production in Jiangxi (Ye *et al*., 1999, 2001; JXAAS, 2001; Li *et al*., 2003c; Zeng *et al*., 2005). Improved fertilizer management through SSNM could lead to improved soil fertility in the long run (Witt *et al*., 2002), and to reduced damage by insect pests and diseases, thereby reducing the need for and costs of pesticides (Wang *et al*., 2007). However, these effects have not been taken into account in the generation of inputs and outputs through TechnoGIN. Technically, dissemination of SSNM in practice is not feasible in the near future for all crops. Realization of nutrient omission plots for each crop and each land unit requires large investments. In addition, strong institutional support is required for implementing SSNM (Wang *et al*., 2007). Lack of young and educated workers in rural areas further limits the adoption of SSNM.

Biocide use can be reduced significantly when adopting IPM, as experiences in Jiangxi have shown. However, implementation of IPM appears difficult in practice. First, the required daily and field-specific monitoring of the occurrence of pests and diseases is difficult to realize following the collapse of the agricultural extension systems in China (Huang *et al*., 2001). Then, crop monitoring and implementing hygienic measures are both labour- and knowledge-intensive. Some hygienic measures, for instance clearing of bunds, ditches and irrigation canals from weeds, require cooperation of farmers. Such actions are often difficult to organize. Moreover, total production costs are not much lower with IPM, since biocides are cheap and their share in the total costs of non-labour inputs is low (Chapter 2). Currently, most farmers prefer to apply biocides in preventive actions, mainly because risk for crop damage is much lower (JXAAS, 2001; Li *et al*., 2004).

With mechanization in rice production, labour requirements can be reduced while the returns to labour can be increased significantly. Experience in Jiangxi has shown that mechanization in rice production facilitates rice production by farmers and allows farmers to work off-farm and earn higher wages in the cities (Deng, 2007).

Adoption of improved technologies often results in higher economic surplus and less environmental contamination in crop production (cf. Schipper *et al*, 2000). In this study, also a win-win situation is apparent, *i.e.*, the considered alternative cropping systems result in higher economic returns or more crop production with lower adverse effects on the environment and human health. This implies that adoption of new cropping systems could play an important role in guaranteeing national food security, but also may contribute to attainment of other rural development goals such as increasing income and reducing pollution.

Appendix I

Crop yields in different land units (LU) in Jiangxi (Mg ha^{-1}).

Crop	LU1	LU2	LU4	LU5	LU7	LU8	LU9	LU10	LU11
Early rice long	7.2	7.2	6.6	6.1					
Late rice long	7.2	7.2	6.6	6.1					
Early rice	6.5	6.5	6.0	5.5	3.8				
Late rice	6.5	6.5	6.0	5.5					
Early single rice	7.6	7.6	6.8	6.1	4.1				
Late single rice	7.6	7.6	6.8	6.1					
Sweet potato	23	23	21	18	12	23	17	14	11
Early maize	5.3	5.3	4.7	4.3	2.9	5.3	4.0	3.3	2.7
Late maize	5.3	5.3	4.7	4.3	2.9	5.3	4.0	3.3	2.7
Early sweet maize	5.3	5.3	4.7	4.3	2.9	5.3	4.0	3.3	2.7
Sorghum	5.0	5.0	4.5	4.0	2.7	5.0	3.8	3.1	2.5
Rapeseed	1.5	1.5	1.4	1.2	0.9	1.5	1.4	1.2	0.8
Single rapeseed	1.8	1.8	1.6	1.5	1.0	1.8	1.4	1.1	0.9
Soybean	1.7	1.7	1.5	1.3	0.9	1.7	1.2	1.0	0.8
Peanut	2.6	2.6	2.4	2.1	1.7	2.6	2.4	2.2	1.6
Cotton						1.8	1.6		
Tobacco	1.9	1.9	1.6	1.5	1.1	1.6	1.5	1.3	1.0
Sugarcane	50	50	46	41	33	50	46	41	30
Chinese white cabbage[a]	42	42	38	34					
Celery	55	55	49	44					
Chinese cabbage	60	60	54	49					
Watermelon	38	38	34	30					
Red pepper	34	34	31	28					
Eggplant	48	48	43	39					
Tomato	60	60	54	48					
Cucumber	51	51	45	40					
Radish	34	34	31	28					
Potato	17	17	15	14					
Single potato	21	21	19	17					
CMV[b]	19	19	17	16					
Single CMV	22	22	19	18					
Early silage maize	53	53	47	42	38	53	47	39	33
Late silage maize	45	45	40	36	33	45	40	33	28
Italian ryegrass	60	60	54	49	44	60	54	49	41
Single Italian ryegrass	72	72	65	59	43	72	65	59	48
Dwarf elephant grass					90	120	108	99	80
Hybrid elephant grass					100	130	117	106	88
Chinese kudzu					40	60	54	45	40

[a] In this study, the Chinese white cabbage is assumed to represent the "leafy vegetables". The data of Chinese white cabbage have been derived mainly from the data of "leafy vegetables" obtained from farm surveys in Pujiang.
[b] Chinese milk vetch.

Appendix II

Suitability of land use types for the eleven identified land units in Jiangxi Province.

Land use type	Land unit										
	1	2	3	4	5	6	7	8	9	10	11
Early rice long-late rice long-fallow	X	X		X	X						
Early rice-late rice-rapeseed	X	X		X	X						
Early rice-late rice-potato	X	X		X	X						
Early rice-late rice-CMV[a]	X	X		X	X						
Early rice-late rice-Italian ryegrass	X	X		X	X						
Early silage maize-late rice	X	X		X	X						
Sweet maize-late rice	X	X		X	X						
Tobacco-late rice	X	X		X	X						
Chinese white cabbage-late rice	X	X		X	X						
Watermelon-late rice	X	X		X	X						
Red pepper-late rice	X	X		X	X						
Eggplant-late rice	X	X		X	X						
Tomato-late rice	X	X		X	X						
Cucumber-late rice	X	X		X	X						
Early single rice	X	X	X	X	X	X	X				
Early rice-sweet potato	X	X		X	X						
Early rice-sorghum	X	X		X	X						
Early rice-soybean	X	X		X	X						
Early rice-late maize	X	X		X	X						
Early rice-late silage maize	X	X		X	X						
Chinese cabbage-late single rice	X	X		X	X						
Late single rice	X	X	X	X	X						
Late single rice-single rapeseed	X	X		X	X						
Late single rice-single potato	X	X		X	X						
Late single rice-single CMV[a]	X	X		X	X						
Late single rice-single Italian ryegrass	X	X		X	X						
Celery-Chinese white cabbage-radish	X	X		X	X						
Celery-red pepper-radish	X	X		X	X						
Sweet potato	X	X		X	X		X	X	X	X	X
Early maize	X	X		X	X		X	X	X	X	X
Sorghum	X	X		X	X		X	X	X	X	X
Rapeseed	X	X		X	X		X	X	X	X	X
Soybean	X	X		X	X		X	X	X	X	X
Groundnut	X	X		X	X		X	X	X	X	X
Cotton	X	X		X	X		X	X	X	X	X
Tobacco	X	X		X	X		X	X	X	X	X
Sugarcane	X	X		X	X		X	X	X	X	X
Watermelon	X	X		X	X		X	X	X	X	X
Early silage maize	X	X		X	X		X	X	X	X	X
Late silage maize	X	X		X	X						
Early silage maize-late silage maize	X	X		X	X						
Single Italian ryegrass							X	X	X	X	X
Dwarf elephant grass							X	X	X	X	X
Hybrid elephant grass							X	X	X	X	X
Chinese kudzu							X	X	X	X	X

[a] Chinese milk vetch.

Appenix III

Inputs of fertilizer N (kg N ha^{-1}), fertilizer P (kg P_2O_5 ha^{-1}) and fertilizer K (kg K_2O ha^{-1}), and total costs of fertilizers (Yuan ha^{-1}) in crop production in Jiangxi.

Crop	N	P_2O_5	K_2O	Costs of fertilizers
Early rice long	176	65	120	1298
Late rice long	176	65	120	1298
Early rice	160	59	109	1180
Late rice	160	45	109	1138
Early single rice	165	60	115	1224
Late single rice	165	60	115	1224
Sweet potato	145	25	60	859
Early maize	138	45	90	1009
Late maize	138	45	90	1009
Early sweet maize	138	45	90	1009
Sorghum	170	50	95	1150
Rapeseed	75	38	68	640
Single rapeseed	90	46	82	768
Soybean	20	25	15	208
Peanut	55	65	55	602
Cotton	325	130	250	2523
Tobacco	420	150	200	2814
Sugarcane	390	105	170	2456
Chinese white cabbage	209	69	130	1479
Celery	260	134	150	1954
Chinese cabbage	428	63	132	2356
Watermelon	175	55	140	1328
Red pepper	420	160	120	2592
Eggplant	450	160	145	2793
Tomato	465	180	235	3202
Cucumber	420	150	200	2814
Radish	400	50	68	2000
Potato	100	35	65	812
Single potato	120	43	78	958
Chinese milk vetch	24	27	45	326
Single Chinese milk vetch	28	31	52	375
Early silage maize	163	52	115	1279
Late silage maize	138	45	90	1009
Italian ryegrass	365	73	223	2522
Single Italian ryegrass	430	87	263	2946
Dwarf elephant grass	451	102	268	3085
Hybrid elephant grass	451	102	268	3085
Chinese kudzu	72	102	110	1061

Appendix IV

Biocide use (kg active ingredient (a.i.) ha^{-1}) and costs of biocides (Yuan ha^{-1}) of crop production in Jiangxi.

Crop	Insecticide	Fungicide	Herbicide	Costs
Early rice long	0.72	0.91	0.1	228
Late rice long	0.84	1.53	0.1	359
Early rice	0.65	0.83	0.1	207
Late rice	0.76	1.39	0.1	326
Early single rice	0.91	1.39	0.1	347
Late single rice	0.91	1.39	0.1	347
Sweet potato	0.68	0.14	0.9	65
Early maize	0.42	3.98	0.9	208
Late maize	0.62	3.98	0.9	218
Early sweet maize	1.62	5.38	0.9	310
Sorghum	1.56	0.80	0.27	222
Rapeseed	0.80	1.24	0.9	107
Single rapeseed	0.92	1.43	0.9	118
Soybean	0.69	0.29	0.9	52
Peanut	0.6	3.24	0.9	108
Cotton	8.52	2.42	0.9	1166
Tobacco	1.75	6.59	0.9	468
Sugarcane	2.64	3.38	0.9	349
Chinese white cabbage	1.53	5.40	0.45	919
Celery	1.98	12.13	0.45	949
Chinese cabbage	2.28	5.4	0.45	1039
Watermelon	1.12	9.24	0.45	385
Red pepper	3.64	11.46	0.45	1407
Eggplant	4.21	11.46	0.45	1280
Tomato	5.32	26.01	0.45	1818
Cucumber	4.09	17.61	0.45	1652
Radish	1.15	11.16	0.45	571
Potato	0.7	0.8	0.45	214
Single potato	0.9	1.0	0.54	257
Chinese milk vetch	0.6	0	1.13	75
Single Chinese milk vetch	0.72	0	1.13	81
Early silage maize	0.42	3.98	0.9	208
Late silage maize	0.62	3.98	0.9	218
Italian ryegrass	0.47	1.75	1.13	135
Single Italian ryegrass	0.56	2.10	1.13	153
Dwarf elephant grass	0.47	1.75	0.52	121
Hybrid elephant grass	0.47	1.75	0.52	121
Chinese kudzu	0.69	0	0.9	87

Appendix V

Inputs of seed (kg ha^{-1}), labour requirements (d ha^{-1} or d Mg^{-1}), animal draught (h ha^{-1}), cost of irrigation (Yuan ha^{-1}) and costs of other non-labour inputs (Yuan ha^{-1}) in crop production in Jiangxi.

Crop	Seed	Labour inputs				Ani[e]	Irri[f]	Other
		Pre[a]	Est[b]	Man[c]	Har[d]			Costs[g]
Early rice long	19	40	40	30	6.5	180	136	72
Late rice long	11	40	40	45	6.5	180	188	47
Early rice	19	40	40	30	6.5	180	136	72
Late rice	11	40	40	45	6.5	180	188	47
Early single rice	11	40	40	45	6.5	180	210	46
Late single rice	11	40	40	45	6.5	180	210	46
Sweet potato	450	20	20	48	2.5	90	95	36
Early maize	23	38	55	45	6.5	180	137	42
Late maize	23	38	55	45	6.5	180	190	42
Early sweet maize	23	40	55	75	3.0	180	137	42
Sorghum	21	38	55	45	6.5	180	95	36
Rapeseed	6.0	30	20	20	20	180	7	37
Single rapeseed	6.0	30	20	25	20	180	7	37
Soybean	96	30	23	45	5.0	90	25	44
Peanut	231	45	23	60	7.5	180	75	61
Cotton	21	45	45	80	120	180	236	57
Tobacco	0.4	45	63	95	170	180	18	885
Sugarcane	7836	36	60	150	2.0	180	474	102
Chinese white cabbage	3.0	75	60	155	4.0	180	330	474
Celery	0.8	75	60	150	4.0	180	330	474
Chinese cabbage	6.0	75	64	160	5.0	180	371	339
Watermelon	0.4	45	8	75	1.0	180	330	474
Red pepper	3.0	75	75	165	11	180	669	523
Eggplant	3.0	75	75	165	8.1	180	601	610
Tomato	3.0	75	75	180	8.1	180	550	856
Cucumber	3.0	75	75	165	7.8	180	712	708
Radish	1.4	75	36	64	7.7	180	237	226
Potato	1848	45	36	45	3.0	180	105	357
Single potato	1848	45	36	45	3.0	180	105	357
Chinese milk vetch	30	15	8	31	1.0	0	7	37
Single Chinese milk vetch	30	15	8	31	1.0	0	7	37
Italian ryegrass	45	45	30	45	1.0	180	7	217
Single Italian ryegrass	45	45	30	45	1.0	180	7	217
Early silage maize	23	38	55	45	1.0	180	137	42
Late silage maize	23	38	55	45	1.0	180	190	42
Dwarf elephant grass	450	9	12	119	1.0	96	474	217
Hybrid elephant grass	450	9	12	119	1.0	96	474	217
Chinese kudzu	1800	9	12	119	1.0	96	474	217

[a] Labour inputs in land preparation (d ha^{-1}).
[b] Labour use in crop establishment include labour in nursery and transplanting (d ha^{-1}).
[c] Labour inputs in crop management (d ha^{-1}).
[d] Labour inputs in harvest are expressed as day per Mg product.
[e] Inputs of cattle draught power (h ha^{-1}).
[f] Costs of irrigation (Yuan ha^{-1}).
[g] Costs of other non-labour inputs including agricultural plastic and implements (Yuan ha^{-1}).

5 Quantification of input-output relations of livestock systems

Abstract

This chapter describes the generation of input-output relations of current and alternative livestock systems in Jiangxi, *i.e.* dairy, beef cattle fattening and goat fattening systems. Inputs and outputs of current livestock systems are based on observed animal husbandry practices in Jiangxi. Quantification of inputs and outputs of alternative systems is based on the target-oriented approach, *i.e.* input requirements are calculated to reach well-defined production targets for milk (dairy) and liveweight gain (beef cattle and goat fattening). In alternative systems, better quality replacements (heifers) for dairy, crossbreeds of beef cattle, improved goat breeds and improved management in animal husbandry are adopted. Inputs of livestock systems include nutrients, labour, and non-feed and non-labour inputs. Outputs are the milk, live weight of beef cattle and goats, and manure N. Nutrient requirements of current and alternative livestock systems are based on feeding standards for livestock.

Keywords: Current livestock systems; Alternative livestock systems; Technical coefficients; Linear programming model

5.1 Introduction

The demand for livestock products in China increases rapidly due to a growing population, increasing urbanization and rising living standards (Zhu *et al*., 1999; Brown *et al*., 2002; Nin *et al*., 2004; Fuller *et al*., 2006). As in the rest of the world, pigs and poultry will continue to provide the major proportion of animal products in the future. Commercial pig and poultry production occurs mainly in specialized intensive farms that purchase the majority of the required concentrate feed from domestic and/or international markets. In contrast, ruminants such as dairy cattle, beef cattle and goats are mainly produced on farms with own roughage production comprising the major part of the animal diet (Devendra and Sevilla, 2002). Roughage includes biomass from grassland and forage crops that generally are not transported over large distances (Verburg and Van Keulen, 1999). Hence, ruminants depend mainly on locally produced biomass for their feed requirements. The demand for goat and sheep meat, beef and milk is increasing, but the socio-economic and environmental consequences of an expanding ruminant herd in Jiangxi are unknown.

In this chapter, I focus on ruminants as one of the components in mixed crop-animal systems in Jiangxi.

The objective of this chapter is to describe the generation of inputs and outputs for dairy, beef cattle fattening and goat fattening systems. These systems are incorporated in a regional linear programming (LP) model for agricultural development (Chapter 6) to explore their socio-economic and environmental consequences in relation to rural development goals, available resources and other agricultural activities in Jiangxi.

Section 5.2 describes the current livestock sector in Jiangxi with a focus on dairy, beef and goat meat production. In Section 5.3, current and alternative livestock systems are described. The approaches to quantify inputs and outputs of current and alternative livestock systems are presented in Section 5.4. In Section 5.5, nutrient requirements of dairy cattle are illustrated. In Section 5.6, the input-output relations of current and alternative dairy, beef cattle fattening and goat fattening systems used in the LP model are presented. Finally, the discussion and conclusions are presented in Section 5.7.

5.2 Livestock in Jiangxi

5.2.1 General situation

Traditionally, crop production has dominated the agricultural sector in Jiangxi, but the share of animal production in Jiangxi's agricultural GDP has increased from 13% in 1978 to 32% in 2005, accompanied by a drop in the share of crop production from 74 to 45%. In 2005, the total value of crop and animal production was 5.10 and 3.65 billion (10^9) Yuan, which accounted for 13% and 9% of Jiangxi's GDP, respectively (JXSB, 2006). In animal husbandry, the order of economic importance is pigs, poultry (comprising chicken, ducks and geese), dairy cattle, beef cattle and goats (Figure 5.1).

Intensive large-scale pig and poultry farms produce more than 50% of all pig and poultry products in Jiangxi (DAJX, 2006). Feed sources mainly consist of concentrates, such as maize, wheat bran, fishmeal and soybean meal, which are purchased from both the domestic and international markets. Although the current production of pork, poultry meat and eggs is still economically much more important than that of goat meat, beef and milk (Table 5.1), the growth rate of the ruminant sector is higher (Figure 5.1).

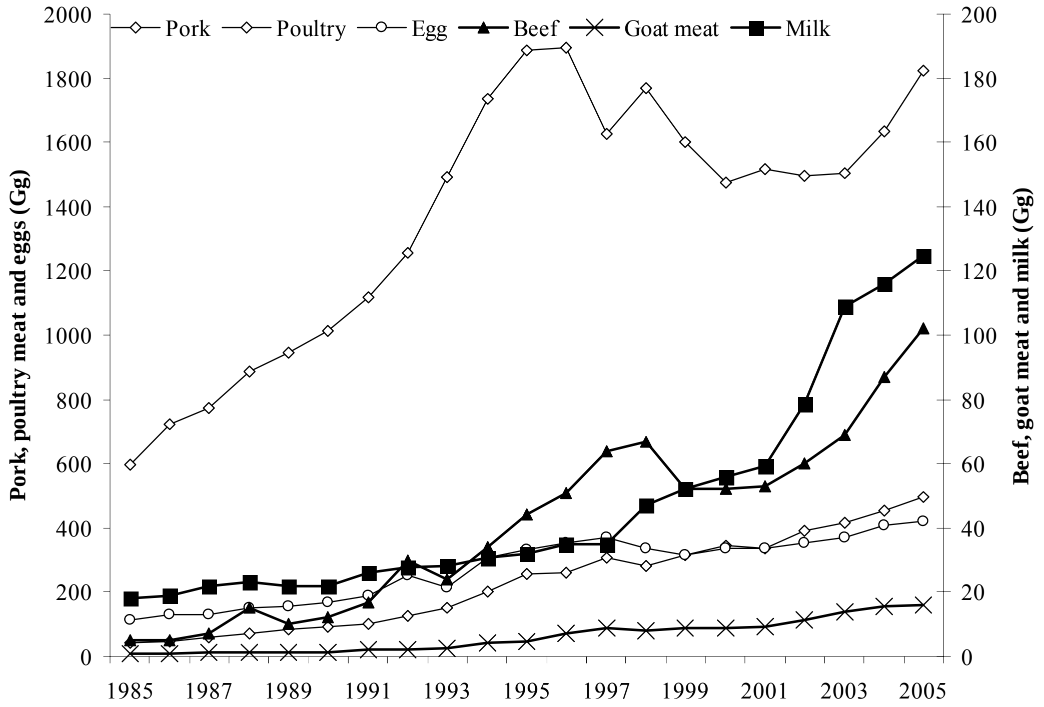


Figure 5.1 Development of animal production in Jiangxi between 1985 and 2005 (Gg = 10^9 g) (Data sources: 1985-1987, Department of Agriculture of Jiangxi Province; 1988-2005, Jiangxi Provincial Statistics Bureau, Jiangxi Statistical Yearbook, issues 1989 to 2006. China Statistics Press, Beijing, China).

5.2.2 Dairy production

Currently, the dairy herd in Jiangxi consists of about 0.4 million head, of which about two-thirds in smallholder mixed crop-livestock systems, and the remainder in specialized dairy farms (Table 5.1). Dairy production largely originates from stall-feeding systems. The majority of the dairy farms sell their milk to dairy processing companies. Chinese Holstein is the dominant breed in Jiangxi, with an average milk yield of about 3000 kg per year (DAJX, 2006). In experiments at Jiangxi Provincial Livestock Farm, milk yields exceeding 10,000 kg per year have been realized (Lai and Huang, 2001), suggesting substantial scope for increased dairy production.

Table 5.1 Animal distribution over farms in Jiangxi in 2004 (Data source: Chinese Animal Husbandry Yearbook 2005. China Agriculture Press, Beijing, China).

Pigs			Broilers		
Number of pigs	Total farms	Average sold pigs per farm	Number of broilers	Total farms	Average sold broilers per farm
55-99	20810	82	2000-9999	6060	2001
100-499	9417	247	10000-49999	491	22960
500-2999	2403	1030	50000-99999	153	50031
3000-9999	199	4921	100000-499999	33	100218
10000-49999	80	13050	500000-999999	4	502325
>50000	8	50175			

Goats and sheep			Laying hens		
Number of goats or sheep	Total farms	Average sold goats[a] per farm	Number of hens	Total farms	Average hens per farm
30-99	6354	63	500-1999	9476	501
100-499	1000	159	2000-9999	2933	2001
500-999	24	600	10000-49999	568	10004
≥1000	3	1067	50000-99999	67	50149
			100000-499999	14	100714

Beef fattening			Dairy		
Number of cattle	Total farms	Average sold cattle per farm	Number of dairy cattle[b]	Total farms	Average cows per farm
10-49	7436	15	5-19	465	12
50-99	395	54	20-99	100	35
100-499	72	285	100-199	8	156
500-999	8	563	200-499	2	283
			500-999	1	502
			≥1000	2	1150

[a] Goats or sheep.
[b] Not including heifers.

5.2.3 Beef production

Currently, more than 80% of the beef is produced in smallholder mixed crop-livestock systems and the remainder in specialized beef fattening operations, finishing more than 10 cattle per year (Table 5.1). These operations are based mainly on stall-feeding in winter and grazing in other seasons. Various cattle breeds are used in beef production in Jiangxi, but the dominant breeds are local "yellow cattle" (Qiu *et al*., 2007), such as Jianhuangniu, Jinjianghuangniu and Guangfengtietiniu, with relatively low productivity (Lai and Huang, 2001). Live weight of adult yellow cattle is less than 300 kg, and average daily liveweight gain (ADG) is about 0.5 kg d^{-1} (Xie *et al.*, 2002). Average carcass weight is 97 kg per animal, which is far below the national average of 135 kg and the world average of 200 kg (Deng and Ye, 2004a, b). To increase animal productivity, cattle breeds such as Simmental, Charolais, Limousin and Piedmont have been imported to produce crossbreeds that combine high productivity, better meat quality and high dressing percentage (carcass weight as fraction of total live weight). For a given (balanced) ration, ADG of crossbreeds is much higher than that of local yellow cattle, reaching maxima of between 0.8 and 1.0 kg d^{-1}. Mature live weight of crossbreeds may reach 450 kg (Lou *et al.*, 2000; Lai and Huang, 2001; Qiu *et al.*, 2000b). Dressing percentage of local yellow cattle is generally less than 50%, while that of crossbreeds can exceed 55% (Lai and Huang, 2001; Qiu, 2000). Despite their more favourable performance, only about 1.5% of the total herd in Jiangxi consists of crossbreeds.

5.2.4 Production of goat and sheep meat

More than 95% of the meat from small ruminants in Jiangxi is goat meat. About 60% of the goat meat is produced on specialized farms (Table 5.1), with average herd size of 78 head. A large proportion of goat meat production is based on grazing systems. Body size of the native goat breeds such as Wanzaishanyang and Guangfengshanyang is small. Although the productivity of these native goat breeds is low, they can produce at high temperatures and on poor quality feed (Jiang and Tao, 1988; Lai and Huang, 2001). Recently, the highly productive breed Nanjianghuangyang, originating from Sichuan Province in Southwestern China, has been introduced (Wang, 2003; DAJX, 2005a). The imported goat breed Boer is sensitive to some poisonous plants in natural grassland of Jiangxi (Qiu *et al.*, 2000a). Boer goat is mainly used as male parent to produce crossbreeds, of which the productivity is much higher than that of either of the parents. Currently, ADG of local breeds ranges from 50 to 100 g d^{-1}, but can be as high as 180 g d^{-1} for crossbreeds under good management (Huang, 2003b).

Although the quality of sheep meat is better than that of goat meat, sheep meat production is very low, since few meat sheep breeds are suitable for the physical environment, particularly the humid and hot summer in Jiangxi. Currently, the breed Xiaoweihanyang from Shandong Province in Northern China is the only breed used in commercial sheep meat production, and a crossbreed of Charolais × Xiaoweihanyang is being tested.

5.2.5 Feed resources

There is about 3 Mha natural grassland in Jiangxi (Yu, 2000). The share of feed from natural grasslands in ruminant feed rations is declining because grazing is banned or discouraged in hilly and mountainous areas to reduce soil erosion (JPRST, 2004), while the number of cattle and goats is increasing. Especially, browsing goats jeopardize fragile hillsides. About 0.2 Mha grassland in the flood plains of Poyang Lake provides excellent vegetation for grazing and the production of hay (Hu *et al*., 1992). However, part of these grasslands has been set aside as conservation area for migratory birds.

The combination of reduced availability of natural grassland and increasing ruminant numbers has resulted in rapid expansion of the area with forage crops (DAJX, 2006). Both, annual and perennial forage crops are grown in Jiangxi. Major annuals comprise Italian ryegrass (*Lolium multiflorum* Lam.), silage maize (*Zea mays* L.), sudangrass (*Sorghum sudanense* (Piper) Stapf) and Chinese milk vetch (*Astragalus sinicus* L.). Major perennials comprise dwarf elephant grass (*Pennisetum purpureum* Schum cv. Mott), Guimu No.1 hybrid elephant grass ((*Pennisetum americium* × *Pennisetum purpureum* Schum cv. Mott) × *Pennisetum purpureum* Schum cv. Mott), kinggrass (*Pennisetum purpureum* × *Pennisetum typhoides*) and Chinese kudzu (*Pueraria edulis* Pamp.).

Italian ryegrass is mainly grown in rice-based cropping systems, such as early rice-late rice-Italian ryegrass and single rice-single Italian ryegrass. The Italian ryegrass provides fresh forage from February to May, when other fresh forages are scarce. Usually, three to four cuts can be harvested in this period. Incorporation of Italian ryegrass in rice systems provides forage to livestock without requiring additional land and contributes to improved soil quality (Xin *et al*., 1998; Chen *et al*., 2000; Xin and Yang 2004). Rice yields usually increase following Italian ryegrass (Yang *et al*., 1997; Xin *et al*., 2002). The rice-Italian ryegrass-livestock system has shown to be an economically feasible and environmentally friendly mixed crop-livestock system (Chen *et al*., 2000; Xiong *et al*., 2003b). Another important annual forage crop is silage maize, which is grown in both rice land and non-rice land. The area of silage maize steadily increases thanks mainly to the availability of high-yielding varieties (Pan *et al*., 2002; Chen and Tang, 2003).

Similar to Italian ryegrass, Chinese milk vetch provides fresh forage to livestock when other fresh forages are scarce (Wu *et al*., 1997). Chinese milk vetch is mainly grown in rotations with early rice and late rice, or with single rice. Traditionally, Chinese milk vetch is grown as green manure to supply nutrients to crops rather than as feed to livestock (Ellis and Wang, 1997; Huang, 2000a). Parallel to the decreasing importance of Chinese milk vetch as green manure, its importance as feed resource is growing. However, it can only provide fresh forage in March and April.

Perennial forage crops, such as elephant grass, kinggrass and Chinese kudzu, supply fresh forage from May to November with five cuts per season, while the graminaceous forages are also used for silage. They are mainly grown in non-rice land, particularly in less fertile hilly and mountainous areas, contributing to erosion control by providing year-round soil cover and increasing soil fertility (Wang, 1997; Zhang and Wang, 1999; Devendra and Sevilla, 2002; Fan and Wu, 2004; Lu *et al*., 2006; Yue *et al*., 2007).

In addition to forage crops, agricultural by-products, such as rice straw, sweet potato vines, peanut haulms, and sugarcane tops, are used as feed resources. Since the nutritive value of rice straw can be improved significantly through urea or ammonia treatment (Luo *et al*., 2004), this technology is stimulated in the province. Sweet potato, one of the major food crops in Jiangxi, is often also used as feed to livestock. Often, small amounts of concentrates, such as maize, rice bran, cotton seed meal, rapeseed meal, soybean meal and fish meal, are supplemented.

5.2.6 Manure use

Most of the animal manure is used in the production of fruits, tea, vegetables and rice. However, application of manure in cropping systems is labour-demanding. Jiangxi is one of the leading provinces in China in using manure to produce biogas, with more than one million households (about 13% of all rural households in the province), which contributes to rural energy supply (Zhu, 2007). Both, the residues and waste water of biogas production are used in cropping systems, contributing to the nutrient supply of crops and to soil organic matter (Wen, 2000; Wu, 2006). In order to promote the development of biogas in rural areas, favourable policies, such as subsidies for building biogas facilities and technical assistance, have been implemented (Zhou *et al*., 2001; Wu, 2006).

5.3 Identification of current and alternative livestock systems

Current livestock systems are based on observed animal husbandry practices in Jiangxi, while in alternative systems (Table 5.2) new livestock technologies are adopted. In the alternative beef fattening systems, crossbreeds such as Charolais × Jinjianghuangniu, Simmental × Jianhuangniu and Piedmont × (Simmental ×

Jinjianghuangniu) are adopted. In the alternative goat fattening systems the improved breeds with high productivity (*e.g.* Nanjianghuangyang) are adopted. Chinese Holstein dairy cattle are used in both the current and alternative dairy systems, but better quality replacements (heifers) are introduced in the alternative systems. Improved management in animal husbandry are assumed in all alternative livestock systems. All these improvements contribute to higher production targets in alternative livestock systems (Table 5.2). Improvements are expressed in monetary terms in the LP model, *i.e.* the costs of non-feed and non-labour inputs of the alternative systems are higher than those in current systems.

Table 5.2 Characteristics of current and alternative livestock systems defined for the regional linear programming model.

Livestock category	System	Annual production	Animal breed
Dairy cattle	Current	3000 kg milk	Chinese Holstein
	Alternative	4340 kg milk	Chinese Holstein
Beef cattle	Current	fattening 56 kg calf to 239 kg	Local yellow cattle
	Alternative	fattening 81 kg calf to 382 kg	Crossbreed
Goat	Current	fattening 10 kg goat kid to 35.1 kg	Local breed
	Alternative	fattening 15 kg goat kid to 62.5 kg	Improved breed

5.4 Quantification of inputs and outputs of livestock systems

For each livestock system, a unique combination of inputs results in a unique combination of outputs. Inputs and outputs are also called ‘technical coefficients’ (Hengsdijk *et al.*, 2000). Inputs include nutrients, labour, and non-feed and non-labour inputs. Nutrient requirements considered in this study comprise dry matter, energy and crude protein. The non-feed and non-labour inputs, which are expressed in monetary terms, include young animals (heifers, fattening calves and goat kids), buildings, machines and other equipment, water, electricity, fuel, animal health care, feed additives, costs of artificial insemination (for dairy only), taxes and miscellaneous expenses. Outputs are the milk, live weight of beef cattle and goats, and manure N. Outputs are expressed in both physical and monetary terms, but manure N is expressed in physical terms only.

A technical coefficient generator, programmed in Delphi, has been used to calculate the input and output relations for both current and alternative systems, although in a different way. Quantification of inputs and outputs of alternative systems is based on the target-oriented approach (Hengsdijk and Van Ittersum, 2002; Van de Ven *et al.*, 2003): Input requirements are calculated to reach well-defined production targets for milk (dairy), and liveweight gain (beef cattle fattening and goat fattening). For quantification of inputs and outputs of current systems, the technical coefficient generator has been used in an input-oriented way. Labour requirements, non-feed and non-labour inputs, milk yield, and liveweight gain of beef cattle and goats are based on observed data from farm surveys and experiments. Nutrient requirements of current and alternative systems are based on the general available feeding standards for livestock. The amount of manure N production has not been measured in practice, but has been calculated on the basis of a balance method, *i.e.* manure N production equals N intake minus economic N output and unavoidable N losses (Sub-section 5.4.2).

The calculation procedure for the dairy systems is shown in Figure 5.2 and that for beef cattle fattening and goat fattening systems in Figure 5.3. All inputs and outputs of livestock systems are expressed per animal.

5.4.1 Nutrient requirements

5.4.1.1 Dairy cattle

Nutrient requirements of dairy cattle are calculated on the basis of feeding standards for Chinese Holstein dairy cattle (Liang, 2002; Qiu, 2002; MAPRC, 2004a), taking into account maintenance, growth, lactation, gestation and physical work. Using tabular nutrient requirements for these processes, intermediary values are derived using linear interpolation (Tables 5.3, 5.4 and 5.5). Nutrient requirements are specified in terms of dry matter (DM), net energy for lactation (NEL) and crude protein (CP). Only nutrient requirements for lactating cows are taken into account, as it is assumed that heifers are bought just before first calving.

First, the annual target milk yield of one dairy cow is defined, which is the average yield over all lactations of the cow's productive life. Then the milk yield in each lactation is calculated from the milk yield distribution over the cow's life cycle. A typical Chinese Holstein dairy cow has the highest yield in the middle of the lactation cycles (Dong and Wang, 2002; Liang 2002; Qiu, 2002). Data on the number of lactations and calving intervals of a cow are obtained from farm surveys. For illustrative purposes, milk yield distributions for three levels of lifetime milk production are shown in Table 5.6. An annual milk yield of 3000 kg represents current average milk production in Jiangxi, 4340 kg per year can be achieved under improved management, while 6071 kg represents best practices. Subsequently, mean daily milk yield in each month is derived from annual milk yield on the basis of a schematized lactation curve (Table 5.7). Data in both Table 5.6 and Table 5.7 are user-defined and can be changed based on available information. For each lactation cycle, the following data are user-defined: date of (artificial) insemination, length of pregnancy, length of the 'dry' period, live weight of cow, milk fat content, walking distance during grazing and proportion of daily DM intake covered through grazing. With the date of insemination and length of pregnancy, the date of the next calving is automatically produced.

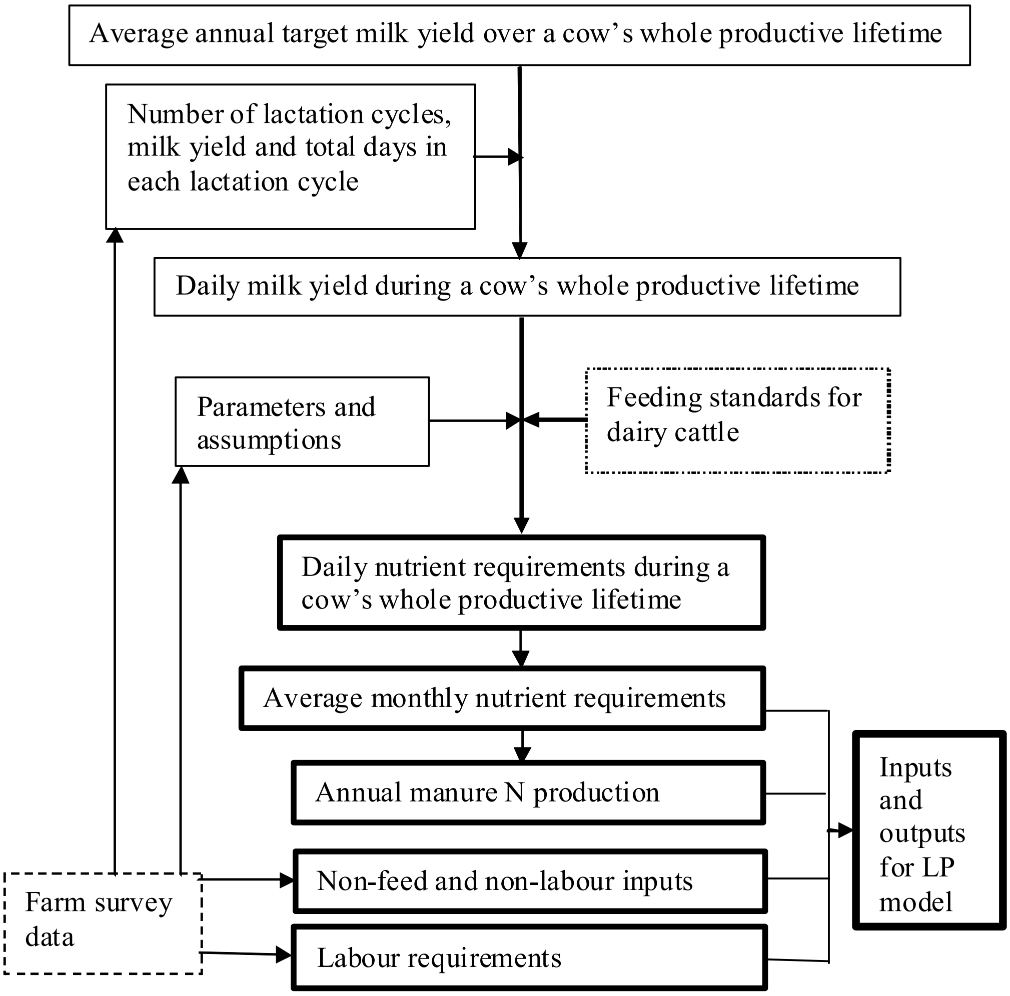
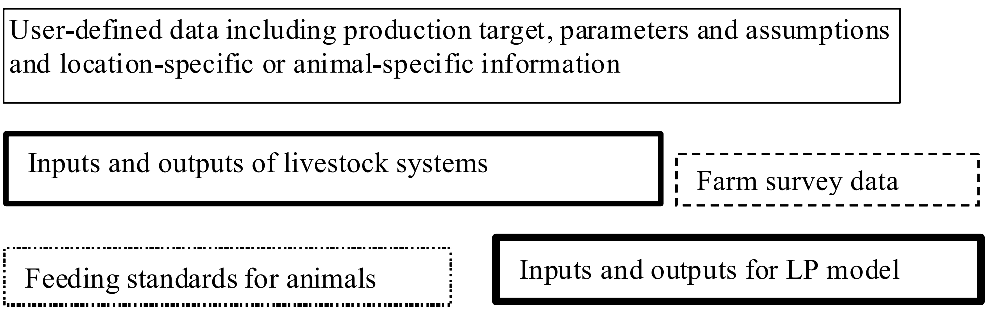


Figure 5.2 Procedure for quantification of inputs and outputs of dairy production systems.

Note: Meaning of different types of boxes:



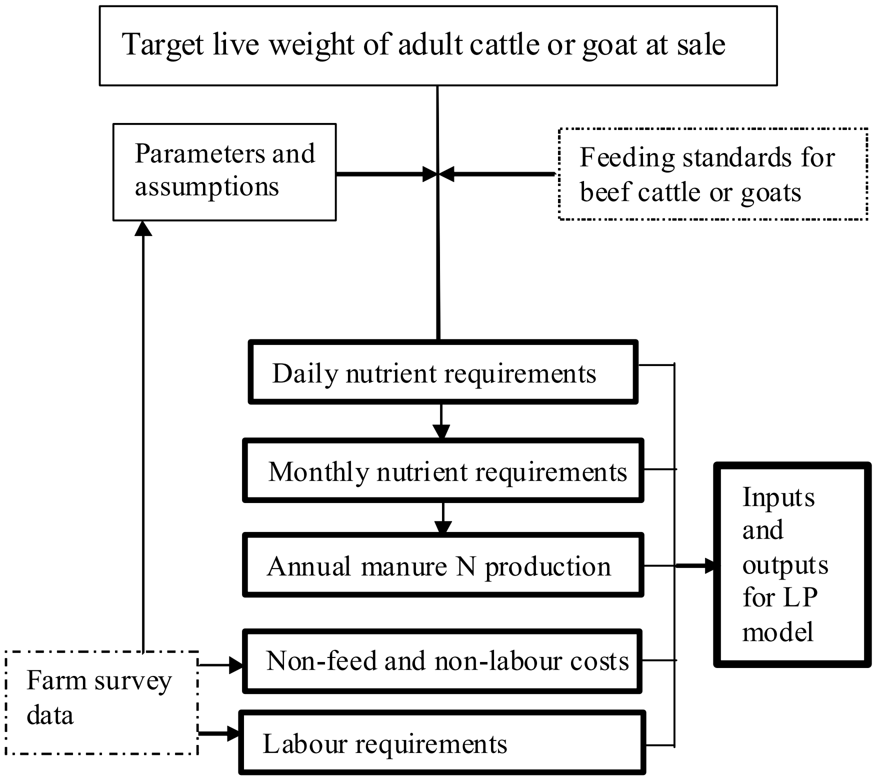


Figure 5.3 Procedure for quantification of inputs and outputs of beef cattle and goat fattening systems (see Figure 5.2 for meaning of different boxes).

Table 5.3 Daily nutrient requirements for maintenance from the day of calving till and including the 5th month of gestation for Chinese Holstein dairy cattle of different live weight (Data sources: Liang, 2002; Qiu, 2002; MAPRC, 2004a).

Live weight (kg)	DMI[a] (kg)	NEL[b] (MJ)	CP[c] (g)
350	5.02	28.79	374
400	5.55	31.80	413
450	6.06	34.73	451
500	6.56	37.57	488
550	7.04	40.38	524
600	7.52	43.10	559
650	7.98	45.77	594
700	8.44	48.41	628
750	8.89	50.96	661

[a] Dry matter intake.
[b] Net energy for lactation.
[c] Crude protein.

Table 5.4 Daily nutrient requirements for maintenance for the last four months of gestation of Chinese Holstein dairy cattle of different live weight (see Table 5.3 for abbreviations and data sources).

Live weight (kg)	Month of pregnancy	DMI (kg)	NEL (MJ)	CP (g)
350	6	5.78	32.98	451
350	7	6.28	35.90	518
350	8	7.23	41.33	629
350	9	8.70	49.71	777
400	6	6.30	35.99	489
400	7	6.81	38.91	557
400	8	7.76	44.34	668
400	9	9.22	52.72	815
450	6	6.81	38.91	528
450	7	7.32	41.83	595
450	8	8.27	47.29	706
450	9	9.73	55.64	854
500	6	7.31	41.80	565
500	7	7.82	44.72	632
500	8	8.78	50.18	743
500	9	10.24	58.52	891
550	6	7.80	44.56	602
550	7	8.31	47.48	669
550	8	9.26	52.94	780
550	9	10.72	61.29	928
600	6	8.27	47.29	637
600	7	8.78	50.21	705
600	8	9.73	55.64	815
600	9	11.20	64.02	963
650	6	8.74	49.96	671
650	7	9.25	52.88	738
650	8	10.21	58.34	849
650	9	11.67	66.68	997
700	6	9.22	52.59	705
700	7	9.71	55.51	772
700	8	10.67	60.97	883
700	9	12.13	69.32	1031
750	6	9.65	55.13	738
750	7	10.16	58.08	806
750	8	11.11	63.51	917
750	9	12.58	71.89	1065

Table 5.5 Nutrient requirements for the production of one kilogram of milk with different fat contents (see Table 5.3 for abbreviations and data sources).

Milk fat (%)	DMI (kg)	NEL (MJ)	CP (g)
2.5	0.33	2.51	68
3.0	0.36	2.72	74
3.5	0.39	2.93	80
4.0	0.42	3.14	85
4.5	0.46	3.35	89
5.0	0.49	3.52	97
5.5	0.52	3.72	102

Table 5.6 Milk yield distribution over the life cycle of a Chinese Holstein dairy cattle (10 lactations) in Jiangxi for three average annual milk yield levels.

Lactation	1	2	3	4	5	6	7	8	9	10
Relative yield[a] (%)	77	87	94	98	100	94	88	82	76	70
Milk yield level (kg y^{-1})										
3000	2668	3015	3257	3396	3465	3257	3049	2841	2633	2426
4340	3859	4360	4711	4912	5012	4711	4411	4110	3809	3508
6071	5398	6099	6589	6870	7010	6589	6169	5748	5328	4907

[a] As a fraction of the highest annual milk yield (realized in the fifth lactation) in the cow's productive life.

From the daily milk yield for each day of the cow, the daily nutrient requirements are calculated. Then nutrient requirements in each month are calculated based on the entire life cycle of a cow. Last, average monthly nutrient requirements are computed. Using monthly requirements the seasonality of roughage availability can be captured in the LP model.

Dry matter intake (DMI)

For calculation of DMI, a correction factor for heat or cold stress is taken into account (Roseler *et al*., 1997; Eastridge *et al*., 1998; Dong and Wang, 2002; Qiu, 2002; West, 2003).
When 5 ºC ≤ T ≤ 20 ºC:

$$DDMI = DMImain + DMImilk \times DMY \quad (1)$$

Table 5.7 Mean daily milk yield (kg) in each month of Chinese Holstein dairy cattle for different annual milk yields (Data sources: Dong and Wang, 2002; Liang, 2002; Qiu 2002).

Annual milk yield (kg)	Month 1	2	3	4	5	6	7	8	9	10
1800	8	9	8	7	7	6	5	4	4	2
2100	9	10	9	8	8	7	6	5	5	3
2400	10	11	11	10	9	8	7	6	5	3
2700	11	12	12	11	10	9	8	7	6	4
3000	12	14	13	12	11	10	9	8	6	5
3300	13	15	14	13	12	11	10	9	7	6
3600	14	17	15	14	13	12	11	10	8	6
3900	16	18	16	15	14	13	11	10	9	7
4200	17	19	17	16	15	14	13	11	10	8
4500	18	20	19	17	16	15	14	12	10	9
4800	19	22	20	19	17	16	14	13	11	9
5100	20	23	21	20	18	17	15	14	12	10
5400	21	24	22	21	19	18	16	15	13	11
5700	23	25	24	22	20	19	17	15	14	12
6000	24	27	25	23	21	20	18	16	14	12
6300	25	28	26	24	22	21	19	17	15	13
6600	27	29	27	25	23	22	20	18	16	14
6900	28	30	28	26	24	23	21	19	17	16
7200	29	31	29	27	25	24	22	20	18	16
7500	30	32	30	28	26	25	23	21	19	17
7800	31	33	31	29	27	26	24	22	20	18
8100	32	34	32	30	28	27	25	23	21	19
8400	33	35	33	31	29	28	26	24	22	20
8700	34	36	34	32	30	29	27	25	23	21
9000	35	37	35	33	31	30	28	26	24	22
9300	36	38	36	34	32	31	29	27	25	23
9600	37	39	37	35	33	32	30	28	26	24
9900	38	40	38	36	34	33	31	29	27	25
10200	39	41	39	37	35	34	32	30	28	26
10500	40	42	40	38	36	35	33	31	29	27
10800	41	43	41	39	37	36	34	32	30	28
11100	42	44	42	40	38	37	35	33	31	29

When T > 20 ºC:

$$\text{DDMI} = [\text{DMImain} + \text{DMImilk} \times \text{DMY}] \times \{1 - [(T - 20) \times 0.005922]\} \quad (2)$$

When T < 5 ºC:

$$DDMI = [DMImain + DMImilk \times DMY] \div \{1 - [(5 - T) \times 0.004644]\} \quad (3)$$

Where:

T = temperature (ºC);

DDMI = daily dry matter intake (kg);

DMImain = daily dry matter requirements for maintenance (kg; Tables 5.3 and 5.4);

DMImilk = daily dry matter requirements for the production of one kilogram milk (kg; Table 5.5);

DMY = daily milk yield (kg).

The user of the technical coefficient generator can neglect the effect of temperature on DMI by selecting equation (1).

Net energy for lactation (NEL)

For the dairy cattle, NEL (net energy for lactation) is used to represent the requirements for energy. The energy requirements for maintenance are also corrected for heat and cold stress (Table 5.8) (Liang, 2002; Qiu, 2002). Liveweight gain requires energy beyond maintenance and production requirements, while energy requirements exceeding intake lead to liveweight loss. Dairy cattle require additional energy for grazing, the magnitude of which depends on the distance covered during grazing, the proportion of dry matter intake ingested during grazing in total daily dry matter intake and live weight. The gain or loss of live weight of a cow during the lactation cycle is also considered in the calculation of daily energy requirements (Ji, 2001; Liang, 2002; Qiu, 2002):

When a cow gains weight:

$$DNELG = NELmain \times TP + NELmilk \times DMY + DWG \times 8 \times 3.138 + BW \times 0.00188 \times GD + BW \times 0.00837 \times DMIs \quad (4)$$

When a cow loses weight:

$$DNELL = NELmain \times TP + NELmilk \times DMY - DWL \times 6.56 \times 3.138 + BW \times 0.00188 \times GD + BW \times 0.00837 \times DMIs \quad (5)$$

Where:

DNELG = daily NEL requirement (in MJ) in situation with liveweight gain;

NELmain = daily NEL requirement (in MJ) for maintenance (Tables 5.3 and 5.4);

TP = Correction factor for heat or cold stress (Table 5.8);
NELmilk = daily NEL requirement (in MJ) for the production of one kilogram milk (Table 5.5);
DMY = daily milk yield (kg);
DWG = daily liveweight gain (kg);
BW = live weight of cow (kg);
GD = grazing distance (km);
DMIs = proportion of dry matter intake ingested during grazing in total daily DMI;
DNELL = daily NEL requirement (in MJ) in situations with liveweight loss;
DWL = daily liveweight loss (kg).

The temperature in calculating TP in equations (4) and (5) is the same as that used in calculating DMI. By setting TP equal to 1, the effect of temperature on NEL requirements can be ignored. An explanation of the numerical constants in equations (4) and (5) is complex and beyond the scope of this study.

Table 5.8 Heat and cold stress correction factors used to modify the requirement for net energy for maintenance of Chinese Holstein dairy cattle (Data sources: Liang, 2002; Qiu, 2002).

Temperature (ºC)	-15	-10	-5	0	5	10	19	25	30	32	36
Correction factor	1.27	1.22	1.18	1.12	1.07	1.0	1.0	1.1	1.22	1.29	1.34

Crude protein (CP)

Daily CP requirements are calculated as (for situations of liveweight gain or loss, respectively) (Liang, 2002; Qiu, 2002):

$$DCPG = CPmain + CPmilk \times DMY + DWG \times 500 \quad (6)$$

$$DCPL = CPmain + CPmilk \times DMY - DWL \times 385 \quad (7)$$

Where:
DCPG = daily CP requirement (in g) in situation with liveweight gain;
CPmain = CP requirement for maintenance (in g) as shown in Tables 5.3 and 5.4;
CPmilk = CP requirement (in g) for producing one kilogram of milk (Table 5.5);
DMY = daily milk yield (kg);
DWG = daily liveweight gain (kg);
DCPL = daily CP requirement (in g) in situation with liveweight loss;
DWL = daily live weight loss (kg).

5.4.1.2 Goats

Tabular data of feeding standards for goats (Tables 5.9 and 5.10) are used to calculate their nutrient requirements (Zhang and Tan, 2001; Huang, 2003b; Wang, 2000; Wang, 2003). Intermediary values are derived using linear interpolation. First, the daily nutrient requirements in the fattening period are calculated. Then, the monthly nutrient requirements, which are used in the LP model, are calculated.

Table 5.9 Daily nutrient requirements for maintenance of stall-fed goats (Data sources: Wang, 2000; Wang, 2003).

Live weight (kg)	DMI[a] (kg)	DE[b] (MJ)	CP[c] (g)
10	0.28	2.93	22
20	0.48	4.94	38
30	0.65	6.65	51
40	0.81	8.28	63
50	0.95	9.79	75
60	1.09	11.21	86
70	1.23	12.59	96
80	1.36	13.89	106
90	1.48	15.19	116
100	1.60	16.44	126

[a] Dry matter intake.
[b] Digestible energy.
[c] Crude protein.

Table 5.10 Nutrient requirements for different daily liveweight gain (DG) of goats (see Table 5.9 for abbreviations and data sources).

DG ($g\ d^{-1}$)	DMI (kg)	DE (MJ)	CP (g)
50	0.18	1.80	14
100	0.36	3.68	28
150	0.54	5.52	42
200	0.72	7.36	56

Dry matter intake (DMI)

Daily dry matter intake (DMI) is calculated as:

$$DDMI = DMImain + DMIgain \quad (8)$$

Where:
DDMI = daily dry matter intake (kg);

DMImain = dry matter intake (in kg) for maintenance (Table 5.9);
DMIgain = dry matter intake (in kg) for liveweight gain (Table 5.10).

Digestible energy (DE)

Digestible energy (DE) is used to express the energy requirements of goats. When the goat is stall-fed:

$$DDE = DEmain + DEgain \tag{9}$$

Where:
DDE = daily DE requirements (MJ);
DEmain = DE (in MJ) required for maintenance (Table 5.9);
DEgain = DE (in MJ) required for liveweight gain (Table 5.10).

Crude protein (CP)

Daily crude protein requirements are calculated as:

$$DCPR = CPmain + CPgain \tag{10}$$

Where:
DCPR = daily crude protein requirement (g);
CPmain = crude protein requirement (in g) for maintenance (Table 5.9);
CPgain = crude protein requirement (in g) for liveweight gain (Table 5.10).

5.4.1.3 Beef cattle

The procedure for beef cattle is similar to that for goats (Figure 5.3), but the calculation of nutrient requirements of beef cattle is based on the original equations of the Feeding Standards for Beef Cattle released in 2004 in China (MAPRC, 2004b). Nutrient requirements for beef fattening are expressed in dry matter (DMI), net energy for maintenance and fattening (NEMF) and crude protein (CP). Calculation of nutrient requirements in each month in the fattening period is based on the daily nutrient requirements.

Dry matter intake (DMI)

Daily dry matter intake (DDMI, kg) is calculated as:

$$\mathrm{DDMI} = 0.062 \times \mathrm{W}^{0.75} + (1.5296 + 0.0371 \times \mathrm{W}) \times \mathrm{ADG} \tag{11}$$

Where:
W = live weight of beef cattle (kg);
ADG = average daily liveweight gain (kg d^{-1}).

Net energy for maintenance and fattening (NEMF)

In the Feeding Standards for Beef Cattle in China, NEMF is used to express the energy requirement (MAPRC, 2004b). Daily NEMF (DNEMF, MJ) is calculated as:

$$\mathrm{DNEMF} = \{322 \times \mathrm{W}^{0.75} + [\frac{(2092 + 25.1 \times \mathrm{W}) \times \mathrm{ADG}}{1 - 0.3 \times \mathrm{ADG}}]\} \times \mathrm{F} \tag{12}$$

Where:
F = correction coefficient (Table 5.11).

F is an empirical factor derived from the Feeding Standards for Beef Cattle in China (MAPRC, 2004b).

Crude protein (CP)

Daily crude protein requirement (DCPR, g) is calculated as:

$$\mathrm{DCPR} = 5.5 \times \mathrm{W}^{0.75} + \frac{\mathrm{ADG} \times (168.07 - 0.16869 \times \mathrm{W} + 0.0001633 \times \mathrm{W}^2) \times (1.12 - 0.1233 \times \mathrm{ADG})}{0.34} \tag{13}$$

The user of the technical coefficient generator can also select to consider the effects of temperature on requirements for DM and energy. For beef cattle, knowledge and information is lacking to account for these effects. Here, the method and the correction factor for heat or cold stress used in dairy cattle (Sub-section 5.4.1.1) are used to modify the DDMI calculated with the Equation 11. The daily energy requirement is equal to DNEMF (calculated with the Equation 12) multiplied by TP (Table 5.8) when the effect of temperature on energy requirement is considered.

5.4.2 Manure N production

Manure N production of cattle and goats is calculated on the basis of a balance method, *i.e.* manure N equals N intake minus economic N output and unavoidable N losses.

5.4.2.1 Dairy cattle

Intake of N is calculated from intake of CP, which is converted into N by dividing by 6.25. Output of N is in milk and meat. Available N in manure is calculated on a daily basis, taking into account unavoidable N losses through volatilization and leaching:

$$\text{Daily manure N} = (\text{Nintake} - \text{Nmilk} - \text{Ngain}) \times (1 - \text{Nloss}) \tag{14}$$

$$\text{Nintake} = \frac{\text{DCPG}}{1000 \times 6.25} \tag{15}$$

or

$$\text{Nintake} = \frac{\text{DCPL}}{1000 \times 6.25} \tag{16}$$

$$\text{Nmilk} = \frac{\text{DMY} \times \text{CPM}}{6.25} \tag{17}$$

$$\text{Ngain} = \frac{\text{DWG} \times \text{CPW}}{6.25} \tag{18}$$

Where:

Daily manure N =	daily contribution to available N from manure (kg);
Nintake =	feed N intake (kg);
Nmilk =	N in milk (kg);
Ngain =	N in liveweight gain (kg);
DCPG =	daily CP requirement (in g) in situation with liveweight gain;
DCPL =	daily CP requirement (in g) in situation with liveweight loss;
CPM =	CP content of milk (kg kg^{-1});
CPW =	CP content of body tissue (kg kg^{-1});
Nloss =	fraction unavoidable losses of N from manure.

On the basis of the daily manure N production, total manure N production per animal per year is calculated.

Table 5.11 Correction coefficient used to calculate NEMF (net energy for maintenance and fattening) of beef cattle (Data source: MAPRC, 2004b).

Live weight	Average daily liveweight gain (kg d^{-1})											
(kg)	0	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
150	0.850	0.960	0.965	0.970	0.975	0.987	0.988	1.000	1.020	1.040	1.060	1.080
200	0.850	0.960	0.965	0.970	0.975	0.987	0.988	1.000	1.020	1.040	1.060	1.080
225	0.864	0.974	0.979	0.984	0.989	0.992	1.002	1.014	1.034	1.054	1.074	1.094
250	0.877	0.987	0.992	0.997	1.002	1.005	1.015	1.027	1.047	1.067	1.087	1.107
275	0.891	1.001	1.006	1.011	1.016	1.019	1.029	1.041	1.061	1.081	1.101	1.121
300	0.904	1.014	1.002	1.024	1.029	1.032	1.042	1.054	1.074	1.094	1.114	1.134
325	0.910	1.020	1.025	1.030	1.035	1.038	1.048	1.060	1.080	1.100	1.120	1.140
350	0.915	1.025	1.030	1.035	1.040	1.043	1.053	1.065	1.085	1.105	1.125	1.145
375	0.921	1.031	1.036	1.041	1.046	1.049	1.059	1.071	1.091	1.111	1.131	1.151
400	0.927	1.037	1.042	1.047	1.052	1.055	1.065	1.077	1.097	1.117	1.137	1.157
425	0.930	1.040	1.045	1.050	1.055	1.058	1.068	1.080	1.100	1.120	1.140	1.160
450	0.932	1.042	1.047	1.052	1.057	1.060	1.070	1.082	1.102	1.122	1.142	1.162
475	0.935	1.045	1.050	1.055	1.060	1.063	1.073	1.082	1.105	1.125	1.145	1.165
500	0.937	1.047	1.052	1.057	1.062	1.065	1.075	1.087	1.107	1.127	1.147	1.167

5.4.2.2 Beef cattle and goats

Total available manure N of beef cattle and goats in the whole fattening period is calculated as:

$$\text{Total manure N} = [\text{Nintake} - (\text{Ncattle} - \text{N calf})] \times (1 - \text{Nloss}) \quad (19)$$

$$\text{Nintake} = \frac{\sum \text{DCPR}}{1000 \times 6.25} \quad (20)$$

$$\text{Ncattle} = \frac{\text{LWAC} \times \text{CPLA}}{6.25} \quad (21)$$

$$\text{Ncalf} = \frac{\text{LWC} \times \text{CPLC}}{6.25} \quad (22)$$

Where:

Total manure N =	total available N in manure during the fattening period (kg);
Nintake =	total N intake by the cattle or goat during the fattening period (kg);
Ncattle =	total N in body tissue of sold cattle or goats (kg);
Ncalf =	N in body tissue of calf or goat kid (kg);
Nloss =	fraction unavoidable losses of N from manure;
$\sum$ DCPR =	total crude protein requirements by the cattle or goat during the fattening period (g);
DCPR =	daily crude protein requirement by the cattle or goat (g);
LWAC =	live weight of fattened cattle or goats (kg);
CPLA =	CP content in body tissue of fattened cattle or goats (kg kg^{-1});
LWC =	live weight of calf or goat kid (kg);
CPLC =	CP content in body tissue of calf or goat kid (kg kg^{-1}).

5.4.3 Labour requirements and costs of non-feed and non-labour inputs

The costs of non-feed and non-labour inputs, expressed in annual costs per animal, as well as labour requirements have been derived from farm surveys and experiments. Labour requirements are defined per decade (a 10 day-period) per animal, enabling identification of labour peaks in the course of the year.

5.5 Illustration of nutrient requirements of dairy cattle

For illustrative purposes, nutrient requirements of dairy cattle have been calculated for three milk yield levels. Consequences of temperature stress, the effects of grazing distance and feed ration composition on DMI and NEL requirements are illustrated. Daily minimum (when daily minimum temperature is lower than 5 ºC in cold season**)** or maximum (when daily maximum temperature is higher than 20 ºC in hot season), and daily mean temperature in Jiangxi is used in the calculations. Characteristics of the dairy production system used in the example are given in Table 5.12. The date of parturition is set to January 1.

Annual DMI is 2 and 3% lower when daily mean, and minimum or maximum temperature are taken into account (Figure 5.4a), while NEL requirements are about 10% and 11% higher, respectively (Figure 5.4b). DMI and NEL requirements per kg milk production are lower at higher milk yields (Figures 5.5a and 5.5b).

Calculated DMI and NEL requirements for the hottest three months in the year show that DMI in July is 6 and 8% lower (Figure 5.6a), while NEL requirements are 22 and 25% higher (Figure 5.6b), when daily mean and maximum temperature is taken into account, respectively. DMI and NEL requirements per kg milk production show similar trends as the monthly requirements (Figures 5.7a and 5.7b). Lower DMI and higher NEL requirement implies that higher quality feed should be supplied in the hot summer.

Table 5.12 Dairy production system characteristics used in calculation of nutrient requirements and manure N production for Chinese Holstein dairy cattle in Jiangxi.

Characteristics	Value
Total lactation number	10
Calving interval (d)	365
Length of dry period (d)	60
Timing of insemination (d postpartum)	89
Length of pregnancy (d)	276
Milk fat content (%)	3.5
Live weight after 1st calving (kg)	500
Live weight after 2nd calving (kg)	550
Live weight after 3rd calving (kg)	620
Average adult live weight (kg)	620
Crude protein content of milk (%)	3.1
N content in body tissue (%)	2.65
Unavoidable N loss (%)	10

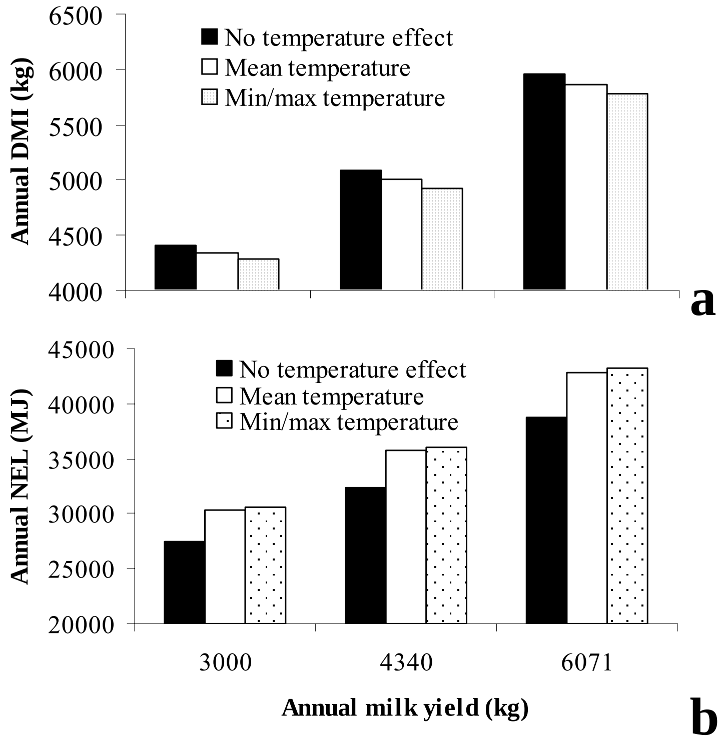


Figure 5.4 Effect of daily mean, minimum or maximum temperature in Jiangxi on requirements for annual dry matter intake (DMI) (a) and annual net energy for lactation (NEL) (b) of Chinese Holstein dairy cattle.

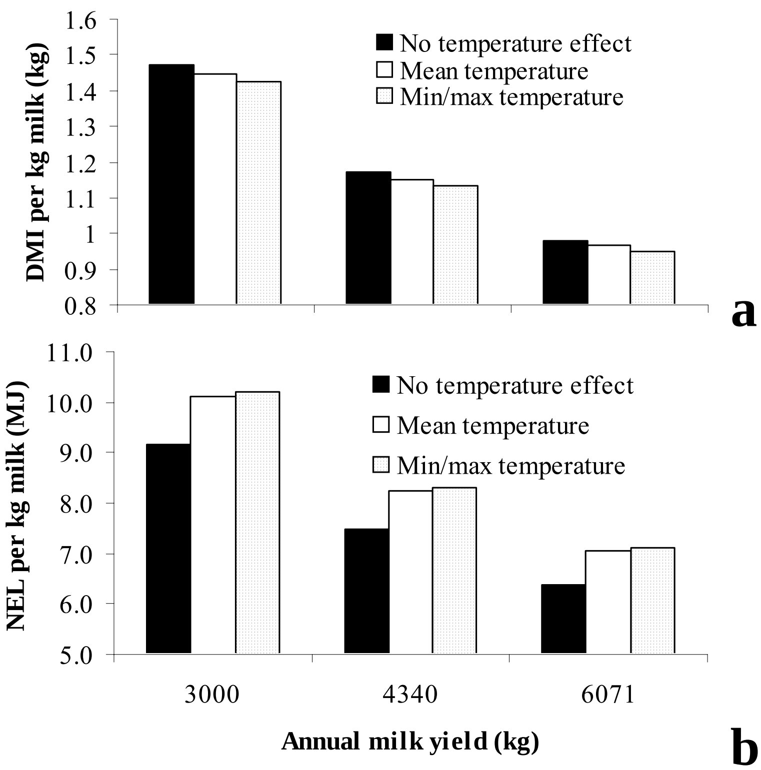


Figure 5.5 Effect of daily mean, minimum or maximum temperature in Jiangxi on requirements for annual average dry matter intake (DMI) (a) and net energy for lactation (NEL) (b) per kg milk production of Chinese Holstein dairy cattle.

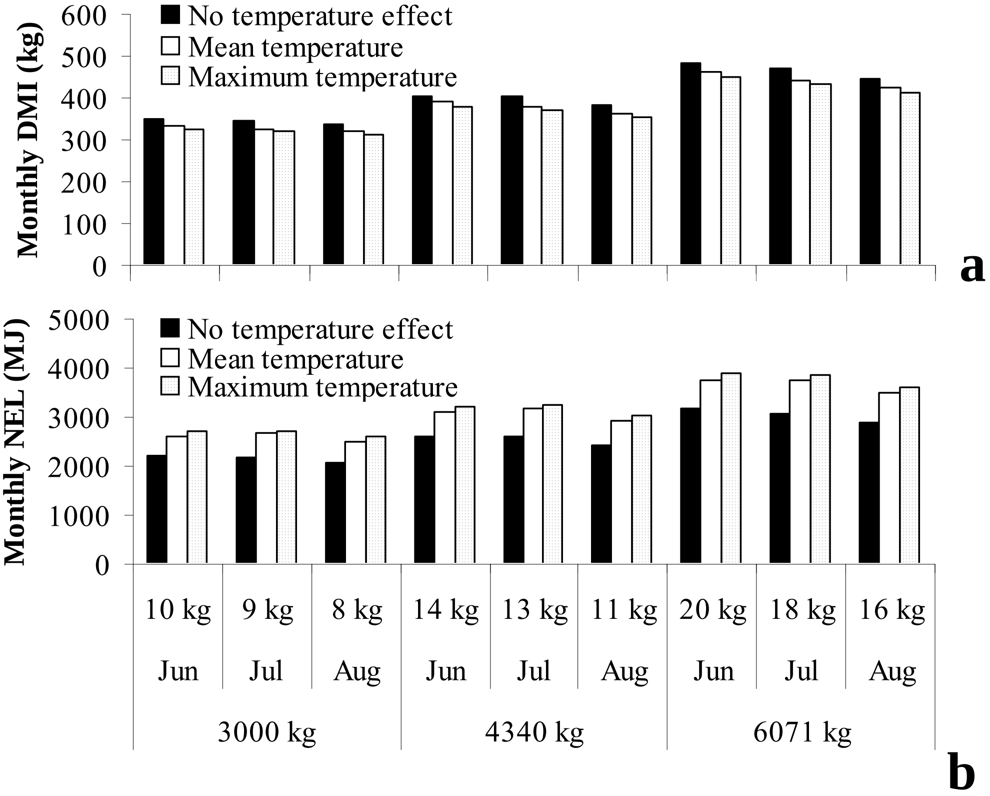


Figure 5.6 *Effect of daily mean and maximum temperature in summer in Jiangxi on requirements for DMI (dry matter intake) (a) and NEL (net energy for lactation) (b) of Chinese Holstein dairy cattle with different daily milk yields in each month under annual milk yields of 3000, 4340 and 6071 kg, respectively.*

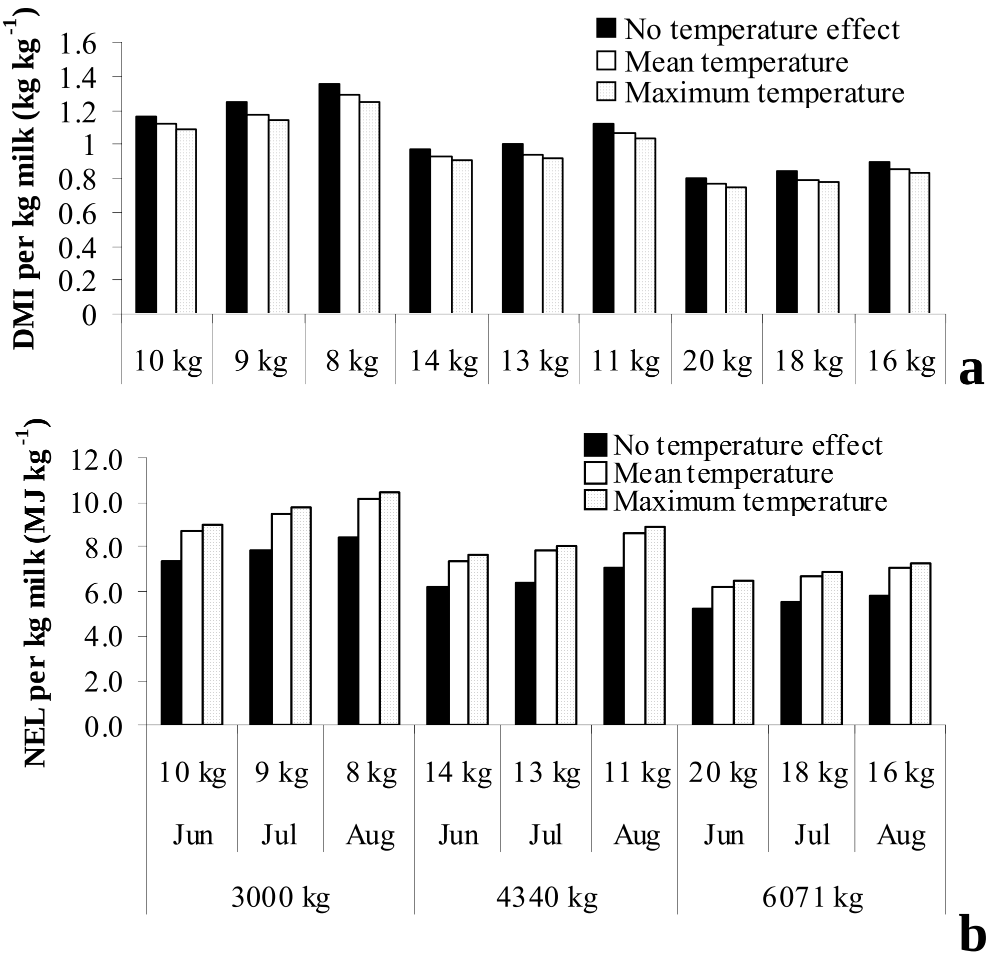


Figure 5.7 Effect of daily mean or maximum temperature in Jiangxi on requirements for DMI (dry matter intake) (a) and NEL (net energy for lactation) (b) per kg milk production by Chinese Holstein dairy cattle with different daily milk yields in each month under annual milk yields of 3000, 4340 and 6071 kg, respectively.

Energy requirements increase with increasing proportions of dry matter intake during grazing in total dry matter intake (Figure 5.8a). For a cow with annual milk yield of 3000 kg with a walking distance (5 km), NEL requirements increase 22 and 26% when the proportion of dry matter intake through grazing in total dry matter intake increases from 0 to 50 and 100%, respectively. The increase in NEL requirement is relatively smaller for the high-yielding cow. NEL requirements increase 14% with a walking distance of 1 km when the proportion of intake through grazing is 50% of total dry matter intake for a cow with 6071 kg milk production while the increase of NEL requirements is 16% for a cow with 3000 kg.

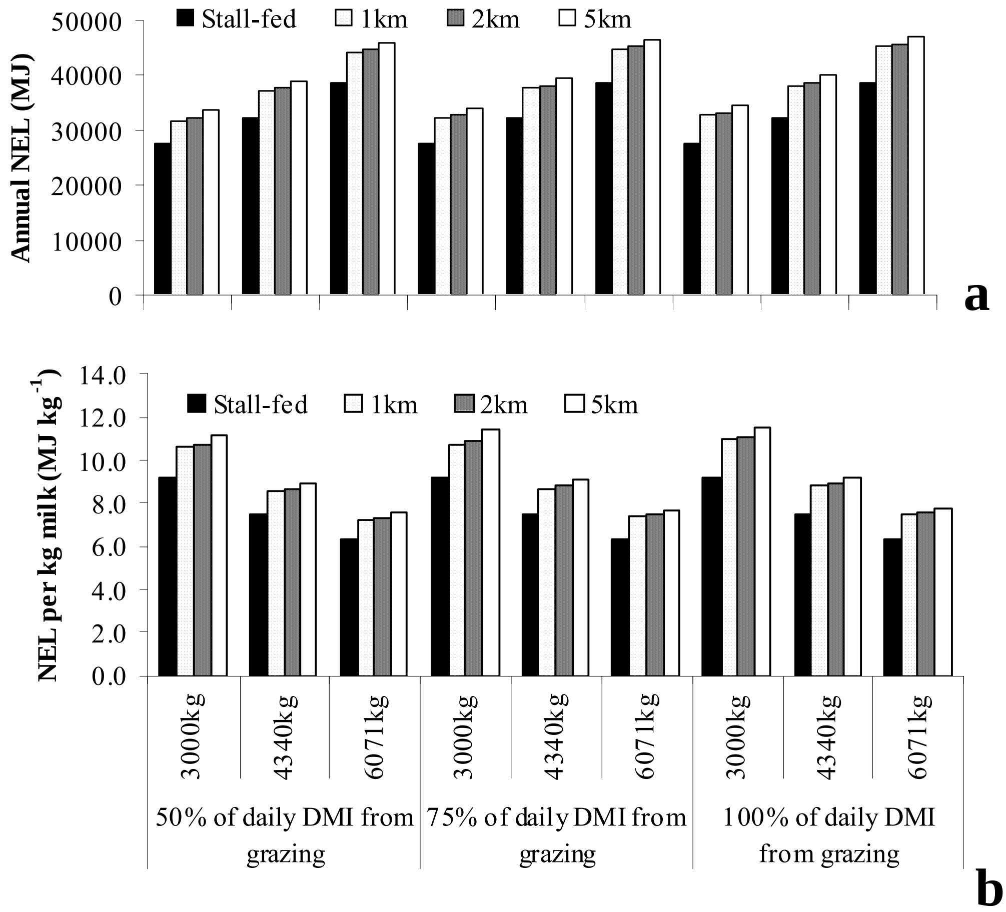


Figure 5.8 Effect of grazing distance on annual requirements for net energy for lactation (NEL) (a) and NEL per kg milk production (b) by Chinese Holstein dairy cattle with different annual yield levels and different proportion of grazed dry matter in daily dry matter intake (DMI).

5.6 Input-output relations of livestock systems for the regional LP model

This section describes the assumptions underlying the calculations of nutrient requirements, labour requirements, costs of non-feed non-labour inputs, and manure N production of both current and alternative systems. To capture the seasonality of available roughage in the LP model, monthly nutrient requirements are calculated. All animals are assumed to be stall-fed. In addition, quality characteristics of feeds, and monthly availability of green feeds and silages are presented in Sub-section 5.6.4.

5.6.1 Nutrient requirements

5.6.1.1 Dairy cattle

Annual milk production of current systems is 3000 kg, while the annual milk production target for alternative dairy systems is set to 4340 kg. Characteristics of both the current and alternative system used in the calculation are given in Table 5.12. The date of parturition is set to January 1. The calculated requirements for DMI, NEL and CP are shown in Table 5.13.

Table 5.13 Monthly nutrient requirements of stall-fed Chinese Holstein dairy cattle with target milk yields of 3000 and 4340 kg y^{-1}.

	3000 kg			4340 kg		
Month	DMI (kg)	NEL (MJ)	CP (kg)	DMI (kg)	NEL (MJ)	CP (kg)
Jan	388	2473	49	460	2996	63
Feb	374	2453	49	444	2977	62
Mar	401	2706	51	468	3228	65
Apr	374	2632	47	434	3109	59
May	368	2717	46	426	3215	58
Jun	335	2608	42	390	3106	53
Jul	326	2666	41	379	3168	52
Aug	319	2514	38	365	2933	47
Sep	322	2389	35	368	2791	44
Oct	347	2355	36	391	2720	45
Nov	368	2347	38	411	2682	47
Dec	419	2503	43	464	2829	52

Note 1: The daily mean temperature has been used in the calculations of DMI and NEL requirements.

5.6.1.2 Beef cattle

In current systems, a yellow cattle calf of 56 kg at weaning is fattened to 239 kg in one year (ADG = 0.50 kg d^{-1}). In alternative systems, a crossbreed calf of 81 kg at weaning is fattened to 382 kg in one year (ADG = 0.83 kg d^{-1}). Calculated requirements for DMI, NEMF and CP of both systems are shown in Table 5.14.

5.6.1.3 Goats

In current systems, the local goat breed is used, and in the alternative systems, the improved breed. The local goat breed is fattened from 10 kg to 35.1 kg in one year

(ADG = 69 g d^{-1}). The improved goat breed is fattened from 15 to 62.5 kg in one year (ADG = 131 g d^{-1}). The calculated requirements for DMI, DE and CP of both systems are shown in Table 5.15.

Table 5.14 Monthly nutrient requirements of stall-fed local yellow cattle and crossbreed beef cattle.

	Local breed fattening from calf of 56 kg to 239 kg at sale			Crossbreed fattening from calf of 81 kg to 382 kg at sale		
Month	DMI (kg)	NEMF(MJ)	CP (kg)	DMI (kg)	NEMF(MJ)	CP (kg)
Jan	71	304	12	106	469	17
Feb	71	311	11	107	488	16
Mar	87	381	13	132	606	18
Apr	91	411	13	140	659	18
May	101	495	14	154	800	20
Jun	102	562	14	157	915	20
Jul	109	671	15	169	1098	21
Aug	118	695	15	182	1144	22
Sep	122	682	15	190	1126	22
Oct	137	674	16	213	1119	23
Nov	139	675	16	218	1124	23
Dec	151	765	17	236	1278	24

Note 1: The value of F used to calculate NEMF is assumed to be 1.0; Note 2: The daily mean temperature has been used in the calculations of DMI and NEMF requirements.

Table 5.15 Monthly nutrient requirements of stall-fed goats of local breed and improved breed.

	Local breed fattening from kid of 10 kg to 35.1 kg at sale			Improved breed fattening from kid of 15 kg to 62.5 kg at sale		
Month	DMI (kg)	DE (MJ)	CP (kg)	DMI (kg)	DE (MJ)	CP (kg)
Jan	20	205	1.6	32	324	2.5
Feb	18	185	1.4	29	293	2.2
Mar	23	235	1.8	34	343	2.6
Apr	25	259	2.0	36	365	2.8
May	26	267	2.0	37	377	2.9
Jun	25	259	2.0	40	406	3.0
Jul	26	267	2.0	42	428	3.3
Aug	30	305	2.3	43	443	3.4
Sep	30	310	2.4	45	459	3.5
Oct	31	320	2.5	46	475	3.6
Nov	30	310	2.4	48	493	3.8
Dec	30	310	2.4	46	468	3.6

Note: The fattening period of local goat breed is 364 days and that of improved goat breed is 362 days.

5.6.2 Manure N production

In the calculation of N excretion of dairy cattle, beef cattle and goats, N content in body tissue of calf and goat kid is set to 2.9% and that in mature body tissue to 2.65%. The CP content of milk is set to 3.1% (Chen, 1999; Ji, 2001; Li and Cao, 2003, Huang, 2003b; Wang, 2003). Unavoidable N losses are set to 10%. The results are shown in Table 5.16.

Table 5.16 Costs of non-feed and non-labour inputs, manure N production and labour requirements of dairy cattle, beef cattle and goats at two production levels.

	Annual milk yield (kg)		Live weight of beef cattle at sale (kg)		Live weight of goat at sale (kg)	
	3000	4340	239	382	35.1	62.5
Costs (Yuan head^{-1} y^{-1})	1769	2463	572	773	172	237
Manure N (kg head^{-1} y^{-1})	60	73	20	28	3.0	4.3
Labour requirements (d decade^{-1} head^{-1})	1.25	1.67	0.4	0.5	0.063	0.083

Note: decade refers to a 10-day period.

5.6.3 Labour requirements and costs of non-feed and non-labour inputs

The labour requirements and costs of non-feed and non-labour inputs for dairy, beef cattle and goats have been estimated on the basis of information from various sources such as farm survey results, experimental results and literature data (Xie *et al*. 2002; NDRC, 2004, 2005, 2006), and are representative for small-scale livestock production in Jiangxi (Table 5.16). Labour requirements associated with the production of silage and ammonia-treated rice straw are not included. Costs are based on the price level in 2005.

5.6.4 Feed quality characteristics

Quality characteristics of feeds included in the LP model have been derived from various sources such as literature (Zhang, 2000; Ji, 2001; Zhang and Tan, 2001; Dong and Wang, 2002; Liang, 2002; Qiu, 2002; Huang, 2003b; Wang, 2003; Li and Cao, 2003; MAPRC, 2004a, b; Xie *et al*., 2004) and unpublished data of the Feed Research Institute of Jiangxi Agricultural University (Table 5.17). The availability of green feeds and silages in the course of the year in Jiangxi is indicated in Table 5.18.

Table 5.17 Quality characteristics (nutritive value) of animal feeds used in the linear programming model (Data sources: Zhang, 2000; Ji, 2001; Zhang and Tan, 2001; Dong and Wang, 2002; Liang, 2002; Qiu, 2002; Li and Cao, 2003; Huang, 2003b; Wang, 2003; MARPC, 2004a, b; Xie et al., 2004; and unpublished data of the Feed Research Institute of Jiangxi Agricultural University).

	Dry matter (%)	Crude protein (%)	NEL[a] (MJ)	NEMF[b] (MJ)	DE[c] (MJ)	Crude fibre (%)
Green feeds:						
Chinese milk vetch	13.0	2.9	0.60	0.57	1.25	4.0
Italian ryegrass	15.0	1.6	1.17	1.11	2.01	4.0
Dwarf elephant grass	18.0	1.6	1.07	1.02	2.23	7.0
Hybrid elephant grass	18.0	1.6	1.07	1.02	2.23	7.0
Chinese kudzu	26.6	3.3	1.17	1.14	2.50	8.0
Sweet potato	22.0	1.1	2.18	2.07	3.83	0.8
Silages:						
Silage maize	22.7	1.9	1.26	1.0	2.25	7.0
Silage dwarf elephant grass	19.8	1.8	1.20	1.10	2.50	7.7
Silage hybrid elephant grass	19.8	1.8	1.20	1.10	2.50	7.7
Crop residues:						
Rice straw	82.9	5.0	2.32	2.0	6.68	27.0
Ammonia-treated rice straw	94.7	16.0	2.84	2.40	8.00	30.8
Maize straw	90.0	5.6	4.64	3.61	9.50	24.9
Sorghum straw	90.0	5.0	4.00	3.00	8.50	25.0
Sugar cane top	24.6	1.3	0.88	0.84	2.23	23.0
Sweet potato vine	13.0	1.3	0.75	0.63	1.37	5.1
Peanut haulm	15.0	1.1	0.74	0.70	1.82	5.2
Concentrates:						
Maize grain	88.0	8.8	8.49	8.06	14.47	2.0
Sorghum grain	88.0	8.8	7.34	6.90	13.31	2.0
Rice grain	86.0	8.8	7.35	6.98	13.00	8.5
Rice bran	90.0	11.9	7.60	7.22	13.93	9.2
Fish meal	91.7	52.5	7.45	7.09	10.79	0
Soybean meal	89.0	45.6	8.16	7.41	14.31	5.7
Rapeseed meal	92.2	36.3	6.84	6.77	13.52	10.7
Cotton seed meal	88.3	39.4	7.12	6.62	13.11	10.7

[a] Net energy for lactation for dairy cattle.
[b] Net energy for maintenance and fattening for beef cattle.
[c] Digestible energy for goats.

Table 5.18 Availability of green feeds and silages in the course of the year in Jiangxi.

Feed source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chinese milk vetch			X	X								
Italian ryegrass		X	X	X	X							
Dwarf elephant grass					X	X	X	X	X	X	X	
Hybrid elephant grass					X	X	X	X	X	X	X	
Chinese kudzu					X	X	X	X	X	X	X	
Sweet potato	X	X	X	X			X	X	X	X	X	X
Silage maize	X	X	X	X	X						X	X
Silage dwarf elephant grass	X	X	X	X	X						X	X
Silage hybrid elephant grass	X	X	X	X	X						X	X

5.7 Discussion and conclusions

Nutrient requirements of beef cattle are calculated with the original equations of the feeding standards (MAPRC, 2004b), derived from nutrition research on crossbreeds. Most of the current beef production in China is based on local yellow cattle breeds, but it may be anticipated that the number of crossbreeds will increase, because of their higher productivity (they can achieve higher ADGs with the same diet) and better meat quality (Yu, 2000; Deng and Ye, 2004a, b). Thus, more beef can be produced from the same feeds and nutrient requirements per kg liveweight gain are considerably lower in crossbreeds. However, costs of non-feed and non-labour inputs in alternative beef cattle fattening systems with crossbreeds are higher, mainly due to the higher costs of calves, feed additives and animal health care.

For dairy cattle, tabulated values derived from the feeding standards (MAPRC, 2004a) are included in the calculation tool. This approach may be less accurate than using the original equations, especially for non-linear metabolic processes. However, the advantage of simplification outweighs the inaccuracies introduced by using tables (Stewart and Dugmore, 1995). Current average annual milk yield is 3000 kg per cow, but in Jiangxi, yields of 6000 kg are attained in an experimental setting with good management and high quality feeds. Nutrient use efficiencies, such as NEL and DMI per kg milk production, increase rapidly if annual milk yields increase from 3000 to 6000 kg. However, costs of non-feed and non-labour inputs are higher, associated with better quality replacements, better veterinary care and higher costs of feed additives. In the feeding standards for dairy cattle (MAPRC, 2004a), effects of sub-optimum temperatures and composition of the ration on total dry matter intake and energy requirement are not considered. In Jiangxi, the high summer temperatures influence nutrient requirements. Therefore, in calculating DMI and NEL requirements for the LP model, mean daily temperature in Jiangxi has been taken into account. Similarly, in the calculations of DMI and NEMF requirements by beef cattle, mean daily temperature has been used.

The approach used to calculate the technical coefficients is generic and modular, parameters and assumptions can be easily adjusted to represent site-specific conditions as those in Jiangxi. The used feeding standards for livestock can also be updated if new insights and data from research become available.

6 Assessing the effectiveness of new crop and livestock technologies in attaining rural development goals: A case study for Jiangxi Province, China

Abstract

In this chapter, the effectiveness of new crop and livestock technologies in achieving a number of rural development goals in Jiangxi is assessed. New crop technologies include Super Rice varieties, site-specific nutrient management (SSNM), integrated pest management (IPM) and mechanization in rice production. New livestock technologies include better quality replacements for dairy, crossbreeds of beef cattle, improved goat breeds, chemical treatment of rice straw and improved management. Rice production and regional income increase substantially using Super Rice varieties as excess land is used to grow more remunerative crops and forage for beef cattle fattening. Application of SSNM and IPM alleviates conflicts between increasing income and reducing the adverse effects associated with the use of agrochemicals. Mechanized rice production reduces total labour needs and provides opportunities for off-farm employment. New livestock technologies increase economic returns and reduce regional biocide use in addition to a number of non-quantified environmental benefits (*e.g.* contribution to soil erosion control and improving soil quality). Integration of new crop and livestock technologies has significant positive effects on economic returns and reduces negative environmental and human health effects associated with the use of agrochemicals. The generated information contributes to the formulation of agricultural policies aimed at achieving various development goals in Jiangxi.

Keywords: Alternative cropping systems; Alternative livestock systems; Linear programming; Regional land use model; Technology assessment

6.1 Introduction

Two of China's major policy challenges are to feed its increasing population and to narrow the gap between urban and rural incomes (CCCPC and SCC, 2004; HBPRST, 2004). In addition to the growing population, urbanization and higher living standards and the associated increase in demand for animal products exert great pressure on food production (Roetter and Van Keulen, 2007). These challenges are faced against the background of decreasing availability of natural resources for agriculture such as water and arable land, and declining labour availability, as a result of rapidly increasing competition from other sectors (De Brauw *et al*., 2002; OECD, 2006; Lichtenberg and Ding, 2008). Moreover, the policies aimed at conservation of environmentally vulnerable areas also decrease the availability of farmland resources (JPRST, 2004).

More than 40% of China's grain production consists of rice, the staple food of more than half of its population (Cheng, 2005; Xie, 2004). Increasing rice production clearly conflicts with the goal of increasing farmers' income (Van den Berg *et al*., 2007). Production of animal feed and fodder competes for the increasingly scarce land and rural labour resources.

As a result of the Green Revolution, China has become self-sufficient in rice, but the associated use of fertilizers and biocides causes increasing public concern (Widawsky *et al*., 1998; Zhu and Chen, 2002; Peng *et al*., 2006; Wei *et al*., 2007). The high inputs of fertilizers and biocides increase production costs, and cause serious environmental, occupational and public health problems, which all bear significant social costs (Li *et al*., 1998; Huang *et al*., 2001). Loss of N and P from farmland is one of the major causes of eutrophication of rivers and lakes (Shi *et al*., 2000; Zhou and Zhu, 2003; Bao *et al*., 2006; Ji *et al*., 2007) and pollution of groundwater (Wang *et al*., 1996; Gao *et al*., 2006a, b). Another possible consequence of the intensive use of biocides is that pest organisms develop resistance to insecticides, reducing their efficiency in protecting crops (Huang, 2003a; Shen, 2003; Zhang *et al*., 2003).

To stimulate grain production, increase farmers' income and alleviate the adverse effects of agrochemicals on the environment and human health, the Chinese government has implemented various policy measures in recent years. Priority has been given to agricultural research and extension to increase yields and mitigate the adverse effects on the environment and human health caused by the use of agrochemicals (CCCPC and SCC, 2004, 2005, 2006).

Therefore, the effectiveness needs to be assessed of different crop and livestock production technologies in attaining rural development goals, *i.e.* increasing grain production, increasing farmer's income and reducing negative environmental impact. At the same time, the potential synergies and conflicts among the various development goals need to be identified.

The major objectives of this chapter are therefore:

1. Assess the economic and environmental consequences of adopting new crop and livestock production technologies in Jiangxi.
2. Explore the opportunities for increased rice and livestock production in Jiangxi through adoption of technological innovations in crop and livestock production.
3. Assess the contribution of new crop and livestock production technologies to alleviating the conflicts between increasing rice production and increasing income,

and between increasing income and reducing the negative effects on environment and human health caused by agrochemicals.

6.2 Methodology

The methodology used consists of four major components: (i) identification of objectives of relevant interest groups with a stake in rural development, (ii) design and quantification of cropping and livestock systems in terms of inputs and outputs, (iii) development of a regional agricultural sector linear programming (LP) model, and (iv) definition of relevant policy scenarios (Figure 6.1).

Quantification of input-output relations of cropping and livestock systems is presented in Chapter 4 and Chapter 5, respectively. In this section, the other three components of the methodology are described.

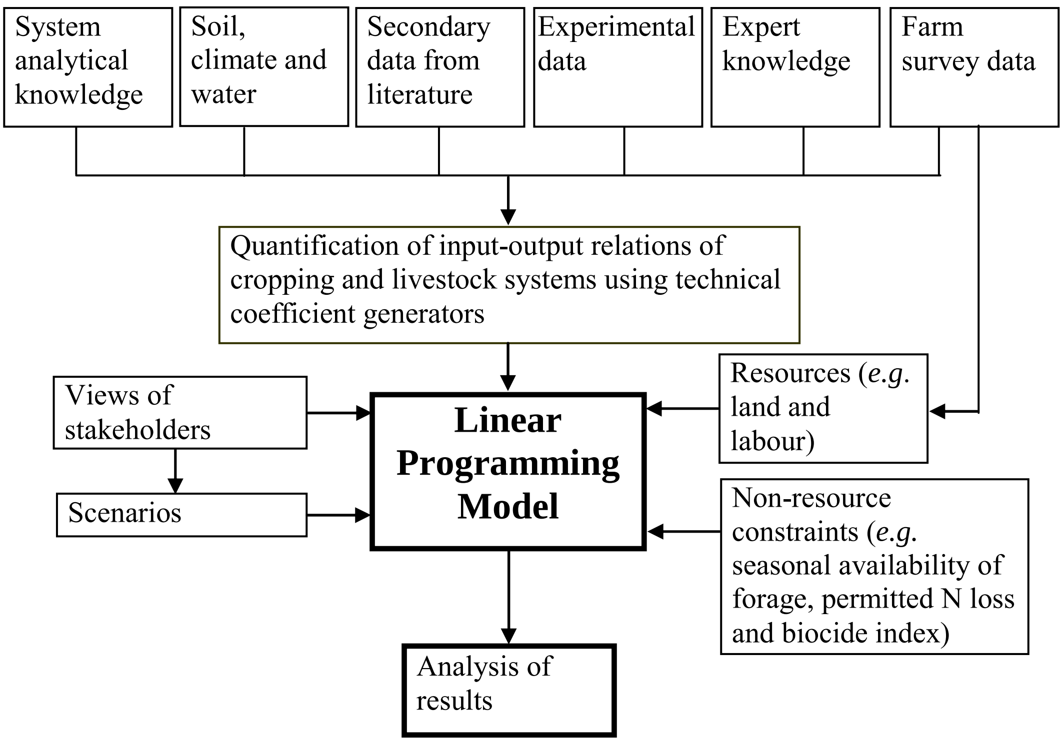


Figure 6.1 The methodology to assess the effectiveness of new crop and livestock production technologies in attaining rural development goals.

6.2.1 Identification of rural development goals

Rural development goals have been derived mainly from official policy documents of the Chinese government, complemented with information from informal interviews with different stakeholders.

The rapidly increasing grain prices in the course of 2003, which were mainly due to limited supply, were a reason for great concern for the Chinese government (Li, 2003; Li, 2005a). As self-sufficiency in grain is a long-term national policy objective of China, favourable policies, *i.e.* a tax reduction, direct subsidy on grain seed, subsidy on purchase and use of machinery in grain production and a minimum farm gate price for grain, were implemented in 2004 (CCCPC and SCC, 2004). The economic returns of grain production improved significantly due to the high prices and the reduced costs of non-labour inputs. Moreover, favourable weather conditions in 2004 contributed to higher yields and thus economic returns (Gale *et al*., 2005). Another, equally important goal is to increase farmers' income. In addition to grain self-sufficiency, Chinese policy also pays attention to protection of the environment through research on and extension of input-saving technologies such as improved nutrient management and integrated pest management (CCCPC and SCC, 2005, 2006). Moreover, biogas technology is promoted to reduce pollution caused by animal manure and the dependence on non-renewable energy resources (Wen, 2000; Zhou *et al*., 2001).

To identify the objectives of other stakeholders, many stakeholders, including farmers, government officials responsible for agriculture at provincial, county, township and village level, and consumers were interviewed. Farmers were interviewed in their own environment during farm surveys. Such informal interviews generally yield more information than official workshops where participants are under social pressure.

Generating sufficient income is a priority, but self-sufficiency in rice is still a major boundary condition for most farmers. Another reason to grow rice is its relatively small price risk as a result of the introduction of a minimum price since 2004. Some high value crops such as vegetables and cotton can be very profitable, but price risks are high due to strongly fluctuating prices. The price risk in milk production is high, since a few dairy processing companies determine the price of milk (DAJX, 2005b, 2006, 2007). Generally, fruit, pork, poultry, fish and beef production are considered more reliable ways to increase income.

In some rural areas, pollution associated with the use of fertilizers and biocides has already affected drinking water resources while there are frequent reports of poisoning due to the use of biocides (Li *et al*., 1998; JXAAS, 2001; Li *et al*., 2004).

Many interviewed farmers were concerned about the pollution due to fertilizers and biocides, and about the potential impact of biocides on their own health.

Almost all local government officials interviewed regard implementation of the Chinese Central Government's rural development policy as their responsibility. In their opinion, increasing farmers' income is most important.

Consumers are concerned about biocide residues in agricultural products, as well as about their prices. The recent price hikes for pork, eggs, beef and poultry and the associated increase in inflation receive wide attention (Fu, 2007; Zhang, 2007a). In contrast, consumer awareness about pollution associated with agricultural production is limited.

6.2.2 Regional linear programming model

Linear programming (LP) is a widely used technique in agricultural land use analysis (De Wit *et al*., 1988; Stoorvogel, 1995; Bouman *et al*., 1998; Bessembinder *et al*., 2000; Roetter *et al*., 2005; Hengsdijk *et al*., 2007). An LP model optimizes an objective function, subject to a set of constraints (Chuvieco, 1993) and is composed of decision variables, constraints and a linear objective function (Nidumolu *et al*., 2007). Decision variables are typically areas allocated to production systems characterized by sets of inputs and outputs. Constraints can be related to resource availability (*e.g.* land and labour), or to product balances (*e.g.* self-sufficiency in agricultural products). The objective function can represent a socio-economic, agricultural and environmental objective (Makowski *et al*., 2000).

To assess the effectiveness of innovative crop and livestock production technologies in attaining rural development goals in Jiangxi Province, a regional LP model has been developed. The objective function used is regional net income, defined as the sum of crop net income and livestock net income. The net inocm is defined as the value of production minus costs of non-labour inputs. Costs of non-labour inputs in crop production consist of the costs of seed, fertilizers, biocides, agricultural plastic, various small implements, animal draught, machines, irrigation and taxes. Costs of non-labour inputs in livestock production consist of costs of forage production, concentrates, young animals (heifers, calves and goat kids), buildings, machines and other equipment, water, electricity, fuel, animal health care, feed additives, artificial insemination (for dairy only), taxes and miscellaneous costs. The costs of ensiling and chemical treatment of rice straw are included in the costs of feed. Although forages are part of crop production, they yield no income. Labour requirements for forage production, chemical treatment of rice straw and ensiling are included in the labour requirements of livestock production.

The constraints in the model are classified into four types: (i) resource endowments (available land and labour), (ii) development targets for non-goal variables (*e.g.* minimum production targets of major crop and livestock products), (iii) goal restrictions imposed by other objectives (*e.g.* regional net income is restricted by different rice production goals, livestock production goals, and permitted N loss and biocide index), and (iv) seasonal availability of forage for livestock.

In this study, only so-called 'land-based' systems are considered in the analysis, since specialized intensive animal production systems typically purchase feeds from national and international markets, and require few local (feed) resources. Both, cropping and livestock systems are defined and quantified in terms of inputs and outputs. A cropping system is a combination of a land unit, land use type and production technique (Chapter 4). The livestock systems include dairy, beef cattle and goat fattening systems (Chapter 5). Total cultivable land area is 2.32 Mha, which is classified into eleven land units (Chapter 4). Capital is not included as a constraint in the model. Labour balances are computed per decade (a 10-day period) to account for labour demand peaks. Immigrant labour is not available, as Jiangxi is typically a province where emigration dominates. Although part of the rural labour force may be working in urban areas, it is assumed to be fully available for agricultural production, as migration is often seasonal. To capture the seasonality of available forages, feed requirements of animals and availability of forages are calculated per month. Green fodders such as elephant grass and Chinese kudzu vine are available between May and November, Italian ryegrass between February and May, and Chinese milk vetch from March to April. From November to May, silage of maize and elephant grass is available. Feed rations of animals are calculated to meet the requirements for dry matter, energy and crude protein. Net energy for lactation (NEL), net energy for maintenance and fattening (NEMF) and digestible energy (DE) are used for dairy cattle, beef cattle and goats, respectively (Chapter 5). Lower and upper limits of crude fibre content in daily feed rations are also defined. All roughages, *i.e.* green fodder, silage and crop residues have to be produced within Jiangxi. Concentrates, including maize grain, rice, sorghum, cotton-seed meal, soybean meal, oilseed meal and fish meal are available year-round from the market. All manure produced by livestock systems is assumed to be used in cropping systems.

6.2.3 Scenario definition

A land use scenario is defined as a set of hypothesized changes in the socio-economic or biophysical environment and/or available technology (Stoorvogel, 1995). Changes in technology can mitigate or aggravate land use conflicts, reduce or increase adverse environmental effects and increase or decrease agricultural production. Technological changes can be sub-divided into: (i) introduction of new or improved crops/animals, (ii) introduction of new inputs, and (iii) management changes (Stoorvogel and Antle, 2001). In this study, Super Rice varieties and crossbreeds of beef cattle are such improved crop (varieties) and animal (breeds), respectively. Ammonia-treated rice straw is an example of a new input. SSNM, IPM and improved livestock management are examples of management changes. In total, six scenarios have been formulated, taking into account the views of different stakeholders (Sub-section 6.2.1).

6.2.3.1 Reference scenario

The reference scenario tries to capture the current situation and its results serve as a basis for assessing the effects of the other scenarios. Most of the input and output coefficients of current cropping and livestock systems have been derived from farm surveys and experiments in Jiangxi. For the financial coefficients, prices of 2005 have been used. Technical coefficients that could not be derived from the farm surveys, such as N loss and biocide index (BIOI) in cropping systems, have been estimated using TechnoGIN (Ponsioen *et al*., 2006; Chapter 4), while the manure N production of animals is calculated on the basis of a balance method, *i.e.* manure N production equals N intake minus economic N output and unavoidable N losses. Taking into account the suitability of land unit-land use type combinations, 243 cropping systems are included in this study, including 108 rice-based systems with one or two rice crops. Three livestock systems, *i.e.* dairy, beef cattle fattening and goat fattening systems, are included. The physical production of the major agricultural commodities in 2005, *i.e.* rice, vegetables, rapeseed, soybean, peanut, sweet potato, cotton, milk, beef and goat meat are imposed as lower production limits in this scenario. The dressing percentages (carcass weight as fraction of total live weight) of both beef cattle and goats are set to 50%. No upper limits are imposed except for tobacco, for which the current production quota is used.

The available cultivable area in this study is set to 2.32 Mha based on the cultivable land area in 1999 according to the Department of Land and Resources of Jiangxi Province (3.09 Mha), taking into account land that is set aside as part of a policy to conserve vulnerable areas (0.67 Mha) and land (0.1 Mha) that was lost due to urbanization between 1999 and 2004 (JXSB, 2000, 2005; Xu, 2001; Wang *et al*., 2003a). Recent estimates indicate that the total area of cultivated land was 2.10 Mha in 2005 (JXSB, 2006).

6.2.3.2 New crop and livestock technologies

In this scenario, available cropping and livestock systems are similar to those in the reference scenario, but new crop and livestock technologies are introduced aiming at increasing crop, animal and labour productivity, and/or reducing fertilizer and biocide use. The new crop technologies comprise Super Rice varieties, SSNM, IPM and mechanization in rice production. The new livestock technologies comprise crossbreeds of beef cattle, improved goat breeds, ammonia-treated rice straw and improved management in animal husbandry. For dairy systems, better quality replacements (heifers) are introduced. The new crop and livestock technologies are described in detail in Chapter 4 and Chapter 5, respectively. In this scenario, the consequences of the availability of these innovative technologies individually or in combination are investigated. The first combination consists of all new crop technologies, *i.e.* Super Rice varieties, mechanized operations in rice production, and SSNM and IPM in both, rice and non-rice crops. The second combination analyses simultaneously all new crop and livestock technologies.

6.2.3.3 Increasing rice production

In this scenario, the agronomic, economic and environmental consequences are assessed of increasing current rice production (18.5 Tg) in steps of 10% up to the maximum attainable production in Jiangxi, given the available resources and using current or new technologies. The results provide an estimate of the possible contribution of yield-increasing technologies (*e.g.* Super Rice varieties) to alleviating potential conflicts between increasing rice production and increasing income.

6.2.3.4 Increasing livestock production

In this scenario, the agronomic, economic and environmental consequences are assessed of increasing current production of milk, beef and goat meat in steps of 100%

up to the maximum attainable production. The major objective is to explore the scope for livestock development created by the new crop and livestock technologies.

6.2.3.5 Mitigating nitrogen pollution

In this scenario, the permitted N loss is reduced in steps of 10% to the minimum attainable level. The objective is to explore the consequences of reduced N loss on the economic returns and to identify the technologies that are most effective in mitigating the conflicts between increasing income and reducing N loss.

6.2.3.6 Reducing biocide use

In this scenario, the biocide index (BIOI; Chapter 4) is reduced in steps of 10% to the lowest attainable level. The lower the BIOI, the lower is the risk for environmental pollution and human health problems (Schipper *et al.*, 2000). The objective of this scenario is to explore the consequences of reduced biocide use on income and to identify the technologies that are most effective in mitigating the potential conflicts between increasing income and reducing biocide use.

6.3 Results and discussion

6.3.1 Reference scenario

Comparison of the results of the reference scenario with the available statistical data in Jiangxi is cumbersome as the latter are incomplete, ambiguous and sometimes conflicting. Despite these inconsistencies, results of the reference scenario are compared with available statistical data in Table 6.1.

In the model solution, the cropping index, defined as the ratio of the total sown area of crop and total area of cultivated land, is 1.95 against 2.54 in the statistics. The latter value seems too high, as physical limitations such as climate and available irrigation water in large parts of Jiangxi do not allow such high cropping intensities (Huang, 1994; Huang, 2000a, b, c; Zhou, 2000). On the other hand, the calculated cropping index may underestimate current cropping intensities, as land use types with Chinese milk vetch are not selected in the reference scenario.

Table 6.1 Production value of crops and livestock (dairy, beef cattle fattening and goat fattening) and cultivated crop areas in 2005 in Jiangxi: Comparison of statistics and results of the reference scenario (Source of statistical data: JXSB, 2006).

	Statistics	Reference scenario
Production value crops (10^9 Yuan)	45.7	48.1
Production value livestock (10^9 Yuan)	2.8	4.5
Rice production (Tg)	18.5[a]	18.5
Area rice (10^3 ha)	3188	2927
Area vegetables (10^3 ha)	544	677
Area forage crops (10^3 ha)	60	127
Area non-rice cereals crops (10^3 ha)	37	13
Area rapeseed (10^3 ha)	410	318
Area peanut (10^3 ha)	135	163
Area soybean (10^3 ha)	99	109
Area sweet potato (10^3 ha)	130	121
Area cotton (10^3 ha)	64	53
Area tobacco (10^3 ha)	11	11
Area sugarcane (10^3 ha)	18	16
Area other crops (10^3 ha)	635[b]	0.0
Total crop area (10^3 ha)	5331	4535
Cultivated land area (10^3 ha)	2098	2320
Cropping index[c]	2.54	1.95
Number of dairy cattle (10^3 head)	39	42
Milk production (10^3 Mg)	125	125
Number of beef cattle (10^3 head)	1014	1922
Beef production (10^3 Mg)	102	229
Number of goats (10^3 head)	1052	912
Goat meat production (10^3 Mg)	16	16

[a] Recent information suggests that this value may have been overestimated and should have been 17.5 Tg.
[b] Including 366 $\times 10^3$ ha of green manures. In the model, the land use types with Chinese milk vetch are not selected in the reference scenario.
[c] Crop area/cultivated land area.

The simulated value of crop production is comparable to the value in the statistics, but the value of livestock production is strongly overestimated (Table 6.1), which is a reflection of the high profitability of beef cattle (Qiu, 2000; Yu, 2000). Consequently, the simulated area of forage crops is twice that in the statistics. Moreover, in reality, part of the livestock is grazing natural pastures, while in the model, all livestock is stall-fed using roughage produced on-farm.

Generally, most of the simulated crop areas are consistent with the observed data. The vegetable area is overestimated in the model by 20%, which reflects the high profitability of vegetables.

As a consequence of the over-estimation of beef and vegetable production in this scenario, the simulated returns to labour exceed 40 Yuan per day, *i.e.* appreciably higher than the average wage level of 30 Yuan per day.

6.3.2 New crop and livestock technologies

6.3.2.1 Super Rice varieties

Regional net income is 45% higher than in the reference scenario when Super Rice varieties are available. Overall land productivity is significantly higher than in the reference scenario (Table 6.2). The increased income mainly originates from increased production of vegetables (an 86% increase in area) and beef cattle (an increase in number of beef cattle from 1.9 million head in the reference scenario to 6.8 million), that profit from the land that becomes available, because of the higher rice yields (total rice production remains equal to the minimum requirement). In addition, income from rice is higher, although the profitability of Super Rice is still lower than that of vegetables. Gross margins (value of production minus the costs of non-labour inputs) of rice production are 30% higher, while the labour inputs per Mg grain yield are 13% lower (Table 6.3).

6.3.2.2 Site-specific nutrient management (SSNM)

Availability of the SSNM has almost no effect on the allocation of crop area (Table 6.2). The marginally higher regional net income is the result of lower costs for fertilizers. Average N use per ha is 18% lower, while P and K use are 5 and 12% higher, respectively (Table 6.4). Average N loss per ha is 37% lower and N loss per 1000 Yuan net income decreases from 15 to 9 kg N (Table 6.5).

Table 6.2 Agronomic, economic and environmental consequences of new crop and livestock production technologies.

	Reference	Super Rice	SSNM[a]	IPM[b]	Mechanization[c]	NLT[d]	Crop-tech[e]	Crop-livestock tech[f]
Regional net income (10^9 Yuan)	37.1	53.9	37.6	37.5	34.8	37.9	54.1	55.1
Land productivity (Yuan ha^{-1})	8184	11259	8353	8277	7683	8293	11183	11341
Total labour use (10^6 d)	881	1256	898	930	721	877	1274	1259
Returns to labour (Yuan d^{-1})	42	43	42	40	48	43	42	44
Cropping systems:								
Net crop income (10^9 Yuan)	35.5	48.1	36.0	35.9	33.2	30.8	49.2	48.0
Labour requirements (d ha^{-1})	188	252	193	198	152	175	251	248
Rice production (Tg)	18.5	18.5	18.5	18.5	18.5	18.5	18.5	18.5
Rice area (10^3 ha)	2927	2338	2928	2927	2927	2955	2355	2358
Vegetable area (10^3 ha)	677	1262	676	677	677	430	1385	1325
Forage area (10^3 ha)	127	416	127	127	127	420	354	433
Area other crops (10^3 ha)	803	766	764	803	803	772	742	742
Livestock systems:								
Net livestock income (10^9 Yuan)	1.6	5.8	1.6	1.6	1.6	7.1	4.9	7.1
Dairy cattle herd (10^3 head)	42	42	42	42	42	29	42	29
Beef cattle herd (10^3 head)	1922	6842	1922	1922	1922	4707	5944	4707
Goat herd (10^3 head)	912	912	912	912	912	512	912	512
Environmental indicators:								
N loss (kg N ha^{-1} y^{-1})	228	313	143	228	228	229	219	220
Biocide index (ha^{-1})	400	581	398	301	400	344	467	458

[a] Site-specific nutrient management; [b] Integrated pest management; [c] Mechanized rice systems; [d] New livestock technologies; [e] Combination of new crop technologies; [f] Integration of new crop and livestock technologies.

Table 6.3 Impact of availability of Super Rice on regional rice production characteristics.

Characteristic	Current rice technology	Super Rice
Rice production (Tg)	18.5	18.5
Sown area with rice (10^3 ha)	2927	2338
Share of rice in crop area (%)	65	49
Rice yield (kg ha^{-1})	6320	7911
Gross margins (Yuan ha^{-1})	6770	8836
Non-labour costs (Yuan Mg^{-1} grain yield)	458	411
Labour input (d Mg^{-1} grain yield)	20	18
Labour intensity (d ha^{-1})	129	141
Returns to labour (Yuan d^{-1})	52	63
N application (kg N ha^{-1})	162	203
P application (kg P_2O_5 ha^{-1})	52	66
K application (kg K_2O ha^{-1})	106	130
N loss (kg N ha^{-1})	105	130
Biocide use (kg a.i. ha^{-1})	2.0	2.7
Biocide costs (Yuan ha^{-1})	270	358

Table 6.4 Simulated use of fertilizer N, P and K with current technologies and with availability of site-specific nutrient management (SSNM).

	N (kg N ha^{-1})		P (kg P_2O_5 ha^{-1})		K (kg K_2O ha^{-1})	
Crop	Current	SSNM	Current	SSNM	Current	SSNM
Rice	162	134	52	60	106	115
Vegetables	328	247	104	75	127	130
Leguminous forages	72	61	102	124	110	156
Graminaceous forages	390	316	87	92	234	302
Non-rice cereal crops	140	118	45	38	90	95
Rapeseed	45	58	23	34	45	68
Peanut and soybean	41	36	49	59	39	52
Sweet potato	145	112	25	19	60	63
Cotton	325	266	130	146	250	257
Tobacco	420	357	150	182	200	283
Sugarcane	390	319	105	118	170	174
Average of crops	181	148	59	62	104	116

Table 6.5 Simulated gross margins, N loss and N loss per 1000 Yuan net income of crops with current technologies and with availability of site-specific nutrient management (SSNM).

	Gross margins (Yuan ha^{-1})		N loss (kg N ha^{-1})		N loss per 1000 Yuan net income (kg N)	
Crop	Current	SSNM	Current	SSNM	Current	SSNM
Rice	6770	6863	105	87	16	13
Vegetables	17986	18477	212	124	12	7
Leguminous forages			49	43		
Graminaceous forages			252	158		
Non-rice cereal crops	5181	5263	91	59	18	11
Rapeseed	2498	2970	29	29	12	10
Peanut and soybean	4053	4079	27	18	7	4
Sweet potato	3753	3195	94	56	25	18
Cotton	15647	15723	210	133	13	9
Tobacco	13020	11654	272	178	21	15
Sugarcane	6221	6450	252	160	41	25
Average of crops	8049	8240	117	74	15	9

6.3.2.3 Integrated pest management (IPM)

Availability of IPM has no effect on the allocation of crop area (Table 6.2). The higher regional income (0.4 billion Yuan) is the result of lower costs for biocides. Insecticide and fungicide use are 33 and 19% lower, respectively (Table 6.6), and average costs of biocides per 1000 Yuan net income decrease from 44 to 32 Yuan (Table 6.7). Overall BIOI decreases 25% to 301 ha^{-1} (Table 6.2).

Table 6.6 Comparison of regional biocide use and biocide index between current practice and availability of integrated pest management.

	Current practice	Integrated pest management
Costs of biocide (10^6 Yuan)	1613	1192
Biocide index (ha^{-1})	400	301
Insecticide use (Mg a.i.)	4685	3153
Fungicide use (Mg a.i.)	12005	9716
Herbicide use (Mg a.i.)	1311	1311

Table 6.7 Comparison of biocide use (kg active ingredient ha^{-1}), costs of biocides (Yuan ha^{-1}) and biocide costs per 1000 Yuan net income between current practice and integrated pest management (IPM).

	Biocide use (kg a.i. ha^{-1})		Biocide costs (Yuan ha^{-1})		Biocide costs in generating 1000 Yuan income (Yuan)	
Crop	Current	IPM	Current	IPM	Current	IPM
Rice	2.0	1.6	270	197	40	29
Vegetables	12.9	10.2	946	701	53	39
Leguminous forages	1.8	1.5	81	66		
Graminaceous forages	3.2	2.6	130	109		
Non-rice cereal crops	4.5	3.7	202	163	39	31
Rapeseed	2.9	2.5	146	120	59	47
Peanut and soybean	3.2	2.6	110	89	27	21
Sweet potato	1.7	1.5	66	56	18	18
Cotton	11.9	8.9	1278	921	82	58
Tobacco	9.3	7.3	508	405	39	33
Sugarcane	6.9	5.4	357	278	57	35
Average of crops	4.0	3.1	356	263	44	32

6.3.2.4 Mechanized rice systems

Labour productivity in rice production can be increased significantly by adopting mechanized rice systems (Table 6.8). Returns to labour increase from 52 to 89 Yuan d^{-1}, while labour inputs per Mg grain production decrease from 20 to 12 days. Although mechanization leads to substantial labour savings, it has no direct influence on the production of other crops or livestock (Table 6.2). Mechanization alleviates especially the problem of labour shortages during peak periods (Table 6.8), thus provides opportunities to work off-farm.

6.3.2.5 New livestock technologies

Most of the 1.6 billion Yuan net income from livestock in the reference scenario is generated through beef cattle fattening (Table 6.9). For both, milk and goat meat production, the minimum targets are realized. Adoption of new livestock technologies leads to higher feed use efficiencies, as reflected in the lower energy consumption per kg milk production and/or per kg liveweight gain of beef cattle and goats. The area of forage crops is 3.3 times that in the reference scenario (Table 6.2), far less than the growth in livestock income (Table 6.9), and the non-labour costs per kg product decrease (Table 6.9). Despite the increase in gross margins per head for dairy cattle

Table 6.8 The impact of adoption of mechanized rice systems on labour productivity in rice production and regional labour requirements during peak labour periods.

	Current	Mechanized
Characteristics of labour use in rice production:		
Returns to labour (Yuan d^{-1})	52	89
Labour intensity (d ha^{-1})	129	75
Labour input (d Mg^{-1} of grain yield)	20	12
Regional labour requirements:		
Labour requirements in 2nd decade[a] in April (10^6 d)	61	37
Labour requirements in 3rd decade in April (10^6 d)	26	18
Labour requirements in 1st decade in May (10^6 d)	80	64
Labour requirements in 1st decade in July (10^6 d)	50	33
Labour requirements in 2nd decade in July (10^6 d)	45	22
Labour requirements in 3rd decade in July (10^6 d)	57	34
Labour requirements in 3rd decade in October (10^6 d)	45	20

[a] Decade refers to a 10-day period.

and goat, their production still does not exceed the minimum targets, which shows that the profitability of beef production is higher than that of dairy and goat meat production.

Regional use of crop residues as feed increases from 3.2 Tg, *i.e.* 15% of the total produced, to 5.8 Tg, because of the higher dry matter intake from crop resiudes (from 1.2 in the reference scenario to 1.7 kg d^{-1} per head beef cattle) and the larger beef cattle herd size (Table 6.9). Regional use of rice straw increases from 0.7 to 3.0 Tg. This reflects that the technology of chemical treatment of rice straw is economically viable (Luo *et al*., 2004). Increased use of crop residues in livestock feeding reduces air pollution, as the common practice of burning the crop residues after harvest contributes significantly to China's emissions of carbon dioxide and other pollutants (Cao *et al*., 2007).

Adoption of new livestock technologies results in reduction of the area under vegetables and cotton with 37 and 10%, respectively, leading to lower crop income. In addition, sugarcane, peanut and soybean are partly replaced by forage crops such as silage maize and elephant grass. About 75% of the silage used in winter comes from maize, the remainder from elephant grass. The area under early rice-late rice-Italian ryegrass (RRG) increases from 41 to 133 kha (k = 10^3). Incorporation of Italian ryegrass in rice-based cropping systems provides green feed to livestock without requiring additional land and leads to improved soil quality (Xin *et al*., 1998; Chen *et* *al*., 2000; Xin and Yang, 2004). Rice yields usually increase following Italian ryegrass (Yang *et al*., 1997; Chen *et al*., 2000; Xin *et al*., 2002), but this yield-increasing effect is not taken into account in quantification of the inputs and outputs of rice-based cropping systems. A large area of less fertile land in hilly and mountainous areas is allocated to elephant grass. In addition to their feeding value, perennial forage crops make an important contribution to erosion control by providing year-round soil cover and increasing soil fertility (Devendra and Sevilla, 2002; Yue *et al*., 2007).

Table 6.9 Impacts of adoption of new livestock technologies on livestock production.

	Current practice	New livestock technologies
Net income from dairy (10^6 Yuan)	55	77
Net income from beef cattle (10^6 Yuan)	1554	6902
Net income from goats (10^6 Yuan)	35	92
Dairy cattle herd (10^3 head)	42	29
Beef cattle herd (10^3 head)	1922	4707
Goat herd (10^3 head)	912	512
Milk yield (kg $head^{-1}$ y^{-1})	3000	4340
Beef production (kg $head^{-1}$ y^{-1})	239[a]	382[a]
Goat production (kg $head^{-1}$ y^{-1})	35.1[b]	62.5[b]
Dairy income (Yuan $head^{-1}$ y^{-1})	1327	2673
Beef cattle income (Yuan $head^{-1}$ y^{-1})	808	1466
Goat income (Yuan $head^{-1}$ y^{-1})	38	179
Milk production costs[c] (Yuan kg^{-1})	1.36	1.18
Beef production costs[c] (Yuan kg^{-1})	5.11	4.66
Goat production costs[c] (Yuan kg^{-1})	9.42	7.63
Milk dry matter consumption[d] (kg kg^{-1})	1.8	1.4
Beef dry matter consumption[d] (kg kg^{-1})	7.7	7.2
Goat dry matter consumption[d] (kg kg^{-1})	14.1	10.6
NEL consumption[e] (MJ kg^{-1})	10.2	8.2
NEMF consumption[f] (MJ kg^{-1})	40.7	38.6
DE consumption[g] (MJ kg^{-1})	158.2	124.7
Dairy cattle dry matter intake (kg d^{-1})	14.4	16.3
Beef cattle dry matter intake (kg d^{-1})	3.9	5.9
Goat dry matter intake (kg d^{-1})	1.0	1.4

[a] Live weight of adult cattle at sale; [b] Live weight of adult goats at sale; [c] Costs of non-labour inputs per kg milk production or per kg live weight of adult beef cattle and goats; [d] Dry matter intake (DMI) per kg milk production or per kg liveweight gain of beef cattle and goats; [e] Net energy for lactation (NEL) per kg milk production; [f] Net energy for maintenance and fattening (NEMF) per kg liveweight gain of beef cattle; [g] Digestible energy (DE) per kg liveweight gain of goats.

Replacement of vegetables and cotton by forage crops also reduces biocide use. The biocide use in vegetables, cotton, Italian ryegrass and elephant grass is 12.9, 11.9, 3.4 and 2.7 kg active ingredient (a.i.) ha^{-1}, respectively. Regional N loss remains unchanged because N use (Table 6.4) and associated N losses (Table 6.5) in non-leguminous forage crops are high. Many graminaceous forage, crops such as Italian ryegrass and elephant grass, receive frequent N fertilizer applications during the growing season. N use in leguminous forage crops, such as Chinese kudzu and Chinese milk vetch, is much lower, but these crops are not selected in this scenario, which implies that they are less economically attractive than other non-leguminous forage crops.

6.3.2.6 Combination of new crop technologies

The impact of availability of the combination of new crop technologies considered on regional income and allocation of crops is similar to that of Super Rice varieties (Table 6.2). The area of both vegetables and forage crops increases significantly at the expense of the rice area. The larger area of forage crops is associated with a 200% increase in net income from livestock. The net income from crop is nearly 40% higher than in the referece scenario. However, the N loss is slightly lower and BIOI is only 17% higher than that in the reference scenario (Table 6.2). Regional net income is slightly higher than that of the scenario of Super Rice, while N loss and BIOI are 30 and 20% lower, respectively (Table 6.2), associated with adoption of SSNM and IPM.

6.3.2.7 Combining new crop and livestock technologies

When all new crop and livestock technologies are made available concurrently, regional net income from both, crops (35%) and livestock (340%) is significantly higher than that in the reference scenario. Overall land productivity is significantly higher than in the reference scenario, associated with much higher production of vegetables and beef (Table 6.2). Production of milk and goat meat remains at the lower limit. The area of forage crops is about 3.5 times that in the reference scenario, most of which is fed to beef cattle, which increases from 1.9 million head in the reference scenario to 4.7 million. Use of crop residue in feeding increases from 3.2 to 5.8 Tg. Manure N application increases from 16 to 50 kg N ha^{-1}.

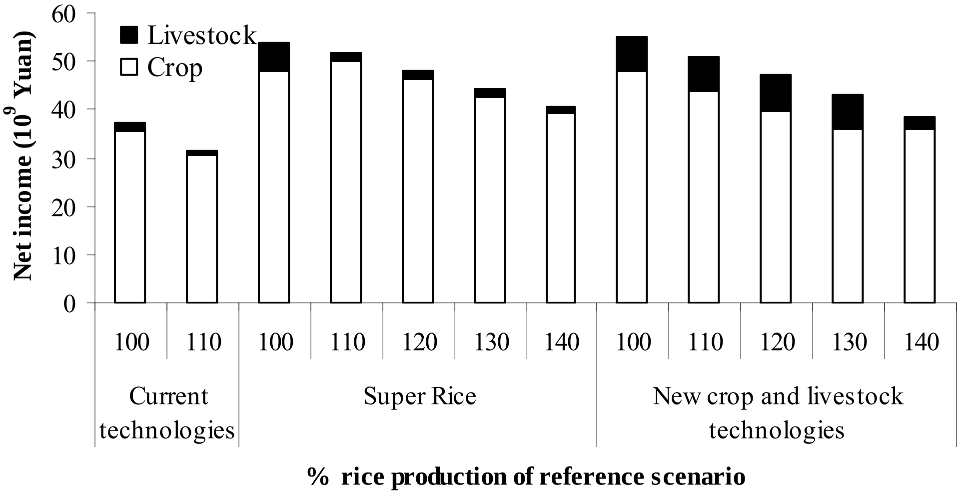
6.3.3 Increasing rice production

The rice production potential in Jiangxi is 20.4 and 26.6 Tg with current technologies and availability of Super Rice varieties, respectively, compared to 18.5 Tg in the reference scenario. With current technologies, increasing the base production by 10% results in a reduction in regional net income of crops and livestock of 14 and 57%, respectively (Figure 6.2a). As a consequence, land productivity decreases significantly as rice replaces vegetables and forage crops (Figure 6.2b). Regional net income decreases by 5.8 billion Yuan (Figure 6.2a), *i.e.* 3114 Yuan per Mg additional rice production (Figure 6.2c).

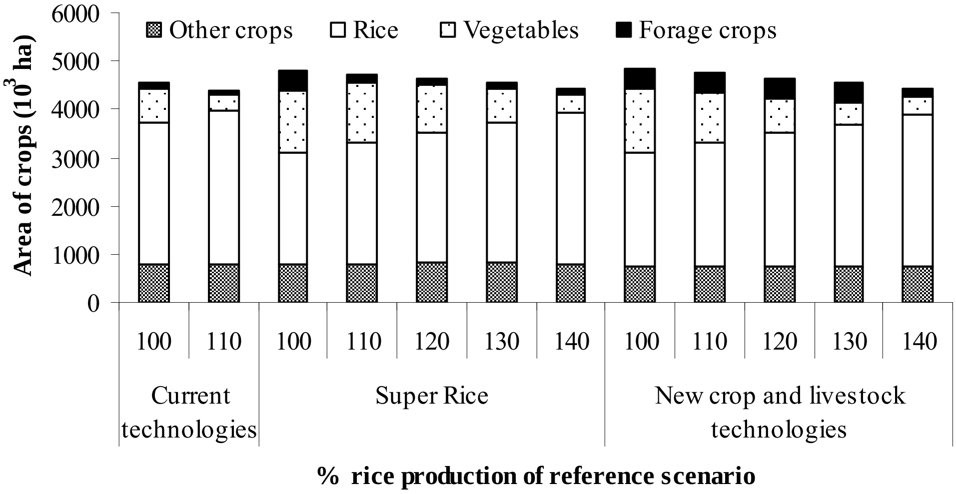
With adoption of Super Rice varieties, net income and associated land productivity increases significantly (Figure 6.2a) and the sacrifice in income per Mg of additional rice production is 1173 Yuan at a 10% higher rice production (Figure 6.2c). The much lower sacrifice in income than with current technologies is associated with higher production of vegetables (Figure 6.2b) and higher profitability of Super Rice varieties (Table 6.3). The area of forage crops and the associated beef cattle herd size are smaller. With further increases in rice production with 20, 30 and 40%, the area under forage crops remains almost unchanged, but the vegetable area gradually decreases (Figure 6.2b). Most forage crops do not compete for land with rice, as they are grown in rotation with rice and/or on non-rice land.

Availability of both, new crop and new livestock technologies results in a higher share of livestock production in regional income (Figure 6.2a), because of the greatly improved profitability of beef production (Table 6.9). Income from livestock remains unchanged when rice production increases to 130% of that in the reference scenario. In that situation, vegetables are affected first, which implies that the profitability of beef cattle with the new technologies is higher than that of vegetables. Crop income is significantly lower (Figure 6.2a), due to the smaller vegetable area (Figure 6.2b). When rice production increases by 40%, net income from crops and livestock is 36.1 and 2.6 billion Yuan, respectively. Both, crop and livestock income are slightly higher than that in the reference scenario (Figure 6.2a and Table 6.2). N loss and biocide use are much lower due to the adoption of SSNM and IPM for all crops. With increasing rice production, average N loss (Figure 6.2d) and BIOI (Figure 6.2e) gradually decrease due mainly to the decrease in area of vegetables (Figure 6.2b).

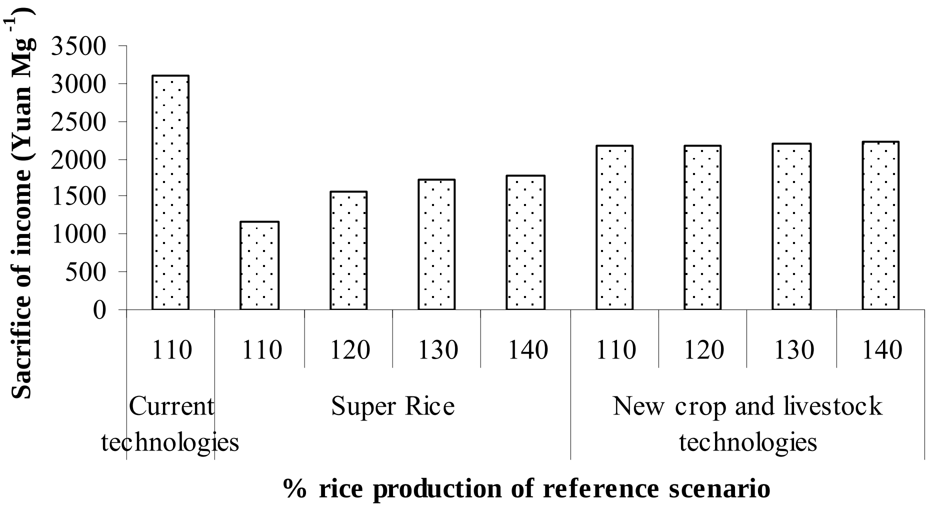
The results demonstrate that adoption of both, new crop and new livestock technologies can alleviate the conflicts between increasing rice production and increasing income, and between increasing rice production and reducing the adverse effects on environment and human health.


60
50
40
30
20
10
0
Net income (10^9 Yuan)
Livestock
Crop
100
110
100
110
120
130
140
100
110
120
130
140
Current technologies
Super Rice
New crop and livestock technologies
% rice production of reference scenario

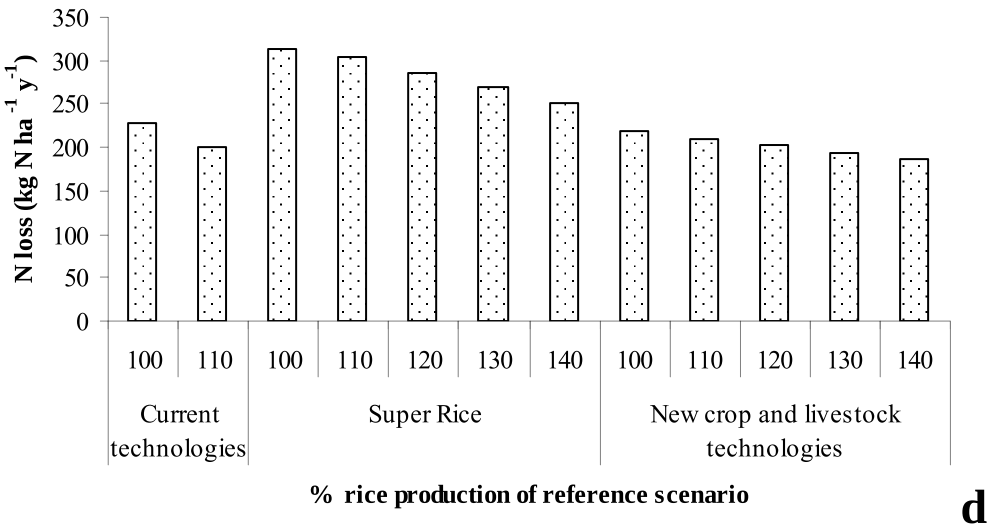
a


6000
5000
4000
3000
2000
1000
0
Area of crops (10^3 ha)
Other crops
Rice
Vegetables
Forage crops
100
110
100
110
120
130
140
100
110
120
130
140
Current technologies
Super Rice
New crop and livestock technologies
% rice production of reference scenario

b


3500
3000
2500
2000
1500
1000
500
0
Sacrifice of income (Yuan Mg^-1)
110
110
120
130
140
110
120
130
140
Current technologies
Super Rice
New crop and livestock technologies
% rice production of reference scenario

c



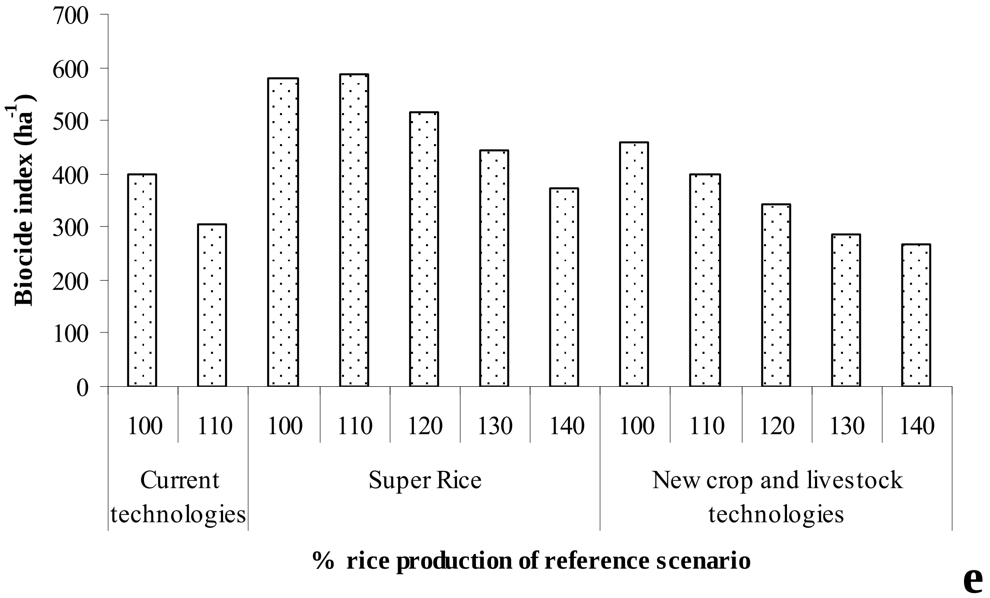
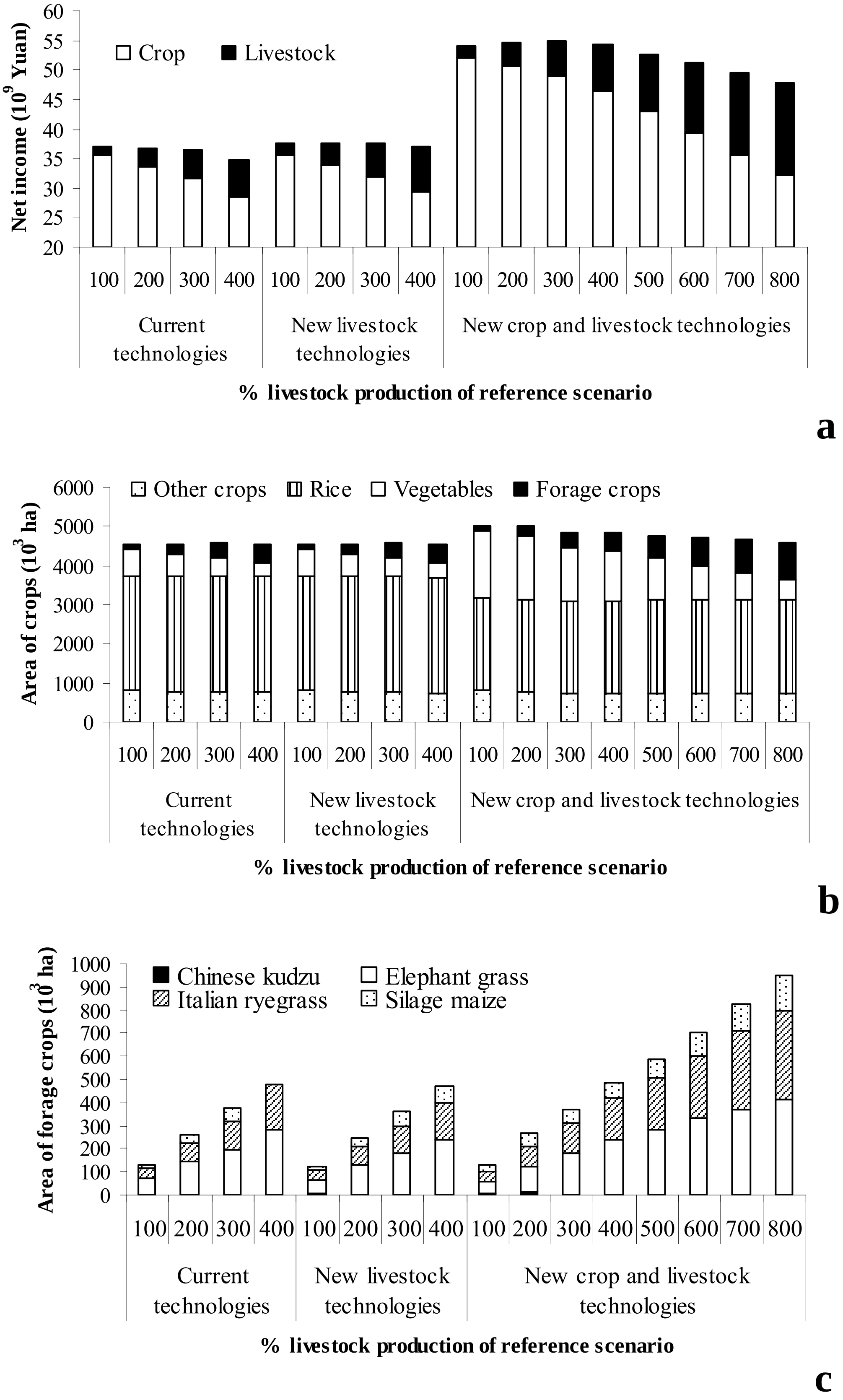


Figure 6.2 *Impact of increasing rice production by 10, 20, 30, and 40% from the reference scenario with current technologies, availability of Super Rice varieties and availability of both alternative crop and livestock technologies on regional net income (a), crop allocation (b), sacrifice of net income per Mg increased rice production (c), N loss (d) and biocide index (e).*

6.3.4 Increasing livestock production

Maximum livestock production with current crop and livestock technologies is four times that in the reference scenario. Regional income is hardly affected up to a livestock production level of three times that in the reference scenario, as the loss in income from vegetables is largely compensated by increased income from livestock (Figure 6.3a). The area under forage crops increases from 127 to 376 kha, mainly with elephant grass and Italian ryegrass (Figures 6.3b and 6.3c).



Net income (10^9 Yuan)
60
55
50
45
40
35
30
25
20
Crop
Livestock
100 200 300 400 100 200 300 400 100 200 300 400 500 600 700 800
Current technologies
New livestock technologies
New crop and livestock technologies
% livestock production of reference scenario
a
Area of crops (10^3 ha)
6000
5000
4000
3000
2000
1000
0
Other crops
Rice
Vegetables
Forage crops
100 200 300 400 100 200 300 400 100 200 300 400 500 600 700 800
Current technologies
New livestock technologies
New crop and livestock technologies
% livestock production of reference scenario
b
Area of forage crops (10^3 ha)
1000
900
800
700
600
500
400
300
200
100
0
Chinese kudzu
Elephant grass
Italian ryegrass
Silage maize
100 200 300 400 100 200 300 400 100 200 300 400 500 600 700 800
Current technologies
New livestock technologies
New crop and livestock technologies
% livestock production of reference scenario
c

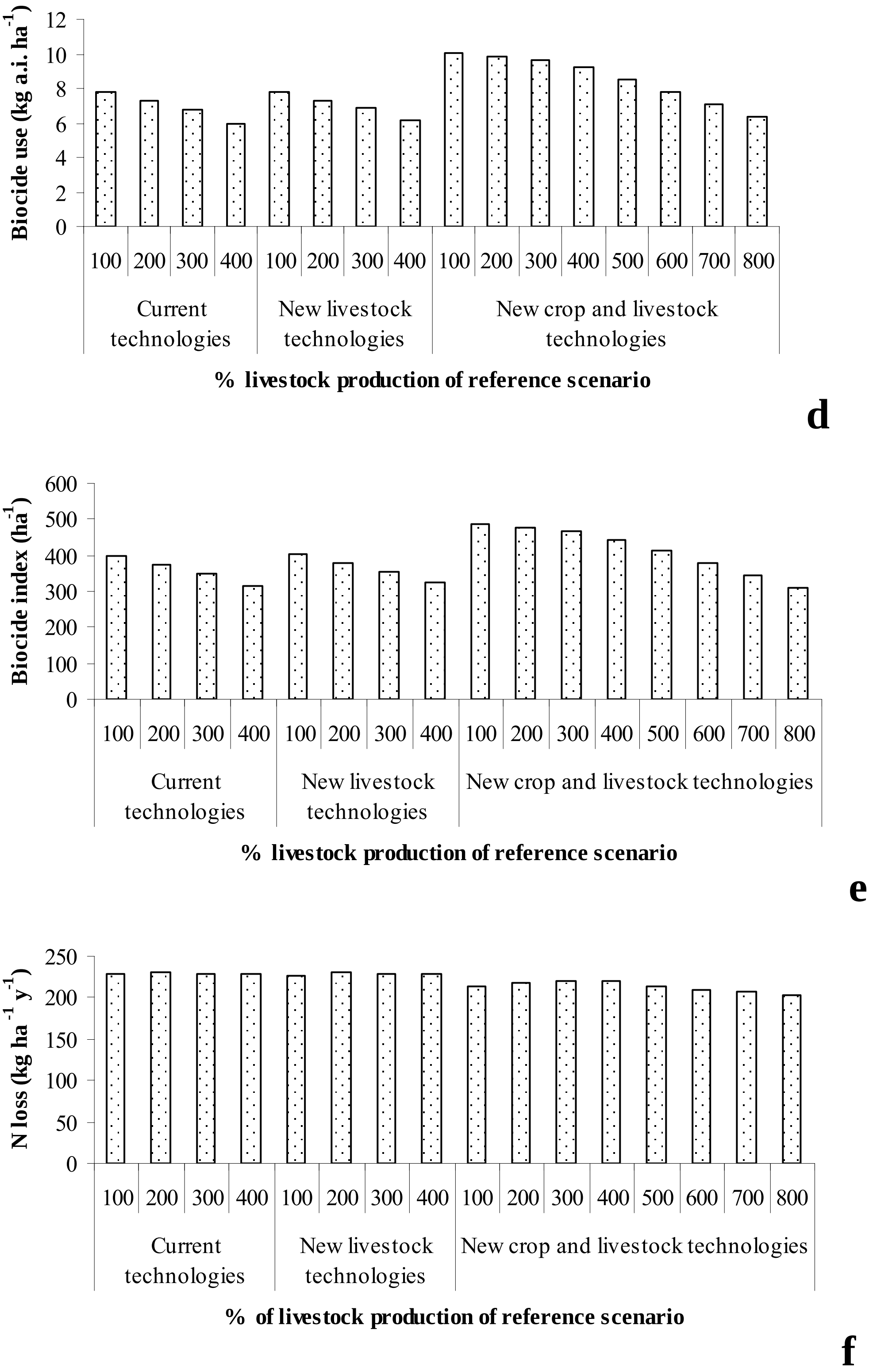


Figure 6.3 Impact of increasing livestock production in steps of 100% to the maximum production potential in Jiangxi with current technologies, availability of new livestock technologies and availability of both alternative crop and livestock technologies on regional net income (a), crop allocation (b and c), biocide use (d), biocide index (e) and N loss (f).

To increase maximum livestock production by a factor eight compared to the reference scenario, new crop technologies are needed to make (more) land available for production of forage crops. When both, new crop and livestock technologies are adoped, regional net income is 49% higher than that in the reference scenario (Table 6.2) and is hardly affected by increasing livestock production up to a factor four (Figure 6.3a). The higher production is realized by using both, rice and non-rice land units with the lowest soil fertility for perennial forage crops to meet the feed requirements. This means that less fertile and erosion-prone land in the hilly and mountainous areas is protected with minor sacrifice in income. With the increase in livestock production, average biocide use and overall biocide index decrease significantly (Figures 6.3d and 6.3e). Therefore, integration of new crop and livestock technologies can play an important role in alleviating the conflict between increasing income and reducing the adverse effects on the environment and human health caused by biocides. With increasing livestock production, the area of grass forage crops particularly the Italian ryegrass and elephant grass increases significantly (Figure 6.3c) at the expense of the area with N-demanding vegetables (Figure 6.3b). This implies that Italian ryegrass and elephant grass are more economically attractive than other forage crops, for example, Chinese kudzu. However, overall N loss remains almost unchanged with increasing livestock production (Figure 6.2f) because the N loss of graminaceous forage crops is still high after adoption of SSNM (Table 6.5).

Regional income gradually decreases when livestock production increases by more than a factor five in comparison to the reference scenario (Figure 6.3a).

6.3.5 Mitigating nitrogen pollution

In the reference scenario, N loss averages 228 kg N ha^{-1} y^{-1}. Nitrogen losses in tobacco, sugarcane, graminaceous forage crops, vegetables and cotton exceed 200 kg N ha^{-1}, and in rice are about 100 kg N ha^{-1} (Table 6.5). In contrast, N loss per 1000 Yuan net income under vegetables and cotton is 12 and 13 kg N, respectively, *i.e.* significantly lower than the 16 kg N under rice (Table 6.5).

With current technologies, N loss can be reduced to 80% of that in the reference scenario. This indicates that the potential to reduce N losses from agriculture using current technologies is very small. Reducing nitrogen losses with 10%, using current technologies, reduces regional net income only by nearly 4% (Figure 6.4a), since the increase in income from beef cattle fattening compensates for the loss in income from vegetables. This higher income from beef production is associated with a substantial increase in the area under forage crops, especially Chinese kudzu and silage maize

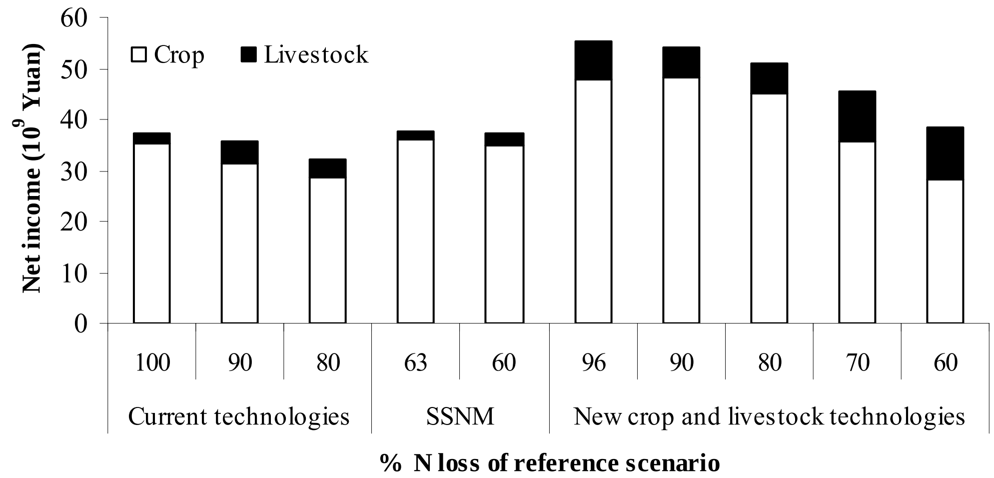
(Figures 4.4b and 4.4c). Nitrogen loss per 1000 Yuan net income decreases from 14 to 13 kg N (Figure 6.4d). When N loss is reduced to 80% of that in the reference scenario, regional net income decreases by about 15%, because in addition to the area under vegetables, the forage area is also reduced, negatively affecting beef production.

When SSNM is available to all crops, N loss is only 63% of that in the reference scenario, while regional net income is slightly higher (Table 6.2) due to reduced costs of fertilizers. Nitrogen loss per 1000 Yuan net income decreases from 14 to 10 kg N (Figure 6.4d). A further (slight) reduction to 60% does not affect regional net income (Figure 6.4a), but leads to selection of the leguminous forage crop Chinese kudzu (Figure 6.4c). Therefore, adoption of SSNM can contribute to alleviation of conflicts between increasing income and reducing N loss.

When both, new crop and livestock technologies are available, regional net income can attain a value 49% higher than that in the reference scenario, while N loss is 220 kg N ha^{-1} y^{-1}, *i.e.* 4% lower than in the reference scenario (Table 6.2). Nitrogen loss per 1000 Yuan net income decreases from 14 to 11 kg N (Figure 6.4d). When N loss is gradually further reduced, from 220 to 137 kg N ha^{-1} y^{-1}, a larger area of forage crops is selected at the expense of vegetables (Figures 6.4b and 6.4c). The increase in forage area is associated with an increasing share of livestock production in regional income (Figure 6.4a). In addition to SSNM, the expansion of the area of leguminous forage crops (Figure 6.4c) can contribute to lower N losses.

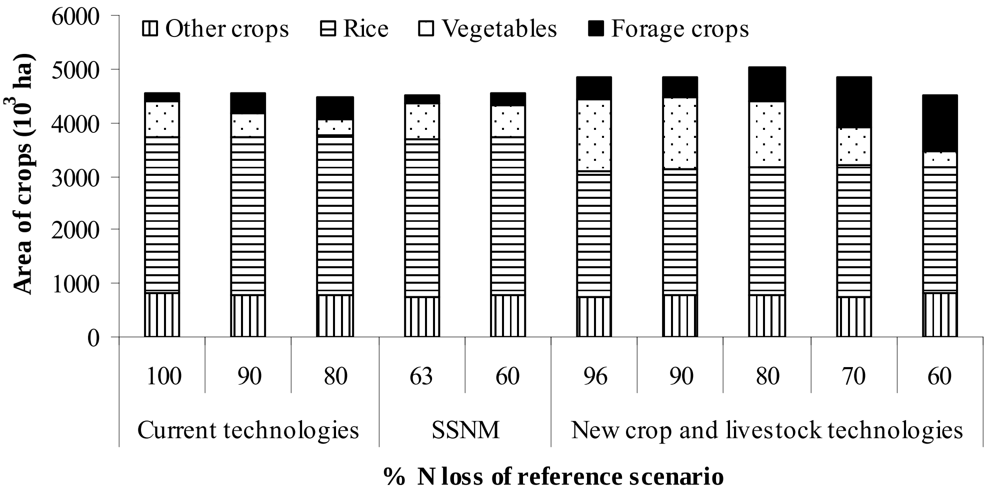
6.4.6 Reducing biocide use

In the reference scenario, average biocide use is 7.8 kg a.i. ha^{-1} y^{-1} and average BIOI is 400 ha^{-1}. With current crop and livestock technologies, BIOI can be reduced by 20% with only minor negative effects on regional net income, as reduction in crop income is compensated by higher income from livestock (Figure 6.5a). Especially the areas of biocide-demanding crops such as vegetables (Figure 6.5b) and cotton are reduced, and of crops with high biocide costs per 1000 Yuan net income (e.g. rapeseed). BIOI per 1000 Yuan net income decreases from 25 to 21 (Figure 6.5d). Both, crop and livestock income are significantly lower when the permitted BIOI is reduced to 70% of that in the reference scenario (Figure 6.5a), associated with a reduction in total crop area, as the less fertile rice land in hilly and mountainous areas is taken out of production. Further reduction in BIOI can only be attained by reducing the minimum production targets of major crop and livestock products.



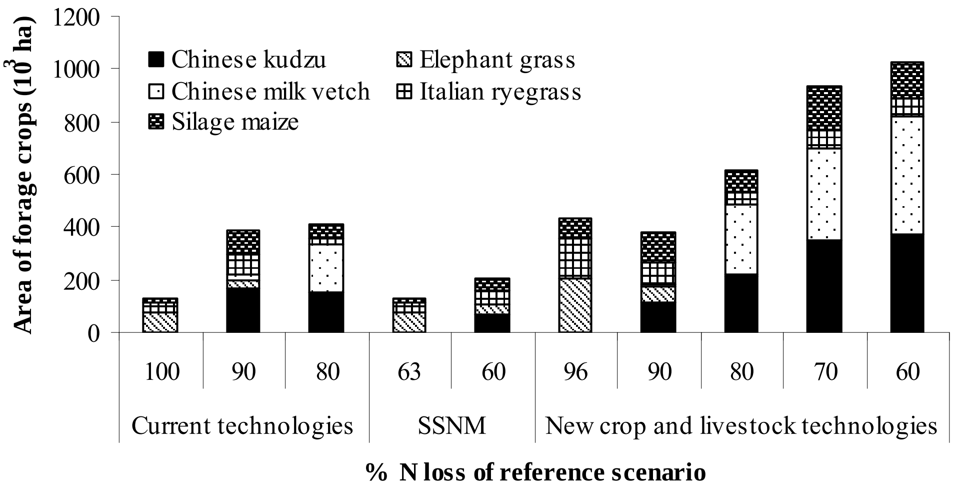
60
50
40
30
20
10
0
Net income (10^9 Yuan)
Crop
Livestock
100
90
80
63
60
96
90
80
70
60
Current technologies
SSNM
New crop and livestock technologies
% N loss of reference scenario

a



6000
5000
4000
3000
2000
1000
0
Area of crops (10^3 ha)
Other crops
Rice
Vegetables
Forage crops
100
90
80
63
60
96
90
80
70
60
Current technologies
SSNM
New crop and livestock technologies
% N loss of reference scenario

b



1200
1000
800
600
400
200
0
Area of forage crops (10^3 ha)
Chinese kudzu
Elephant grass
Chinese milk vetch
Italian ryegrass
Silage maize
100
90
80
63
60
96
90
80
70
60
Current technologies
SSNM
New crop and livestock technologies
% N loss of reference scenario

c

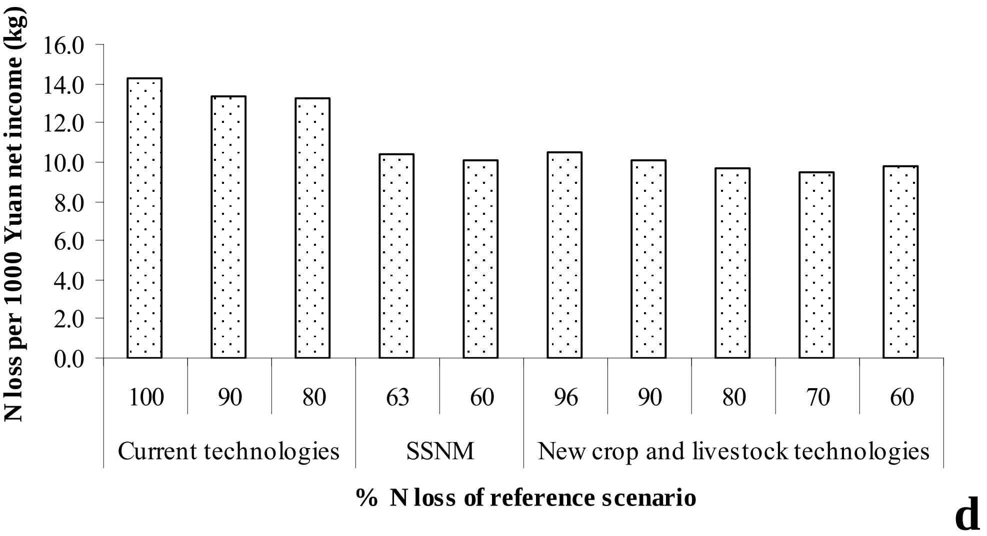
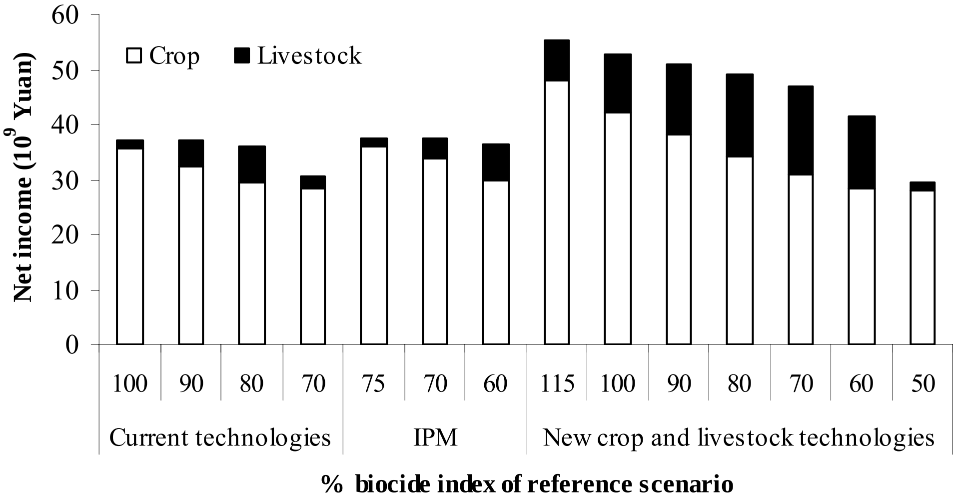


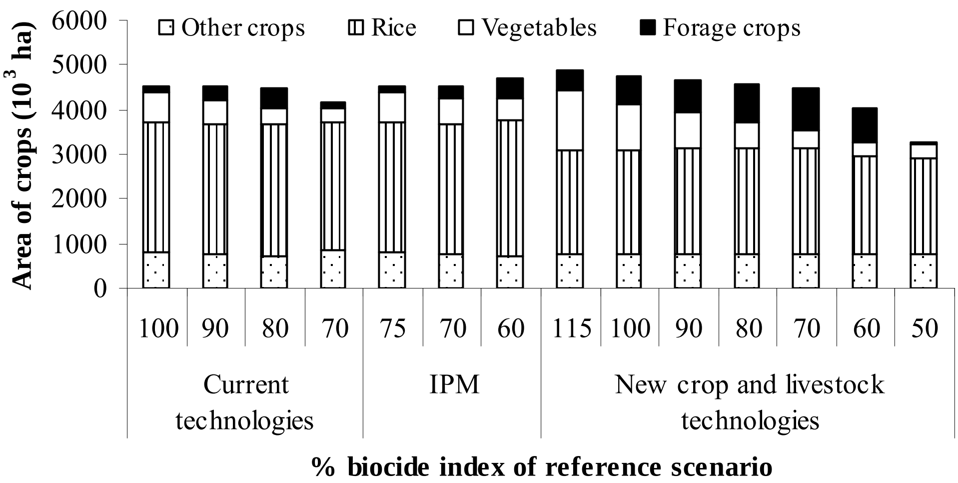
Figure 6.4 Impact of reducing permitted N loss with current technologies, availability of site-specific nutrient management (SSNM) and availability of both alternative crop and livestock technologies on regional net income (a), crop allocation (b and c) and N loss per 1000 Yuan net income generation (d).

With adoption of IPM, overall BIOI is only 75% of that in the reference scenario. The permitted BIOI can be further reduced to 60% of that in the reference scenario with minor effects on net income (Figure 6.5a). The area of forage crops (e.g. Italian ryegrass and elephant grass) increases while that of vegetables and cotton decreases. The higher income from beef production compensates most of the income reduction from vegetables and cotton. BIOI per 1000 Yuan net income is much lower using IPM than with current pest management technologies (Figure 6.5d). If permitted BIOI is reduced to 50% of that in the reference scenario, the model becomes infeasible.

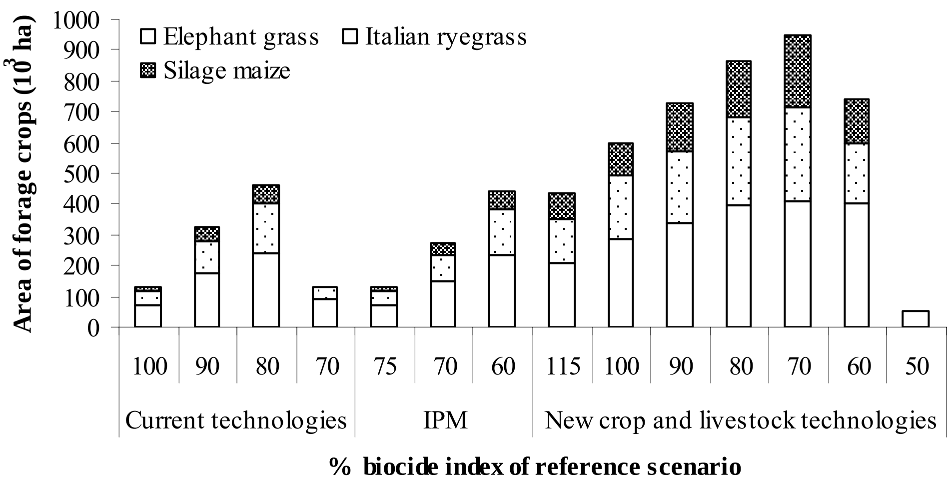
With adoption of both new crop and livestock technologies, average BIOI is 458 ha^{-1}, *i.e.* is 15% higher than that in the reference scenario (Table 6.2), as a result of doubling of the vegetable area (Figure 6.5b) and higher biocide use in Super Rice, despite the use of IPM. However, the BIOI per 1000 Yuan net income decreases from 25 to 19 (Figure 6.5d). Restoring BIOI to the value in the reference scenario yields a regional net income that is 42% higher than in the reference scenario. Especially, beef production contributes to the higher income, as the number of beef cattle increases from 1.9 to 7.0 million head. In this situation, the BIOI per 1000 Yuan net income is 18 (Figure 6.5d). When the permitted BIOI is gradually reduced to 70% of that in the reference scenario, the crop area, particularly that of vegetables (Figure 6.5b), further decreases, leading to lower crop income and total net income (Figure 6.5a). In contrast, income from livestock increases (Figure 6.5a), which is associated with a significant increase in the area of forage crops (Figures 6.5b and 6.5c). However, if the


60
50
40
30
20
10
0
Net income (10^9 Yuan)
Crop
Livestock
100
90
80
70
75
70
60
115
100
90
80
70
60
50
Current technologies
IPM
New crop and livestock technologies
% biocide index of reference scenario

a


6000
5000
4000
3000
2000
1000
0
Area of crops (10^3 ha)
Other crops
Rice
Vegetables
Forage crops
100
90
80
70
75
70
60
115
100
90
80
70
60
50
Current technologies
IPM
New crop and livestock technologies
% biocide index of reference scenario

b


1000
900
800
700
600
500
400
300
200
100
0
Area of forage crops (10^3 ha)
Elephant grass
Italian ryegrass
Silage maize
100
90
80
70
75
70
60
115
100
90
80
70
60
50
Current technologies
IPM
New crop and livestock technologies
% biocide index of reference scenario

c

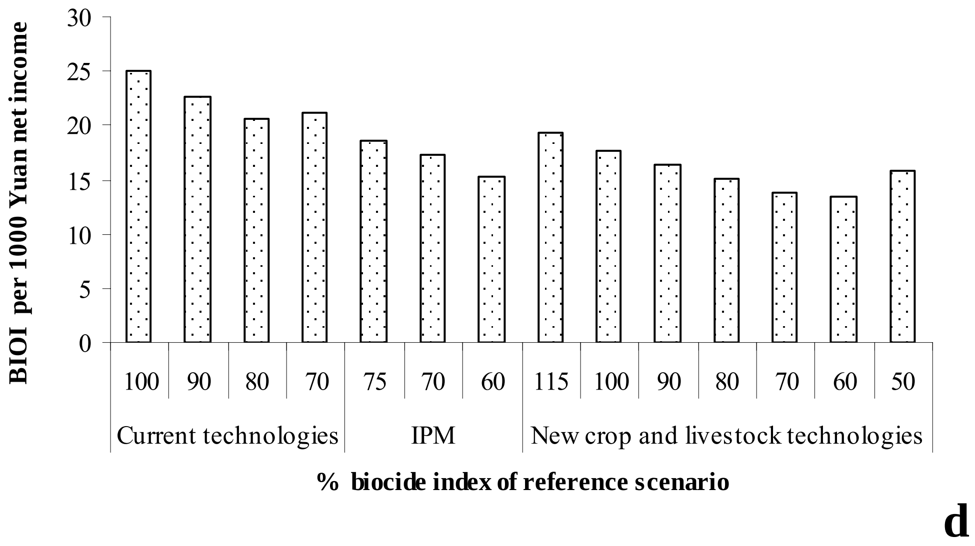


Figure 6.5 Impact of reducing permitted biocide index with current technologies, availability of integrated pest management (IPM) and availability of both alternative crop and livestock technologies on regional net income (a), crop allocation (b and c) and biocide index(BIOI) per 1000 Yuan net income generation (d).

permitted BIOI is further reduced to 60 and 50% of that in the reference scenario, the less fertile land is taken out of production and both, crop and livestock income decrease dramatically (Figure 6.5a) till the lowest production targets are reached.

6.4 Discussion and conclusions

The results presented in this chapter support identification of the most effective technological innovations in crop and livestock production in terms of attainment of rural development goals, *i.e.* increasing rice production, increasing farmers' income and reducing adverse effects on the environment and human health. Such information is valuable for formulation of agricultural policies that aim at realization of various development goals.

Adoption of Super rice varieties with a higher intrinsic production potential is essential to simultaneously increase rice production and income. With current production technologies, rice production can only be increased by about 10%, considering the regional demand for other agricultural products. However, 40% more rice can be produced with Super Rice varieties, resulting in higher land and labour productivity. Higher rice yields release land for more remunerative crops such as vegetables and for forage crops for the profitable beef cattle fattening that are the main sources of the higher regional net income. In conclusion, adoption of Super Rice varieties can alleviate the conflict between increasing rice production and increasing income. The higher yields of Super Rice varieties contribute to self-sufficiency in rice at farm household and national scale.

The conflict between increasing income and reducing N loss can be mitigated through adoption of SSNM, as that leads to substantially lower N-losses per unit net income. Savings in N fertilizer use are moderate, while under SSNM more P and K fertilizers have to be applied. Improved fertilizer management through SSNM may prevent further soil mining of P and K (Witt *et al*., 2002), and reduce pest and disease incidence in rice, thus reducing the need for biocides (Wang *et al*., 2007). Similar to SSNM, adoption of IPM does not result in higher economic returns, but allows a substantial reduction in biocide use. Adoption of both SSNM and IPM can strongly reduce income loss when N loss and BIOI need to be restricted. However, both SSNM and IPM are labour-demanding and knowledge-intensive technologies. Currently, many young and well-educated rural workers migrate to cities, hampering implementation of such technologies. Large-scale implementation of SSNM and IPM will require high investments in both financial and human resources, and in institutional support (CCHPPJ, 2001; Wang *et al*., 2007). Using SSNM and IPM, the same crop and livestock production can be achieved with less adverse effects of agrochemicals on the environment and human health.

Mechanization of rice production strongly reduces labor requirements and leads to higher returns to labour. The much lower labour requirements in the peak periods facilitates households to combine the production of rice with off-farm employment. Although income from rice production is reduced due to the costs of machine rent, wages earned in off-farm activities may be much higher than the income loss in rice production.

Adoption of new livestock technologies leads to higher income and reduced negative impact of biocides on environment and human health. The more efficient feed utilization greatly increases the profitability of livestock production, which increases the competitiveness of forage crops for resources such as land and labour. Moreover, Italian ryegrass and/or Chinese milk vetch, in rotation with rice, are beneficial for soil quality and lead to higher rice yields (Wu *et al*., 1997; Xiong *et al*., 2003b). The perennial forage crops such as elephant grass and Chinese kudzu contribute to erosion control and also improve soil quality, with Chinese kudzu contributing to the soil N stock through N fixation (Fan and Wu, 2004; Lu *et al*., 2006). However, these additional benefits of forage crops on rice production and the environment are difficult to quantify and have therefore not been taken into account in this study. Biocide use in forage crops is much lower than in other arable crops, thus replacement of these crops by forage crops results in lower regional biocide use. However, N use in non-leguminous forage crops is higher than in most other crops, thus the increase in the area with non-leguminous forage crops at the expense of N-demanding crops (*e.g.* vegetables) will not result in lower regional N use. Expansion of the animal herd, combined with chemical treatment of rice straw, results in greater use of crop residues for feeding, thus reducing air pollution caused by burning of crop resiudes. The higher manure production allows savings in fertilizers and is important for maintaining and/or improving soil quality. However, including manure application in cropping systems is very labour-demanding and technologies are required to allow efficient integration of manure in soil and crop management to avoid environmental problems (Hengsdijk *et al*., 2007). In Jiangxi, manure is used to produce biogas and higher manure production may reduce the dependency on other non-renewable energy sources, thus contributing to environmental protection (Chen, 1997; Wu, 2006; Zhang, 2007b; Zeng *et al*., 2007, Zhu, 2007).

The results show that losses in income from crop production could be compensated by increased livestock production. Especially beef cattle fattening seems an attractive activity under the conditions prevailing in Jiangxi. Beef production carries a lower price risk[3] than high value crops, such as vegetables, cotton and tobacco.

In brief, Super Rice is most effective in attaining the goal of national grain security while both Super Rice and new livestock production technologies are most effective in attaining the goal of increasing income. Expansion of livestock production, particularly crossbreed beef cattle fattening, has a strong positive effect on regional income and on reducing biocide use, and on a number of other associated, intangible benefits, including soil protection, improved soil quality, reduced air pollution and increased availability of renewable energy. SSNM and IPM are most effective in reducing the adverse effects caused by N loss and biocide use, and have only small income effects. Adoption of both new crop and livestock production technologies contributes to realizing the interrelated and often conflicting rural development goals of guaranteeing rice security, increasing income, and alleviating the adverse effects on the environment and human health associated with the use of agricultural inputs.

[3] The term 'price risk' is used here to denote the uncertainty that farmers face with respect to the (farm gate) price for their commodities at the time of sale.

7 General discussion

7.1 Food security and rural development

Ever since the alarming publication of Lester Brown in 1995, ‘Who will feed China’, China’s food security has been in the spotlight of national as well as international futurologists, scientists, planners and policy makers (cf. Smil, 1995; 2004a; Paarlberg, 1997; Alexandratos, 1997; Anonymous, 1998; FAO, 1998; Huang and Rozelle, 1998; Findlay, 1999; Bruins and Bu, 2006; Anonymus, 2007a). In the 1990s, projections on food requirements were based on anticipated population growth rates, sometimes modified by taking into account the changing composition of the population (Smil, 2000, 2004b). In recent years, triggered by the continuing strong economic growth in China, the consequences of the increasing income on diet composition, with an increasing share of animal products, such as meat, eggs and milk, are receiving increasing attention (Verburg and Van Keulen, 1999; Zhu *et al*., 1999; Brown *et al*., 2002; Nin *et al*., 2004; Fuller *et al*., 2006).

According to the white Book of China's Grain Issues, released by the State Council of China, the country's grain demand will rise to 550 Tg by 2010 (IOSCC, 1996), compared to an output of 490 Tg in 2006. China will therefore have to increase its annual grain output by at least 15 Tg every year until 2010, or acquire the deficit on the world market (Eyre, 2007). This continuous attention for food security has been exerting great pressure on the agricultural sector.

Following a short period of grain shortage in 2003, as a result of declining production (Roetter and Van Keulen, 2007), with increasing consumer prices, the Chinese government introduced a number of measures to stimulate grain production, such as tax reductions, subsidy on seeds, and subsidy on the purchase and use of agricultural machinery (CCCPC and SCC, 2004; Gale *et al*., 2005). These measures, combined with favourable weather conditions, indeed reversed the trend of declining grain production.

However, since 2006, food prices in China have been increasing again, at a very fast pace, associated with increases in agricultural commodity prices on the world market. These increases have caused great concern to the Chinese population and politicians (Anonymus, 2007b), as well as in the international community. The consumer price index (CPI) in July 2007 reached its highest level in the last decade, with meat, poultry, eggs, grains and vegetables leading the index (DuByne, 2007). The Chinese government fears that the inflation of recent months could ignite social unrest, if food prices continue to soar (Bezlova, 2007). Realizing that production of corn-based ethanol is linked to the rapidly rising food prices, China declared a moratorium on the construction of ethanol plants (DuByne, 2007), at the time that calls for biofuels are politically attractive for European and USA politicians, amid rising petrol prices and concerns about global warming and over-reliance on Middle Eastern oil (Macartney and Reid, 2007).

These developments have led to renewed interest in food production potentials in China and their realization. Increases in food production should be realized in a situation with decreasing availability of resources, such as agricultural land, water and labour (Huang and Rozelle, 1998; Heilig 1999; Lichtenberg and Ding, 2008). China has lost 8 Mha, or 6.6 percent of its arable land in the past decade. Several major factors are contributing to this land loss. In Eastern China, the booming economy and growing urban sprawl have led to increased use of arable land for construction purposes. Over the past five years, half of the country's newly added construction land area, a total of 2.2 Mha, was converted from existing or potential farmland (Ding, 2007). In Western China, where the government is promoting restoration of degraded or fragile ecosystems, lower-quality arable lands have been appropriated for forest or grassland replanting efforts. This has been the dominant driver of arable land loss in recent years, accounting for more than 70% of the annual net losses over the period 2003-2006.

Moreover, the scope for further increasing cropping intensity is very limited due to the limitations set by climate and particularly (irrigation) water availability. Therefore, the increase in agricultural production must predominantly come from increases in crop yields per unit of land. On the other hand, environmental pollution and adverse effects on human health associated with the use of chemical fertilizers and biocides have to be mitigated (Wang *et al*., 1996; Widawsky *et al*., 1998; Huang *et al*., 2001; Zhu and Chen, 2002; Bao *et al*., 2006; Gao *et al*., 2006a, b; Ji *et al*., 2007).

An additional problem facing the agricultural sector in China is that a large proportion of the rural population, especially the young and better educated, migrates to cities attracted by ample work opportunities and higher wages (De Brauw *et al*., 2002; Yang, 2004). To provide incentives for the rural population to continue farming, farmers should be able to generate a parity income in agricultural production. The Chinese government has therefore made it a top priority to increase farm incomes and reduce income inequality between rural and urban areas (CCCPC and SCC, 2004, 2005, 2006; Bezlova, 2007).

Rural development policies in China therefore, aim at pursuing at least three objectives: guaranteeing grain security, increasing farmers' income and alleviating the adverse effects of agrochemicals on environment and human health. These goals are interrelated and often conflicting. More complete realization of these goals can be supported by technological innovation that leads to improved performance of crop and livestock production systems. Huang and Rozelle (1996) concluded that almost all of the growth in crop yields in the late 1980s arose from technological change. China will therefore have to rely on technological progress as the engine of productivity growth (Liu and Wang, 2005), in pursuit of realization of the multiple development goals. However, technological changes may also aggravate land use conflicts and increase adverse environmental effects (Stoorvogel and Antle, 2001).

In this study, Jiangxi Province was selected as a case study area to assess the effectiveness of new crop and livestock production technologies in attaining rural development goals. Jiangxi is one of the major rice producing areas in China (CCJPH, 1999; Liu and Wei, 1999; JXPPG, 2000), located in the Southeast, not far from the country's centre of economic growth, but still one of China's poorest provinces (Heerink *et al.*, 2007). Per capita income in its rural areas is much lower than that in economically more developed provinces, such as Jiangsu and Zhejiang, and also lower than the national average. Jiangxi faces all the problems typical for the agricultural sector in China.

The sown area of rice accounts for about 55% of the total crop area in Jiangxi. Despite the importance of rice in agricultural production and land use, income from rice production is often only about 20% of farmers' total net income (Wang and Shi, 2005). The area of cultivated land, especially of the most fertile land, is decreasing due to urbanization and industrialization (JXSB, 1991, 2006; Li and Lin, 1999; Xu, 2001; Wang *et al.*, 2003a). In addition, 0.67 Mha is returned to forests or pastures as part of an ambitious environmental policy program (JPRST, 2004). Increasing current cropping intensities of 200% is hardly an option, given the biophysical conditions (Huang, 2000a, b, c; Zhou, 2000), unless drainage and irrigation systems can be developed for the water-logged rice lands with drainage problems, or irrigation systems can be improved and/or built for the land in the hilly and mountainous areas. However, both developments would require substantial investments (JXAAS, 2001). Between 1990 and 2005, fertilizer NPK use increased from an average of 356 to 617 kg ha^{-1} y^{-1} (Chapter 2) and biocide use (amount of commercial formulation) from 15.5 to 35.9 kg ha^{-1} y^{-1} (JXSB, 2006), but yields of most crops hardly increased. The intensive use of agrochemical inputs increased production costs and caused undesired environmental and occupational and public health problems (JXAAS, 2001; Liu and Dai, 2003; Li *et al.*, 2004). Many young and well-educated people migrate to the economically developed regions with ample off-farm employment opportunities (Feng, 2006; Shi, 2007). This leads to labour shortage during peak periods and hampers adoption of knowledge-intensive technologies.

7.2 Methodological issues

To assess the effectiveness of innovative crop and livestock technologies in attaining rural development goals, a regional linear programming (LP) model for Jiangxi has been developed, as improvements in crop and livestock production technologies may have a strong impact on the degree of realization of various socio-economic and environmental objectives. This method allows identifying potential synergies and conflicts among the various development goals in Jiangxi.

7.2.1 Some features of the regional LP model

Regional LP models have been used widely in land use studies (Bouman *et al*., 1998; Lu *et al*., 2004; Roetter *et al*., 2005; Hengsdijk *et al*., 2007). For application of that methodology in our study, data on inputs and outputs of current cropping and livestock systems in both physical and monetary terms have been systematically collected. Most of the farm surveys and experiments were carried out in recent years by provincial research institutions, universities and government organizations, giving confidence that these data are representative for the current situation.

Another feature in this study is the integration of livestock systems with cropping systems in the LP model. In analogy to the cropping systems, current and alternative livestock systems are differentiated. Inputs and outputs of current livestock systems are based on observed husbandry practices in Jiangxi. Quantification of inputs and outputs of alternative livestock systems is based on the target-oriented approach, *i.e.* input requirements are calculated to reach well-defined production targets for milk (dairy), and liveweight gain (beef cattle and goat fattening).

7.2.2 Limitations of the methodology

Because of lack of information, the risk associated with implementation of Integrated Pest Management (IPM) practices, probably the most important constraint to their adoption, is not considered. Farmers value pesticides for reducing production risk, as well as for contributing to profit (Zalom, 1993). This attitude results in "insurance" treatments, in which biocides are applied to protect the farmer against, even a low probability of, devastating damage (Stoner *et al*., 1986).

In this study, possible adverse effects from the livestock sector on the environment have not been considered. However, the livestock sector may have substantial negative impacts on water, land and biodiversity resources, and contribute to climate change and air pollution (Steinfeld *et al.*, 2006). In fact, the Department of Agriculture of Jiangxi Province has reported serious pollution of surface- and groundwater as a result of direct discharge of animal waste from the expanding livestock sector (DAJX, 2006).

7.3 Major findings

One of the objectives of this study was to identify potential synergies and conflicts among various rural development goals. Results of this study indicate that integration of Super Rice and beef production with new livestock technologies would result in higher regional income and lower regional biocide use, showing little competition between beef and rice production (Chapter 6). Incorporation of Italian ryegrass in rice-based cropping systems provides high quality feed to livestock without requiring additional land. Perennial forage crops can be grown in the less fertile non-rice lands in the hilly and mountainous areas. Only silage maize is partly in direct competition for land with rice. Profitability of beef production, particularly with crossbreeds and chemical treated rice straw, is high. Expansion of the beef cattle sector results in increased regional income, with a significant reduction in biocide use (Chapter 6). Hence, the goals of increasing income and reducing biocide use can be realized simultaneously through expansion of beef production. However, expansion of the livestock sector will lead to increased N loss from chemical fertilizers. The N-fertilizer use in non-leguminous forage crops is high, while the leguminous forage crops are not economically attractive (Chapter 6). Moreover, possible negative effects associated with strongly increased manure production, as have been experienced for instance in the European Union, have not been taken into account in this study.

This study also shows that increasing income clearly conflicts with increasing rice production. Economic returns are significantly negatively affected, if rice production is further increased. Expansion of the rice area goes at the expense of mainly the profitable non-rice crops (*e.g.* vegetables). Inputs of fertilizers and biocides in the more remunerative crops, such as vegetables and cotton, are much higher than those in other crops, including rice (Chapter 4 and Chapter 6). Hence, the goal of increasing income through expansion of vegetables and cotton is conflicting with the goal of reducing negative impacts on the environment and human health. SSNM and IPM are most effective in reducing such adverse effects.

When both, new crop and livestock production technologies would be adopted concurrently, more favourable values could be attained for the interrelated rural development goals of guaranteeing rice security, increasing income and alleviating the adverse effects of agrochemicals on the environment and human health.

7.4 Rural polices and the research agenda

In the following sections some implications for rural policy development and for the research agenda are addressed based on results from this study.

7.4.1 Rural polices

7.4.1.1 Improving infrastructure

Rice yields in the rice lands without reliable irrigation systems in the hilly and mountainous areas strongly fluctuate from year-to-year, due mainly to variability in rainfall during late July and and September. Lack of reliable irrigation water supply in autumn also limits adoption of many alternative land use types, particularly those with the profitable vegetables (Chapter 2). Improvement or construction of irrigation systems could lead to significantly higher rice yields and expand the scope for diversification to more remunerative crops.

Currently, only one crop can be grown in the rice lands with water-logging problems. Two or three crops could be grown on these lands, if the drainage problems would be solved and reliable irrigation systems would be available.

Mechanization in rice production could alleviate the constraint of labour shortages in rural areas (Chapter 6). However, many hilly and mountainous areas are inaccessible to machinery due to poor road infrastructure. Improvements in infrastructure should, therefore, be an integral component of rural development.

Adoption of improved technologies in beef production could lead to substantial expansion of the beef herd, because of its high profitability. Large areas of the less fertile lands could be used for cultivation of forage crops (Chapter 6). However, transporting these fresh forages to animal farms would be problematic, because most of these lands are located relatively far from villages without adequate road infrastructure. Hence, also development of beef production could be stimulated through road construction.

Moreover, improvements in rural infrastructure could provide rural households better access to off-farm employment opportunities (Feng, 2006).

7.4.1.2 Formulation and implementation of price policies

The significantly higher profitability of rice in 2004 was mainly the result of higher product prices. However, in 2005, profitability declined again as a result of lower rice prices and higher prices of agricultural inputs. Average farm gate prices of both early and late rice were lower than the ‘guaranteed’ prices set by the government, while the costs of inputs, such as chemical fertilizers and biocides, increased (Chapter 2). Therefore, to retain farmers’ willingness to grow rice and guarantee rice security in the country, effective methods should be implemented to enforce the price policies. Moreover, implementation of mechanisms to reduce farm gate prices of inputs such as fertilizers and biocides, for instance through subsidies, would also be effective in increasing profitability and thus maintain or stimulate rice production.

7.4.1.3 Subsidy on purchase and use of machines

Mechanization can play an important role in reducing labour requirements, increasing returns to labour and increasing household income by providing more opportunities to work off-farm. So, in addition to continuing the promotion of mechanization in rice production, subsidies to purchase and use machinery in other crops could increase land productivity and household income.

7.4.1.4 Flexible land policies

One of the major reasons that integrated rice-duck systems are not economically attractive is the small size of the holdings (Chapter 3). The traditional land tenure system has served China’s strategy to support and stimulate industrial growth. However, in the current situation it is limiting the development of a land market, which constrains the increase in agricultural land productivity (Feng, 2006). More flexible land policies that would allow part of the households to manage more land, could stimulate both, crop and livestock production. However, the consequence could be that a substantial part of the population would loose its livelihood, if no alternative employment opportunities are created.

7.4.1.5 Favourable policies to stimulate livestock production

Adoption of new livestock technologies could significantly increase the profitability of livestock production and thus increase farmers' income. However, adoption of new livestock technologies such as crossbreeds and chemical treatment of crop residues requires strong financial and technical support. Development of the livestock sector requires high investments in buildings, young animals and feeds, which most farmers currently cannot afford. Farm households that generate cash from off-farm employment appear to be able to shift production towards more capital-intensive livestock activities (Kuiper, 2005). Therefore, to stimulate development of profitable beef cattle fattening systems and thus contribute to increasing farm income, favourable policies are required for farmers unable to get involved in off-farm employment, to make a similar shift, for example, through the availability of low interest loans, supply of free land to build silos and technical assistance.

7.4.1.6 Reorganizing agricultural extension systems

Adoption of knowledge-intensive technologies, such as site-specific nutrient management, integrated pest management, crossbred beef cattle, animal health care, chemical treatment of crop residues and biogas production, requires well-organized and robust extension services. However, the technicians working at the agricultural extension stations are usually not involved in providing agricultural services to farmers. One of the major reasons is that they have to supplement their income, because of the very low government wages. Due to lack of financial support, many functions, such as installing and maintaining light traps to kill insects, monitoring pest and disease incidence, and development and providing technical assistance, are not fulfilled. Therefore, reorganization of agricultural extension systems and providing enough financial as well as technical support is urgent.

7.4.2 Setting priorities on the research agenda

The Super Rice Project, initiated in 1996 in China, aimed at developing elite rice varieties by combining ideal plant architecture with heterosis by hybridizing *indica* and *japonica* subspecies, to achieve a 'super' high yielding ability (Wang *et al*., 2005). Results of this study show that Super Rice varieties could play a key role in guaranteeing national grain security, as well as in increasing farmers' income (Chapter

6). However, hybrid rice varieties are more susceptible to insect pests and diseases (Chapter 2). Increased use of biocides in rice production threatens the sustainability of rice-based agro-ecosystems through development of biocide resistance in pest organisms, increasing costs of production and causing serious human health problems. Hence, priority should be given to breeding Super Rice varieties with increased resistance to major insect pests and diseases.

N fertilizer use in non-leguminous forage production is high and consequently N losses are higher than in most arable crops. Expansion of the livestock sector, at the expense of vegetable production, does not, therefore, lead to lower regional N losses. Introduction of leguminous forage crops, such as Chinese kudzu and Chinese milk vetch, could reduce regional N losses. However, their production costs are higher than those of graminaceous forage crops (Chapter 6), while they are not suitable for ensiling, restricting their use. Formulation of appropriate N fertilizer recommendations for graminaceous forage crops, resulting in increased fertilizer use efficiency and reduced N losses, is therefore a relevant issue. Moreover, attention should be paid to improving production of leguminous forage crops, either by optimizing production of current species, or examining the scope for introduction of new species, suitable for the physical environment in Jiangxi.

An expanding livestock sector will produce vastly increasing quantities of manure. To attain the efficiencies of utilization of manure in crop production as assumed in this study requires development of sophisticated manure and forage management systems, as has been demonstrated for example in the Netherlands (Van Keulen *et al.*, 2000). Therefore, a systematic research program is required to design and test such integrated livestock farm management systems.

7.5 Concluding remarks

This study highlights the promising role that new crop and livestock technologies could play in attaining rural development objectives in Jiangxi Province. Since the agricultural sector in Jiangxi faces similar challenges as that elsewhere in China, conclusions and lessons are also relevant for other rural areas in China. Despite the optimistic view in this study on the contribution of improved technologies to rural development, socio-institutional problems need to be addressed parallelly to benefit from technological progress. One of the biggest problems facing the agricultural sector is the small size of the holdings that is a serious constraint for the adoption of innovative technologies and for attainment of parity income (Tan, 2005; Van den Berg *et al.*, 2007). Expansion of the farms to an economically viable size would require creation of alternative livelihoods for a large proportion of the current rural population. The question is whether the service and industrial sector can provide sufficient employment opportunities to absorb the surplus labour from agriculture. This issue will require an active planning policy of both regional and national authorities. Programs for improvement of the infrastructure to stimulate the development of industries and services in rural areas, for education and for mobility are required to alleviate the threatening problem of rural unemployment and to halt large scale migration of the rural population (Tan, 2005). Migration is already the most important off-farm activity in rural Jiangxi and is expected to increase in the near future (Kuiper, 2005; Shi, 2007). Dedicated policies should give priority to create local employment opportunities, especially for women and skilled labourers (Shi, 2007). Moreover, in the current situation, the farmland serves as social security for the old-aged in the rural areas. Changing current land rights that would facilitate farm expansion without the development of an alternative pension system will result in social unrest and is bound to fail. Hence, where biophysically and environmentally food security for China might be an attainable objective, relevant economic and social problems need to be solved to realize it.

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Summary

One of the major challenges faced by China is to maintain food security for its large and growing population. In addition, the rapid economic development and the associated increase in living standards result in increasing demands for more luxurious and diverse food products such as vegetables, eggs, meat and milk. At the same time, the availability of resources for agriculture, such as arable land, water and rural labour, decreases. Hence, the major contribution to increased agricultural production should originate from increasing yields per unit of land and per animal, and increasing resource use efficiency. On the other hand, adverse effects on the environment and human health, associated with the use of chemical fertilizers and biocides have to be mitigated. Moreover, the Chinese government is giving high priority to increasing farmers' income to narrow the gap between urban and rural living standards. Among others, new agricultural technologies can play an important role in realization of these interrelated goals. The major objective of this study is to identify the effectiveness of new crop and livestock production technologies in attaining rural development goals. Jiangxi Province is selected as a case study area because it is agriculture-oriented and one of the major rice producing areas in China. The agricultural sector in Jiangxi faces challenges similar to that elsewhere in China.

In Chapter 2, the agronomic, environmental and socio-economic performance of current rice-based agro-ecosystems in Jiangxi is characterized. Based on this characterization, their strengths, weaknesses, threats and opportunities are identified. On the one hand, low economic returns of rice production is a major threat for rice-based farmers. On the other hand, many market chains for non-rice crop products have not (yet) fully developed and these are, therefore, susceptible to strong price fluctuations, presenting a serious risk to most farmers. The main challenge will be to allow rice-based farmers to generate a parity income and increase resource use efficiencies through adoption of improved management practices, reducing costs and avoiding adverse environmental effects. Despite the trend to diversification towards non-rice crops, in the near future, Jiangxi Province will remain an important contributor to realizing national objectives of grain security.

In Chapter 3, a specific rice-based agro-ecosystem, the integrated rice-duck (IRD) system, is analyzed. The IRD system is recommended to rice-based farmers in China as an option to produce rice in an environmentally friendly way and to increase income. The analysis shows that raising ducks in IRD systems is financially far less attractive than in semi-intensive duck (SID) systems mainly due to the lower feed conversion efficiency. Nutrient supply to the rice crop through excretion of ducks in current IRD systems is limited. The lower biocide use may entail high risks for IRD

farmers, as ducks are in the field only part of the growth period of rice, and can adequately control only a few insect pests, and certainly not severe pest outbreaks. The major environmental benefit of IRD systems is that the pollution of duck production to air and water is much lower than that of SID systems. Resource limitations at farm level (land and labour) may constrain farmers to adopt IRD systems, which would become economically more interesting if their products would be eligible for premium prices.

In Chapter 4, TechnoGIN, a technical coefficient generator, has been used to generate input-output relations of current and alternative cropping systems for Jiangxi. Current systems are identified on the basis of observed land use in Jiangxi. Based on characterization of available soil resources, climate, crop types, production techniques and objectives of stakeholders, three types of alternative cropping systems have been distinguished: (i) cropping systems based on Super Rice varieties, (ii) cropping systems based on individual production techniques, *i.e.* SSNM and IPM for both rice and non-rice crops, and cropping systems with mechanized field operations in rice, and (iii) cropping systems combining Super Rice varieties and the alternative production techniques. For quantification of inputs and outputs of current systems, TechnoGIN has been used in an input-oriented way, *i.e.* most inputs and outputs are based on data from farm surveys, experiments and expert knowledge, while outputs that have not been observed in practice, such as N loss and biocide index, have been generated by TechnoGIN. For alternative cropping systems, TechnoGIN has been used in a target-oriented way, *e.g.* crop yields are fixed and inputs and other outputs are calculated, using its databases and generic calculation rules.

Chapter 5 presents the generation of input-output relations of current and alternative dairy, beef cattle fattening and goat fattening systems for Jiangxi. A technical coefficient generator, programmed in Delphi, has been used to calculate input and output coefficients for both current and alternative livestock systems. Inputs of livestock systems include nutrients, labour, and non-feed and non-labour inputs. Outputs are the milk, live weight of beef cattle and goats, and manure N. Inputs and outputs of current systems are based on observed animal husbandry practices in Jiangxi. Inputs and outputs of alternative systems are quantified based on the target-oriented approach, *i.e.* inputs are calculated to attain well-defined production targets for milk (dairy), and liveweight gain (beef cattle and goats). Nutrient requirements of current and alternative livestock systems are based on the feeding standards for livestock. In defining alternative systems, better quality replacements (heifers) for dairy, crossbreeds of beef cattle, improved goat breeds and improved management in animal husbandry have been assumed.

In Chapter 6, the effectiveness of new crop and new livestock technologies for realization of a number of rural development goals in Jiangxi is assessed, using a regional land use model based on linear programming. Results show that adoption of Super Rice varieties could be effective in alleviating the conflict between increasing rice production and increasing rural income, as that allows release of land for production of more remunerative crops and forage crops for livestock production. The higher yields of Super Rice varieties contribute to self-sufficiency in rice, both at farm household and national scale. The conflict between increasing income and reducing N loss could be mitigated through adoption of SSNM, as that leads to substantially lower N losses per unit net income. Similar to SSNM, adoption of IPM would not result in higher economic returns, but allows a substantial reduction in biocide use, however at increased economic risks to the farmers. Mechanization of rice production strongly reduces labour requirements in agriculture, leads to higher returns to labour and provides opportunities to work off-farm. Adoption of new livestock technologies, especially beef fattening with crossbreeds, would increase economic returns and reduce regional biocide use, in addition to contributing to a number of non-quantified environmental benefits (*e.g.* soil erosion control and improved soil quality). Competition between beef and rice production appears limited, as high quality feed can be produced in rotation with rice during winter without requiring additional rice land, and on non-rice land. Integration of new crop and livestock technologies has significant positive effects on regional economic returns and reduces negative environmental and human health effects associated with the use of agrochemicals.

This study concludes with discussing a number of enabling policies, to support adoption of new technologies in practice. In addition, priorities for a research agenda are identified based on the technologies analyzed in this study. Despite the optimistic view in this study on the contribution of technologies to rural development, socio-institutional related problems need to be addressed to benefit from technological progress. One of the biggest problems facing the agricultural sector is the small size of the holdings that is a serious constraint to adoption of innovative technologies and for attainment of parity income. Programs for improvement of the infrastructure to stimulate the development of industries and services in rural areas, for education and for mobility are required to alleviate the threatening problem of rural unemployment that would be associated with increasing farm size. Hence, where biophysically and environmentally food security for China might be an attainable objective, relevant economic and social problems need to be solved to realize it. Since the agricultural sector in Jiangxi faces challenges similar to that elsewhere in China, results of this study are of relevance for the formulation of agricultural policies and a research agenda aiming at rural development in China.

Samenvatting

Eén van de belangrijkste uitdagingen waar China voor staat is het garanderen van de voedselzekerheid voor zijn omvangrijke en nog steeds groeiende bevolking. Bovendien leidt de snelle economische ontwikkeling en de daarmee samengaande verbetering van de levensstandaard tot een toenemende vraag naar luxe en gevarieerd voedsel, zoals groenten, eieren, vlees en melk. Tegelijkertijd verminderen de beschikbare hulpbronnen voor de landbouw, zoals land, water en agrarische arbeid. Kortom, de belangrijkste bijdrage aan verhoging van de landbouwproductie moet komen van toenemende opbrengsten per eenheid land en dier, en een verbeterde benuttingsefficiëntie van hulpbronnen. Anderzijds moeten nadelige effecten op het milieu en de gezondheid van mensen die samenhangen met het gebruik van kunstmest en gewasbeschermingsmiddelen worden verminderd. Daarnaast is het verhogen van het inkomen van boeren een belangrijke prioriteit van de Chinese overheid, om het verschil in levensstandaard tussen de stedelijke en de plattelandsbevolking te verkleinen. Bij het verwezenlijken van deze met elkaar samenhangende doelen kunnen onder anderen nieuwe landbouwtechnologieën een belangrijke rol vervullen. De belangrijkste doelstelling van deze studie is om de effectiviteit vast te stellen van nieuwe productietechnologieën in akkerbouw en veeteelt bij het verwezenlijken van de doelstellingen voor plattelandsontwikkeling. Het onderzoek is uitgevoerd voor de provincie Jiangxi, die sterk is georiënteerd op de landbouw en één van de belangrijkste rijst-producerende provincies is in China. De landbouwsector in Jiangxi staat voor dezelfde uitdagingen als die elders in China.

In hoofdstuk 2 worden de landbouwkundige, milieukundige en sociaal-economische karakteristieken van de huidige, op rijst gebaseerde agro-ecosystemen in Jiangxi geschetst. Gebaseerd op deze karakterisering, zijn de sterke en zwakke punten van en de bedreigingen en kansen voor deze systemen in Jiangxi geïdentificeerd. Aan de ene kant vormt de lage winstgevendheid van rijstproductie een ernstige bedreiging voor boeren. Aan de andere kant zijn veel marktketens voor alternatieve gewassen (nog) niet goed ontwikkeld, waardoor die gewassen sterke prijsfluctuaties vertonen, en daarom een groot risico vormen voor de meeste boeren. De grootste uitdaging is om te zorgen dat rijstboeren een paritair inkomen verdienen en de benuttingsefficiëntie van hulpbronnen verhogen door adoptie van verbeterd management met lagere kosten en vermijding van nadelige effecten op de omgeving. Ondanks de trend tot diversificatie in de richting van niet-rijst gewassen, zal Jiangxi in de nabije toekomst een belangrijke bijdrage blijven leveren aan de nationale voedselzekerheid.

In hoofdstuk 3 wordt een specifiek rijst agro-ecosysteem geanalyseerd, namelijk het geïntegreerde rijst-eend (IRD) systeem. Dit systeem wordt Chinese boeren

aanbevolen als een mogelijkheid om het inkomen te verhogen en de milieubelasting van rijstproductie te verminderen. De analyse laat zien dat het produceren van eenden in IRD systemen financieel veel minder aantrekkelijk is dan in semi-intensieve eenden (SID) systemen, voornamelijk door de lagere voederconversie. De bijdrage van de eenden aan de nutriëntenvoorziening van rijst is in de gangbare IRD systemen uiterst beperkt. De verlaging van het gebruik van gewasbeschermingsmiddelen verhoogt het risico voor IRD boeren, omdat eenden slechts een deel van het rijstgroeiseizoen in het veld verblijven. Bovendien beschermen de eenden het rijstgewas slechts tegen enkele insecten, en zeker niet tegen epidemieën. Het belangrijkste milieuvoordeel van IRD systemen ten opzichte van SID systemen is de vermindering van lucht- en waterverontreiniging. De beperkte beschikbaarheid van land en arbeid op de veelal kleine bedrijven vormt een belemmering voor adoptie van IRD systemen, die economisch aantrekkelijker zouden worden als de producten via certificering afgezet zouden kunnen worden tegen hogere prijzen.

In hoofdstuk 4 zijn met behulp van TechnoGIN, een technische coëfficiënten generator, input-output relaties van huidige en alternatieve gewassystemen in Jiangxi berekend. Huidige systemen zijn geïdentificeerd op basis van waargenomen landgebruik in Jiangxi. Op basis van karakterisering van de beschikbare bodems, gewastypen, productietechnieken en doelstellingen van verschillende belanghebbenden, zijn drie alternatieve gewassystemen onderscheiden: (i) gewassystemen met Super rijstrassen, (ii) gewassystemen met alternatieve productietechnieken, gebaseerd op precisie nutriëntenbeheer (SSNM) en geïntegreerde gewasbescherming (IPM), voor zowel rijst als niet-rijst gewassen, en gemechaniseerde rijstsystemen, en (iii) gewassystemen die Super rijstrassen combineren met alternatieve productietechnieken. Voor de kwantificering van inputs en outputs van huidige systemen is TechnoGIN gebruikt op een inputgerichte manier: de meeste inputs en outputs zijn gebaseerd op gegevens verkregen uit interviews met boeren en deskundigen en veldproeven, terwijl outputs die niet zijn gemeten, zoals stikstofverliezen en een kengetal voor het gebruik van gewasbeschermingsmiddelen, zijn berekend met TechnoGIN. Voor alternatieve gewassystemen is TechnoGIN toegepast op een ‘doelgerichte’ manier, dat wil zeggen dat eerst een doelstelling, zoals bijvoorbeeld de gewasopbrengst, wordt vastgesteld en dat vervolgens de daarbij behorende inputs en andere outputs in TechnoGIN worden berekend met behulp van gegevensbestanden en generieke rekenregels.

In hoofdstuk 5 worden de berekeningen van input-output relaties van huidige en alternatieve melkvee-, vleesvee- en vleesgeitensystemen in Jiangxi met behulp van een technische coëfficiënten generator, geprogrammeerd in Delphi, gepresenteerd. . De onderscheiden inputs van veeteeltsystemen zijn nutriënten, arbeid, en overige inputs, en de outputs melk, rundvlees en geitenvlees, en stikstof (N) in mest. Inputs en outputs van huidige systemen zijn gebaseerd op de waargenomen veeteeltpraktijken in Jiangxi. Inputs en outputs van alternatieve systemen zijn berekend op basis van de doelgerichte benadering, dat wil zeggen dat inputs zijn berekend om expliciet gedefinieerde productiedoelstellingen voor melk (melkvee), en aanwas (vleesvee en geiten) te verwezenlijken. Voederbehoeften van huidige en alternatieve veeteeltsystemen zijn gebaseerd op Chinese veevoedernormen. Bij het definiëren van alternatieve systemen is rekening gehouden met een betere kwaliteit van jongvee (vaarzen) voor het melkvee, verbeterde rassen voor vleesvee en geiten, beschikbaarheid van met ammonium behandeld rijststro en voedingsadditieven en verbeterde veterinaire zorg.

In hoofdstuk 6 wordt de effectiviteit van nieuwe gewas- en veeteelttechnologieën getest voor het verwezenlijken van een aantal doelstellingen voor plattelandsontwikkeling in Jiangxi, met behulp van een regionaal landgebruiksmodel gebaseerd op lineaire programmeringstechnieken. De resultaten tonen aan dat adoptie van Super rijstrassen een effectief middel is om de tegenstelling tussen het verhogen van de rijstproductie en het verhogen van rurale inkomens te verminderen, omdat daarbij land vrijkomt voor de productie van meer winstgevende voedselgewassen en van betere kwaliteit veevoer. De hogere opbrengsten van Super rijstrassen dragen bij aan de zelfvoorziening in rijst op zowel bedrijfs-, als nationaal niveau. De tegenstelling tussen verhogen van het inkomen en verminderen van de stikstofverliezen zou kunnen worden verzacht door adoptie van SSNM omdat dat leidt tot aanzienlijk lagere N verliezen per eenheid netto inkomen. Adoptie van SSNM en/of van IPM zou niet leiden tot betere financiële resultaten, maar het zou een aanzienlijke vermindering in het gebruik van gewasbeschermingsmiddelen met zich meebrengen, evenwel ten koste van grotere risico's voor de boeren. Mechanisering van de rijstproductie vermindert de arbeidsbehoefte in de landbouw aanzienlijk, resulteert in hogere arbeidsinkomens en verschaft boeren de mogelijkheid om buiten het bedrijf te werken. Adoptie van nieuwe veeteelttechnologieën, met name introductie van nieuwe vleesveerassen, zou leiden tot hogere winsten en verminderd gebruik van gewasbeschermingsmiddelen, en bijdragen aan een aantal niet-gekwantificeerde milieudoelstellingen (bijvoorbeeld vermindering van bodemerosie en verbetering van de bodemkwaliteit). Competitie tussen veeteelt en rijstproductie is beperkt, omdat goede kwaliteit veevoer kan worden geproduceerd in gewasrotaties met rijst gedurende de winter, zonder dat dit extra land vergt, en op bodems die ongeschikt zijn voor de productie van rijst. Integratie van nieuwe gewas- en veeteelttechnologieën heeft significant positieve effecten op de regionale financiële opbrengsten en vermindert de negatieve effecten op het milieu en de volksgezondheid die samenhangen met het gebruik van landbouwchemicaliën.

In het laatste hoofdstuk worden een aantal ondersteunende beleidsmaatregelen besproken om de adoptie van nieuwe technologieën in de praktijk te stimuleren. Bovendien worden prioriteiten voor een onderzoeksagenda geïdentificeerd op basis van de in deze studie getoetste technologieën. Ondanks de optimistische visie in deze studie op de positieve bijdrage die nieuwe technologieën kunnen leveren aan plattelandsontwikkeling, moeten sociaal-institutionele problemen worden opgelost om te kunnen profiteren van technologische vooruitgang. Eén van de grootste problemen waar de agrarische sector voor staat is de geringe bedrijfsomvang die een ernstige belemmering vormt voor de adoptie van innovatieve technologieën en voor het bereiken van een paritair inkomen. Programma's voor verbetering van de infrastructuur om de industriële sector en de dienstensector verder te ontwikkelen, voor scholing en voor mobiliteit zijn nodig om het dreigende probleem van rurale werkeloosheid te aan te pakken dat samenhangt met uitbreiding van de omvang van boerenbedrijven. Kortom, agro-technisch en milieukundig gezien lijkt voedselzekerheid voor China een haalbaar doel, maar belangrijke economische en sociale problemen moeten worden opgelost om het te verwezenlijken. Omdat de agrarische sector in Jiangxi voor dezelfde uitdagingen staat als die elders in ruraal China, zijn de resultaten van deze studie relevant voor de formulering van landbouwbeleid en een onderzoeksagenda gericht op plattelandsontwikkeling in China.

PE&RC PhD Education Certificate

With the educational activities listed below the PhD candidate has complied with the educational requirements set by the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC) which comprises of a minimum total of 32 ECTS (= 22 weeks of activities).

<u>**The Project**</u>

Review of Literature (5.6)
Current situation of rice-based crop production systems in Jiangxi, China (2003**)**

Writing of project proposal (7.0)
Options for rice-based farming systems in a humid subtropical region: a case study for Jiangxi, China (2003)

Laboratory Training and Working Visits (1.5)
Dairy production systems in the Netherlands (2003)
Inputs and outputs of cropping systems (2004)

<u>**Courses**</u>

Post-Graduate Courses (3.0)
Methods for analyzing EU Agricultural Policy: Impacts on Rural Employment (2007)

Deficiency, Refresh, Brush-up Courses (11.2)
Systems analysis, simulation and systems management (2003)
Quantitative analysis of land use systems (QUALUS) (2005)

Competence Strengthening / Skills Courses (1.4)
Writing English (2003)

<u>**Meetings**</u>

- **National**
  Discussion Groups / Local Seminars and Other Scientific Meetings (5.6)
  Sustainable land-use and resource management (2003)
  Rice-based farming systems and mixed crop-livestock systems (2004-2006)

  PE&RC Annual Meetings, Seminars and the PE&RC Weekend (1.2)
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  PE&RC Day: Collapse (2007)

- **International**
  Symposia, Workshops and Conferences (4.5)
  The 4th international crop science congress (2004)
  The 3rd International N conference (2004)

Curriculum vitae

Jiayou Zhong was born in a mountainous village in Huichang County, Jiangxi Province, P.R. China, on June 6th, 1966. His father was a high school teacher and his mother a farmer.

He graduated from Nanjing Agricultural University with a BSc degree in plant genetics and breeding in 1987. From 1987 to 2002, he worked as research scientist at Jiangxi Academy of Agricultural Sciences (JAAS). From 1990 to 1994, he was involved in research on photo-thermo sensitive genic male sterile rice and breeding of high-yielding two-line hybrid rice varieties. From 1995 to 1997, he participated in a research project of the Ministry of Science and Technology on development of new technologies for sustainable agricultural development in the hilly red soil area in Northeastern Jiangxi Province. In 1999, he was appointed to associate professor at JAAS. From 1998 to 2002, he was the project leader of two agricultural research and development projects in Jiangxi Province.

In January 2003, he started his PhD studies at Wageningen University in the framework of the Water for Food and Ecosystems programme, in a project jointly carried out by the Plant Production Systems Group and the BU Agrosystems Research of Plant Research International, under the auspices of the C.T. de Wit Graduate School for Production Ecology and Resource Conservation (PE&RC).