Breaking the Spiral of Unsustainability

An Exploratory Land Use Study for Ansai, the Loess Plateau of China

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打破黄土高原的非持续链

区域农业系统分析模型
与安塞县土地可持续利用对策

吕 昌 河

该项目由荷兰瓦格宁根大学资助，并得到“九五”国家重点科技攻关课题，
“脆弱生态区综合整治与可持续发展研究”的部分支持。

Abstract

Lu, C. H., 2000. Breaking the spiral of unsustainability: an exploratory land use study for Ansai, the Loess Plateau of China. Ph.D. Thesis, Wageningen University, Wageningen, the Netherlands. 256 pp.

Serious soil loss, food insecurity, population pressure, and low income of the rural population are interrelated, and consequently result in a spiral of unsustainability in the Loess Plateau, China. This thesis takes Ansai County in the Loess Plateau as a case study, to explore strategic land use options that may break the unsustainability spiral and meet goals of regional development. A systems analysis approach has been applied, in which fragmented and empirical information of the biophysical and agronomic conditions is integrated with well-adapted production ecological principles and other knowledge sources.

With respect to the land use problems and regional development objectives, alternative production activities (systems) have been identified and quantified using a 'target-oriented approach' and the concept of 'best technical means', and based on information obtained from a quantitative land evaluation, experimental data, literature and expert knowledge. Production activities have been quantified for cropping, fruit, grassland and firewood production systems, and animal husbandry. Production techniques emphasize soil conservation, productivity, use efficiency or low emission of chemicals. The quantified production activities, resource constraints, and socio-economic and environmental objectives have been incorporated into a multiple goal linear programming model that is used to optimize land use allocation, evaluate trade-offs among objectives and evaluate policy scenarios.

The results reveal that the goals of food security and soil conservation in Ansai can be easily achieved from a biophysical and agro-technical point of view. Current slope cultivation and the resulting serious soil loss can be greatly reduced, while still guaranteeing food security for the rural population (in 2020). The soil loss control is, to a large extent, in line with the goals of increasing crop productivity and labor productivity (net agricultural return per laborer). In the long term, terracing and crop rotations with alfalfa could be the best options for soil conservation and also for agricultural production. The large rural labor force can be used for terrace construction. Alfalfa can fix nitrogen, and thus greatly reduce the demand for fertilizer N, and also improve soil fertility.

The large rural population and the lack of off-farm employment opportunities could be the most important factor affecting rural development in Ansai. This is evident from the trade-off results, i.e., increasing the total employment in agriculture leads to an apparent adverse effect on many other objectives. However, there is a potential for maintaining high agricultural employment at a reasonable income level. The current low net return due to the very limited external inputs and poor crop and soil management can be substantially improved by efficient resource use and appropriate inputs.

This research work contributes to the understanding of regional problems and agricultural development potentials. The results show agro-technical possibilities for breaking the spiral of unsustainability in this very fragile and poorly endowed region. Soil conservation, food security, employment and income for the rural population can be greatly enhanced by appropriate land use and agro-techniques. To promote actual development towards the identified options, appropriate policy measures aimed at improving the land tenure system and controlling population growth must be developed and implemented. The explored land use options enable a much more targeted policy development. In addition, the study can contribute to the formulation of a research agenda for research at field, crop and animal level.

Keywords: land use, sustainability, soil loss, soil conservation, food security, quantitative land evaluation, linear programming, trade-off analysis, policy scenarios, Ansai, the Loess Plateau, China

Preface

The work reported in this thesis was funded by the Sandwich Program of Wageningen University, and also partly supported by the project 'Integrated control of degraded environments and sustainable development in fragile regions of China', which is financially supported by the Ministry of Sciences and Technology of China. The proposal for this research was formulated during my preparatory study in the Department of Theoretical Production Ecology (TPE) of Wageningen University from October 1993 to March 1994. Data collection and a literature review were completed at the Institute of Geography, Chinese Academy of Sciences in Beijing from April 1994 to June 1998. Data processing, modeling and analysis of the results, and finally writing of the thesis, were done at TPE-WU from July 1998 to March 2000.

For this study, focussed on exploration of land use options in Ansai, a variety of knowledge and information from several disciplines was required. Trying to integrate the information and write this thesis during the past two years has been a big challenge. Without the help and support of many people, my research would not have resulted in this thesis.

I am very grateful to my promotor, Prof. Dr. Rudy Rabbinge, for his scientific guidance. His critical comments on all chapters and his suggestions for the structure of the thesis were very important and helpful to me. I also wish to express my thanks to him and his wife, Marja, for their hospitality.

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I am grateful to the Department of TPE, Group of Plant Production Systems, and Wageningen University for the financial support. I thank the staff members of TPE, Plant Research International (former AB-DLO) and the Dean's Office for International Students, who all have contributed to a vivid memory of my stay in Wageningen.

I am grateful to the Institute of Geography (now Institute of Geographical Sciences and Natural Resources), Chinese Academy of Sciences, for granting me such an extended stay in the Netherlands. Special thanks are due to Prof. Liu Jiyuan, Prof. Lu Dadao, Prof. Li Xiubin, Prof. Liu Yi, Prof. Tang Dengyin, Prof. Wang Wuyi and Academician Prof. Zheng Du. I also wish to express my appreciation to Wang Fengxian and Shu Xiaoming for helping me get permission for my extended stay in the Netherlands. Many of my colleagues at the institute gave their help, in one way or another, to this project. Zhao Mingcha, Dr. Zhang Hongye, Leng Shuying, Wang Qiang, Zhen Shuping, Dr. Wang Xiuhong, Zhang Yili, Dr. Zhang Ming, Wang Shuhua, Yu Jingjie and Shen Yuancun are specifically acknowledged. Prof. Liang Yimin at the Ansai Experimental Station for Integrated Water and Soil Conservation of the Chinese Academy of Science is acknowledged for his help during my fieldwork in Ansai. I also thank many officers in Ansai County and Yan'an Prefecture for their support in the data collection. I thank all my Chinese friends in Wageningen for their help. In particular, I would like to acknowledge Dr. Liu Chunming, Dr. Xu Han, Dr. Cheng Xiaofei, Dr. Yu Qiang, Chen Xinwen, Dr. Zhao Xiaomin, Huang Jiang, Li Yaling, Ge Yaxin, Li Guangming, Zhao Min, Wang Hanzhong, Dr. Yin Xinyou, Wang Minghui, Li Tao, Chen Dongsheng and Zhang Liru.

Finally, I express my sincerest gratitude to my wife, Ying, and my son, Jianhao. As a consequence of this thesis, we have spent most of the past two years apart. Thank you both for your moral support, understanding and patience. I am indebted to my parents, and to my parents-in-law and Yanqiang, for helping to take care of Jianhao.

LU Changhe
Wageningen, April 25, 2000

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Chapter 1 General Introduction

Food security and sustainable development are two fundamental and strategic goals in China. In the past four decades, China has made great achievements in supplying food for its huge population, over one-fifth of the world's total population, using 7% of the world's total arable land. However, this achievement has been made, to a certain extent, at the cost of environmental degradation and resource deterioration (Cheng 1998). Land degradation problems are widespread, including severe soil loss in the Loess Plateau, wind erosion (land sandification or desertification) and salinization in northwestern China, soil erosion in the hilly areas of southern China, and soil salinization in the North China Plain (Lu 1993, Lu 1998a).

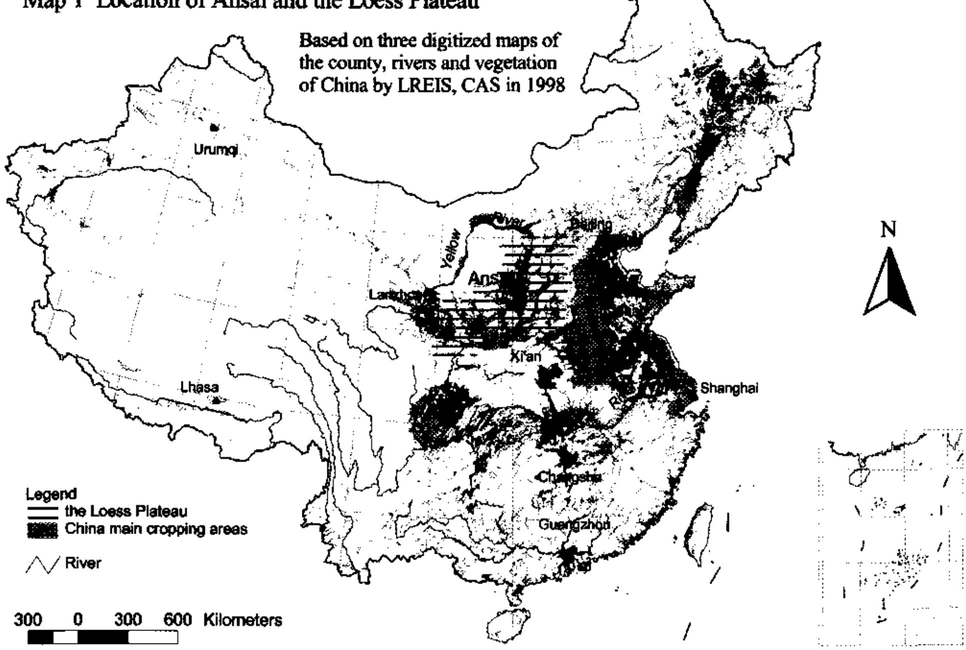
Arable land in China is mainly distributed in the eastern part of the country (Map 1) in regions of high population density. There are three main food production areas in China, i.e., the Plain of the Mid-Lower Reaches of the Yangtse River, the North China Plain and the Northeast China Plain. From Map 1, it can be seen that the mid-reaches of the Yellow River also cover rather a large area of cropland, which includes the Loess Plateau and the fluvial plains surrounding it.

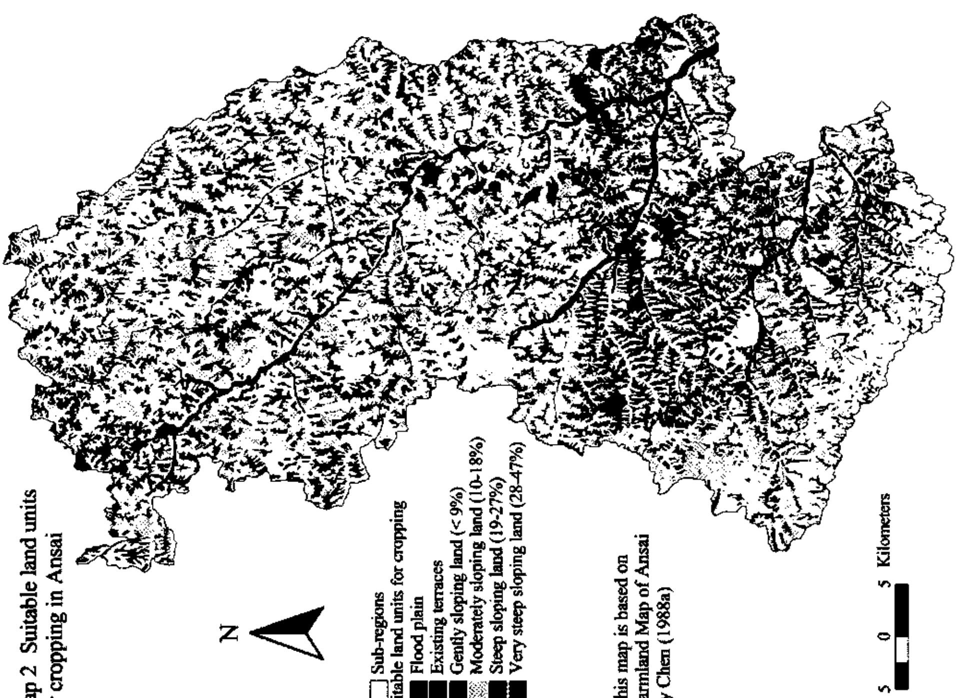
The North China Plain, which is one of the most important food-producing areas in China, is currently threatened by potential flooding as a result of massive siltation caused by serious soil erosion in the Loess Plateau. The riverbed in the lower reaches of the Yellow River is still rising, even though it is already 4-10 m higher than the flood plain (Tang & Chen 1991). Thus, the control of soil loss and the sustainable use of land resources in the Loess Plateau are important not only for that region, but also for region in the lower reaches of the Yellow River.

1.1 Problems and policy issues in the Loess Plateau

Issues surrounding the debate about sustainable development in the Loess Plateau always center on the question of how to reduce the severe soil loss while simultaneously providing sufficient food for the large population. Numerous papers and research reports (e.g., NIWSC 1995, Tang & Chen 1991, Peng *et al.* 1991, Zhu 1981, Huang 1955) have been published during the past decades, which greatly contribute to the understanding of the problems and bottlenecks that stand in the way of achieving sustainable land use. In the following subsections, major problems and policy issues in the Loess Plateau are discussed.

Map 1 Location of Ansai and the Loess Plateau





Map 2 Suitable land units for cropping in Ansai

1.1.1 Main problems

The Loess Plateau (Map 1) covers Shanxi, northern Shaanxi, eastern Gansu, and southern Ningxia provinces. Most of the area is dominated by loess hills. Due to the high potential of soil erosion, most of the land, including the parts that are currently cultivated, is not at all or only marginally suitable for arable farming. The land is normally cultivated with limited inputs, and thus crop yield is low and varies from year to year with variations of rainfall. The population density is rather high, ranging mostly from 30 to 200 persons km^{-2} for counties in the hilly area of the Loess Plateau. Accessibility is largely limited by the poor infrastructure and the dissected relief.

Slope cultivation is very common in the hilly Loess Plateau, resulting in very serious water erosion, with a mean soil loss of over 50 t ha^{-1} per year (Tang & Chen 1991). Small catchment surveys (*ibid.*) revealed that the soil loss from cropland covered 50-60% of the total soil loss, and from gullies and grassland around 25% and 8-18%, respectively. On extremely steep farmland (*ibid.*), annual soil loss can exceed 100 t (slope gradient > 47%), up to 300 t ha^{-1} (slope gradient > 70%), and even 500 t ha^{-1} in newly reclaimed steep land (slope gradient > 70%).

Population growth in the Loess Plateau is very high compared to the average in China as a whole. In the period of 1953-1985, the average population growth rate in the Loess Plateau was 3.58% per year (Tang & Chen 1991), 86% higher than the national average of 1.92% (1953-1982). This high population growth considerably increased the food requirements and pressure on agricultural employment, further leading to a great expansion of slope cultivation. Every increase of 10 persons in the population had resulted in 1.8 ha, up to 7.9 ha in the area of land reclamation in the Loess Plateau (*ibid.*).

The availability of fertilizers and capital is generally very limited, resulting in widespread extensive cultivation, and consequently low productivity and low income. Due to the restrictions of a poor infrastructure and limited educational systems, the market is underdeveloped, and the proportion of the population that is illiterate or semi-illiterate is still very high. For instance, illiterates and semi-illiterates in Ansai made up 54% of the total population aged 15 and above, and 71% of the female population (based on 1990 census). The hilly Loess Plateau is still one of poorest areas in China. Many counties in this region have been listed as 'poverty counties' that need financial supports from the government.

Each of these problems is often enhanced by others, which results in an increase of the combined effects. This can be illustrated by familiar sayings in China, such as 'the poorer the population is - the more (marginal) land will be reclaimed, and the more land that is reclaimed - the poorer the population will be', and 'the poorer the population is – the higher the birth rate will be and the higher the birth rate is, the poorer the population will become'. The consequences of the adverse factors can be presented as a 'spiral of unsustainability' (Fig. 1.1), in which each factor is not only the result, but also the cause of other problems.

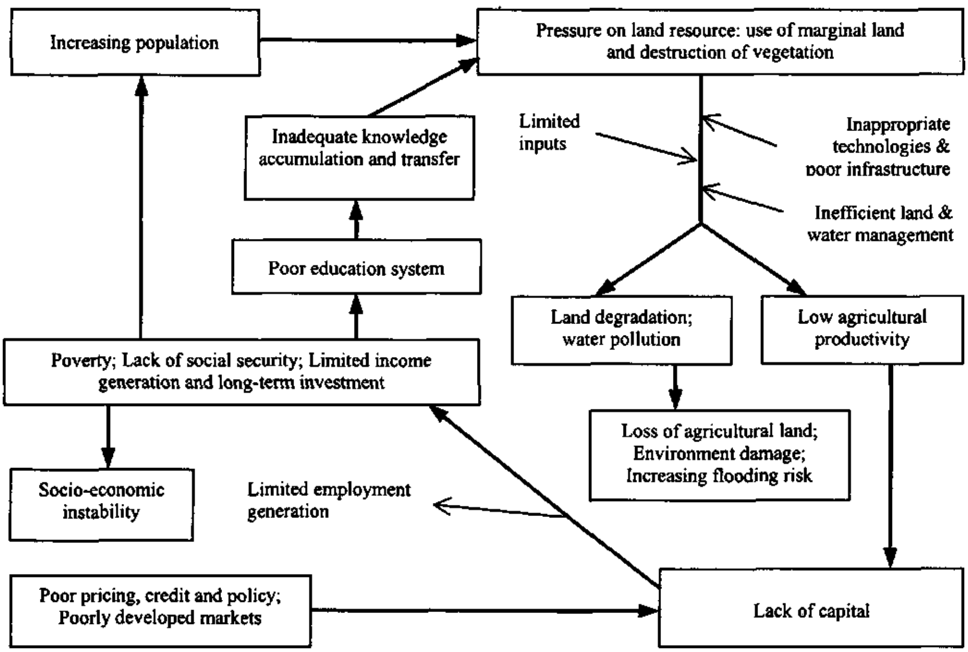


Figure 1.1 The spiral of unsustainability in the Loess Plateau. The idea and some terms adopted from Rhoades & Harwood (1992, cited by Rabbinge 1997)

1.1.2 Policy issues for sustainable land use

The 'spiral of unsustainability' can be broken by improving efficiency in the use of agricultural resources via appropriate policies. To approach sustainable land use or sustainable agricultural development, the following policy goals and measures should be addressed.

Promoting a more sustainable use of marginal land currently exploited for arable farming

Cultivation of marginal land and destruction of natural vegetation, which is strongly driven by the increased population and requirements for agricultural products, is often acknowledged as the key factor in the 'spiral of unsustainability'. 'Returning land used for arable farming to grass or forests' is frequently mentioned as a goal in the literature and government documents concerning the land degradation control. In general, the current debates surrounding this topic are greatly based on present knowledge and actual production techniques, and seldom consider options outside the present playing field.

There is a potential to reduce the area used for arable farming and to mitigate land degradation through conservation in the Loess Plateau. However, many questions have not yet been answered, such as how much cropping area can be reduced and what is the potential impact on the rural community (e.g., income, employment, etc.), taking into account food security, changing diets and population growth, and the increasing demand for improvement in the quality of life.

In the past, conversion of arable land to grass or forests has been strongly restricted by the inappropriate pricing system, a high labor resource and instability in the 'right to use land' (see footnote 1). Due to the high price of fertilizers and high available labor, farmers often produce enough to satisfy the food requirement by using more land, rather than by increasing crop yield with higher inputs. This situation has improved, to some extent, in recent years, particularly because of the implementation of guaranteed crop prices, market construction and an increased supply of fertilizers. Further improvements could be anticipated in the future.

Improving food security

In the Loess Plateau, food security has not yet been fully safeguarded, particularly for the staple food grains such as wheat that are still in short supply. Control of land degradation by reducing the cropping area or by restoring the natural vegetation may be intractable if the food supply is not sufficient, because household-based agriculture is basically oriented towards producing the subsistence requirements, and the import of food grains is normally restricted and expensive due to the poor infrastructure.

Increasing income

Increasing income for the rural population is another policy objective. Many factors can affect agricultural return and thus the income of rural people, particularly the low pricing, limited markets and the poor infrastructure, the lack of income-generating opportunities, limited and marginal land, high population growth and low agricultural productivity. Other factors include high labor input, small farm-scale, and inappropriate production techniques. For rather a long period, all these factors have resulted in a general feeling that agriculture in China is a low, even non-beneficial production sector. In the Loess Plateau, where agricultural production takes place largely on marginal land, this situation is even worse since high costs (inefficient use of nutrients and water and a high labor requirement) are incurred to obtain a reasonable production. This may partly explain why marginal land are so often cultivated extensively (with very limited or no inputs) not only in this region, but also in other areas of China.

To improve these general phenomena, appropriate policies are needed. The guaranteed price of food grains and the policy for free circulation of food grains (based on markets), can promote this change. This may also promote investment in agriculture, and efficient crop and soil management. Experiments show that investments in soil conservation can greatly improve the land productivity. For instance, crop yield on terraced land can be highly increased compared to that on sloping land in the Loess Plateau.

Decreasing population growth

Improvement of agricultural production and income can increase food and social security, and perhaps further help to decrease the population growth. Although the implementation of family planning has been very successful in China during the last two decades, population

(6) What potential impacts on the environment can be expected if chemical use (fertilizers and biocides) increases to improve agricultural productivity in the future?

(7) How much room is left for stakeholders (policymakers, rural communities) to make choices for future agricultural development?

Each of these questions in general presents an aspect that may be of interest to policymakers, regional planners or rural communities. From a policy viewpoint, some of these questions can be interpreted as different development directions that are preferred or accepted by a specific stakeholder, such as policymakers or farmers. The government's emphasis is on soil loss control, since the heavy soil loss causes serious land degradation, but also and more importantly, the eroded soil leads to siltation of the Yellow River, which further increases the potential flooding risk and pressure on flooding protection in the lower reach area. The rural people are mostly concerned about crop production and improvement of income; they prefer the continuation of current agricultural production, since they are used to and familiar with this traditional form of agriculture.

Taking into account the problems and policy issues mentioned above, a list of policy objectives can be identified that cover environmental (minimization of soil loss, cropping area, N loss, biocide use, etc.) and socio-economic (maximization of agricultural employment, crop production, net return, etc.) aspects. These policy objectives can be prioritized in different ways, thus reflecting different views on the future land use and regional development. Examples include aiming at minimum soil loss while guaranteeing food security; maximum agricultural employment for a given net return; maximum net return within a given limit of soil loss; or minimum emission of chemicals to the environment, etc.

As a first step towards the formulation of specific policies, it is useful to explore biological and technical opportunities under different priorities of societal, economical and political objectives. Such an explorative study can reveal possibilities of agricultural development, and help policymakers to make choices by showing the consequences of different policy directions. This requires a systems analysis method capable of integrating biophysical and socio-economic information. Explorative land use studies can operationalize such a method (Van Ittersum *et al.* 1998).

A systems analysis concerning future land use in the Loess Plateau was conducted using a case study of Ansai, a typical hilly county in the Loess Plateau (for details, refer to Chapter 2). The aims of the study were to contribute to the understanding of the problems involved in sustainable agriculture in the Loess Plateau, and to supply information to the stakeholders for decision-making.

1.2 Objectives of the study

This study uses Ansai county in the Loess Plateau as a case study, to operationalize a methodology for land use exploration, with specific emphasis on soil conservation, food security and regional development objectives. Strategic land use options are explored, using a systems analysis of information with respect to the agricultural production, and the agro-ecological and socioeconomic environment of the county. More specifically, the following scientific and applied research objectives are aimed:

(1) To operationalize a methodology for the exploration of strategic land use options, with specific reference to the conditions and land use problems of the Loess Plateau in China.

(2) To derive and present results of such an explorative land use study that are meaningful for strategic policy development.

(3) To integrate scattered knowledge about different aspects of the land use systems in Ansai and to identify knowledge gaps and potential research for the benefit of future agricultural development.

The land use study enables us to:

- reveal the crop production opportunities and limitations in Ansai;
- identify feasible techniques to raise the land productivity and serve the aim of soil conservation;
- evaluate the consequences of different land use priorities, evaluate the possibilities of satisfying various objectives and to reveal trade-offs between different objectives;
- evaluate the possible consequences of a growing population and changing food requirements on the land use, agricultural production, economic return and environment, and vice versa (i.e., what are the consequences of, e.g., restricted land use and agricultural production on the possibilities of feeding a growing population with changing food requirements).

1.3 Methodology and assumptions

The land use study presented focuses on exploring particular policy scenarios and their ultimate consequences, based on an approach often used in explorative studies as a tool to integrate biophysical and socio-economic information. The approach (Van Ittersum *et al.* 1998, Rabbinge 1995, Van Keulen 1990) is based on knowledge of biophysical processes underlying agricultural production possibilities, and a Multiple Goal Linear Programming (MGLP) model. With this approach, possible options concerning future land use can be explored by considering value-driven (what is considered 'good' or 'desirable') and technical (what is 'feasible' or 'attainable') aspects and including the weighting of ecological, agricultural and socio-economic objectives (Van Ittersum *et al.* 1998).

Various explorative land use studies using MGLP technology have been conducted (Rossing *et al.* 1997, Van Ven 1996, Bouman *et al.* 1998, Veeneklaas *et al.* 1991, WRR 1992, Van Latesteijn 1999). Many papers concerning explorative land use studies have been published, with regard to concepts and methodology (e.g., Van Ittersum *et al.* 1997, Van Keulen 1990, De Wit *et al.* 1988); technical coefficient generation (e.g., Hengsdijk *et al.* 1999, De Koning *et al.* 1992); and scenario generation and presentation of optimization results (e.g., Bakker *et al.* 1998). This section describes the methodology and assumptions used in this study.

tural practices are carried out according to the principle of best technical means, assuming efficient and appropriate use of inputs and techniques. Other assumptions that will be further elaborated in the various chapters are discussed below.

Delimitation of geographical regions and time horizon

Considering the availability of socio-economic data, the small size of the study area (with rather homogeneous loess soils), and the lack of data of spatial climatic variation, the geographical regions are delimited according to administrative units. The total 14 townships/towns in Ansai are grouped into 6 sub-regions (Map 1), based on catchment and road connections. The time horizon is set to 2020, with the assumption that the supposed changes could be achieved.

Fixed relations of input and output

The input-output coefficients for each production activity are determined using a target-oriented approach, i.e., the outputs are given first, and then the required inputs such as nutrients, capital and labor to realize them are calculated. For land-based agricultural production activities, it is assumed that each of the nutrients (N, P and K) is applied in an amount equal to the total removed (including the losses). For the soil loss, an upper limit of 15 t ha^{-1} is used for the scenario analysis (Chapter 7), which means that land use activities with soil loss exceeding this limit are excluded in the model optimizations.

The upper limits of crop yield under potential, water-limited and N-limited production situations are simulated with the EPIC model (Erosion and Production Impact Calculator) (Mitchell *et al.* 1997). The target yields for all cropping activities are lower than these simulated yield ceilings, since several reduction factors, such as climatic hazards, imperfect management, and rotation problems due to soil-borne diseases and insects, have been taken into account, based on literature data.

Available land resources

The land resources are divided into four types: (1) suitable land that can be used for growing crops, and apple, sowing grass and planting shrubs; (2) natural grass and shrub land that can only be used for grazing animals or for producing firewood; forest land that is assumed to be preserved; and (3) bad-land including gullies and extremely steep land that are not usable. In a specific model optimization, the area of suitable land that is not allocated to agriculture is assumed to be allocated for nature conservation. The area used for grazing (or for firewood collection) can be less than the natural grass area (or the natural shrub area). The unused part of the natural grass or shrub area is used for nature conservation. The soil and N losses include those from all production activities on the suitable land, excluding those from the natural grass and shrubs, forest and bad-land in the current version of the MGLP model.

Other assumptions

The following assumptions are made:

- Differences in land accessibility or in the transportation infrastructure among different areas in the county do not affect land productivity and resource use efficiency.
- Prices of agricultural products, fertilizers, biocides, labor and use of draught animals, etc., are fixed, and based on the prices of 1997-98; no price differences among regions, or variations in the market or quality of products are considered. The model can, however, be used to evaluate consequences of different prices.
- Farm size and the land tenure systems, know-how level of farmers, and the costs of capital (interests), industry processing of food and storage of agricultural products are not considered.

1.4 Outline of the thesis

This thesis comprises 8 chapters, starting with the problem definition and a description of the methodology, research objectives and assumptions (Chapter 1). This is followed by a general description of the case area and definition of land use and animal activities in Chapter 2. In Chapter 3, a quantitative land evaluation is described, in which the crop production potentials under irrigated, rainfed and N-limited conditions are determined. A total of 816 land use systems, i.e., combinations of land use types (combinations of crop rotations with different production technologies) and land units are quantitatively evaluated, with regard to the yield, soil and N loss, and irrigation and N requirements. In Chapter 4, the input-output coefficients of the land use and animal activities are determined using a target-oriented approach, based on data from quantitative land evaluation and literature. Chapter 5 presents the mathematical description of the land use and animal activities, constraints and objective variables.

In Chapter 6, the basic constraints and requirements for agricultural products in the MGLP model are discussed, and the extreme values and trade-offs of the objective variables are presented. Finally, the effects of changing food requirements are evaluated, and conclusions are drawn. In Chapter 7, four policy scenarios are evaluated, in combination with a sensitivity analysis of the model results, and then conclusions are given. Finally, the main achievements, policy implications and future research are discussed in Chapter 8.

1971-1993. Year-to-year variation of monthly rainfall is even more evident (Fig. 2.2).

Table 2.1 Average monthly data (1971-1993) at Ansai meteorological station (at 1068 m, 36°53'N and 109°19'E). TMX and TMN: maximum and minimum air temperature, PRCP: rainfall in mm, DAYP: monthly days of daily rainfall ≥ 0.2 mm, P5MX: maximum half-hour rainfall in mm; RHUM: relative humidity in %, and WSPD: wind speed at height of 10 m in m s^{-1}

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
TMX	1.4	4.4	10.5	19.0	24.4	28.0	28.7	27.0	22.2	16.9	9.4	2.9	16.2
TMN	-12.9	-8.9	-2.3	3.5	9.2	13.5	16.5	15.6	10.0	3.6	-3.6	-10.0	2.9
PRCP	3.6	6.3	15.6	23.6	40.0	65.3	117.2	116.8	82.4	33.9	11.8	3.9	520.3
DAYP	1.8	3.0	4.9	5.2	6.7	7.8	11.3	12.1	9.6	6.0	2.8	2.0	73.2
P5MX	2.2	2.7	5.1	7.5	14.6	25.7	32.4	21.8	45.7	10.8	6.4	2.4	
RHUM	56	54	56	48	51	58	71	77	77	72	64	59	62
WSPD	1.7	2.0	2.2	2.6	2.5	2.1	1.7	1.5	1.5	1.7	1.9	1.7	1.9

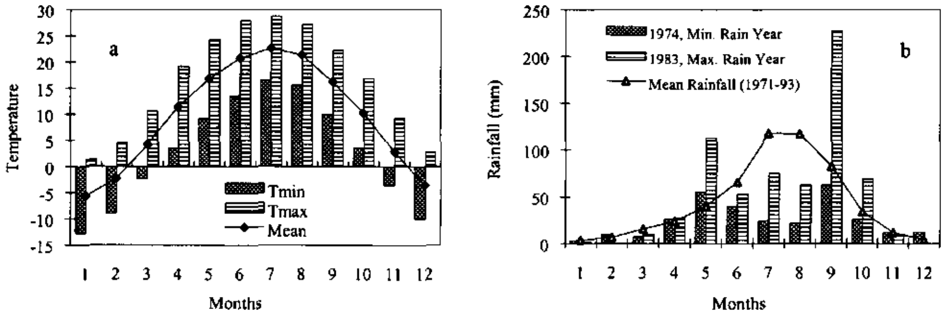


Figure 2.1 a) Monthly average of daily, minimum and maximum air temperature (°C, 1971-93), and b) monthly rainfall (mm) of the long-term average, minimum and maximum rain year.

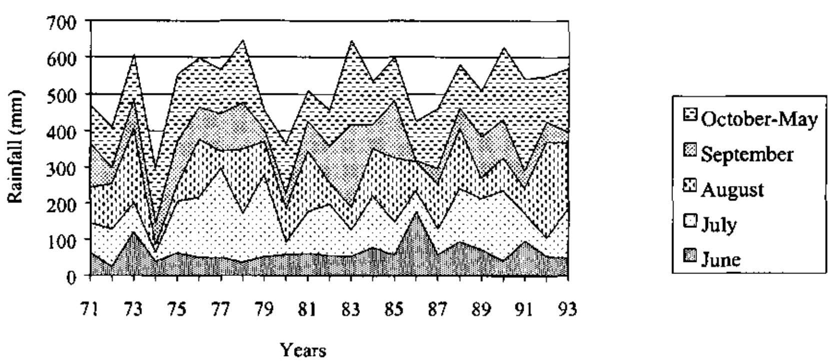


Figure 2.2 Monthly rainfall (mm) in June, July, August, and September, and total rainfall in October-May from 1971 to 1993

Formed on deep loess sediment, the soils are rather homogenous over Ansai in terms of soil depth and texture, comprising 60-75% silt (0.002-0.05 mm), 9-15% clay (< 0.002 mm) and less than 30% sand (> 0.05 mm). Soil field capacity is high, at around 235 mm m^{-1} (Yang *et al.* 1992). Due to low content of clay and organic matter, soil CEC is low, ranging within 5-10 cmol kg^{-1}. Soil leaching hardly occurs, which is indicated by the fact that both soil pH (more than 8) and content of calcium carbonate (mostly 9-14%) are high in the whole soil depth. Soil bulk density is between 1.2 and 1.4 t m^{-3}, varying with the cultivation conditions and types of land use. Due to serious soil erosion, soil fertility is low in terms of content of organic matter and organic nitrogen; for instance, the content in cropland is normally only 0.4-0.7% and 0.03-0.05%, respectively. The soils are very susceptible to water erosion due to the high content of silt and the steep slope.

The natural vegetation in Ansai comprises grass, shrubs, and forests. Due to population growth and increased food requirements, most natural vegetation near the residential areas has been destroyed, and converted to cropland. By 1987 (Chen 1988a, Luo & Zhang 1988, Wang *et al.* 1988), 40.4% of the total area was cultivated for crops, while only 29.7% of the area was under grass (14.9%), shrubs (4.4%), and forests (10.4%). The remainder 29.9% of the total area was gullies (very low coverage of vegetation), water-bodies (river and reservoirs), and non-agricultural land (village, town, road, mining plots, etc.).

2.2.2 Land resources for agriculture

The land resources for agriculture comprise four categories, i.e., 1) suitable land for arable farming, 2) natural grassland that can be used for animal grazing, 3) natural shrub-land that can be used for firewood production, and 4) forest-land. The area of each category is presented in Table 2.2. The suitable land for arable farming is derived from the survey data of cropland by Chen (1988a), and the grassland area is based on Wang *et al.* (1988). The area of natural shrub-land and forestland is from Luo & Zhang (1988). The forestland is assumed to be available only for natural conservation, because it is controlled by the government, and cutting for firewood or timber is not allowed. Since the expansion of cropland has already led to serious problems of vegetation destruction and land degradation, it is assumed that the natural grassland and shrub-land should not be reclaimed for growing crops.

According to Chen (1988a), the total land area used for cropping in Ansai was 119.4 10^3 ha, comprising mainly sloping land (Table 2.3). Due to the high potential soil loss, measures for water and soil conservation should be used for most sloping land types to grow crops. For gently sloping land types, the potential soil loss can be alleviated or controlled by agronomic measures, such as contoured tillage, furrow-ridging, and residue mulching. For steeply sloping land types, terracing could be used, as the potential soil loss may not be controlled by agronomic measures.

For very steep land, terracing may not be feasible, for technical and economical reasons. Song *et al.* (1995) suggested that terracing should not be used for land with a slope gradient exceeding 47% (25°). Above this slope gradient, the terrace becomes instable, since the height is too high to make the terrace wide enough for crop cultivation. Land types with slope

to the narrow width.

Chapter 2

2.3 Current agricultural systems and problems

2.3.1 General characteristics of the agricultural systems

Agriculture in Ansai comprises three types of production systems, i.e., cropping system, livestock system, and orchard system. The orchard system comprises mainly apple and some pear production, practiced on flood plains and on hilly slopes near the main roads. The total growing area of apple was 420 ha in Ansai according to the 1992 Yearbook of Ansai. A brief description of the cropping and livestock systems is given in the following subsections.

Cropping systems

Two cropping systems are practiced in Ansai, i.e., irrigated and rainfed. The irrigated cropping system is limited in the flood plain, and it is mainly used for growing corn, potato, tobacco, vegetables, and soybean. The irrigated crop yield (fresh weight) is relatively high, normally within a range of 5-8 t ha^{-1} for corn, 13-20 t ha^{-1} for potato, and 1-1.3 t ha^{-1} for soybean.

Two types of rainfed cropping systems may be distinguished. One includes the production of corn, millet, winter wheat and soybean, which is carried out manually with animal power and limited fertilizer use, mainly on terraces and relatively gently sloping land and partly on the flood plain. Crop yield is normally 2-4 t ha^{-1} for corn, 0.9-2 t ha^{-1} for millet, and 0.8-1.5 t ha^{-1} for winter wheat. Another system for the production of broomcorn millet, millet, beans, potato, buckwheat, sorghum, seed flax, sesame seed, sunflower, etc., is carried out by hand with limited use of animal power, and without or with very low application of fertilizers. This cropping system is widespread on steep slopes, with the crop yield mostly less than 1.5 t ha^{-1}.

Livestock systems

Livestock production system includes goats, sheep, pigs, cattle, donkeys, mules, and poultry, and can be divided into four categories: mutton, pork, draught animal and poultry production, based on its main products. The mutton production systems include goat and sheep, grazed on pastureland for producing meat and wool or cashmere. The products are mainly for sale. The pork production is a very traditional activity in China, not only for producing meat but also for manure. Pigs are normally slaughtered just before the Spring Festival (Chinese New Year). A small part of the pork is reserved for family consumption during the festival and the rest is sold at the local market or within the village. This tradition still continues in most rural areas of China. Draught animals, including cattle, donkey, mule, and horse, are used for supplying farm traction and transportation power. Poultry production systems include chicken and very limited numbers of ducks and geese for producing eggs and meat. The products are mainly for family consumption. Milk and beef production is not practiced in the region.

The productivity of animal husbandry is very low at present. Based on the 1994 Yearbook of Yan'an Prefecture, the off-take rate (ratio of number of culled animals to total animals) of goats and sheep in Ansai was estimated at 24% and 28% respectively, and meat production per culled head was around 12 kg for both types of animal.

2.3.2 Problems and policy goals

Chapter 1 discussed in general terms the problems and policy issues in the Loess Plateau. This subsection presents in more detail the key problems and policy goals for future land use that should be dealt with in Ansai.

Serious soil loss

The main problem of the current land use is severe soil erosion. CAAC (1993) reported that the average sediment yield (ratio of sediment measured at hydrology station to the total area) for all of Ansai is 84 t ha^{-1}, i.e., around 6.5 mm topsoil eroded per year. This serious soil loss is largely caused by slope cultivation and vegetation destruction. Of the total cultivated land, about 80% is steep land with a slope steepness of more than 19% (Table 2.3).

Regarding these problems of land degradation, two policy objective goals could be operationalized: *minimization of total (or per unit area) soil loss* and *minimization of land area under crops (or maximization of land productivity)* to promote the restoration of natural vegetation.

Increasing population pressure

During the past four decades, total population in Ansai increased from 6.0 10^4 persons in the first census of 1953, to 14.7 10^4 persons in the last census of 1990, representing an average growth rate of 2.46%. This growth rate was much higher than the national average of 1.47% in China (Table 2.5). Although the policy of population control and family planning has been implemented in China since the late 1970s, it seems not successful in this region. For example, the population growth rate in Ansai even increased in the period of 1982-1990, in comparison with that of 1964-1982 (Table 2.5). The rapid population growth leads to an increased requirement for agricultural products and an increased number of labor to be employed in agriculture.

Table 2.5 Size and growth rate of population in Ansai and China based on the four censuses. Years in bracket of the first row are the end or start year for mean growth rate of population

	1953 (-64)	1964 (-82)	1982 (-90)	(53-) 1990
Population size (10^4 persons)	6.0	8.6	12.2	14.7
Relative mean growth rate (%) of population	3.34	1.95	2.34	2.46
Relative mean growth rate (%) of population of China	1.64	2.09	1.47	1.83

Increasing food requirements and risk of food insecurity

An increase of demands for agricultural products (food and firewood) in the future is expected due to high population growth and demands for food improvement. Statistics have shown that this rapid growth of population also considerably increased crop cultivation. According to Tang & Chen (1991), the sloping cropland in Ansai increased 2.8 times in 1985, compared to that in 1964.

Current crop production in Ansai depends very much on the large area of sloping cropland. Due to the extensive cultivation, and high runoff of rainfall on hilly land, crop production varies with annual precipitation. In some years, the total crop production can be reduced by more than 20%, even up to 50% (CAAC 1993), due to the climatic hazards of drought, hail, frost and rainstorms. Although Ansai achieved an average crop production of over 400 kg GE (grain equivalent) per capita in 1992, food security is still the most important issue for the rural population, because of the high potential for crop failure due to climatic hazards, pests and diseases.

As an important policy goal in Ansai, the objective of food security can be operationalized by *maximizing total crop production* or *minimizing the food deficit.*

Employment pressure on agriculture

Employment for the rural population strongly depends on agriculture due to the lack of non-agricultural employment opportunities. Based on the 1990 census data, around 90% of the total employed labor in Ansai was involved in agricultural production. Of the total employment in agriculture, 97% was engaged in arable farming. Non-agricultural production sectors such as rural enterprises are hardly developed in the rural areas of Ansai, which is illustrated by the fact that 97% of the total rural production value of Ansai was from agriculture in 1992. Due to the limited land resources available, it is estimated that unemployment may be more than 50% in the rural areas of Ansai. The potential to alleviate this unemployment problem can be explored by *maximizing total employment in agriculture.*

Demands for an increase of income

Income of the rural population in Ansai is low, e.g., the average gross production value per capita was 927 yuan and the net income was 438 yuan (1992 price) in 1992. Many factors may contribute to this low benefit, such as the lack of off-farm income generating opportunities, low efficiency of agricultural production, inappropriate pricing systems, and limited market. These problems of low efficiency can be alleviated by efficient management of agriculture, by improved pricing and marketing systems, by growing cash crops such as apple, and by promoting development of animal husbandry.

Three policy objectives related to these problems should be analyzed, i.e., *minimization of total cost for agricultural production, maximization of total net agricultural return* and *maximization of net return per laborer.* The first policy goal focuses on exploration of the possibility to meet the regional demand with the lowest total input in monetary terms. The second is to achieve a maximum total benefit from agriculture, while the third policy goal is to achieve maximum labor productivity.

Minimum use of chemicals to serve the environmental goals

The current agricultural systems in Ansai are mostly not sustainable, due to extensive slope cultivation associated with low efficiency and serious soil erosion problems. This unsustainability of agriculture should be changed by innovative cropping systems that are based on ecological principles, good management, and appropriate external inputs. For environmental aims, and considering the limited availability of fertilizers and biocides in Ansai due to restrictions from lack of capital and a poor infrastructure, these cropping systems should have high use efficiency of chemicals, i.e., a low requirement of fertilizers and biocides per unit product, and low N losses to the environment per unit product. These issues can be interpreted as three policy goals, i.e., *minimization of total fertilizer N use*, *minimization of total biocide use*, and *minimization of total N emission to the environment.*

Poor accessibility

Accessibility is generally very limited due to poor road systems and steep terrain that is dissected by dense and deeply incised gullies. All-weather roads are only located along the valley of Yanhe River with a limited length, while most of the rural area is connected by only poor dirt roads that are often closed due to rainstorms during rainy season. Based on the 1992 Yearbook of Ansai, 80% of villages were inaccessible to traffic. Donkeys are still the main transport means for the rural population in Ansai. Since more than 90% of the population lives in the rural area, and because transportation is limited, market-oriented production such as vegetables is heavily restricted by the lack of markets.

2.3.3 Agricultural measures to alleviate the problems

Since this thesis deals with agricultural and land-use options that could alleviate the identified problems and satisfy a range of objectives, measures related to land use and agriculture are introduced in this subsection. The agricultural measures commonly applied in the Loess Plateau or mentioned in the literature (e.g., Lu 1998b, Song *et al.* 1995, Shan & Chen 1993, Tang & Chen 1991) include:

- Intensification of agricultural production to reduce the area of sloping farmland by increasing inputs and improving agricultural management.
- Change of land use patterns. This emphasizes the more natural land-use types of grass, shrubs, or forests. Attention is also paid to various multiple cropping systems such as rotational/strip cropping of perennial (leguminous) forage crops and food crops.
- Conservation-oriented production methods. These include contoured tillage, crop residue mulching, and furrow-ridging (Fig. 2.2) aimed at conserving water and soil losses from runoff and water erosion.
- Land improvement by constructing terraces on sloping land.
- Integrated management of small catchment. This emphasizes the integrated use of land resources, by a rational arrangement of different land use types such as crops, grasses, and forests according to land conditions (slope and elevation). This can be combined with

construction of a series of small dams across gullies that are mainly used for damming-up sediment from soil erosion on the gully and hilly slopes. Construction of dams needs a high capital input, which is normally invested by the government.

These measures have been promoted by the government via administrative measures and financial supports. The construction of 'Wan Mu' (Chinese area unit, equal to 667 ha), a high yielding demonstration project, has been implemented during the last five years in Ansai, with the aim of achieving an annual crop production of 0.5-1 t mu^{-1} (1 ha = 15 mu). Conservation farming based on the so-called 'furrow-riding' cultivation technique was already practiced in this region about two decades ago. Integrated management of small catchment is being extended in the Loess Plateau, based on the government plan for the integrated control of soil loss. A more flexible land policy will be probably introduced, such that farmers can buy 'the right to use land' for up to 100 years. During the contract period, they can sell or transfer the land to other people.

2.4 Alternative agricultural production activities

2.4.1 Forms of agricultural production and the relationships

To alleviate the problems with land use and environmental impacts, to meet the regional food requirements and to serve the socio-economic and environmental goals, alternative and innovative agricultural production systems must be identified. For application in the MGLP model, such systems should be described quantitatively. Five major types of agricultural production systems can be distinguished in Ansai:

1) cropping systems for producing food grains and forage;
2) fruit systems for income generation;
3) grassland production systems for supplying grazing pasture;
4) firewood production systems, i.e., growing shrubs to meet energy requirement of the rural population;
5) animal production systems for income generation, supplying animal traction and manure.

Each of these agricultural systems comprises various production activities characterized by well-defined production techniques with specified and quantified inputs and outputs. The defined techniques based on expert knowledge are not differentiated for differences in current socio-economic conditions. The concept of 'best technical means' is applied to all production activities, which implies that minimum inputs are applied to achieve specified target yield levels. Differences in the know-how of farmers, market conditions and agro-infrastructure are therefore not taken into account, assuming that these factors will not affect the outputs and resource use efficiency.

The livestock system is connected to other production systems. The feed required by animals is provided by grassland and crop products (residues, forage, corn) of the crop activities. Manure produced from the animal production systems is applied to crops, grassland,

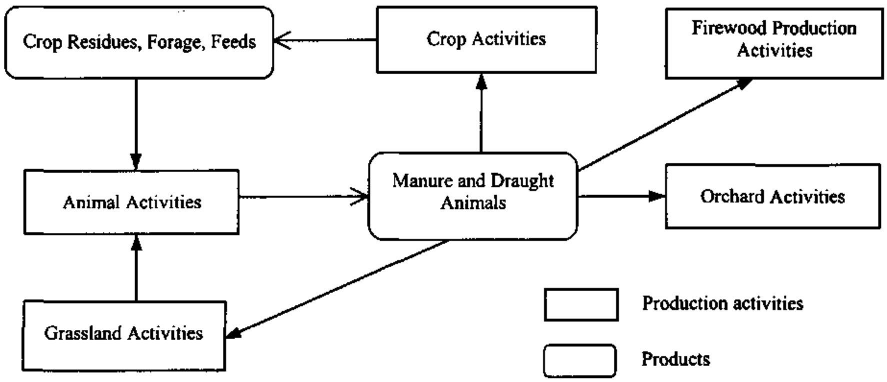


Figure 2.1 A diagram presenting the relationships among the five major types of production activities

and apples. The draught oxen are used for land preparation, sowing of crops and grass, weeding, and transportation of manure and agricultural products. Donkeys are used for transportation of manure, agricultural products, and firewood. These relationships are presented in Fig. 2.1.

2.4.2 Cropping activities

A cropping activity is a crop or crop rotation cultivated in a particular physical environment, completely specified by its inputs and outputs (Van Ittersum & Rabbinge 1997). Cropping activities are defined by three criteria, 1) crop rotations, 2) production technologies that determine the inputs and outputs, and 3) types of physical environments.

Crop rotations

Cropping activities are defined on a rotation basis, because of agro-technical and environmental reasons. Rotational cropping systems are less dependent than mono-cropping systems on inputs of nitrogen and protection agents because of their diversification of crops in time and/or space (Stinner & Blair 1991). Relatively less or even no nitrogen is required when legumes are included in a rotation. Incidence of diseases, pests, nematodes, and weeds, especially soilborne pathogens can be alleviated by growing crops in appropriate rotations. Some pathogens and pests that are found on or with different crops can even be fully controlled by properly arranged rotations, through which the reproductive cycles of those species are broken (Francis & Clegg 1991). Higher yield can be achieved for crops grown in rotations than in mono-cropping, e.g., yields of corn and sorghum are higher after legumes or non-legumes than when grown in mono-culture (*ibid.*). Soil losses can be reduced by rational arrangement of crops in rotations.

Five crop types are considered, i.e., cereal crops of millet, corn, and winter wheat; tuber crops of autumn and summer potatoes; leguminous crops of soybean; oil-bearing crops of linseed; and forage crops of alfalfa. Other crops such as broomcorn millet and buckwheat that are normally grown on steep land are strongly related to the current extensive farming. Those two crops may have limited development potential due to their low yields. This is evidenced by the shrinkage in sowing area in recent years. Emphasis in this thesis is on production of major staples, therefore production of vegetables and tobacco is not considered.

Theoretically, these seven crops can be combined into numerous crop rotations, if crop sequences and length of rotation cycles are taken into account. However, it may not be possible/necessary to consider all possible combinations, otherwise it will make the MGLP model too complex. Thus, a limited but representative number of crop rotations are defined, assuming that each of the defined rotations is always in the same sequence. Table 2.6 presents the defined crop rotations that are grouped in three categories, i.e., mono-cropping, food crop rotations, and mixed crop rotations with alfalfa.

- *Mono-cropping*: This means that a crop is grown continuously on the same land. Only corn and winter wheat are selected, and other crops are excluded due to problems of high occurrence of diseases and pests.
- *Crop rotations*: This crop system is aimed at producing food grain only, and comprises cereals, tuber and cash crops growing in rotations. The rotation cycle is set to 2-5 years, and a limited number of representative crop rotations is selected.
- *Mixed crop rotations*: This is a mixed cropping system for producing food grains but also forages. In this cropping system, the perennial forage crop alfalfa is grown for some subsequent years, followed by some years with food crops, and then alfalfa again. Alfalfa can grow for up to 8-9 years and reaches its maximum biomass production at around its fourth year in the Loess Plateau. In this study, a growing period of 3-5 years is assumed. This cropping system serves environmental aims because it has a lower risk of soil loss and low nitrogen requirements.

Three aspects are considered for the definition of crop rotations. First, crop-sowing time should be feasible. In Ansai, corn, millet, soybean and autumn potato are normally sown in April-May and harvested mid-September to early October. Winter wheat cannot be grown after these crops, as it must be sown in early September to ensure germination before winter. Alfalfa is sown in summer when it follows flax or winter wheat that are harvested in July.

Table 2.6 Defined crop rotations

Rotation type	Defined crop rotations
Mono-cropping	W, C
Crop Rotations	PWC, CSC, MSC, CMP, FWPM, PWCM, WPMCF, MSMP
Mixed Crop Rotations	A3CM, A3CPM, A3MPM, A4MPM, FWA4MC, FA4CMCM, FA5MC

C: corn, W: winter wheat, M: millet, S: soybean, P: summer potato in PWC and PWCM, P: autumn potato in other rotations, F: seed flax, A: alfalfa, and number: growing years of alfalfa.

Second, problems of diseases, pests, and weeds should be as limited as possible based on available knowledge. In general, wheat and corn have fewer problems related to soil-borne diseases than other crops do when they are grown in continuous cropping and narrow rotations. Millet, soybean, potato, and flax should be grown in wide rotations, due to the high incidence of diseases and pests in narrow rotations[2]. Soybean, potato, and flax may not be grown sequentially, because they can be susceptible to or the host of *Rhizoctonia solani* Kuhn, *Scerotinia sclertiorum* (soybean and potato) and weed of *Cuscuta chinensis* Lam.

Third, the crop rotation should be helpful for soil loss control and water use. Row crops rotated with small grains such as millet, wheat or closely seeded alfalfa can reduce the potential soil loss. Growing winter wheat after crops harvested in summer (flax, summer potato or winter wheat) can reduce water stress during the long dry period of winter and spring, because rainfall after these crops are harvested in July can be stored in the soil.

Production technologies

Production technologies are differentiated by three criteria, i.e., 1) production levels, 2) mechanization levels that determine the intensity of labor inputs, and 3) agro-technical options for water and soil conservation (Table 2.7). Three yield levels are distinguished, mainly by the availability of water and nutrients. These defined yields can be realized with machinery or manual labor. Thus, two mechanization levels are defined, called semi-mechanized, and non-mechanized, respectively. Four types of agro-technical measures of soil conservation are specified, based on two tillage methods and two options of crop residue management. Thus, a production technology is defined as a feasible combination of these three factors.

Table 2.7 Definition criteria of production technologies

Definition factors	Defined options
Production level	Three yield levels: 1) Attainable irrigated yield; 2) Attainable rainfed yield; and 3) (Attainable) N-limited yield
Mechanization level	Two mechanization levels identified, 1) Semi-mechanized, use of herbicides and no use of draught animals; and 2) hand labor and animal traction, no use of herbicides and machinery
Agro-technical measures for water and soil conservation	Four measures: 1) Contoured tillage and crop residue removed; 2) Contoured tillage and crop residue mulching; 3) Furrow-ridging and crop residue removed; and 4) Furrow-ridging and crop residue mulching

[2] Literature (ECPP 1996, SAAS 1987, HPRI-CAAS 1995, IBP-CAAS 1993, Wang & Huang 1995) show that the continuous cropping or growing in a rotation once in two years may have problems due to high occurrence of 1) soilborne diseases, e.g., millet downy mildew caused by fungi *Sclerospora graminicola*, potato diseases caused by soilborne fungi *Verticillium albo-atrum, V. dahliea, Rhizoctonia solani* Kuhn, and *Fusarium spp.*, etc., soybean spot caused by *Pseudomonas glycinea* and flax anthracnose caused by *Colletotricum linicolum;* 2) pests, e.g., millet pests *Chilo infuscatellus* and *Atherigona biseta,* soybean pest *Leguminivora glycinivorella;* 3) weeds such as giant foxtail, *Setaria viridis* var. major and *Cuscuta chinensis* Lam.; 4) nematodes, e.g., millet nematode *Aphelenchoides olyzae* Yokoo, soybean nematode *Heterodera glycines* and various potato nematodes.

Production level

Crop yield is determined by its growth factors. These growth factors can be divided into three categories (Rabbinge 1993): 1) growth-defining factors comprising incoming solar radiation, air temperature and crop physiological properties; 2) growth-limiting factors including water and nutrients, and 3) growth-reducing factors comprising diseases, pests, weeds, and pollutants. Under normal (field) conditions, farmers cannot influence the yield-defining factors that determine the crop production potential at a specific location. However, the growth-limiting and growth-reducing factors can be manipulated by man, i.e., the conditions of which can be improved by applying irrigation, fertilizers, and biocides.

In practice, growth-limiting and growth-reducing factors may not be fully removed. Shortages of nutrients and water often exist during part of the growing season, due to their supply not at the right time and at the right place. Diseases, pests, and weeds may not be fully controlled for field crops, because crop management may not be perfect, and the control of some minor pests may be neglected due to lack of economic attractiveness. Climatic hazards such as hail, frost, rainstorms and windstorms can also cause reduction of crop yield. In general, potential production may be achievable only in protected cultivation; it is hardly ever realized for field crops (Penning de Vries & Rabbinge 1995).

Alleviation of the problems of over-cultivation and destruction of natural vegetation to cultivate crops in low-lying areas, requires crop systems oriented at maximizing crop productivity per unit area. However, the realization of maximum productivity may be constrained by limited markets, restricted regional demand for agricultural products, and the availability of other resources such as fertilizers and capital. The land can thus be used in a less intensive way, in which the goal is to achieve a lower yield with acceptable external inputs. Examples include various cropping systems with intermediate to moderately high yields, that are often recommended by Chinese agronomists based on experiences of field experiments and the practices in better-managed farms in the Loess Plateau.

With respect to productivity per unit area, three production or yield levels are distinguished: attainable irrigated yield, attainable rainfed yield, and (attainable) N-limited yield. Attainable irrigated production (yield) is restricted mainly by unavoidable growth-stress factors such as climatic hazards. Attainable rainfed production is mainly limited by water shortage during part of the growing season. N-limited production is restricted not only by a shortage of nitrogen, but also often by water.

- *Attainable irrigated yield*: This production aims at obtaining maximum attainable yields with sufficient inputs of water, nutrients (N, P and K), and protection agents. Target yields are based on the potential yields, taking into account unavoidable yield reductions due to climatic hazards (hail, rainstorms, etc.), and soil-borne pest and disease problems. The crop yields is around 80% of the potential yields under irrigated conditions.
- *Attainable rainfed yield*: The crop yield is determined by availability of soil water, which depends on weather and land conditions, crop and soil management, and water conservation measures. Required nutrients and biocides are sufficiently supplied. Target yields are based on the water-limited yields, taking into account the reductions caused by unavoid-

able yield-reducing factors. The crop yield is about 80% of the water-limited yield (rainfed conditions).

- *Nitrogen-limited yield*: Crop yields are determined by available nitrogen under rainfed conditions. The biocides, P and K needed to realize the yield are amply supplied. Two yield levels are differentiated, i.e., (1) the target yield is determined by legumes-fixed nitrogen without inputs of chemical and manure N; and (2) the target yield is based on the crop yield currently achieved in better-managed farms. The first option applies to only mixed crop rotations with alfalfa, while the second option applies to only crop rotations without alfalfa.

Mechanization level

Concerning the mechanization of arable farming, there are in theory three possible options: (fully) mechanized, semi-mechanized and non-mechanized or manual. Mechanized farming refers to all farm work carried out mechanically, while semi-mechanized farming implies that part of the farm operations, such as high labor-demanding operations (land preparation, harvesting), carried out with machinery. Non-mechanized (manual) farming refers to crop cultivation carried out manually with draught animals, without use of power-driven machinery. This labor-intensive farming is still widely practiced in Ansai, and in the rest of China, because it is highly suited to the household-based (family labor) farming systems, which are characterized by small farm size and production predominately for self-consumption.

Mechanized farming in this hilly area is restricted by land accessibility. Large-scale machinery may not be suitable due to limitations of terrain and small land parcels. In large areas where the land slope is steep, crop cultivation can be carried out only manually. Another restriction is the small farm size (less than 4 ha per family), high labor resource, and lack of employment opportunities in non-agricultural production sectors. These may lead to a low requirement for machinery use.

Considering the limitations, fully mechanized arable farming may not be economically attractive in this region. Thus, two levels of mechanization are defined, i.e., semi-mechanized, and non-mechanized (hand labor and animal traction).

- *Semi-mechanized*: This refers to the plowing, sowing, fertilization, interrill plowing, transportation and harvests carried out by power-driven and small-scale machines. Weeds are controlled by herbicides. Application of biocides are carried out by hand with powered knapsack sprayers. If irrigated, sprinkler irrigation is used.
- *Hand labor and animal traction*: Animal traction is used for plowing and sowing instead of machines. Transportation of manure and harvests are carried out by donkeys and oxen. Furrow irrigation is used. Weeding is carried out by hand without use of herbicides.

Agro-technical measures for water and soil conservation

Four agro-technical measures for the control of water and soil losses are defined, based on two criteria, i.e., tillage method and crop residue management. These measures do not only affect soil losses, but also affect the crop yield and the associated inputs (particularly labor).

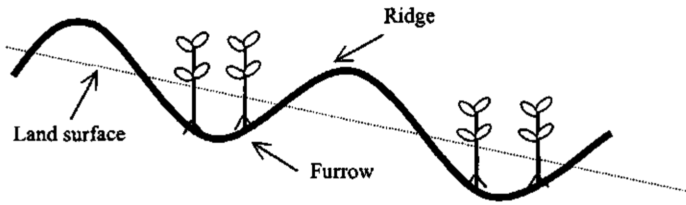


Figure 2.2 A schematic illustration of furrow-ridges

Tillage affects soil erosion and overland runoff of rainfall. Two tillage methods are defined: *contouring* and *furrow-ridging* (Table 2.8). Contoured cropping means that tillage and planting are on the contour. Furrow-ridging (Fig. 2.2) is a practice of conservation tillage, which was adopted in the Loess Plateau during the last two decades. For this cultivation technique, temporary furrows and ridges on the contour are normally prepared together with manure application (in furrows) just before sowing in spring. Depending on the crops to be grown, furrow width varies from 40 to 100 cm and ridge height from 15 to 30 cm. Crops are planted in the furrows. These two tillage methods can be used for flat land and sloping land.

Crop residue management refers to a strategy of residue harvesting. In this study, two options are defined, i.e., crop residues are mostly removed, and crop residue is partly left in field (Table 2.8). The first option is commonly practiced in the area, with the crop residues harvested for firewood and feeding animals. Residue mulching means that the crop residues are not fully harvested (by high stubble cutting) or they are returned to fields after the on-farm processing. Residue mulching can increase crop yield in semi-arid areas by reducing water loss from soil evaporation and runoff and reduce soil loss. It can also increase the soil temperature in winter, therefore reducing the plant death of winter wheat during winter dormancy (Zhao *et al.* 1996, Shen 1998).

Table 2.8 Definitions of the tillage methods and options of crop residue management

Defining factor	Class and definition
Residue Removed	80% of crop residues are harvested for all crops except potato (100% left on fields) and soybean (60% harvested, as most leaves fall at maturity).
Residue Mulching	Half of the crop residues are left on or returned to fields for all food crops except potato (100% left on field).
Contoured Tillage	Tillage and planting are on the contour.
Furrow-Ridging	Furrow-ridges and dikes across the furrows are built just before the crop is planted. The furrows and ridges are all on the contour.

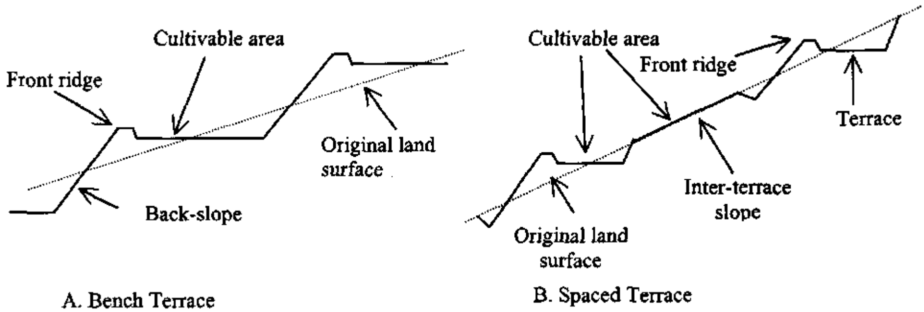


Figure 2.3 A schematic illustration of bench and spaced terraces

Types of physical environment and terracing

Crop yield, soil losses, and the requirement of external inputs are affected by the physical environment, under which a cropping activity takes place. A physical environment can be interpreted as a land type (or land unit) characterized by similar climatic, soil and topographic conditions. In this study region, six land types suitable for arable farming are distinguished, comprising the floodplain, existing terraces and four sloping land types.

The physical conditions of sloping land units can be improved by terracing, a very important engineering measure for protecting soil and water from losses in the Loess Plateau. Two terracing types (Fig. 2.3) are defined, i.e., bench terracing and spaced terracing, both of which can be applied to each of the sloping land units to improve the land qualities. Bench terracing, in which the sloping land is fully terraced is a traditional and widely used soil conservation measure in the Loess Plateau. Spaced terracing, in which the sloping land is partly terraced is not common in the region. However, since it needs lower capital and labor inputs and is efficient in controlling soil erosion, this measure is also considered in this study. Terraces can be constructed mechanically or manually. This results in four types of terracing: *mechanized bench terracing, manual bench terracing, mechanized spaced terracing* and *manual spaced terracing.*

2.4.3 Fruit production activities

Tree crops grown in Ansai include apple, hawthorn, jujube, walnut, pear, apricot and peach, among others. Apple production has a relatively large area (420 ha in 1992), while other tree crops have limited growing area in Ansai. In the current version of the MGLP model, only apple is included as an indicator tree crop. Other tree crops are excluded, since limited markets may restrict their development potential, and data availability required for their quantitative description is very poor. To include those activities, an in-depth analysis of development potential is needed, which may be beyond the scope of this study.

For apple, two production activities are defined: *irrigated apple production* and *rainfed* *apple production*. Irrigated apples can be grown only in the floodplain with irrigation and ample nutrients, resulting in a high yield. Rainfed apples are assumed to grow on hilly land units without irrigation. For the rainfed activity, soil and water conservation measures such as orchard terracing are applied. The target yields for both production activities are based on data from literature, experiments and well-managed farms in the Loess Plateau.

2.4.4 Grassland production activities

Natural grassland

Natural grassland is mostly distributed on hilly slopes. For this grassland activity, no conservation measures and inputs are used. The grassland can be grazed during summer, autumn or winter. The grass production is based on survey data and literature.

Sown grassland

Sown grassland has a very limited area at present in Ansai. As mentioned before, the severe soil erosion mainly results from slope cultivation. In the future, the sloping farmland could be changed into a more sustainable use such as grassland. For this purpose, two sown grassland activities are defined, sown grassland with ample nutrient inputs, and sown grassland without external N use. For both activities, it is assumed that perennial grasses are sown and re-sown every six years, and P and K are sufficiently applied. These two grass production activities are assumed to take place on sloping land units only.

2.4.5 Firewood production activities

Currently in Ansai, the energy (firewood) requirement of the rural population is mainly covered by crop residues and natural shrubs. Tree and shrub plantations are strongly promoted by the government to resolve the problems of rural energy shortage and soil loss associated with firewood collection (destruction of vegetation). In this study, two firewood production activities are defined: natural shrub-land and (newly) planted shrub-land. For the first activity, the firewood is produced from the natural shrub-land, while for the second activity the firewood is assumed to be produced from newly planted shrub-land. For both activities, it is assumed that the shrubs are harvested once in four years, and no fertilizers are applied. Yields and soil loss will be determined using survey and experimental data in the Loess Plateau. Detailed descriptions are given in Section 4.5 in Chapter 4.

During the last decades, forest (tree) plantation has been financially promoted by the government for soil conservation. The planted and natural forests are strictly controlled by the local government, and cutting is normally not allowed, hence, it is assumed that the forest-land is conserved in this study.

2.4.6 Livestock production activities

Livestock activities are based on the main animal species, i.e., goats, sheep, cattle, donkeys, and pigs. Mule and horse are not selected because they are very limited in number and they are of minor importance. Poultry production is indirectly related to land use, and therefore excluded. Dairy and beef production are not considered; they may have limited development potential, since the steep terrain is not suitable for cow and beef cattle grazing; the rural people do not have dairy products; and the market is limited because Ansai is far away from an urban area and transport conditions are poor.

Goats and sheep are the main domestic animals that are suitable for the hilly conditions of Ansai. Cattle are the main source of farm traction and donkeys are mainly used for transportation. Pigs are an important producer of meat and manure. For sheep, two activities are defined, i.e., fine-wool sheep with relative low productivity and small-tail sheep with relative high productivity. For cattle or donkeys, two activities are distinguished. One aims at producing draught animals that can be sold or kept in the region for farm operations, and another activity aims at raising (adult) draught animals (draught oxen or transport donkeys) for farm traction or transport power. For the four activities of cattle, draught oxen, donkeys and transportation donkeys, the meat can be used for consumption when the animals become obsolete and are slaughtered. The main animal activities identified and the main products are shown in Table 2.9. Detailed descriptions are given in section 4.6 of Chapter 4.

Table 2.9 Basic characteristics of the eight animal production activities

Animal activity	Main production aims	By-products
Cashmere goat	Mutton and cashmere	Wool and manure
Fine-wool sheep	Mutton and wool	Manure
Small-tail sheep	Lamb meat	Wool and manure
Cattle	Draught animals (oxen)	Meat and manure
Donkey	Transport donkeys	Meat and manure
Draught oxen	Animal traction for farm operations and transportation	Meat and manure
Transport donkey	Animal traction for transportation	Meat and manure
Pigs	Pork	Manure

Chapter 3 Quantitative Land Evaluation Using the EPIC Model

3.1 Introduction

Quantification of the agricultural production activities for the MGLP model is based on a quantitative land evaluation using crop simulation models in combination with expert knowledge. The objective of this chapter is to present the quantitative assessment of different land use systems, based on the EPIC (Erosion and Production Impact Calculator) simulation model (Mitchell *et al.* 1997). This assessment allows us to obtain quantitative information on 1) crop production; 2) soil and nitrogen losses; and 3) efficiency of measures for water and soil conservation, and crop rotations, in raising crop yield and controlling losses of soil and nutrients. The results of the quantitative land evaluation will be used to derive the input-output coefficients of the crop activities (Chapter 4). Although not all simulation results can be validated with experimental data, an advantage of the presented procedure is that one model is used as a basis for the quantification of crop yields, losses of nitrogen and soil for all crop and management variants.

3.2 Methodology

The methodology for quantitative land evaluation (Fig. 3.1) comprises definition of land use types; characterization of land use systems; and quantification of crop yields, environmental impacts, and associated inputs (e.g., nutrients, water) for each land use system. A land use type is defined as a crop rotation with a specified measure for water and soil conservation, growing under a well-defined production situation. Three production situations are distinguished in this chapter, based on availability of water and nitrogen (Table 3.1), assuming that growth-reducing factors including pest, weeds and diseases are fully controlled, and climatic hazards (e.g., hail, rainstorms) have no effects on the crop growth.

The defined land use types can be combined with the suitable land units, as determined in Chapter 2. A feasible combination is called a land use system. Each of the defined land use systems is quantitatively characterized by a data set comprising weather, soil, crop parameters, factor values for runoff and water erosion, and crop management data. These data are obtained or integrated from different sources, including meteorological stations, reports of land resource surveys, and literature. Using the EPIC model with the data set as input, the yields, soil loss and associated inputs of water and nutrients can be calculated for each land use system.

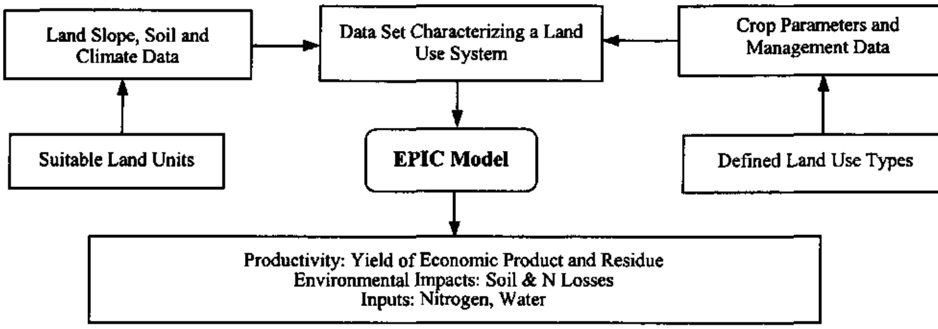


Figure 3.1 Diagram of quantitative land evaluation based on the EPIC model

Table 3.1 Definition of the three production situations

Production situation	Definition
Potential	Irrigation and nutrients are optimally supplied, and protection agents are sufficiently used to eliminate any effects of weeds, pests and diseases on crop growth. This results in a potential yield.
Water-limited	Crop production fully determined by weather and land conditions (slope and soils) without irrigation. Nutrients and crop protection agents are optimally supplied. This results in a water-limited yield.
N-limited	Rainfed and limited N input (for crop rotations without alfalfa); Rainfed and N supplied by legumes fixation (for mixed crop rotations with alfalfa). Crop growth is determined by the availability of nitrogen and water, assuming that P and K, and crop protection agents, are optimally supplied. This results in a N-limited yield.

3.2.1 The EPIC model[1]

The EPIC is a comprehensive simulation model, consisting of ten integrated modules including plant growth, hydrology, erosion, nutrient cycling, soil temperature, weather, pesticide fate, tillage, crop and soil management, and economics. It is capable of simulating major biophysical processes, and can quantify crop yield, soil and nutrient losses, and water and nutrient requirements under different crop and soil management conditions. The model is validated with experimental data from the USA and many other countries in the world. The crop growth module of EPIC has also been used in the Loess Plateau, northern China. Li (1997) reported that the ALMANAC crop model, which is based on the EPIC crop module, reasonably simulated yields of corn and wheat in several experiments under irrigated conditions in the Loess Plateau.

In the EPIC model, a general plant module is used to simulate a single crop or crops grown in rotations, by giving crop specific values for the model parameters. Potential daily

[1] This subsection is largely based on Mitchell *et al.* (1997).

increase of biomass is simulated with Monteith's approach (Monteith 1977), and interception of solar radiation is estimated with a Beer's law equation (Monsi & Saeki 1953). Phenological development of the crop is calculated as a function of the heat unit index (HUI), the fraction of accumulated heat units of the potential heat units (PHU) required for maturation. The leaf area growth and senescence, nutrient uptake, and partitioning of dry matter among roots, shoots, and economic yield are all related to the HUI.

The model computes evaporation from soils and plants separately by an approach similar to that of Ritchie (1972). Water use from a soil layer is estimated as a function of potential evapotranspiration, soil depth, and water content. The EPIC offers four choices for estimating potential evapotranspiration: Hargreaves & Samani (1985), Penman (1948), Priestley & Taylor (1972), or Penman-Monteith (Monteith 1965). In this study, the Penman-Monteith equation is used. Daily crop demand of N is estimated as the difference between the crop N content and the ideal N content for that day. The optimal crop N concentration declines with increasing growth stage (Jones 1983), and it is computed as a function of HUI. Requirements of irrigation water and nitrogen are based on a supply and demand approach.

Crop growth is constrained by growth-limiting factors of water, nutrient, soil surface temperature, and aeration. These growth-limiting factors are scaled from 0 to 1, and estimated in daily steps by the model. The water-limiting factor is calculated as the ratio of water supplied by soil to the water required by the crop for potential growth. The N-limiting factor is based on the ratio of simulated plant N content to the optimal value, and it varies non-linearly from 1.0 at optimal N content to 0.0 when N content is half the optimal level (Jones 1983). Given a value (e.g., 0.85) for the limiting factors, the EPIC model can 'apply' irrigation or nitrogen to remove the limitations when the given value is approached.

The hydrology module simulates runoff, percolation, lateral subsurface flow, snowmelt, and water flow through the soil layers. In this study, the surface runoff is simulated with the SCS-CN method (SCS 1972), and the peak runoff is calculated with the modified Rational equation (see Section A1.3 of Appendix 1). EPIC offers a module, called furrow-diking to estimate soil surface water storage. Runoff occurs only when the simulated amount exceeds the surface water storage estimated by the furrow-diking module. Flow from a soil layer occurs when soil water content exceeds field capacity (Cavero *et al.* 1998).

Erosion caused by rainfall and runoff, and by irrigation, can be computed using any one of six modified USLE (Universal Soil Loss Equation) equations. The default equation for EPIC, the so-called MUST (see Section A1.3 of Appendix 1) is used in this study. This equation uses only the runoff variable to simulate erosion and sediment yield. Runoff variables increased the prediction accuracy, eliminated the need for a delivery ratio (used in the USLE to estimate sediment yield), and enable the equation to give single storm estimates of sediment yields. The crop cover and management factor for the MUST equation is calculated in daily steps based on plant biomass simulated by the crop module. The energy component is computed as a function of surface and peak runoff.

The N cycling module simulates the processes of fertilization, transport by runoff and sediment, nutrient movement by soil evaporation, denitrification, ammonia nitrification and volatilization, mineralization, immobilization, bio-fixation, contribution of rainfall and irrigation, and NO_3-N leaching. The mineralization, nitrification and gaseous losses are all affected by soil temperature, which is simulated by the temperature module in daily steps for each soil layer according to weather, soil water content, land cover (snow, plant and residues), and soil bulk density. When soil temperature is below 0 °C, the soil layer is frozen, which influences vertical water flow.

The bio-fixation for legumes is estimated daily as a fraction of daily plant N uptake. The fraction is estimated as a function of HUI, water content, and soil NO_3-N. The N fixation occurs only when the HUI is between 0.15 and 0.75. The soil water content factor reduces N fixation when the water content at the top 0.3 m is less than 85% of field capacity (Albrecht *et al.* 1984, Bouniols *et al.* 1991). N fixation is reduced when the NO_3-N content of the root zone is greater than 100 kg ha^{-1} m^{-1} and zero at N content greater than 300 kg ha^{-1} m^{-1}.

Data required for the EPIC simulation includes weather, tillage, and crop management data. The daily weather data of rainfall, air temperatures, solar radiation, wind and relative humidity can be inputted or generated by the weather module using average monthly values as inputs. The effect of tillage operations on soil hydrology, nutrient cycling and erosion is estimated with the tillage module. The module for crop and soil management provides options for dates of planting and harvest, irrigation, artificial drainage, fertilization, tillage, diking and runoff control for irrigation. The pesticide fate module simulates pesticide movement with water and sediment as well as degradation on foliage and in soil. The economic module is a simple accounting package for calculating the costs of inputs and returns. Both modules are not used in this study.

Appendix 1 gives a more detailed description of the modules of plant growth, nutrient cycling and soil erosion. Complete details of EPIC have been described by Mitchell *et al.* (1997), and Sharpley & Williams (1991).

3.2.2 Defined land use systems

In Chapter 2, 17 crop rotations were defined (Table 2.6). For each crop rotation, 48 land use systems are identified, based on three production situations (Table 3.1), the four agrotechnical measures for water and soil conservation (Table 2.8, Chapter 2), and the six land units (Table 2.4, Chapter 2). The feasible combinations of these three definition criteria are shown in Table 3.2. For the flood plain (FLP), 12 land use systems (3 production situations × 4 conservation measures) are defined. For other land units, irrigation is not feasible, and thus the potential production situation cannot be realized. For terraced land, including where terraces will be built in the future, the furrow-ridging defined for conserving water and soil is not applied, as we assume that a front ridge (see Fig. 2.3, Chapter 2) surrounding the terrace should be built for conserving rainwater. Therefore, 4 land use systems (2 production situations × 2 conservation measures) for the terraced land, and 8 land use systems for the sloping land units (2 production situations × 4 conservation measures) are distinguished for each of the four sloping land units. This leads to 48 land use systems (12 + 4 + [8 × 4 sloping land units]) defined for each crop rotation; and thus total 816 land use systems (48 × 17 crop rotations) are differentiated. Each of these is simulated with the EPIC model.

Table 3.2 Feasible combinations of the three definition criteria for each crop rotation

Land units	Feasible combinations	Comments
Flood plain	3 production situations × 4 measures for soil conservation = 12	All combinations are feasible; for contoured tillage, irrigation is with sprinkler; for furrow-ridging, surface irrigation is assumed
Terraced land	2 production situations × 2 measures for soil conservation (crop residue management) = 4	Potential production situation is not feasible; and furrow-ridging is not applied
Sloping land units	2 production situations × 4 measures for soil conservation × 4 land units = 32	Potential production situation is not feasible
Total	(12 + 4 + 32) × 17 crop rotations = 816 land use systems	

3.2.3 Basic data

Crop parameters

Crop-specific values for the model parameters are given for simulating a single crop or crops grown in rotations. The values of the major parameters are presented in Table A1.1 in Appendix 1. Values of some crop parameters for the EPIC model have been modified with literature data, such as harvest index, concentration of N in biomass and storage organ, and partitioning factor of crop biomass to root. The potential heat units from emergence to maturity (PHU), and the temperature sums required for germination are based on literature data.

Factor values for runoff and erosion

For the model simulation, factor values for surface runoff and soil erosion should be provided. These include SCS curve number (CN), the crop cover and management factor (*CE*), the erosion control practice factor (*PE*), and the slope length and steepness factor (*LS*). The CN is derived from the SCS hydrology handbook (SCS 1972), and the values of *CE* and *PE* are derived from Wischmeier & Smith (1978). For the *LS*, average slope steepness is used for each land unit, and the slope length is set to 60, 35, 15 and 10 m for the sloping land units of GSL, MSL, STL and VSL, respectively, assuming that hillside ditches are built to cut the slope length shorter and to drain surface runoff. The parameter values of these factors are presented in Table A1.2 in Appendix 1.

Furrow-ridging is a practice of building temporary furrow-ridges on the contour to store excess rainfall and to prevent soil loss in the Loess Plateau. The EPIC has a furrow-diking module for calculating water storage volume of furrows, by assuming that the furrow and dike are triangular and the dike side slopes are 2:1 (Mitchell *et al.* 1997). The estimated volume of water storage with this method is too low for sloping land, especially for steeply sloping land, since it is assumed that the furrows are up and down the slope. In this study, it is assumed that the furrow-ridges are built along the contour line. Therefore, a calculation method is developed, and the estimated water storage of contoured furrow-ridges for different land units and crops are presented in Appendix 2.

Weather and soil data

The weather data are from Ansai meteorological station (36°53'N, 109°19'E and 1068 m above sea level), which is located around the middle of Ansai and situated in the basin of the Yanhe River. For all simulations, the latitude and altitude at the Ansai meteorological station is used, and one ha is assumed for the watershed area, as the EPIC model requires a watershed area to calculate runoff and sediment yield. The input climatic data include daily rainfall; maximum monthly half-hour rainfall; and monthly average data of minimum and maximum air temperature, relative humidity, and speed and direction distribution of wind at height of 10 m in the period of 1971-1993. The values of other climatic parameters (Table 3.3) are generated with the EPIC weather module, using daily rainfall and daily (min. and max.) temperatures from 1980 to 1993. For all land units, the same weather data are used[2].

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[2] Relief, elevation and slope aspects may influence the climate. Temperature normally decreases with an increase of elevation, but spatial variation of temperature is complicated due to relief in the Loess Plateau. Temperature variation due to elevation is not obvious in some conditions. According to observation data of 2 years (Su & Zheng 1992), annual temperature is 9.9 °C at valley bottom, 10.0 °C on hill slope, and 9.9 °C on hilltop at an altitude of 965, 1051 and 1155 m, respectively. The temperature in the valley is the same as that on the hilltop, although the elevation of the valley is 190 m lower. However, a rather apparent difference in temperature can also be found (*ibid.*): annual temperature on the flat highland (1220 m) is 9.1 °C, 0.8 °C lower than that on the hilltop (1155 m), although the altitude is only 65 m higher. It can be concluded that temperature variation may be more affected by landform than by elevation in the hilly Loess Plateau.

Another important factor that leads to variation in climate is slope direction. In Ansai and the Loess Plateau, many research works are focused on influences of slope aspects on soil moisture conditions, as soil moisture can reflect integrally climatic difference caused by slope aspects. Observed data indicated that southern slopes have much poorer soil moisture condition than northern slopes do, due to the higher potential evapotranspiration associated with higher temperatures and higher solar radiation received. Observations of two years by Liu *et al.* (1990) in Ansai showed that total water storage in the 140 cm soil depth was 25.5% more on the northern slope than on the southern slope (both slopes are 24° and fully fallowing), although 2.5% more rainfall was received on southward slope than northward slope. The soil moisture difference between the two slopes decreases with a decrease of slope steepness.

With an increase of altitude, temperature normally decreases, but wind speed increases. The two factors have opposite affects on soil moisture condition. Reported data in literature (Liu *et al.* 1990, Yang *et al.* 1992, Hou and Wei 1992) show that the water content in soils on hilltops is lower than that in soils on hill slopes.

Based on the above information, possible effects of climatic variation by altitude and slope directions have been analysed with the EPIC model. The results show that yields on southern slopes are likely to be lower than yields simulated for the flood plain, and that yields on northern slopes may be higher than those simulated for the flood plain conditions, mainly due to less and more favourable moisture conditions respectively. However, effects of the various climatic factors are not unambiguous: negative effects on yield of higher temperatures and evapotranspiration on southern slopes are compensated to some extent by positive effects of higher rainfall and radiation levels. Simulation results further suggest that lower temperatures and higher wind speeds due to an elevation increase have opposite effects on yield, resulting in apparently negligible effects on crop yields.

The above analysis is based on rather arbitrary assumptions regarding climatic differences due to slope direction and elevation levels. Climatic differences in temperature, wind speed, radiation, rainfall and relative humidity cannot be estimated simply by using interpolation or extrapolation techniques, without having detailed information on elevation levels and slope direction. Detailed maps with such information are required to assess microclimatic differences within Ansai, and unfortunately such maps are not available. In addition, no experimental data are at hand to validate simulated consequences of assumed climatic differences on crop productivity. (*to be continued next page*)

Two soil types are distinguished according to soil forming materials: alluvial and loess soils. The major characteristics including soil depth, texture, soil pH, and bulk density, as well as contents of organic C and calcium carbonate are shown in Table 3.4 (fluvial soils) and Table 3.5 (loess soils). Soil data in Table 3.4 are used for the land unit of flood plain, and the same soil data in Table 3.5 are used for other land units. These soil data are based on Xu (1988), CADAC (1988), OSSS (1992), and OCSS (1995).

Table 3.3 Weather parameter values generated by the EPIC weather module (SDMX and SDMN: standard deviation of daily maximum temperature; SDRF: monthly standard deviation of daily rainfall in mm; SKRF: skew coefficient of daily rainfall; PW/D: the probability of a wet day after a dry day; PW/W: probability of a wet day after a wet day; and RAD: average monthly solar radiation in MJ cm^{-2} d^{-1}).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SDMX	4.1	4.7	5.2	4.9	4.8	3.5	3.2	3.3	4.0	4.7	5.4	4.6
SDMN	3.9	4.6	4.3	3.6	3.4	2.9	2.5	2.9	3.5	4.3	4.2	4.0
SDRF	1.7	1.9	3.4	5.4	8.4	9.4	15.0	12.4	11.6	6.0	4.8	2.1
SKRF	1.77	1.74	2.56	2.00	3.22	2.13	2.65	2.16	3.25	2.04	2.22	2.21
PW/D	0.049	0.077	0.123	0.146	0.178	0.205	0.317	0.289	0.223	0.147	0.072	0.043
PW/W	0.209	0.338	0.342	0.310	0.350	0.417	0.446	0.550	0.528	0.389	0.299	0.362
RAD	10.0	11.8	15.3	21.6	25.0	26.4	24.3	22.1	19.9	16.6	12.3	9.7

Table 3.4 General characteristics of fluvial soils

Layer	0-20 cm	21-70 cm	71-120 cm	121-200 cm
Sand (>0.05mm)	26.6	24.4	31.7	27.2
Silt (0.002-0.05mm)	63.3	64.7	60.1	62.9
Bulk density (t m^{-3})	1.22	1.30	1.30	1.33
pH	8.3	8.4	8.3	8.4
Organic C (%)	0.45	0.24	0.16	0.12
$CaCO_3$ (%)	9.6	9.9	9.5	9.1

Table 3.5 General characteristics of loess soils

Layer	0-20 cm	21-70 cm	71-120 cm	121-200 cm
Sand (>0.05mm)	21.0	19.0	19.0	18.4
Silt (0.002-0.05mm)	67.5	68.0	67.5	67.8
Bulk density (t m^{-3})	1.28	1.30	1.33	1.33
pH	8.3	8.4	8.5	8.4
Organic C (%)	0.30	0.15	0.13	0.10
$CaCO_3$ (%)	11.8	11.9	12.6	13.2

Based on the above facts, I conclude a lack of spatially explicit information, and also a lack of firm grounds to assume unambiguous yield effects of climatic variation within Ansai on crop yields. Therefore the present study has insufficient basis to quantify consequences of spatial variation of climate. Hence, spatial variation of climate is not considered.

3.2.4 Sowing dates and management operations

The EPIC model provides flexible options for determining the dates of sowing and maturity; harvest methods; application of irrigation water and fertilizers; and use or removal of furrow-diking. The determination of the starting and ending dates of crop growth and other management data are described in this subsection.

Sowing date

Calendar date and the mean accumulated temperature sum (to that date), expressed as a fraction of annual temperature sum of ≥ 0 °C since January 1, are used to determine the sowing date. Sowing on a particular date can occur only if the given fraction of the annual temperature sum has been reached before that date. Otherwise, the sowing occurs on the first day that the accumulated temperature sum has reached the given fraction of the mean annual total.

Based on CADYP (1987), CADAC (1988), CAAC (1993), HPRI-CAAS (1994) and SAAS (1987), the sowing dates are set to: March 25 for summer potato and flax, and April 18 for corn, millet, autumn potato and soybean. The required heat unit fractions corresponding to these dates are 0.02 and 0.10 of the annual heat units, respectively. The sowing date of winter wheat is set to September 12, as 550-650 °Cd (SAC 1994) should be required for the germination and initial growth before winter dormancy.

Crop emergence is related to the temperature sum required for germination and available water in the topsoil. Under water-limited and N-limited production situations, available water depth in a topsoil layer of 20 cm is arbitrarily set to 15 mm as the threshold for crop germination. Thus, crop emergence can occur only when both conditions are approached. No soil water limit is given in the potential production situation.

Harvest options

In the EPIC model, the grain or tuber can be removed ('harvested') first, followed by the crop residues. All harvests occur when the accumulated temperature units from the emergence approach the PHU for crop maturity. For crop residues, two harvest options are considered, i.e., 80% (for crop residue removed) and 50% (for residue mulching) of the straw is harvested for food crops except for soybean (60% and 50%) and potato (residue always left on the field). Alfalfa should be harvested at around the flowering stage to obtain a good quality of forage and high yield. Three harvests per year are considered for alfalfa: the first harvest after winter is set to 0.7 of the PHU, in consideration of the dry condition during spring; and the following two harvests are set to 0.55, around the flowering stage. Crop growth stops when the accumulated temperature equals the PHU (the value is presented in Table A1.1 of Appendix 1).

Fertilization, irrigation and diking

For potential and water-limited production levels, nitrogen is optimally supplied, which is calculated by the model. For N-limited production, a limited amount of nitrogen for non-alfalfa rotations is given before the crop sowing. No nitrogen is applied for the mixed crop rotations with alfalfa. For all production levels, sufficient P (and K) input is assumed.

The EPIC model is sensitive to types and depth of fertilization in predicting N losses. In this study, we assumed that the applied chemical fertilizer is 50% as ammonia N and 50% as nitrate N. All chemical fertilizers are placed at a soil depth of 8 cm, according to the suggestion by Xi (1994).

For the potential production, irrigation water is optimally supplied during the growing season, as determined by the model. It is assumed that 5% and 10% of irrigated water is lost by runoff for sprinkler irrigation and for furrow irrigation, respectively. No irrigation is supplied during fallow and winter periods.

Generation of the input files and simulation running

Each of the land use systems identified has a unique data file for the model simulation. Two simple programs are developed using DOS batch language: one for generation of the input files, and another one for the simulation of all defined land use systems.

3.3 Analyses of the simulation results

Long-term average results simulated by the EPIC model are presented in this section. The crop yields under potential, water-limited and N-limited conditions, as well as losses of soil and N are discussed. The yield for each crop presented in this section is the average of yields for that crop grown in different rotations.

3.3.1 Simulated yields (in Dry Matter)

Potential yield

Potential yield is simulated by EPIC under the given conditions: (1) during the growing period, irrigation water is applied when the water-limiting factor[3] equals 0.85; (2) no limitation of P and K; (3) for non-leguminous crops, N is "supplied" by the model when the N-limiting factor equals 0.85. For soybean, 50 kg N is given on the sowing date if crop residues are removed, and 25 kg N is given if crop residues are left on the field. N is not applied to alfalfa.

Under the given conditions, water and nutrient limitations are not completely removed. These limitations result in a small variation of the simulated yields for a crop grown in different rotations due to the slight difference in soil water and nutrients caused by the preceding crops. Simulated yield of corn ranges from 13.8 to 14.1 t ha^{-1}, millet from 10.3 to 10.5 t ha^{-1}, summer potato 10.0 to 10.4 t ha^{-1}, and seed flax from 3.0 to 3.1 t ha^{-1}. A slightly higher variation is found for autumn potato, ranging from 12.3 to 13.2 t ha^{-1}. Wheat yield among different rotations is 5.5-5.8 t ha^{-1}. This yield difference could be mainly due to water limitation, as we assume that irrigation during winter is not allowed. The crop residue management op-

[3] The water- and N-limiting factors used here are the default values for the EPIC simulation. The results of calculation with my data indicate that the simulated yield is slightly (less than 3%) lower than the yield under 'no limiting conditions (the limiting factors = 1)'. With this value (0.85), the EPIC model can give a reasonable estimation of requirements for irrigation water and nitrogen.

tions have almost no influence on the yields for all non-leguminous crops. Yield of soybean and alfalfa is slightly affected by crop residue management options. The average yield of soybean and alfalfa is 4.2 and 21.1 t ha^{-1}, respectively, under residue mulching conditions, and 4.0 and 21.0 t ha^{-1}, respectively, under conditions in which crop residues are mostly removed. Table 3.6 gives the average yield of the selected crops simulated by the EPIC model.

The simulated yields correspond reasonably well with empirical data. The reported maximum yields (fresh weight) in the similar areas of the Loess Plateau (Hou & Cao 1990) are 14.8-16.2 t ha^{-1} for corn, 9.0-9.3 t ha^{-1} for millet, and 7.9 t ha^{-1} for winter wheat. The Ansai Agricultural Bureau reported that a maximum yield of 15.8, 6.5 and 8.2 t ha^{-1} for corn, winter wheat, and millet was achieved respectively; an average yield of 10.4 t ha^{-1} for corn was obtained in a high yielding demonstration area of 700 ha in Ansai in 1994. The highest reported yield for soybean achieved by farmers is 2.6 t ha^{-1} (Zhang *et al.* 1991).

Table 3.6 Average potential yield (t ha^{-1}) of crops simulated by the EPIC model

	Corn	Millet	Wheat	Autumn potato	Summer potato	Seed flax	Soybean	Alfalfa
Dry matter	14.0	10.5	5.7	12.7	10.2	3.1	4.1	21.1
Fresh weight	16.5	12.2	6.5	57.7	46.4	3.5	4.7	-

Water-limited yield

Water-limited yield is simulated under the same assumptions as those for the potential yield, but no irrigation is used. The simulated yields vary obviously among different crop rotations, different crop management and land units.

Table 3.7 presents mean yield for each of the selected crops grown in different rotations under different production conditions and land units. From the simulation results (Table 3.7), it is clear that higher yield can be obtained using furrow-ridging or with crop residue mulching, because of less water loss by runoff. Compared to residue mulching, furrow- ridging is more efficient because of the surface water storage of furrows. Under climatic conditions in Ansai, runoff of rainwater can be mostly prevented by building a 30 cm high front ridge surrounding the terrace. This results in the highest yield achieved on the terraced land. Crop yields decrease from flat land to very steep land units due to increased water loss by runoff. Soil erosion and nutrient loss do not influence the simulated yields because of the deep soil depth and amply supplied nutrients.

The long-term average of the EPIC-simulated yields varies apparently for a crop growing in different rotations, due to varying soil moisture conditions caused by the different proceeding crops. The yield is normally lower for the crops grown after corn or alfalfa due to the high depletion of soil water by both crops. Higher yield for a crop can be achieved when it is grown after winter wheat, flax or summer potato, as these crops are normally harvested in early July; therefore, most of the rainfall in the rainy season is not used by crops.

Yields of annual crops can probably be improved under rainfed conditions by sowing crops later. The sowing dates used for crop simulations are in mid-April for corn, millet, soybean, and autumn potatoes, based on the current practices and recommendations of agronomists (from literature). Simulation results indicate that sowing dates may be delayed to late May or early June, to reduce the period of water limitation before the rainy season. This should be validated by experiments, as this later sowing can lead to crops that maturate very late (up to late November in some years), and thus the crop may be damaged by frosts in October and November.

Current crop production under rainfed conditions is low in Ansai and the hilly Loess Plateau, normally ranging from about 20 to 60% of the water-limited yields simulated by the EPIC model. Yield (fresh weight) achieved in relatively well-managed farms is 4.5-6.0 t ha^{-1} for corn, 2.3-3.8 t ha^{-1} for millet, 1.2-1.5 t ha^{-1} for soybean, 12-20 t ha^{-1} for potato, and 1.2-2.2 t ha^{-1} for winter wheat.

Table 3.7 Average water-limited yields (kg^{-1} DM) of the selected crops grown in different rotations. N: contoured cultivation, F: cultivation with furrow-ridging, R: crop residues removed, and M: crop residues left on field. NR, NM, FR and FM are combinations of these.

	Corn	Millet	Soy	Wheat	Autumn potato	Summer potato	Seed flax	Alfalfa
Flood plain (FLP)								
NR	8.2	5.9	2.5	3.4	7.0	4.0	1.5	15.2
NM	8.5	6.1	2.6	3.6	7.2	4.2	1.6	15.3
FR	8.8	6.2	2.7	4.0	7.3	4.3	1.7	15.4
FM	8.9	6.3	2.7	4.1	7.4	4.4	1.7	15.4
Terraced land (TRL)								
NR	9.3	6.6	2.8	4.9	6.9	3.3	1.8	15.7
NM	9.3	6.6	2.8	4.9	7.0	3.3	1.8	15.7
Gently sloping land (GSL)								
NR	7.7	5.5	2.5	2.9	6.7	3.1	1.2	14.6
NM	7.9	5.7	2.6	3.1	6.9	3.3	1.3	14.6
FR	8.1	5.9	2.7	3.4	7.1	3.3	1.4	14.7
FM	8.2	5.9	2.7	3.5	7.1	3.4	1.4	14.8
Moderately sloping land (MSL)								
NR	7.3	5.3	2.2	2.6	6.2	3.2	1.2	14.1
NM	7.6	5.5	2.4	2.8	6.4	3.5	1.2	14.2
FR	7.9	5.6	2.4	3.0	6.6	3.7	1.3	14.2
FM	8.0	5.7	2.5	3.2	6.7	3.8	1.3	14.3
Steeply sloping land (STL)								
NR	7.0	5.0	2.2	2.3	5.9	3.0	1.1	13.6
NM	7.3	5.2	2.2	2.6	6.1	3.1	1.1	13.6
FR	7.4	5.3	2.3	2.7	6.2	3.3	1.2	13.7
FM	7.6	5.4	2.4	2.8	6.2	3.4	1.2	13.7
Very steeply sloping land (VST)								
NR	6.6	4.7	2.0	2.1	5.6	2.7	1.0	12.9
NM	6.8	4.9	2.1	2.3	5.7	3.0	1.0	12.9
FR	6.9	4.9	2.2	2.4	5.8	3.0	1.1	13.0
FM	7.0	5.0	2.2	2.5	5.9	3.0	1.1	12.9

Table 3.8 Average yield increase (%) by crop residue mulching and furrow-ridging (NM, FR and FM) for the different crops in comparison with the contoured tillage (NR).

	Corn	Millet	Soybean	Wheat	Autumn potato	Summer potato	Seed flax	Alfalfa
Flood plain (FLP)								
NM	3.3	3.0	4.0	7.7	2.6	4.5	4.6	0.3
FR	6.6	5.4	7.5	18.8	4.7	8.3	9.2	0.9
FM	7.6	6.3	8.3	23.2	5.6	10.3	10.5	1.4
Gently sloping land (GSL)								
NM	3.4	3.6	3.6	9.5	3.1	6.6	8.3	0.4
FR	6.1	6.0	8.1	19.3	5.7	8.9	15.7	1.0
FM	6.8	6.7	8.5	22.8	6.7	10.5	18.2	1.5
Moderately sloping land (MSL)								
NM	4.1	4.4	5.8	9.3	3.7	8.4	6.1	0.4
FR	7.9	6.8	8.5	17.5	6.5	15.0	13.9	0.8
FM	9.0	8.4	10.7	23.0	8.3	17.4	13.9	1.3
Steeply sloping land (STL)								
NM	4.2	4.4	2.8	9.4	2.4	2.3	2.8	0.4
FR	6.5	6.6	5.5	16.7	4.6	9.9	11.1	0.7
FM	8.9	9.0	9.2	20.5	5.6	12.9	11.1	1.1
Very steeply sloping land (VST)								
NM	3.7	3.6	6.5	8.2	3.1	11.0	8.3	-0.2
FR	4.6	4.4	8.0	14.9	3.8	11.0	13.5	0.2
FM	6.6	6.8	10.5	19.7	5.6	11.0	11.5	-0.1

Reported experimental yields vary due to the influence of specific weather conditions of years when the experiments were conducted. Experimental yields of winter wheat under rain-fed conditions in Weibei[4] are 3.5-6.5 t ha^{-1} (Li & Lu 1991, Han *et al.* 1992, Zhang 1991, Deng 1989). Experimental[5] yield of corn (with plastic film mulching), reported by Jiang *et al.* (1992) was 10.3 t ha^{-1} in 1990 and 14.0 t ha^{-1} in 1991. Yang (1996) and Gao (1997) reported that the maximum yield of rainfed millet was 5.1-7.8 t ha^{-1} achieved by farmers in areas very similar to Ansai. An experimental yield of alfalfa (dry matter) of 13.5 t ha^{-1} averaged over 5 years was reported by Wu (1997) in an area (annual temperature is 6.2 °C and rainfall 455 mm) of western Loess Plateau. Potato yield reported by Luo & Liu (1992) varied greatly from year to year and was 11.3-27.3 t ha^{-1} under rainfed conditions in three-year experiments in the area north of Ansai.

The effect on crop yields of the furrow-ridging and crop residue mulching varies with different crops and land conditions (Table 3.8). The yield of winter wheat, summer potato and seed flax can be markedly improved by those measures, especially on sloping land units. This is because of the improvement of soil moisture conditions in the dry season (winter and

[4] Weibei is the main wheat producing area in the Loess Plateau of northern Shaanxi province. It is south of Ansai, and has better weather conditions than Ansai. The mean annual temperature in the region of Weibei is above 10 °C and rainfall is more than 550 mm.

[5] The experimental area is located in Qianxian county, south of Ansai, and has a mean annual temperature of 9 °C and a mean annual rainfall of 586 mm.

spring). For the autumn crops of corn, millet, soybean and autumn potato, the yield increase is normally less than 10%, because the growing period of those crops is well matched to the rainy season. For alfalfa, the yield increase is very limited, and for the land unit of VST, a small decrease is found. This is probably because the higher yield increase in the annual crops leads to an increase in soil water use, and thus soil water available to the perennial alfalfa is not or only slightly improved compared to the contoured tillage.

N-limited yield

Two input levels of N are considered: with limited fertilizer N input and without fertilizer N input. The first one is applied to non-alfalfa crop rotations, and the second one is applied to crops grown in the mixed crop rotations with alfalfa. For both N-limited growing conditions, no limitations for P and K, and sufficient control of insects, diseases and weeds are assumed.

For the first condition, 80-100 N ha^{-1} is applied for crops of corn, millet and winter wheat, 60-80 N ha^{-1} for potatoes and flax, and no N is applied for soybean. These given amounts of fertilizer N are based on the recommendation for fertilizer use by agronomists to achieve a moderately high crop yield in the Loess Plateau. The simulated yields are mostly 5.0-7.5 t ha^{-1} for corn, 4.0-5.0 t ha^{-1} for millet, 1.6-2.5 t ha^{-1} for winter wheat, 4.0-6.0 t ha^{-1} for autumn potato, 1.6-2.3 t ha^{-1} for soybean, and 1.0-1.4 t ha^{-1} for flax. In addition to the difference in amount of fertilizer N applied, a number of other factors also cause this large variation in crop yield, including effect of residue N from the preceding crops, crop residues and land conditions. For instance, in a 3-year rotation of summer potato-winter wheat-corn, the simulated yield is 2.3, 3.7 and 7.4 t ha^{-1}, while in another 3-year rotation of millet-autumn potato-corn the yield is 4.6, 4.6 and 6.4 t ha^{-1}, respectively. Both crop rotations are simulated under conditions of flood plain, with a mean annual N input of 81 kg ha^{-1} and the crop residues removed. In the first rotation type, a much higher yield for corn is attained because of the lower N use by other two crops. In general, these simulated yields are within the range of the crop yields currently achieved in the well-managed farms in Ansai and the hilly Loess Plateau.

Under conditions without nitrogen input, crop growth fully depends on nitrogen fixed by alfalfa and water availability. Since the crop growth is more restricted by a shortage of N than by a shortage of water, crop yields (Table 3.9) are less influenced by land conditions and water conservation measures that affect water availability, than the water-limited yields (Table 3.7). The mean yield for each non-legume crop simulated by the EPIC model in different rotations is similar for the various land units, tillage and residue management levels. However, the crop yield varies markedly with the frequency of alfalfa and sequence of the crop in the rotations. The simulated yield of corn, millet, winter wheat, autumn potato and seed flax is within the range of 4.1-5.3, 3.6-4.5, 1.1-1.9, 2.7-3.7 and 0.7-1.3 t ha^{-1}, respectively, mainly caused by sequence effect within rotations. Yield of alfalfa is slightly higher than the water-limited yield, because the lower yield of non-legume crops reduces the water use, and thus more water is available for alfalfa.

Table 3.9 Average EPIC-simulated yields (t ha^{-1} DM) under conditions without N input for the crops grown in the mixed rotations with alfalfa. FLP-VST: suitable land units, C: contoured tillage and F: furrow-ridging; and potato: autumn potato. Yield is the average of the crop under different crop rotations.

	Crop residue removed						Crop residue mulching					
	Corn	Millet	Wheat	Potato	Flax	Alfalfa	Corn	Millet	Wheat	Potato	Flax	Alfalfa
FLP-C	4.9	4.2	1.7	3.2	1.1	15.3	5.1	4.4	1.8	3.6	1.2	15.4
FLP-F	4.9	4.3	1.8	3.2	1.2	15.5	5.0	4.4	1.9	3.4	1.3	15.6
TRL-C	5.0	4.4	1.9	2.9	1.1	15.9	5.3	4.5	2.0	3.4	1.2	15.9
GSL-C	4.9	4.3	1.6	3.3	1.0	14.7	5.2	4.5	1.7	3.7	1.1	14.7
GSL-F	5.0	4.3	1.8	3.3	1.0	14.7	5.0	4.4	1.9	3.6	1.2	14.9
MSL-C	4.8	4.1	1.4	3.2	0.9	14.2	5.0	4.4	1.6	3.5	1.0	14.3
MSL-F	4.8	4.2	1.6	3.1	0.9	14.4	4.9	4.3	1.7	3.4	1.0	14.4
STL-C	4.4	3.9	1.3	3.0	0.8	13.2	4.8	4.2	1.5	3.4	0.9	13.7
STL-F	4.6	4.0	1.5	2.9	0.8	13.8	4.7	4.1	1.5	3.2	0.9	13.8
VST-C	4.1	3.6	1.1	2.7	0.7	13.0	4.4	3.9	1.4	3.0	0.8	13.1
VST-F	4.3	3.7	1.3	2.7	0.7	13.0	5.0	4.3	1.5	3.5	0.9	14.5

3.3.2 Nitrogen losses

From the simulation results, losses of N mainly result from volatilization, runoff and soil erosion (Table 3.10). In the flood plain, 87-91% of the N losses are due to volatilization. Under terraced conditions, 98% of the N losses are caused by volatilization, and N losses from runoff and sediment are near to zero. The runoff and soil loss increases from the gentle slope to very steep land, resulting in an increase of N losses by runoff and sediment. Crop residue mulching and furrow-ridging can reduce the N losses by decreasing the water and soil losses from runoff and water erosion. Of the total N loss, 70-78% is caused by volatilization and 20-28% by runoff under irrigated conditions. This increased N loss from runoff is because of irrigation, as 5-10% runoff loss of the irrigation water is assumed for the simulations.

Denitrification and leaching of N hardly occurs, because of low rainfall and high potential evapotranspiration. Annual average potential evapotranspiration (1971-1993) calculated by the EPIC model using the Penman-Monteith equation is 1215 mm, 2.4 times the annual rainfall. A good match between the growing period and the rainy season may also be an important factor in explaining low leaching. These simulation results are in line with the conclusion that nitrogen, in general, is hardly lost by leaching and denitrification under semi-arid conditions (Van Duivenbooden *et al.* 1996). Chen *et al.* (1950) and Zhu (1977) concluded that losses of N in calcareous soils were mainly via volatilization.

Volatilization of N can be greatly reduced by using nitrate N and by under-surface fertilization. From the simulation results (Table 3.11), N losses are rather low, i.e., less than 20% of the applied fertilizer N (not including N in crop residues and N fixed by legumes) on the flat land types. On sloping land types, the N losses increase greatly from the gently sloping to the very steep land, due to the increased losses by sediments and runoff. The average of simulated total N losses from the mixed crop rotations with alfalfa is within a range of 14-

32 kg ha^{-1} for the sloping land units, and 50-78% of that amount from the crop rotations without alfalfa. The percentage of N losses is higher for the mixed crop rotations (Table 3.11) because the input of fertilizer N is low, and alfalfa-fixed N is subjected to losses. The furrow-ridging and residue mulching have a small effect on the N losses for crops grown on the flat or gently sloping land, but can markedly reduce the N losses on steeply sloping land.

Relatively higher N losses are found for crops grown under potential production (irrigated) conditions, with the N losses totaling 21-22% of the applied nitrogen. This increase is mainly caused by N loss from runoff of irrigation water. Under N-limited production conditions, a lower fraction of N losses has been found for the land units of FLP, TRL and GSL (the N loss is 0.5-1.5% lower), compared to that under water-limited (ample N input) production situations. A higher fraction of N losses is predicted for the land units of MSL and STL, farmed without use of furrow-ridges or residue mulching. For the VST, much higher N losses have been found, except for the crop rotations cultivated with both furrow-ridging and mulching. For instance, an average of 42% of the applied N is lost for the crop rotations (limited N input) farmed only with contouring. This increased N loss is caused by the increased water and soil loss due to the poor plant coverage.

Use efficiency of N for the long-term based on the simulation results is mostly within the range of 0.70-0.85, depending on land conditions and soil conservation measures used. Currently in Ansai and the Loess Plateau, the use efficiency of N is very low, at a range of 0.3-0.5. This inefficiency of N use is due to severe soil loss and surface application of NH_3-N (main fertilizer type is urea in Ansai) that causes high volatilization loss.

Table 3.10 N losses (% of total N loss) by different processes under water-limited production conditions for the different land units. NVOL: N loss by volatilization, NO3: N loss by runoff, YON: N loss by sediment (soil loss), and DN: N loss by denitrification; FLP-VST is suitable land units (See Table 2.4 in Chapter 2). The data are average of all crop rotations.

	Crop residue removed				Crop residue mulching			
Land unit	NVOL	NO3	YON	DN	NVOL	NO3	YON	DN
Contoured tillage								
FLP	87.3	10.3	1.3	1.1	89.1	9.0	0.7	1.2
TRL	97.6	0.2	0.0	2.2	97.6	0.2	0.0	2.2
GSL	73.1	17.4	7.6	1.9	78.6	15.3	4.0	2.0
MSL	54.9	24.2	18.7	2.2	65.3	21.4	11.1	2.2
STL	38.9	26.6	32.4	2.1	45.2	28.8	23.4	2.6
VST	28.4	24.5	45.8	1.3	32.5	29.4	36.2	1.9
With furrow-ridging								
FLP	91.3	7.2	0.4	1.2	91.1	7.4	0.2	1.2
GSL	82.3	13.3	2.5	2.0	81.5	14.7	1.6	2.2
MSL	70.0	20.2	7.7	2.1	72.7	20.4	4.6	2.2
STL	50.4	28.1	18.9	2.6	60.4	25.6	11.5	2.5
VST	36.4	29.1	32.5	1.9	38.9	33.5	25.2	2.4

Table 3.11 Average N loss of the defined land use types under water-limited production conditions for the different land units. Numbers before slash are kg ha^{-1}, and numbers after slash are percentage of the nitrogen input (excluding N in crop residues and fixed by legumes). NR, NM, FR and FN are the same as those in Table 3.7. For TRL, furrow-ridging is not applied, and thus no simulation results are shown in the table.

Land units	Crop rotation (no alfalfa)				Mixed rotations (with alfalfa)			
	NR	NM	FR	FM	NR	NM	FR	FM
FLP	32 / 19	26 / 17	32 / 17	27 / 17	15 / 18	13 / 18	16 / 17	13 / 18
TRL	32 / 16	29 / 16	-	-	15 / 17	14 / 17	-	-
GSL	32 / 21	28 / 21	35 / 20	28 / 19	18 / 23	15 / 23	16 / 21	14 / 21
MSL	20 / 21	27 / 21	34 / 21	31 / 23	20 / 27	18 / 28	20 / 25	17 / 26
STL	36 / 22	26 / 26	30 / 21	29 / 22	21 / 30	19 / 30	20 / 27	20 / 30
VST	49 / 36	32 / 29	37 / 27	28 / 24	32 / 43	25 / 40	26 / 36	22 / 36

3.3.3 Soil loss

The predicted soil loss varies greatly with different land units, crop rotations and crop management. Table 3.12 presents the average rates of soil loss for non-alfalfa crop rotations and mixed crop rotations with alfalfa under water-limited production conditions. Compared to the mixed crop rotations, non-alfalfa crop rotations have very high soil loss. When furrow-ridging or crop residue mulching is used, soil loss is markedly reduced. Under N-limited conditions, soil loss increases due to lower plant coverage of the soil because of the lower biomass production (the results not presented here).

The simulated soil loss may be over-estimated for crop rotations growing on steeply sloping land, in comparison to the experimental data reported by Li (1990) (Table 3.13). For instance, the simulated soil loss is 35.8 t ha^{-1} for the contoured (NR) crop rotations cultivated on the STL, about 50% higher than that of the similar condition of plot 3 in Table 3.13. For the sloping land units of GSL and MSL, the simulated soil loss (NR) is more similar to the experimental data presented in Tables 3.13-3.14. In Ansai, Hou & Cao (1990) reported that the average of measured soil loss in 10 years was 30.3 t ha^{-1} on a very steep (slope gradient of 51.0%) cropland plot. By four-year experiments, Lu *et al.* (1988) found that the average soil loss was 38.7 and 45.5 t ha^{-1} on the steep experimental cropland (slope gradient of 56.5%) under millet and potato, respectively. However, very high soil loss at a rate of 150 t ha^{-1} (slope steepness of 28.7%) and 157 t ha^{-1} (slope steepness of 38.4%) were reported by Shan & Chen (1993) in the Loess Plateau. Soil loss for the mixed crop rotations with alfalfa may be under-estimated, compared to data reported by Shan & Chen (1993), Lu *et al.* (1988) and Hou & Cao (1990).

These comparisons can only give a general impression of the accuracy of the simulated soil loss by the EPIC model, as soil loss greatly depends on weather and land conditions, land use and crop management. In the Loess Plateau, the severe soil losses are mainly caused by unusually heavy rainstorms that do not occur every year (Lu 1991). The simulation results are actually not very comparable to the reported data, since the reported data were based on experiments for just few years, and thus the data may not be representative.

Table 3.12 Simulated average soil loss (sediment yield, t ha^{-1}) under water-limited production conditions for the different sloping land units (NR, NM, FR and FN refer to Table 3.7). The figures are average over all crop rotations with same measure for water and soil conservation

Land unit	Crop rotations (without alfalfa)				Mixed rotations (with alfalfa)			
(mean slope gradient %)	NR	NM	FR	FM	NR	NM	FR	FM
GSL (7.0)	5.7	1.9	1.7	0.6	0.8	0.4	0.3	0.2
MSL (13.2)	15.2	5.8	5.5	2.1	2.9	1.5	1.2	0.7
STL (22.2)	35.8	14.0	15.1	5.7	7.3	3.7	3.5	2.2
VST (36.4)	81.7	31.5	37.4	14.7	20.0	10.3	11.1	6.6

Table 3.13 Average soil loss of 9 experimental years (contoured tillage, mean annual rainfall of 534.6 mm) in Tianshui Experimental Station for Water and Soil Conservation in southwestern Loess Plateau (Li 1990)

Plot No.	Land slope gradient %	Average crop yield (t ha^{-1})	Soil loss (t ha^{-1})
1	Around 7.0	2.1	8.3
2	10.5 - 14.1	1.8	14.8
3	23.1 - 26.8	1.6	24.2
4	30.1 - 32.5	1.6	30.6

Table 3.14 Experimental data for soil loss (the plot 5 m × 20 m) in Weibei, the Loess Plateau of northern Shaanxi (mean rainfall of the 3 experimental years: 492.2 mm). Source: Liu *et al.* (1995)

Plot No.	Land slope gradient %	Growing crop	Soil loss (t ha^{-1})
1	4.4	wheat	0.6
2	7.4	wheat	4.7
3	9.4	wheat	2.9
4	12.9	corn, soybean	10.7
5	11.0	fallowing	19.5

3.3.4 Concluding remarks

The simulated crop yields under potential and water-limited production conditions are reasonable compared to experimental data reported in Ansai and the Loess Plateau. For the gently sloping land units (GSL and MSL), the simulated soil loss is closer to experimental data, but for the steeply sloping land units (STL and VST), the soil loss may be over-estimated. Simulated N loss seems plausible, but the accuracy cannot be validated due to a lack of experimental data. The simulation results reveal a great potential in improving the N use efficiency.

The three soil conservation measures, i.e., furrow-ridging, residue mulching and mixed crop rotations with leguminous forage of alfalfa are all efficient in preventing soil losses, compared to contoured tillage (Table 3.12). The yields of all crops, especially the summer-harvested crops of winter wheat, summer potato and seed flax can be substantially improved by furrow-ridging and residue mulching under rainfed conditions (Table 3.8). The mixed crop rotations could be a promising practice that can greatly reduce the losses of soil and N and the requirement of nitrogen, and improve the soil fertility.

The EPIC model is very sensitive to the CN-values (see Section A1.3 of Appendix 1) that greatly determine surface runoff and soil losses. The CN-values and other parameters for estimations of soil loss, such as the *CE* and *PE* are based on SCS (1972), and Wischmeier & Smith (1978). Those parameter values should be validated for the conditions of the Loess Plateau. For each land unit, the average data (e.g., land slope steepness, soil texture) are used, and for all simulations, a single data set of weather is applied. These may cause some uncertainty because of variation of land and climatic characteristics.

As leaching and denitrification of N is very low, the nitrogen loss highly depends on types of applied fertilizers (ammonia, nitrate and organic N), and the depth of fertilization. In EPIC, nitrate N is subject to leaching, denitrification and runoff loss; ammonia N is subject to nitrification and volatilization; and the organic N can be mineralized, and the loss is only caused by sediments. Under Ansai conditions, the predicted N losses are much higher if ammonia N is applied at a shallow depth below the soil surface. Very low N loss is simulated if only nitrate or organic N is applied (results are not presented).

Chapter 4 Determination of Input-Output Coefficients of Agricultural Production Activities

4.1 Introduction

In this chapter, agricultural production activities, as defined by the definition criteria identified in Chapter 2, will be described with their input and output coefficients. This quantification is based on a target-oriented approach, assuming that the best technical means are applied, i.e., minimum amount of all inputs are applied to realize the target (e.g., production level), and to maintain the resource base (e.g., nutrient stocks in the soil) (De Wit 1992, Van Ittersum & Rabbinge 1997). The information used for this quantification includes data from the quantitative land evaluation (Chapter 3), and data from literature. The quantified production activities will be used in the MGLP model to generate land use scenarios for the long-term sustainable agricultural development in Ansai.

This Chapter describes the quantification of all agricultural production activities, including 2006 cropping activities, 6 fruit activities, 9 grassland production activities, 3 firewood production activities, and 8 animal production activities. Procedures for quantification of cropping activities are described in more detail, as they are more closely linked to the problems with food security and soil conservation in Ansai. Some examples of the cropping activities are presented in Tables A4.1-4.2, and the input-output tables of fruit, grass and firewood production activities are presented in Tables A4.3-4.5 in Appendix 4, and those for animal activities are Table A5.6 in Appendix 5.

4.2 Quantification of cropping activities

This section presents the quantification of cropping activities, each of which is specified by the outputs and inputs needed to realize the given yield levels, including labor, nutrients, biocides, farm equipment, machinery or animal traction and costs. The target yields, fertilizer requirements, irrigation water, soil and N losses are based on the EPIC-simulation results, taking into account possible yield reductions.

4.2.1 Production technologies

Production technologies determine various inputs (e.g., labor, nutrients) needed to realize the targets of economic (e.g., crop yield) and environmental protection (e.g., soil loss control). In

Chapter 2, three yield levels, two mechanization levels, and four measures for water and soil conservation (see Table 2.8 of Chapter 2) are defined. Some detailed descriptions related to the production means are needed. For the different yield levels, activities related to applications of nutrients and biocides, and weeding are given in Table A3.4 in Appendix 3. The two mechanization levels are mainly differentiated by power sources: the use of power traction or animal traction. One is called the semi-mechanization level, which refers to a situation in which most of the farm operations are carried out with machinery; weeds are controlled with herbicides; and sprinklers are used for irrigation (if applicable). Another one is called non-mechanization options, in which animal traction is used for farm operations instead of machinery, and irrigation water is supplied with surface irrigation. Detailed descriptions of the mechanization levels are given in Table A3.5 in Appendix 3. Because of limitations by the rugged terrain and small farm size, only light machinery and equipment are considered.

4.2.2 Determination of target yields

In Chapter 3, crop yield for each of the 816 land use systems was calculated. These simulation results are used to determine target yields of cropping activities, taking into account unavoidable yield reductions due to problems of climatic hazards, soil-borne diseases and pests, and imperfect management.

Yield reductions due to climatic hazards

Climatic hazards that often lead to crop yield reduction in Ansai are hail, drought and rainstorms or flooding. The drought effect on crop yields has been taken into account by the EPIC model. Rainstorms or flooding mainly happen during the rainy season and often cause crop yield loss and destruction of cropland. Hail occurs almost every year, sometimes several times per year (Table 4.1). As temperature is rather marginal for the growth of corn, soybean, millet and winter wheat in spring and autumn, frost hazards often happened in April-May and September in Ansai. During the period of 1972-1982, the county experienced 7 years with frost hazards, in which crop yields were reduced, or even completely destroyed for an annual sowing area ranging from 1633 to 8000 ha (CAAC 1993).

During the period of 1976-1989, an average of 14.8% (Table 4.1) of the crop sowing area per year was affected by hail and rainstorms/flooding. Information on the production loss due to the hazards is incomplete; available data show that crop production loss ranges from 1.5% to 24.0% of the annual total. Average yield loss of cropping area affected by the climatic hazards is estimated to be about 40-50% from data reported by CAAC (1993). By multiplying this 40-50% yield loss with 14.8%, the average area subjected to hazards, mean annual yield loss is estimated at 6.0-7.5%. Considering possible additional yield loss caused by frost, a yield reduction of 10% due to climatic hazards including hail, frost and rainstorms/flooding, is assumed for all crops.

Table 4.1 Area subjected to hail and rainstorms and production loss caused by the hazards. Compiled based on data from CAAC 1993). na = not available.

Year	Hazards	Crop Area Affected		Fully failed crop area (ha)	Reduced Grain Production	
		Area (ha)	% of sowing area		10^3 t	% of annual total production
1976	Hail	3867	12.5	400	2.7	9.8
1977	Hail, rainstorm-flooding	4193	13.6	1081	0.6	1.5
1978	Hail, rainstorm	6170	20.4	na	na	na
1979	Hail, rainstorm, flooding	3467	11.2	na	na	na
1980	Hail	1587	5.2	29	2.0	5.5
1981	Hail	4807	16.0	na	1.4	4.0
1982	Hail	2000	6.5	na	0.8	1.9
1984	Hail	9565	30.7	na	na	na
1985	Hail, rainstorms	14467	48.2	9067	9.8	24.0
1987	Hail, rainstorms	3457	11.5	1262	4.5	17.4
1988	Hail, rainstorm-flooding	4636	13.7	na	3.5	7.7
1989	Hail, rainstorm-flooding	5203	18.0	na	3.2	7.0
Mean		4556	14.8	na	na	na

Reductions due to soil-borne diseases and pests

The EPIC-simulated crop yields are calculated under the assumptions that the growth reducing factors of disease, pest and weeds are fully controlled, and the required nutrients are optimally supplied. Under actual conditions, these production situations may not be realized due to lack of timeliness in applying the required nutrients, water and crop protection agents.

A crop is normally subject to several kinds of diseases and insects, each of which may lead to some yield reduction. In practice, only important ones that may cause serious yield reductions are controlled by applying biocides on a regular basis. Some diseases or pests that have a limited effect on crop yields are often ignored due to the lack of economic attractiveness of protecting the crop. For example, maize smut (*Ustilago maydis*) occurs widely in China, with a yield loss normally less than 2% in areas grown with smut-resistant maize species (ECPP 1996). Biocide control for this maize smut may not be economically attractive.

Any crop protection measures cannot approach 100% efficiency (Zhou & He 1995) in controlling crop diseases and pests, even weeds, and thus some yield loss may be unavoidable. A reduction factor of 5% is assumed for winter wheat, corn and millet to account for the yield loss due to incomplete control of diseases and pests. A higher yield reduction of 10% is assumed for soybean, potato and flax, as they have more problems caused by diseases and pests. For alfalfa, no biocides are applied and 10% yield reduction is assumed for this crop due to possible diseases and pests. For cropping activities with surface irrigation, a 5% yield reduction is assumed because irrigation water may be unevenly supplied.

Mono-cropping or narrow rotations may cause yield loss due to high occurrence of diseases and pests, especially soil-borne and crop-specific ones. In this study, the possible yield reductions owing to soil-borne diseases and rotation problems are roughly estimated based on limited information. The reduction factors, major diseases and pests that may cause yield losses in Ansai are shown in Tables A3.1-3.3 in Appendix 3. The yield reductions considered are summarized in Table 4.2.

Table 4.2 A summary of yield reductions considered for deriving the target yields

Affects	Yield reduction	Causes
Climatic hazards	All crops: 10%	Hail, frost, rainstorms and flooding
Imperfect soil and crop management	Wheat, corn and millet: 5% Soybean, potato, flax and alfalfa: 10%	Lack of timeliness of applying fertilizers and crop protection agents
	Surface irrigated cropping activities: 5%	Unevenness of applying irrigation water
Soil-borne diseases and pests	Crop-specific reduction shown in Table A3.1 in Appendix 3.	Soil-borne diseases and pests in narrow rotations, and due to specific crop sequences

Determination of the target yield

The target production (per year) for each crop of a cropping activity can be computed with an equation:

$$Yt_i = \frac{L_i}{RL} \cdot Y_i \cdot (1 - fc_i) \cdot (1 - fm_i) \cdot (1 - fp_i) \cdot (1 - LF) \qquad 4.1a$$

$$RS_i = \frac{L_i}{RL} \cdot R_i \cdot (1 - fc_i) \cdot (1 - fm_i) \cdot (1 - fp_i) \cdot (1 - LF) \qquad 4.1b$$

in which, Yt_i and Y_i are respectively the target yield and the simulated yield of crop $_i$ in kg ha^{-1} DM. RS_i and R_i are the (target) harvested and the EPIC-simulated (harvested) residue of crop $_i$ in kg ha^{-1} DM. L_i is frequency (years) of crop $_i$ in a crop rotation of RL years, and fc_i, fm_i and fp_i are yield reduction factors (Table 4.2) for crop $_i$ due to climatic hazards, imperfect management and soil-borne diseases and pests, respectively. LF is land fraction occupied by hillside ditches or by back-slope and front ridge of terrace. The value of LF is calculated with Eqn A3.2b for terrace (variable LF_t) and A3.3b for hillside ditches (variable LF_d), and the values are given in Tables A3.10 and 3.11 of Appendix 3.

For each of the cropping activities with spaced terracing, a weighted average of simulated yield (or residue) on the sloping land and terraced land is used for Y_i (or R_i), based on the fraction of inter-terraced area and terraced area. It is assumed that yield reductions do not affect harvest index, i.e., the partitioning of aboveground biomass between the economic product and crop residue is not changed by the reduction factors defined above. Therefore, the same form of the equation as used for determining the target crop yields and the same reductions are used to derive the harvested crop residues.

4.2.3 Environmental aspects: determination of chemical inputs and losses of soil and N

Maintenance of land productivity and minimizing negative impacts on the environment are important aspects of sustainable farming. To maintain land productivity, sufficient crop and soil management, and efficient use of external inputs, are required. To minimize possible impacts on the environment, chemicals such as fertilizer N and biocides could be used at a possible low level, and soil erosion should be limited. In this study, three factors are used as indicators of the ecological sustainability of cropping activities: soil nutrient balance, soil and nitrogen losses, and biocide use. Quantification of these aspects and requirement of irrigation water is presented in this subsection.

Soil loss

Soil erosion is an often-used indicator of sustainability for arable farming in the Loess Plateau. For each cropping activity, soil loss is based on the simulation results by the EPIC model (Chapter 3). Due to the unavoidable yield reductions, the target yields of cropping activities are lower than the EPIC-simulated yields. These yield decreases can cause a small increase in soil loss due to slightly lower plant coverage associated with the lower biomass production. This small increase in soil loss is not taken into account, i.e., the simulated soil loss by the EPIC model is used for each cropping activities. For spacing terraced land, it is assumed that 80% of the soil loss from the inter-terrace slopes deposits on the down terrace.

Nutrient inputs and N losses

The cropping activities are defined and quantified in such a way that soil nutrient stock does not change over a rotation cycle, i.e., the total input of nutrients (N, P and K) equals the amount exported by crop removal plus the losses.

Nitrogen requirement and losses

The N requirements and losses are calculated on a rotation basis. The EPIC simulation results (Chapter 3) are used to derive the requirements and losses of N for the cropping activities. Annual N input per cropping activity (*Binp* in kg N ha^{-1}) is calculated with Eqn 4.2a:

$$Ninp = Nhar + Nlos - Nbio - Nrain \qquad 4.2a$$

in which *Nhar* (kg ha^{-1} yr^{-1}) is average of the harvested N per crop rotation per year, i.e., the total N removal by marketable products and harvested residues. *Nlos* (kg ha^{-1} yr^{-1}) is total N losses. *Nbio* (kg ha^{-1} yr^{-1}) is the N-fixation by leguminous crops, i.e., soybean and alfalfa. *Nrain* (kg ha^{-1} yr^{-1}) is N deposition through rainfall, estimated by annual precipitation and N concentration in rainwater (0.8 ppm).

Nhar is calculated with Eqn 4.2b, in which Yt_i (or RS_i) is dry weight (kg ha^{-1}) of economic yield (or harvested crop residue) calculated with equation 4.1a (or 4.1b), and *Cg* (or *Cs*) is N concentration (kg kg^{-1} DM) of economic yield (or harvested residue) of crop $_i$.

$$Nhar = \sum_i \left(Yt_i \cdot Cg_i + RS_i \cdot Cs_i\right) \qquad 4.2b$$

Total N losses (*Nlos*) include gaseous losses by volatilization and denitrification, losses by leaching and surface runoff, and loss of organic N by sediments (soil loss), calculated using Eqn 4.2c[1]. *Nfls* is the mean fraction (kg kg^{-1}) of N loss as the total N input, calculated with the EPIC-simulation results for each cropping activity. It is assumed that *Nfls* is not af-

[1] N losses are estimated with Eqn 4.2c for flood plain, terraced land and sloping land. For sloping land that is terraced with spaced terracing, a large part of N losses by runoff and sediment from the inter-terrace slopes can be intercepted by the down terrace. In this study, it is assumed that 80% of the N loss by runoff and sediment from the upper sloping land is deposited on the down terrace. The N losses by runoff and erosion can be derived from the simulation results of the EPIC model.

fected by the reduction factors as discussed in Subsection 4.2.2.

$$Nlos = Ninp \cdot Nfls \qquad 4.2c$$

Nbio is estimated with equation 4.2d, where L_i is frequency of crop $_i$ (= alfalfa or soybean) in a crop rotation of *RL* years, and $Nfix_i$ is the EPIC-simulated amount (kg N ha^{-1}) of N fixed by alfalfa or soybean. The same reductions (see Eqn 4.1 and Table 4.2) as those for crop yields are applied to derive the N-fixation by the two legumes, assuming that N fixation is proportional to their biomass production (It is not defined that crop rotations simultaneously include both alfalfa and soybean).

$$Nbio = \frac{L_i}{RL} \cdot Nfix_i \cdot (1 - fc_i) \cdot (1 - fm_i) \cdot (1 - fp_i) \cdot (1 - LF) \qquad 4.2d$$

Determination of inputs of P and K

The required inputs of P and K are used to calculate the share in production costs. Due to lack of information, the fraction of losses or use efficiency of P and K is simply derived from that of N. A sample formula is used to determine the requirements of P and K, as presented:

$$Pinp = \frac{Phar}{0.4 \cdot (1 - Nfls)} - \Pr ain \qquad 4.3a$$

$$Kinp = \frac{Khar}{(1 - Nfls)} - Krain \qquad 4.3b$$

in which *Pinp* (*Kinp*) is required input of P (K) in kg ha^{-1}, *Phar* (*Khar*) is harvested P (K) in kg ha^{-1}, as calculated with the same equation 4.3b for N, *Prain* (*Krain*) is P (K) deposition through rainwater (kg ha^{-1}), and *Nfls* is average fraction (kg kg^{-1}) of N losses expressed as the total N inputs and calculated with the EPIC-simulation results for each cropping activity.

Apparent P recovery fraction is normally within a range of 0.1-0.3 (ISF-CAAS 1994, Van Duivenbooden *et al.* 1996, Bessembinder 1997), as P is, to a large extent, fixed by soil. According to data cited by ISF-CAAS (1994), high use efficiency of P, e.g., potato at 0.37 and wheat 0.30 can be attained when P has been continuously applied for a long period. In this study, the use efficiency of P is assumed to be 40% of that of N (the use efficiency of N is defined as [1 – *Nfls*]). This implies that the average use efficiency of P used in this study is mostly within a range of 0.2-0.3 for different cropping activities.

From data reported by Van Duivenbooden *et al.* (1996), the average recovery of K is at a rather similar level to that of N. Losses of K are mainly due to fixation by clay lattice, soil erosion and runoff. K loss by leaching hardly occurs, as water can rarely percolate out of the rooting zone in this region. K-fixation depends on clay content and types of clay minerals, e.g., illite has a much higher K-fixing ability than kaolinite (ISF-CAAS 1994). In Ansai, clay content in the loess soils is low, normally around 10%, but the clay comprises mainly illite. There is no information for a reasonable estimate of K-fixation, and thus it is assumed that the fraction of K losses by fixation, runoff and sediment is the same as that of N, in other words, the use efficiency of K is the same as that of N. Deposition of P and K by rainwater is estimated as a function of annual precipitation: 0.7 g P and 5 g K per mm rainfall (Van Duivenbooden 1992).

Concentration of N, P and K in crop products

Concentration of N, P and K varies with crop types and input level of nutrients. The simulation results of EPIC and experimental data from literature (Dai *et al.* 1991, Chen *et al.* 1996) indicate that N concentrations in grains and crop residues are higher with ample N inputs than limited N inputs. Under no nutrient-limiting conditions, concentrations of N, P and K for the crops are given in Table 4.3, based on the EPIC data and literature (Dai *et al.* 1991, Chen *et al.* 1996, Van Duivenbooden *et al.* 1996, Yu *et al.* 1991, De Koning *et al.* 1992, Bolton 1962, Khem Singh Gill 1987). The N concentrations in Table 4.3 are applied to the production levels (attainable irrigated and rainfed yield) with sufficient N inputs. The N concentration of the economic products is set to 90%, and the crop residues to 85% of the values in Table 4.3 for the N-limited yield level. These fractions are roughly estimated with the EPIC simulation results and experimental data (Dai *et al.* 1991, Suo *et al.* 1997, Chen *et al.* 1996).

Table 4.3 Concentration (% of dry matter) of N, P and K for the crops grown under the conditions without N-limitation

Crop	Economic products			Crop residues		
	N	P	K	N	P	K
Corn	1.75	0.26	0.39	0.85	0.12	1.33
Millet	1.62	0.34	0.42	1.01	0.11	1.66
Wheat	2.34	0.41	0.30	0.55	0.05	2.20
Soybean	6.50	0.91	1.47	1.20	0.13	1.30
Potato	1.50	0.14	2.50	2.50	0.15	2.25
Flax	4.00	0.33	0.61	1.00	0.12	1.43
Alfalfa (forage)	3.00	0.24	2.36	-	-	-

Requirement of biocides

Determination of biocide requirement needs information on occurrence and possible crop damage of disease and pests. Based on limited information (CAAC 1993, Hua & Wang 1996, Jiang 1998), the most important viruses, diseases and insects in Ansai are wheat yellow dwarf virus, potato late and early blights, millet downy mildew (*Sclerospora graminicola*), aphids, corn and millet corers, armyworm, yellow-legged lema, bean hawk moth and zokor. The other diseases and pests shown in Tables A3.2 and A3.3 in Appendix 3 may also cause crop damage.

Biocide requirements for controlling diseases, viruses and pests are estimated, based on the minimum amounts advised in the literature (HPRI-CAAS 1994, Jiang 1998, Liang *et al.* 1995, Li & Shang 1994, Qi & Xiang 1992, Pei 1997, SAAS 1987, Sun *et al.* 1992a, Wang *et al.* 1989, Zheng 1992). The estimated requirements of biocides are presented in Table 4.4, which are the average of active ingredients (a.i.) of various biocides recommended in the above literature, assuming that use of biocides is alternated to avoid development of biological resistance. These biocide requirements (Table 4.4) are considered applicable for the attainable rainfed yield level. For the irrigated crops, 15% more fungicide use is assumed due to higher crop density, and more favorable conditions for fungi.

For N-limited cropping activities, much lower requirements of fungicides and pesticides are assumed. For corn, millet, wheat, soybean and flax, fungicides are used only for seed dressing, resulting in a reduction of 70% in fungicide use. Pesticides are applied to control the most important pests of *Leucania separata Walker*, *Chilo infuscatellus* and *Ostrinia furnacalis*. The required pesticide use can be 50% lower. For potato, pesticide is not used and only 50% of the fungicide is needed for controlling the major disease of late blight (*Phytophthora infestans*). For soybean, 60% of the amount of pesticides is needed for the control of soybean pod borer (*Leguminivora glyniuorella*) and soybean aphid (*Apbis glycines*).

Table 4.4 Requirements of biocides (active ingredient, kg ha^{-1}), applicable to crops at the attainable rainfed yield level. No biocides are applied to alfalfa.

Biocide	Wheat	Corn	Millet	Autumn potato	Summer potato	Soybean	Seed flax
Herbicide	1.0	1.2	1.0	0.9	0.8	1.7	0.8
Fungicide	1.5	0.7	0.4	7.5	7.0	1.1	0.9
Insecticide	0.5	0.5	0.3	0.2	0.2	1.6	0.4
Total	3.0	2.4	1.5	8.6	8.0	3.4	2.1

Irrigation requirements

Requirements of irrigation water are based on simulation results by the EPIC model, assuming that water requirements are proportionally reduced with the unavoidable yield reductions.

Field application efficiency, i.e., ratio of crop water use and total application, depends on irrigation systems, soil and climate. For sprinkler irrigation systems, the irrigation efficiency is averaged 0.6 in a hot, dry climate and 0.8 in a humid and cool climate from data cited by de Koning *et al.* (1992). Song *et al.* (1995) reported that 7-28% of water supplied with a sprinkler irrigation system was lost due to influence of wind in northern China. In this study, the field application efficiency of 0.75 is used for irrigation with sprinklers.

Field application efficiency of surface irrigation depends on quality of irrigation channels. Song *et al.* (1995) reported that the field application efficiency was 0.57-0.73, and a remaining fraction 0.27-0.43 of the irrigated water is subjected to losses by field channel seepage, runoff, evaporation and soil leaching. Field application efficiency can be much improved if surface irrigation is supplied with a low-pressure pipe irrigation network (*ibid.*). In this study, the surface irrigation is assumed to be supplied with low-pressure pipes, and the application efficiency is set to 0.7, slightly lower than that of sprinkler irrigation.

4.2.4 Labor requirements

Labor requirements depend on crop types, yield level, production techniques and land types. General knowledge and information from literature, and various assumptions are used to derive labor requirements. The labor required for construction and maintenance of roads and irrigation systems, administration and food processing is not considered. This subsection presents the procedures used to determine the requirement of labor, machines, draught animals and costs to achieve the target yields. Detailed data for determining the labor inputs are presented in Section A3.2 in Appendix 3.

Operation periods

Farm operations have to be carried out in a certain period to ensure timeliness of soil and crop management. Some farm operations are highly labor intensive and should be carried out in a limited period. Distinction of operation periods helps to identify labor peaks and bottlenecks. In this study, five labor requirement periods are distinguished and presented in Table 4.5.

The selected crops can be classified into three categories: winter wheat, summer crops and autumn crops according to the growing season. Winter wheat is sown in September and harvested in early July. Summer crops including flax and summer potato are sown in mid-March to early April, and harvested in early July. Autumn crops including corn, millet, soybean and autumn potato are normally planted in April or May, and harvested in September to mid-October. Land preparation can be carried out in autumn or in spring before the sowing. Based on this information, four periods (P1-P4) of high labor requirement are identified (Table 4.5), which may create bottlenecks for the labor availability. Harvesting of winter wheat, flax and summer potato occurs during the early rainy season, and thus a rather short available period is given. Per year, total working days are set to 240 days, by excluding unworkable days (due to rains and cold temperatures) and holidays.

Table 4.5 Labor demand periods and its available days and major farm operations in each period

Period	Total days	Major operation activities
P1: Early March to early April	30	Land preparation, sowing for summer potato and flax; weeding and application of biocides for winter wheat
P2: Early April to late May	45	Land preparation, sowing, herbicide application, first weeding, thinning (millet) for autumn crops; second weeding for winter wheat
P3: Early to mid-July	15	Harvests of summer potato, flax and winter wheat
P4: Early September to mid-October	45	Harvests of autumn crops, land preparation and sowing for winter wheat, third harvest of alfalfa
P5: Remainder of the growing season	105	Other crop operations, harvesting of alfalfa, terracing, building of hill-side ditches, maintenance of terraces, etc.
Non-working days	125	Holidays, and unworkable days due to rainfall and cold temperature

Labor requirements for field operations

Labor requirement is defined in terms of task-time, i.e., the time required to carry out an operation under standard conditions by a skilled male laborer working at a normal pace, with standard equipment and with maximum efficiency (Van Heemst *et al.* 1981). The task-time depends on crop types, operation methods (e.g., with or without machinery use), operation activities (plowing, sowing or weeding, etc.) and land units. The task-time (*Lab*) is expressed in man-hours per hectare or per ton, as calculated with Eqn 4.4, and the basic data for the calculations are given in Tables A3.6 and A3.7 in Appendix 3.

$$Lab = \frac{Ta}{(1-P)\cdot(1-t)}(1+L) \qquad 4.4a$$

$$t = \frac{1}{8}\left(\frac{2\cdot d}{v}\right) \qquad t < 1.0 \qquad 4.4b$$

Ta is the time (h ha^{-1} or h t^{-1}) required for the actual work.

P is the time needed for preparation of farm equipment, production materials (loading of seeds, fertilizers, biocides, etc.), and simple maintenance of farm equipment, expressed as a fraction of the task-time. A value of 0.15 is used for all field operations with power/animal traction, according to data reported by ECHATE (1983), ACTER (1986) and Van Heemst (1981).

t is the time required to transport farm equipment and production materials or to travel between homestead and field, expressed as a fraction of an 8-hour-work day. In this study, one trip between homestead and field is assumed per working day of 8 hours. t is estimated with equation (4.4b) that is related to average distance (d, km) between homestead and field and traveling speed (v, km h^{-1}). The travel speed is 2.2 km h^{-1} for working with oxen, 20 km h^{-1} with tractors, and 4.0 km h^{-1} for manual laborers without use of animals or tractors. For sowing operations of potato with animal traction, additional travel time is taken into account for transport of potato seeds from the homestead to the field.

L is a land slope factor, expressed as fraction of increased labor requirement due to land slope. Based on data from NAC (1993), efficiency of field operations decreases non-linearly with increasing slope steepness. In this study, L is set to 0 for the land unit of FLP, 0.05 for GSL, 0.2 for MSL, 0.4 for STL and 0.6 for VSL[2].

Labor requirements for transport

Time needed for transport of manure and harvested products depends on power sources and equipment. In this study, we assume that the transport activities are carried out with donkeys, oxen, or tractors. Crop products or manure are loaded and unloaded manually. It is assumed that only one laborer is involved in the transport activities with animal traction, and two laborers for tractor transport. Man-hours needed for transporting a ton of products from field to homestead are calculated with Eqn 4.5, and the basic data for the estimation of labor inputs are given in Table A3.8 in Appendix 3.

$$Tlab = n \Big/ \left[\left(\frac{2\cdot d}{v} + \frac{C\cdot Ln}{n}\right)\cdot C\right] \qquad 4.5$$

in which, $Tlab$ is labor requirement in h t^{-1}, and n is number of laborers involved. C is carrying

[2] These values are applied to the natural conditions without terracing. When the sloping land units (*GSL-VSL*) are terraced, a value of 0 is used for the factor L.

weight in ton per trip, d is a distance (km) between the farmstead and fields, and v is average travel speed in km h^{-1}. Ln (h t^{-1}) is time required for a laborer to load and unload one ton of crop products, assuming that an adult man can load and unload one ton per hour.

Labor requirements for on-farm processing

On-farm processing includes threshing, winnowing, drying and storage of grains, as well as sorting and storage of potato. Basic data for the estimation of labor requirements of on-farm processing are given in Table A3.9 in Appendix 3.

Labor requirements for terracing

Two terracing types are defined in Chapter 2: bench-terracing and spaced-terracing. For sloping land units, hillside ditches along the contour lines should be constructed to drain surface runoff, if no terracing is applied. Section A3.3 in Appendix 3 supplies the procedure to determine terrace width, interval of terraces and hillside ditches, as well as the calculation of earthwork, labor requirements, and costs.

4.2.5 Requirement of draught animals and machinery

The same method as that for the labor requirement is used to estimate the requirement of draught animals and machinery. Oxen are not only used for field operations, but also for transport and on-farm processes of the produce. Donkeys are only used for transport. For plowing and sowing with oxen traction, the required ox-days are the same as the labor requirement. For on-farm processes, the oxen requirement is half of the labor requirement, as work such as winnowing and drying must be done manually. For hilly land units, it is assumed that 30%, 30% and 40% of the transport is carried out with donkey-drawn carts, ox-drawn carts and donkeys, respectively, since use of the animal-drawn carts may be limited due to poor accessibility by relief. For the flood plain, half of the transport is done with donkey-drawn carts and half with ox-carts.

For field operations, hours needed for tractors and the complementary machines are the same as labor hours. For transport, half time of the labor requirement is needed, as we assume that two laborers including the driver are needed to assist the tractor transportation. For on-farm processes, the machinery (threshing and winnowing machines) time is 20% of that for labor requirement.

4.2.6 Costs and return

Production costs include those for seeds, nutrients (N, P and K), irrigation water and biocides, farm equipment (including sowing machines, knapsack sprayers, plough, hoes, cutters and threshers), labor, animal traction and tractors. For all operations, farm equipment and machinery uses are transformed into cost per hour. Costs for labor, use of draught animals, and inputs of seeds, nutrients and biocides, and irrigation water are estimated according to prices in yuan (one US dollar equals about 8.3 yuan, 1999). The net return is calculated as the difference between gross production value (prices multiplying the total production) and costs. Basic data used to calculate the costs and net return are shown in Section A3.4, Appendix 3.

4.2.7 Examples of the input-output coefficients

For each of the 17 crop rotations, 118 cropping activities (feasible combinations) are distinguished, based on the definition criteria (including production level, mechanization level, soil conservation measures, terracing options, and suitable land units). Thus a total of 2006 cropping activities (= 118 * 17) are identified. All data for determining the input-output coefficients are organized by the technical coefficient generator that has been developed using EXCEL, which includes the EPIC-simulation results and other basic information, such as yield reduction factors, nutrient (N, P and K) concentrations in crop storage organ and residues, task-time per farm operation, prices of crop products, fertilizers and biocides.

The defined activities and their input-output coefficients for each crop rotation are illustrated with an example of a three-year crop rotation of corn-soybean-corn (CSC), as presented in Tables A4.1 and A4.2 in Appendix 4.

4.3 Quantification of fruit activities

Two fruit activities are defined in chapter 2: irrigated and rainfed apple production activities, with the assumption that the irrigated apple is grown only on the flood plain and the rainfed apple only on the sloping land units. In addition, it is assumed that all apple orchards are distributed around the homesteads with a maximum area of 15% per land unit being available for apple production. The target yield and required inputs are described in this section.

4.3.1 Target yields

From the survey data reported by Chen *et al.* (1995) in five counties in the Loess Plateau of Shaanxi Province, average apple yields (three years) are 11.6-37.0 t ha^{-1}. From my survey in 1996, apple yield is about 30 t ha^{-1} in better-managed and irrigated apple orchards in Ansai. Apple is normally planted in China in a row spacing of 2-5 m and plant spacing of 1-4 m, depending on soil fertility, climate and types of apple (Tang & Yong 1990). Density in intermediate to high yielding orchards is 540-1845 of apple plants per hectare in the southern Loess Plateau of northern Shaanxi province (Chen *et al.* 1995). In this study, the plant density is set to 600 and 1200 plants per hectare, and the target yield is set to 16 and 38 t ha^{-1} for the rainfed and irrigated fruit activities, respectively.

4.3.2 Nutrient requirements and N losses

Nutrient requirement is derived from the target yield and concentration of nutrients in the fruit. According to Zeng (1987, cited by ISF-CAAS 1994), concentration of nutrients per ton of apple fruit is 4.4 kg N, 0.9 kg P_2O_5 and 4.0 kg K_2O. These data are used to determine the requirement N, P and K for realizing the target yields. Average recovery is set to 0.6 for N and K, and 0.25 for P under irrigated conditions, and 0.55 for N, K, and 0.2 for P under rainfed conditions. It is assumed that 30% of the applied N for irrigated apple and 35% for rainfed apple are lost by volatilization, denitrification, and runoff, and 10% is accumulated in soil to improve the soil fertility. For rainfed fruit activities on sloping land, it is required that necessary conservation measures such as orchard terracing (very narrow terraces) are adopted, and soil and water losses are well controlled. Thus, the same yield level can be achieved for all sloping land units. The estimated requirements of nutrients per hectare are 166 kg N, 53 kg P and 145 kg K for rainfed apple, and 266 kg N, 74 kg P and 232 kg K for irrigated apple. These values are much lower than the amount applied at present[3].

4.3.3 Biocide and labor requirements and costs

For both apple production activities, all operations are carried out manually. Manure and apple fruit are transported with oxen and donkey power. Furrow irrigation is used to apply the required water. Manual weeding is carried out three times per year, and 10 applications of biocides with a hand knapsack sprayer are needed per year.

Requirement of biocides

Apple production needs high inputs of biocides to control diseases and insects. Main diseases include those caused by fungi and bacteria such as *Glomerella cingulata, C. gloeosporioide, Colletotrichum gloeosporioides Podosphaera leucotricha, Venturia inaequalis, Physalospora pivicola* and *Gymnosporangium yamadai;* and main insects are *Adoxopbyes* spp., *Panonycbus urmi,* etc. (Pei 1997). Biocide requirement is estimated at 7 kg a.i ha^{-1} for the rainfed apple, and 14 kg a.i. ha^{-1} for the irrigated apple, based on data of Pei (1997), and Tang & Zhou (1990), assuming that the amount of biocides is proportional to the number of apple plants. Use of growth regulators is not considered.

Labor requirements and costs

Labor requirement includes that for weeding, application of fertilizers and biocides, irrigation, branch pruning and harvesting, as well as maintenance of the orchard terrace. Management operations are carried out in period P4 and P5, as defined for the cropping activities. Maturity of apple is normally in September, so, apple is harvested in P4, and all other operations are carried out in P5. For the apple production activities, 3 fertilizations are required per year. The tree branches are pruned once per year. At each of the four irrigations, 60 mm water is applied, totaling 240 mm water per year for irrigated apple production activity. Data from ACTER (1986) and CADAC (1988) are used to estimate the labor requirements.

Costs are estimated on the basis of amount of inputs (fertilizers, biocides and water), young apple trees, land preparation (orchard terracing for sloping land) and other necessary inputs like small equipment. Gross margin is calculated by multiplying the apple price with the yield, minus the costs including labor. An average price of 2.4 yuan kg^{-1} in 1997-1998 is

[3] Use of chemical fertilizers is currently very high, within a range of 168-1080 kg of N, 133.5-861 kg of P_2O_5, and 0-369 kg of K_2O per hectare from the data reported by Chen *et al.* (1995).

used to calculate the gross production value. The input-output coefficients for all fruit activities are presented in Table A4.3 in Appendix 4.

4.4 Quantification of grass production activities

Two types of grass activities are distinguished: sown grassland and natural grassland, and both are used for grazing. It is assumed that the sown grassland activities can be practiced on all (suitable) sloping land units.

4.4.1 Sown grass

Two activities are differentiated for sown grass production: intensive grassland with sufficient input of nutrients and semi-intensive grassland without external N input. Both grass activities are supplied with sufficient P and K. It is assumed that the grassland comprise 25% leguminous species. Forage production, soil and N losses are estimated with the EPIC model. No biocides are used for both grass activities, which results in an assumed reduction of 10% for the simulated yields. The same procedure as for cropping activities is used to derive the required inputs of nutrients, and soil and N losses. Grass is sown with animal-drawn planters and re-sown after six years. The input-output coefficients for these grass activities are presented in Table A4.4 of Appendix 4.

4.4.2 Natural grassland

The natural grassland is mostly distributed on hill and valley/gully slopes. Forage production of natural grassland is very low due to steep slope (high runoff) and overgrazing. Average actual annual yield of all grassland in Ansai estimated by Liu *et al.* (1988) based on the survey data with remote sensing images was 3.9 t ha^{-1} (fresh weight). Yield reported by Jin *et al.* (1990) from measured data at sample plots was much lower: 0.75-3.0 t ha^{-1} (fresh weight) for grassland on gully slopes under overgrazing conditions. These data represent actual conditions under which the grassland is generally overgrazed. Without overgrazing, much higher yields can be attained. For instance, forage production of the overgrazed grassland selected for comparison increased to 3.3-5.5 t ha^{-1} from 0.9 t ha^{-1} (fresh weight) after two years without grazing in Ansai (*ibid.*).

For the natural grassland, forage production highly depends on slope steepness and slope directions. Survey data based on infrared air photos by Wang *et al.* (1988) and Liu *et al.* (1988) integrated both effects on grassland production in Ansai, which are used to estimate forage production of the natural grassland. The basic data including area and average yield per township are shown in Table 4.6.

Forage production of the natural grassland in Ansai may be mostly limited by nutrients. Analyses with the EPIC model indicate that forage production can be greatly improved if fertilizers are applied. Under conditions without use of fertilizers, the EPIC-simulated biomass (fresh weight) is around 4.0 t ha^{-1} (slope gradient of 51%) and rather similar to the measured yields. The simulated yield is 1-2 times higher when 30-50 kg N ha^{-1} is used.

Under no overgrazing conditions, leguminous species of herbaceous plants in the grassland can be well grown, and thus it is assumed that 30 kg N per hectare is fixed by the leguminous plants. Based on the simulation results and measured data from sample plots by Jin *et al.* (1990), forage production of the natural grassland is set to 2 times the yields surveyed (Table 4.6) by Wang *et al.* (1988) and Liu *et al.* (1988).

Soil loss due to water erosion depends on vegetation coverage of soil and land slope steepness. Soil loss observed on a 20×5 m plot with a 51% slope gradient and 60% plant coverage, was averaged 11.5 t ha^{-1} over 10 years (Hou & Cao 1990) in Ansai. From a conservation point of view, the natural grassland in Ansai should be preserved, or used with a limited intensity, as intensive grazing may lead to severe soil loss problems. In this study, it is assumed that the natural grassland is properly used with rotational grazing, and 35% of the forage production is available for animals. Average content of crude protein in the grass dry matter is 12%, estimated according to data of Jin *et al.* (1990). Since it is assumed that the natural grassland should be used only for grazing with limited use intensity, the soil losses can be within an acceptable level. Thus, the soil loss of natural grassland is not included in the input-output tables, i.e., it is not optimized by the MGLP model.

Table 4.6 Area and mean yield (t ha^{-1}, fresh weight) of natural grassland in Ansai, based on the surveyed data of Wang *et al.* (1988) and Liu *et al.* (1988)

Township	Area (ha)	Mean yield (t ha^{-1})	Township	Area (ha)	Mean yield (t ha^{-1})
Gaoqiao	1834	3.2	Wanjiawan	3855	4.8
Haojiaping	2466	2.3	Wangyao	4347	2.7
Huaziping	4985	3.7	Xihekou	987	5.4
Liandaowan	5474	4.9	Yanhewan	2366	3.9
Louping	869	4.8	Zhaoan	3712	4.7
Pingqiao	6041	4.6	Zhenwudong	2769	3.0
Tanjiawan	3002	2.4	Zhuanyaowan	1392	4.8
			Total/average	44099	3.9

4.5 Quantification of firewood production activities

Two types of firewood activities, i.e., natural shrub and planted shrub activities are selected, both of which are used to produce firewood. As mentioned in Chapter 2, forests (trees) are controlled strictly by the local government, and thus they are considered to be preserved, and cannot be used as firewood production.

Natural shrubs

Similar to the natural grassland, the shrubs are normally distributed on very steep areas. In the Loess Plateau, biomass growth of shrub stops at 7-8 years, within which the growth rate decreases with aging; and the accumulated wood at 3-8 years mostly is 2.5-8.5 t ha^{-1} DM (Zhao *et al.* 1994). The cutting intervals of shrubs for firewood are normally 3-5 years. Annual dry wood production is around 1 t ha^{-1}. In this study, the shrub cuttings are set to once per 4 years. The annual available firewood is set to 0.8 t DM ha^{-1}, considering that not all shrub-land may be accessible, since they are normally distributed on steep slopes and far away from the homesteads. Areas of the natural shrub-land (Table 4.7) are based on Luo & Zhang (1988).

Table 4.7 Area of natural shrub-land in Ansai, based on Luo & Zhang (1988)

Township	Area (ha)	Township	Area (ha)	Township	Area (ha)
Gaoqiao	346	Pingqiao	839	Yanhewan	464
Haojiaping	35	Tanjiawan	173	Zhaoan	469
Huaziping	607	Wangjiawan	2182	Zhenwudong	472
Liandaowan	412	Wangyao	441	Zhuanyaowan	1169
Louping	1059	Xihekou	4300	Total	12966

Planted shrubs

This firewood production activity refers to the expectation that shrubs will be planted in the future. For this activity, we assume that it can be practiced on both steep (STL) and very steep (VSL) land units. The target dry wood production is set to 2.0 t ha^{-1} for STL and 1.6 t ha^{-1} for VSL per year, with a cutting interval of 4 years. This target yield is estimated according to the reported biomass production of two commonly used shrub species of *Hippophae rhamnoides* and *Caragana microphylla* (pall) lam., both of which have nitrogen-fixing ability (Zhao *et al.* 1994).

Under well-growing conditions, soil losses can be controlled by the shrubs. A ten-year observation by Hou & Cao (1990) in Ansai indicated that mean soil loss per year was only 0.05 t ha^{-1} on a steeply sloping land unit (slope gradient of 51%) covered by preserved and full-grown shrub of *C. microphylla*. However, much higher soil losses were also reported by Hou & Cao (1990). On the steep plots covered by young shrubs (2-4 years) of *C. microphylla* (plant coverage of 10-40%) and *H. rhamnoides* (plant coverage of 40-90%), the mean soil loss over three years was 14.7 and 5.8 t ha^{-1}, respectively. For the land units of STL and VSL, the mean slope steepness is 22.2% and 36.4%, respectively, much lower than that of the sloping land mentioned above. In this study, the average soil loss is arbitrarily set to 0.5 t for STL and 1.2 ha^{-1} for VSL, taking into account the slope steepness, and assuming that the planted shrubs are well-managed.

Labor requirement

Data are not available for labor requirements. In this study, it is assumed that shrubs are harvested by hand in late autumn, with a rate of 150 kg per man-day. The shrub woods are transported to the homestead by donkeys, with a transport rate of 300 and 400 kg from the natural and the newly planted shrub-land, taking into account the distance and land conditions. For planted shrub-land, 3 man-days are needed annually for the necessary management and land preparation for the planting. Thus, annual labor and donkey requirements are: 5.3 man-days and 2.7 days of donkey for the natural shrub activity, 16.3 and 5.0 for the planted shrubs on the land unit of STL, and 13.7 and 4 for the planted shrubs on VSL.

4.6 Quantification of Livestock production activities

Four categories of livestock activities have been defined: sheep/goats, cattle/donkeys, draught animals and pigs. For sheep activities, two breeds are included, and for draught animal activities, two animal types. Thus, eight livestock activities are distinguished, i.e., cashmere goats, fine-wool sheep, small-tail sheep, cattle, donkeys, draught oxen, transport donkeys and pigs. The cattle activity produces draught oxen, and the donkey activity produces transport donkeys. The draught oxen are for supplying farm traction and the transport donkeys are for supplying transport power.

Livestock production and feed requirements of the sheep/goat and cattle/donkey activities are based on a stable herd structure. A simple model based on modeling approaches by Van Duivenbooden *et al.* (1991) and Hengsdijk *et al.* (1996) has been developed to determine the herd structure, and to derive the input-output coefficients for the animals. The modeling approach is described in Appendix 5. Draught oxen, transport donkeys, and pigs are treated as individual animals.

Feed requirements are expressed in terms of digestible energy (DE) and digestible crude protein (DCP). For each animal activity, it is assumed that a diet is selected that meets the minimum requirements of both DE and DCP using the target-oriented approach. Production parameters and determination of the input-output coefficients will be discussed in the following subsections.

4.6.1 Characterization of livestock activities and the target outputs

Goat/sheep activities

Goats and sheep are mainly kept for producing mutton, cashmere and wool in Ansai. The productivity at present is very low due to extensive management. In this study, the three goat/sheep activities are defined according to much-improved production techniques.

The current conditions

Goats are a main meat producer in Ansai and comprise three breeds, i.e., local black goats, Liaoning white-cashmere goats and crossbreeds of these two breeds (CAAC 1993). The white-cashmere goat was introduced from Liaoning province, northeastern China at the end of the 1970s. Reported average slaughter liveweight is 26 kg for castrated male goats and 26.7 kg for the doe, with the dressing rates (ratio of carcass weight to liveweight) of 0.41 and 0.40, respectively. Yearling weight of male kids averages 17.2 kg, 0.36 of which is carcass. First kidding of the doe is at 1.5-2 years of age and mean annual number of kids per doe 1.0-1.1 (CAAC 1993, CADYP 1987, CADAC 1988). Gross cashmere production of an adult male white goat is 0.65 kg, 2-4 times that of the black goat (CADAC 1988, CAAC 1993).

Two sheep breeds are kept in Ansai, i.e. Mongolia sheep and Northern Shaanxi fine-wool sheep, a crossbreed of Mongolia sheep with fine-wool sheep from Xinjiang of northwestern China. Mongolia sheep are small-sized, with average mature weights of 33 kg for the ram and 27 kg for the ewe, producing 1.2 and 1.0 kg wool per year, respectively (CADAC 1988). Average dressing rate of castrated rams and ewes is 0.4. Due to its low productivity, the proportion of Mongolia sheep strongly decreased from about 80% of the population in the early 1980s, to only 18% in 1994. Fine-wool sheep are more productive than Mongolia sheep. Average mature weight of ram and ewe is 49 and 34 kg, respectively, and of yearlings 36 and 30 kg. The reported mean dressing rates (at maturity) are 0.40 and 0.39 for castrated rams and ewes, respectively (*ibid.*). Mean birth rate is 1.1 lambs per ewe per year (CADYP 1987). This information describes the current condition of sheep production in Ansai.

The definition of the goats/sheep activities

For the three animals, i.e., cashmere goats, fine-wool sheep and small-tail sheep[4], the reproductive period is set to 1-5 years, and annual mortality rate is assumed to be 15% and 5%, below and above 1 year of age, respectively. For goats and fine-wool sheep, it is assumed that the kidding/lambing occurs in spring, and 40% of the kids/lambs excluding those kept for replacement are sold in the following late autumn after 8 months of feeding, and the remainder is sold the next year in early autumn (1.5 years of age). For the small-tail sheep, all lambs, except those kept for replacement, are sold after 8 months of feeding, when the liveweight approaches 40 kg. The animals are grazed on pasture in summer-autumn, and fed indoors in winter-spring. Other characteristics for the goats (Zhang 1995, Yu 1995), the fine-wool sheep (Yu 1995), and the small-tail sheep (Mo & Zhao 1997) are presented in Table 4.8. The target production of meat, wool/cashmere, and manure are calculated with the model presented in Appendix 5.

Table 4.8 Characteristics of the three types of goats/sheep, based on Zhang (1995), Yu (1995), and Mo & Zhao (1997). Fecundity rate refers to the number of kids/lambs that a breeding female animal gives birth to per year. Dressing rate is ratio of carcass to the liveweight.

Animals	Mature / yearling liveweight (kg)		Marketable wool production for adult/yearling (kg yr^{-1})		Fecundity rate	Dressing rate
	Male	Female	Male	Female		
Cashmere goats	50 / 43	40 / 36	0.4* / 0.2*	0.3* / 0.15*	1.3	0.45
Fine-wool sheep	90 / 54	50 / 38	5.0 / 2.3	2.8 / 1.3	1.3	0.5
Small-tail sheep	80 / 56	55 / 44	2.8 / 1.2	1.5 / 0.7	2.5	0.5

*cashmere

Cattle activity

Two types of cattle, i.e., Mongolia breed and a crossbreed with the large-sized cattle of the Qinchuan breed are reared in Ansai to provide draught power. According to CADAC (1988), average mature weight of the Mongolia breed is 302 kg for the males and 227 kg for the females, and of the Qinchuan breed 408 kg for the males and 284 kg for the female. Reproduc-

[4] The small-tail sheep are native to Shandong Province of northern China. Because of its high productivity, the small-tail sheep has recently extended to other regions in northern China. Although this sheep activity is not practiced at present, it can be adopted in the future in Ansai, as the climatic conditions are similar to those in the native region of the sheep.

tive life is 10-11 years from 3 to 13-14 years of age. A cow gives birth to 6-8 calves in its whole life. Adult cattle, including the females are mainly used for plowing or transport in Ansai. Based on this information, the cattle activity is defined below.

The active period for breeding is set to 10 years starting from 3 years of age. After 10 years of use, the animals are culled. Mature weight of male cattle is 400 kg, reached at 6 years, female 280 kg, reached at 5 years of age. Annual mortality rate is set to 0.08 and 0.03, below and above 1 year of age, respectively. First calving of a cow is between 3 and 4 years of age with an average fecundity rate of 0.8 calves per year. The calves, except for those kept for replacement, are taken off at three years of age. Liveweight is supposed to remain stable after reaching mature weight. Meat from the obsolete cattle is consumable.

Donkey activity

There are two types of donkeys in Ansai: Shanbei donkeys with average mature weights for males of 188 kg and for females 154 kg; and Jiami crossbred donkeys with average mature weights for males and females of 224 kg and 175 kg, respectively (CAAC 1993). The active life of a donkey is 12-13 years, starting from 2-3 years of age (CADAC 1988). Donkeys are mainly used for transport. A female donkey produces 7-9 foals in its whole life (*ibid.*). In this study, the active period for breeding is set to 12 years, starting at 3 years of age. The final weight of 220 kg for males and 180 kg for females is reached at 6 and 5 years of age, respectively. Female donkeys give birth for the first time at 3 to 4 years of age. Their mean fecundity rate is 0.75 foals per year during their active life. Foals, except for those kept for replacement, are off-taken (sold or used for transport) at three years of age. Donkey meat is consumable.

Draught oxen and transport donkeys

Oxen are used for farm operations (plowing, sowing, etc.) and transport, and donkeys are used only for transport. It is assumed that the mean weight of a draught ox unit (an adult male cattle equivalent) is 400 kg during the active period of 10 years; and that of a transport donkey unit (an adult male donkey equivalent) is 220 kg during the active life period of 12 years. After 10 or 12 years of use, the animals are slaughtered: the meat can be consumed. The feed requirement is simply calculated as a function of daily feed intake and the metabolic weight. The calculations and technical coefficients for both animals are presented in Appendix 5.

Pig activity

Pigs in Ansai are normally fed for about one year and slaughtered at an average liveweight of 80-96 kg, of which about 64% is carcass (CADAC 1988). Daily growth rate averages 0.25-0.28 kg. Each family generally raises 1-4 pigs in a small corral, for producing meat and manure. In this study, a much more productive pig activity is defined: it is slaughtered after 6 months of indoor feeding at a liveweight of 90 kg, of which 70% is carcass, assuming that piglets are bought from markets at a liveweight of 10 kg. Feed requirements are calculated per pig. Feed requirements for the pigs from birth to weaning, sow and boar, are not included.

The feed requirements in Table A5.6 in Appendix 5 are estimated according to data of Li *et al.* (1989).

4.6.2 Feed quality and feed requirements

Types of feed and their feeding values

Available types of feed include crop residues, grass, alfalfa, grain husks and cakes of oil crops, as well as corn and potatoes. Crop residues of corn, millet and wheat are used to feed sheep, goats, cattle and donkeys. The availability of crop residues as feed is set to 75% of their harvested yield, considering that not all residues are consumable. Fodders from the natural and sown grassland are used for grazing.

Corn is the major type of feed for pigs. In this study, corn is not only used to feed pigs, but also ruminants. Potatoes, especially small-sized ones are also often used to feed pigs. It is assumed that 5% of the total potato production is used for pig feeding.

The feeding value of a feed type is animal-dependent. Table 4.9 gives the digestible energy, concentration of crude protein (CP), and the digestibility of CP for all types of feed. The values of DE and digestibility of CP are based on Li & Ji (1997), Mo & Zhao (1997), Li *et al.* (1990) and Li (1996). For donkeys and goats, the feeding value of a feed type is set equal to that for cattle and sheep, respectively.

Table 4.9 Feeding values of grasses and other feedstuffs for different animals

Feed type	CP concentration (% of DM)	DE content (MJ kg^{-1} DM)			Digestibility of CP	
		Cattle	Sheep	Pig	Cattle	Sheep
Corn residue	5.3	9.3	8.8	-	0.33	0.24
Millet residue	6.3	9.0	8.5	-	0.56	0.40
Wheat residue	3.4	7.0	6.6	-	0.14	0.10
Soybean residue	7.5	7.3	6.8	-	0.34	0.29
Wheat husk	16.3	13.2	11.8	13.8	0.76	0.73
Millet husk	8.3	11.9	12.3	12.6	0.72	0.69
Soybean cake	46.7	15.8	15.4	15.5	0.85	0.87
Seed flax cake	36.3	15.0	15.7	13.6	0.88	0.81
Alfalfa	18.8	10.6	11.2	5.4	0.73	0.77
Natural grass	12.0	10.1	8.9	-	0.57	0.60
Sown grass	15.6	10.2	9.7	-	0.62	0.67
Potatoes	9.4	-	-	14.8	-	-
Corn	10.9	16.4	16.3	17.2	0.69	0.57

Feed quality

Feed quality is expressed in terms of the ratio of DE (MJ) to DCP (kg). For each animal activity, a maximum ration of DE:DCP in the diet is given (Table 4.10). These ratios represent a minimum content of DCP in the diet, which are estimated on the basis of recommended diets for sheep (Li 1996), and data from NAC (1993). For small-tail sheep aimed at producing fat lamb meat, higher protein diets (lower ratio DE:DCP) are needed. For cashmere goats, fine-wool sheep, cattle and donkeys, lower protein diets with a higher ratio of DE:DCP are used, as growth is slower, i.e., a high proportion of feed energy is used for maintenance.

For each animal activity, the upper limits of feed intake from grassland are defined, as shown in Table 4.10. Corn is not only a high quality feed for animals, but also a staple food. Therefore, limited use for feeding the ruminants is indicated in Table 4.10. Potatoes are used only for feeding pigs, with the assumption that the fraction in the total DE intake should not exceed 40%. In the pig diet, alfalfa use is assumed to not exceed 10% of the total DE intake according to a recommended dietary ration (Zhao 1996). The data shown in Tables 4.8 and 4.9 will be used to calculate the amount of a specific type of feed consumed by an animal, and to determine N in the animal excreta in Chapter 5.

Table 4.10 Feed quality and feed sources for each animal activity

Animal type	Feed quality (MJ DE kg^{-1} DCP)	DE fraction from grazing	Feedstuffs (figure indicating upper limit of that type of feed in the diet, expressed as fraction of total DE in the diet)
Cashmere goats	140	≤ 0.6	Crop residues, alfalfa, grain husks, and corn (< 15%)
Fine-wool sheep	130	≤ 0.6	The same as for goats
Small-tail sheep	125	≤ 0.5	Alfalfa, grass, crop residues, husks and corn (< 30%)
Cattle	165	≤ 0.5	Crop residues, alfalfa, grain husks and corn (< 25%)
Donkeys	165	≤ 0.5	The same as for cattle
Draught oxen	200	≤ 0.2	The same as for cattle
Transport donkeys	200	≤ 0.2	The same as for cattle
Pigs			Corn, potato (< 40%), wheat husk, and alfalfa (< 10%)

Determination of feed requirement

Feed requirements for maintenance and growth are expressed in terms of DE and DCP. The maintenance requirements of all ruminants are estimated as a function of their metabolic weight. Daily DE intake for maintenance is set to 0.586 MJ $W^{-0.75}$ for all ruminants according to NAC (1994). The growth requirement of feed for sheep and goats is calculated on the basis of utilization efficiency of metabolic energy (UEM) for the net body-weight gain (Eqn 4.6). The UEM, defined as the ratio of energy retention (in body gain) to metabolic energy (ME) intake, decreases with increase in age, and varies for different animals. Value of UEM reported by Bondi (1982) is 0.35-0.47 for sheep. In this study, an average value of 0.41 for UEM is used for both sheep and goats. Net weight gain of an animal unit (defined as 500 kg liveweight of total goats/sheep in the herd) equals total liveweight of the culled animals per year. Total energy stored in the animal products is based on protein and fat content in the carcass. For cattle and donkeys, the DE requirement for growth is calculated with a different procedure, as described in Appendix 5.

$$GDE = \frac{W \cdot DR \cdot (23.85 \cdot C_p + 38.49 \cdot C_f)}{0.82 \cdot UEM} \cdot (1 + f) \qquad 4.6$$

in which GDE is total DE required for growth (MJ), W is total liveweight of culled sheep or goats (kg) per animal unit, and DR is dressing rate, i.e., ratio of carcass weight to liveweight of the culled animals. C_p and C_f are concentration of protein and fat in animal carcass. In this study, the following values (kg kg^{-1}) are used: protein 0.15 and fat 0.26 for sheep, and 0.21 and 0.04 for goats according to Li (1996), Yu (1995) and AHDMA (1993). f is a factor used to take into account energy stored in fur, wool, etc., and a value of 0.15 is used. Constants 23.85 and 38.49 are heat of combustion value (MJ kg^{-1}) of animal protein and fat (NAC 1993), respectively, and 0.82 is the efficiency of conversion of DE into ME by ruminants.

From the calculated DE demand, the requirement of DCP can be determined by dividing the required DE with the defined ratio of DE:DCP for each ruminant animal. Feed requirement of pigs is based on information from literature. The feed requirements, and the production of meat, and wool/cashmere for all animals are given in Table A5.6 in Appendix 5.

4.6.3 N exported by animal products

Small part of N in feed consumption by an animal is transformed into animal products. The amount of N exported by animal products (N_p, kg N) can be calculated with Eqn. 4.7. The remaining amount is excreted in faeces and urine, which can be used for plant production. Determination of total N in faeces and urine, and the availability for agricultural production, will be described in Chapter 5.

$$N_p = \frac{DR \cdot W \cdot C_p}{6.25} + WL \cdot C_N \qquad 4.7$$

in which WL is wool production (kg), and C_N fraction of N in wool, which is set to 0.16 according to AHDMA (1993). The value of 6.25 is a constant and used to convert N to protein.

4.6.4 Labor requirements and costs

Labor requirements refer to herding, feeding and shearing of goats and sheep. According to Yu (1995), one herdsman can handle a small herd with 40-80 goats. Labor requirements for herding of both goats and sheep are set to 0.15 man-days per animal unit (equal to 16.7 goats, 13.2 fine-wool sheep and 14.5 small-tail sheep in this study). A sheep or goat is generally clipped once a year in spring. One laborer is required for shearing 20-30 sheep manually (*ibid.*). Cattle and donkeys are reared individually per family. Grazing is normally on grassland near to the homesteads. It is assumed that half a man-hour per day is needed for taking the animals to pastures and back.

For animal feeding in corrals, no data on labor requirements are available. It is assumed that the same labor, i.e., one-third man-day is needed for feeding an animal unit of goats and sheep; 0.12 and 0.10 man-days are required for feeding a draught cow and transport donkey, respectively. Pig rearing is homestead-based, with 1-4 pigs per family. It is assumed that 0.10 man-days are needed per two pigs. Costs include those for veterinary care, salt and corrals. For pigs, additional cost for buying piglets is required. The costs excluding concentrates (e.g., corn) shown in Table A5.6 in Appendix 5, are estimated on the basis of information from literature (ACTER 1986, AHDMA 1993, ECHATE 1983, Yu 1995).

Chapter 5 Mathematical Description of the MGLP Model for Optimization of Land Use Options

In this chapter, a mathematical description of the MGLP model is presented. Section 5.1 describes the land use activities (land-based agricultural production activities), Section 5.2 the animal activities, Section 5.3 the objective functions, and Section 5.4 the constraints. The presented structure, relationships among the production activities and the constraints, and formulae will be used as the basis of the model construction using the XPRESS software (Dash Associates 1997).

5.1 Land use activities

Four categories of land use activities are defined, i.e., cropping (*CA*), fruit (*FA*), grass (*GA*) and firewood (*WA*) activities. The land use activities are land-based, so the input-output coefficients are quantified per hectare per year.

Not all land can be used for agriculture (Fig. 5.1). Excluded areas are preserved and unusable land including forest-land, bad-land (extremely steep land), water bodies (river and reservoirs) and non-agricultural land (residence areas, urban areas and roads, etc.). These excluded areas are not part of model optimization, and they always belong to the category 'preservation'. The land available for agriculture (*land*) is divided into three categories: 1) suitable land (*Suit*) that can be used for growing crops, apples, (sown) grasses and (planted) shrubs; 2) natural grassland (*Ngl*) that can be used only for animal grazing; and 3) natural shrub-land (*Nsl*) that is used only for firewood collection. Use of these types of agricultural land can be optimized by the MGLP model. If the total area allocated to different land use types is less than the available area for a model optimization, the unused part is assumed to be preserved (Fig. 1.1). The land allocation among different land use activities and the available land area can be mathematically described as:

$$\sum_{l} AC_{l,g} + \sum_{l} AF_{l,g} + \sum_{l} AG_{l,g} + \sum_{l} AW_{l,g} = Suit_g \qquad 5.1.1a$$

$$Suit_g + Ngl_g + Nsl_g = Land_g \qquad 5.1.1b$$

in which AC is land area (ha) used for crops, AF for apple, AG for sown grassland, and AW for planted shrubs (firewood). The subscript $_l$ represents the suitable land units and $_g$ the sub-regions, as classified according to administrative units. Available land resources, labor and draught animals, and population size differ among the sub-regions, but the input-output

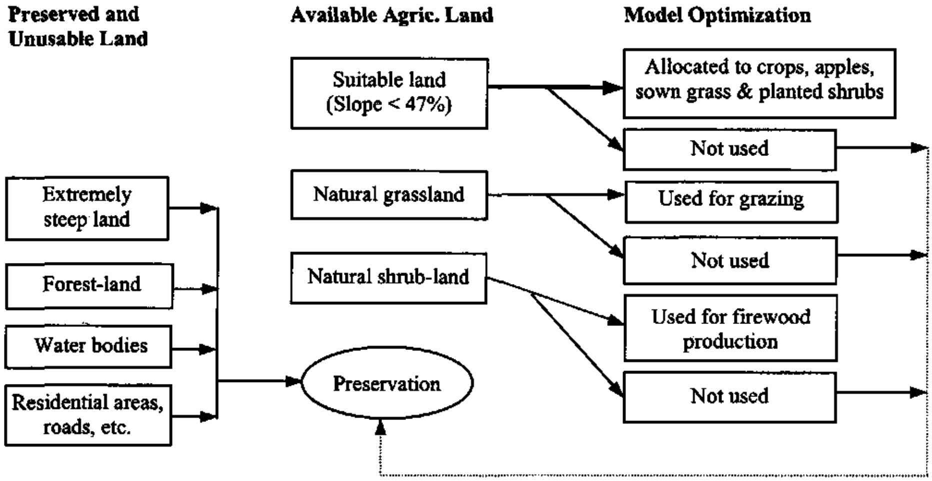


Figure 5.1 Available land types and land allocation

coefficients of the activities are not related to the sub-regions, as we assumed that the climate is homogeneous throughout the county.

Mathematical descriptions concerning the inputs-outputs for all production activities will be given in the next subsections.

5.1.1 Definition of land use activities

Land use activities are characterized by several defining factors, and the input-output coefficients. Each definition factor is normally divided into different classes. In this subsection, mathematical definitions for the land use activities, and indices used to indicate the defining factors and the coefficients are presented.

Cropping and terracing activities

Cropping activities are differentiated by crop rotations ($_r$), soil conservation (tillage method per s and crop residue management) ($_t$), production levels ($_p$), mechanization levels ($_h$), terracing options ($_c$), suitable land units ($_l$) and sub-regions ($_g$). A cropping activity ($CA_{r,t,p,h,c,l,g}$) is a feasible combination of the defining factors (Table 5.1). Excluding the infeasible combinations (e.g., terracing cannot be used on the flood plain), a total of 2006 cropping activities, grouped into 5 categories and 11 sub-categories for each sub-region are defined (Table 5.2).

Inputs for terracing and manure use are not included in the input tables of the cropping activities. Terracing and application of manure are treated as separate activities. A terracing activity ($TRC_{c,m,l,g}$) is defined as a combination of terracing types (for soil conservation measures $_{c\,=\,BT,\,ST}$), terracing methods ($_m$), land units and sub-regions. The terracing activities are related to the cropping activities with Eqn 5.1.2, i.e., the total cropping area with terracing land unit per sub-region should be equal to the construction area for that terrace type (bench or spaced terrace).

$$\sum_{m} TRC_{c,m,l,g} = \sum_{h}\sum_{p}\sum_{t}\sum_{r} CA_{r,t,p,h,c,l,g} \qquad 5.1.2$$

For activities of manure application, the definition is given at the end of this subsection.

Table 5.1 Lists of indices and abbreviations used for defining cropping activities and for the input-output items in the MGLP model

Index and description		Classes of the definition factors and their abbreviations
r	Crop rotations	17 crop rotations as shown in Table 2.2
t	Soil conservation	*CR*: none or contour tillage, crop residue removed; *CM*: none or contour tillage, crop residue left on field; *FR*: furrow-ridges, crop residue removed; *FM*: furrow-ridges, crop residue left on field
p	Production levels	*AIP*: attainable irrigated yield; *ARP*: attainable rainfed yield; *NLP*: N-limited yield
h	Mechanization levels	*SM:* semi-mechanized; *HM:* non-mechanized/hand labor
c	Terracing options	*DT*: none or hillside ditches; *BT*: bench terracing; *ST*: space terracing
l	Suitable land units	*FLP*: flood plain; *GSL*: gently sloping land: *MSL*: moderately sloping land; *STL*: steep sloping land; *VST*: very steep sloping land; and *TRL*: existing terraced land
g	Sub-region	6 sub-regions
m	Terracing methods	*BD*: by bulldozer; *HL*: by manual labor
i	Main (marketable) crop products	*CRN*: corn; *WHT*: winter wheat; *MLT*: millet; *SOY*: soybean; *POT*: autumn potato; *SPT*: summer potato; *FLX*: seed flax; and *ALF*: alfalfa
u	Crop residues	*RCRN*: corn residue; *RWHT*: wheat residue; *RMLT*: millet residue; *RSOY*: soybean residue; *RFLX*: flax residue
f	Mineral nutrients	*N*: nitrogen; *P*: phosphorus; *K*: potassium
j	Labor demand periods	*LP1, LP2, LP3, LP4, LP5*, corresponding to labor demand periods 1, 2,..., 5.
a	Draught animals	*OXN*: draught cattle (oxen); *DNK*: transport donkeys

Table 5.2 Cropping activities as feasible combinations of the defined production techniques

Group of the defined cropping activities	Code of the activities
1. Semi-mechanized, attainable irrigated yield	
1.1 None for soil conservation	$CA_{r,\, t(=CR,\, CM),\, p(=AIP),\, h(=SM),\, c(=DT),\, l(=FLP),\, g}$
2. Hand labor and animal traction, attainable irrigated yield	
2.1 None for soil conservation	$CA_{r,\, t(=CR,\, CM),\, p(=AIP),\, h(=HM),\, c(=DT),\, l(=FLP),\, g}$
3. Semi-mechanized, attainable rainfed yield	
3.1 None or with hillside ditches for conservation	$CA_{r,\, t,\, p(=ARP),\, h(=SM),\, c(=DT),\, l(=FLP,\, GSL,\, MSL),\, g}$
3.2 With bench terracing for soil conservation	$CA_{r,\, t(=CR,\, CM),\, p(=ARP),\, h(=SM),\, c(=BT),\, l(=GSL,\, MSL),\, g}$
3.3 With spaced terracing for soil conservation	$CA_{r,\, t,\, p(=ARP),\, h(=SM),\, c(=ST),\, l(=GSL,\, MSL),\, g}$
4. Hand labor and animal traction, attainable rainfed yield	
4.1 None for soil conservation	$CA_{r,\, t(=CR,\, CM),\, p(=AIP),\, h(HM),\, c(=DT),\, l(=FLP),\, g}$
4.2 With bench terracing for soil conservation	$CA_{r,\, t(=NR,\, NM),\, p(=ARP),\, h(=HM),\, c(=BT),\, l(=GSL,\, MSL,\, STL,\, VST),\, g}$
4.3 With spaced terracing for soil conservation	$CA_{r,\, t,\, p(=ARP),\, h(=HM),\, c(=ST),\, l(=GSL,\, MSL,\, STL,\, VST),\, g}$
5. Hand labor and animal traction, N-limited yield	
5.1 None or with hillside ditches for soil conservation	$CA_{r,\, t,\, p(=NLP),\, h(=HM),\, c(=DT),\, l(=FLP,\, GSL,\, MSL,\, STL),\, g}$ $CA_{r,\, t(=NM,\, FR,\, FM),\, p(=NLP),\, h(=HM),\, c(=DT),\, l(=VST),\, g}$ $CA_{r,\, t(=CR,\, CM),\, p(=NLP),\, h(=HM),\, c(=DT),\, l(=TRL),\, g}$
5.2 With bench terracing for soil conservation	$CA_{r,\, t(=CR,\, CM),\, p(=NLP),\, h(=HM),\, c(=BT),\, l(=GSL,\, MSL,\, STL,\, VST),\, g}$
5.3 With spaced terracing for soil conservation	$CA_{r,\, t,\, p(=NLP),\, h(=NM),\, c(=ST),\, l(=GSL,\, MSL,\, STL,\, VST),\, g}$
6. Terracing activities	$TRC_{c(=BT,\, ST),\, m,\, l(=GSL,\, MSL,\, STL,\, VST),\, g}$

Fruit activities

Fruit (apple) activities are characterized by land unit and water availability (irrigation or rainfed). For each land unit, only one fruit activity is defined, i.e., for the floodplain the fruit activity is irrigated, and for the hilly land units, the activities are rainfed (refers to Section 4.6 of Chapter 4). Thus, a fruit activity ($FA_{l,g}$) is a unique combination of a suitable land unit and a sub-region.

Grass activities

Two types of grassland are distinguished: sown grass and natural grass. The sown grass activities are differentiated into two yield levels ($_n$), i.e., *WGL*, with external N inputs and *NGL*, without external N inputs. Other defining factors used for cropping activities, such as terracing, furrow-ridging and mechanization level, are not used for grass activities. Thus, a sown grass activity ($GA_{n,l,g}$) is characterized by production levels, suitable land units and sub-regions. The sown grass activities are assumed to be practiced only on hilly land units, and therefore the index $_{l}$ = $_{GSL, MSL, STL, VST}$. The natural grassland is not treated as activities, as we assume that the area and the total grass production per sub-region are permanent.

Firewood production activities

Two firewood production activities are defined: planted and natural shrubs. The planted shrubs are assumed to be growing only on steep and very steep land units, with an identical production technique. Thus, a planted shrub activity ($WA_{l,g}$) is characterized by suitable land units ($_l$ = $_{STL, VST}$) and sub-regions. For natural shrub-land, the firewood production and required inputs per hectare, such as labor and transport animals (for firewood collection), are assumed to be identical throughout the county.

Manure application

Manure can be used for crop, fruit and (sown) grass production. Requirements of labor and draught animals, and costs (for tractors and transport tools) for manure applications depend on transport means, land slope, and distance between homesteads and fields. As production techniques are different among cropping, fruit and grass activities, the manure application is defined for each of the three categories. For manure applied to crop production, an activity for manure application ($CMN_{h,c,l,g,s,j}$) is characterized by power source (mechanization levels, $_h$), terracing options ($_c$), land units, sub-regions, source of the manure ($_s$ = animal types, see Table 5.3), i.e., the manure from which animal activity, and labor period in which the manure is applied. For manure applied to apples and sown grassland, the manure application activities ($FMN_{l,g,s,j}$ and $GMN_{l,g,s,j}$, respectively) are characterized only by land units, sub-regions, source of the manure, and labor requirement period.

5.1.2 Physical crop production

Total crop production

Products of a crop include the main product (consumable or marketable: grain, tuber, bean or forage), and the by-product (harvested residue) that can be used for feeding animals or for firewood. Per sub-region, the total amount of main product (refers to net production that is corrected for harvest and post-harvest losses) and available residue (excluding losses) is a summation of the production over all activities for a particular crop, as calculated with Eqns 5.1.3-4, respectively:

$$CAPRD_{g,i} = \sum_{l}\sum_{c}\sum_{h}\sum_{p}\sum_{t}\sum_{r} CA_{r,t,p,h,c,l,g} \cdot yld_{r,t,p,h,c,l,i} \cdot nyld_i \qquad 5.1.3$$

$$RSP_{g,u} = \sum_{l}\sum_{c}\sum_{h}\sum_{p}\sum_{t}\sum_{r} CA_{r,t,p,h,c,l,g} \cdot rsh_{r,t,p,h,c,l,u} \cdot nrsh_u \qquad 5.1.4$$

in which the variables (kg DM, in sub-region $_g$) $CAPRD_{g,i}$ = total production of crop product $_i$, and $RSP_{g,u}$ = total amount of available crop residue $_u$. The coefficients for unit area production (kg DM ha^{-1}) of cropping activities ($CA_{r,t,p,h,c,l}$) $yld_{r,t,p,h,c,l,i}$ = main crop product $_i$ and $rsh_{r,t,p,h,c,l,u}$ = harvested residue $_u$. Correction factors (kg kg^{-1}) for the harvest and post-harvest losses of $nyld_i$ = main crop product $_i$, and $nrsh_u$ = harvested crop residue $_u$.

Apple production

Apple production is a summation of yield over all activities, minus the losses during harvest and storage, as calculated by equation:

$$FAPRD_g = \sum_{l} FA_{l,g} \cdot ayld_l \cdot nayd \qquad 5.1.5$$

in which the variable $FAPRD_g$ = total apple production (kg, fresh weight) in sub-region $_g$, and the coefficients $ayld_l$ = apple yield in fresh weight (kg ha^{-1}) of fruit activities in land unit $_l$ and $nayd$ = correction factor (kg kg^{-1}) for the harvest and storage losses of apple.

Grass production

Total grass production per sub-region is a summation of the production over all sown grass activities, plus the production from natural grassland that are used for grazing, presented as:

$$GAPRD_g = \sum_{l}\sum_{n} GA_{n,l,g} \cdot sgyld_{n,l} + NGA_g \cdot ngyld_g \qquad 5.1.6a$$

$$NGA_g \le Ngl_g \qquad 5.1.6b$$

in which the variables $GAPRD_g$ = total grass production (ton in DM) in sub-region $_g$ and NGA_g = area (ha) of the natural grassland used for grazing in sub-region $_g$. The coefficients (kg DM ha^{-1}) $sgyld_{n,l}$ = yield of the sown grassland with N-input level $_n$ in land unit $_l$, and $ngyld_g$ = average (accessible) yield of the natural grassland in sub-region $_g$.

Firewood production

Total firewood is total production of the natural shrub-land used for firewood production and the planted shrub-land, as calculated with equation:

$$WOOD_g = \sum_l WA_{l,g} \cdot pwyld_l + NWA_g \cdot nwyld \qquad 5.1.7a$$

$$NWA_g \leq Nsl_g \qquad 5.1.7b$$

in which the variables $WOOD_g$ = total firewood production (kg DM) of sub-region $_g$, $WA_{l,g}$ = area (ha) of a planted shrub activity practiced on land unit $_l$ in sub-region $_g$, and NWA_g = area (ha) of the natural shrub-land used for firewood production in sub-region $_g$. The coefficients (t DM ha^{-1}) $pwyld_l$ = annual firewood production of planted shrub activities in land unit $_l$, and $nwyld$ = annual firewood production of natural shrub-land.

5.1.3 Soil and N losses

Soil losses

For each category of the land use activities, total soil losses per sub-region are a summation over all activities in that land use category. Total soil losses ($CANLS_g$ in ton) from cropland equals area (ha) of a cropping activity ($CA_{r,t,p,h,c,l,g}$) multiplied by the unit soil losses ($slha_{r,t,p,h,c,l}$, t ha^{-1}), summed over all activities:

$$CANLS_g = \sum_l \sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot slha_{r,t,p,h,c,l} \qquad 5.1.8$$

Total soil losses ($FANLS_g$, ton) from fruit activities are calculated with Eqn 5.1.9, where $asls_l$ is unit area soil loss (t ha^{-1}):

$$FASLS_g = \sum_l FA_{l,g} \cdot asls_l \qquad 5.1.9$$

Total soil losses ($GANLS_g$, ton) from grass activities equals area of a sown grass activity multiplied by the soil losses ($gsls_{n,l}$, t ha^{-1}), summed over all sown grass activities:

$$GASLS_g = \sum_l \sum_n GA_{n,l,g} \cdot gsls_{n,l} \qquad 5.1.10$$

Total soil losses ($WANLS_g$, ton) from planted shrub-land equals area of a planted shrub activity multiplied by the soil losses ($pwsls_l$, t ha^{-1}), summed over all activities:

$$WASLS_g = \sum_l WA_{l,g} \cdot pwsls_l \qquad 5.1.11$$

N losses

Similar equations to those given for soil losses are applied for the calculation of total N losses from cropping, fruit, sown grass and planted shrub activities, as presented below:

$$CANLS_g = \sum_l \sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot nlha_{r,t,p,h,c,l} \quad 5.1.12$$

$$FANLS_g = \sum_l FA_{l,g} \cdot anls_l \quad 5.1.13$$

$$GANLS_g = \sum_l \sum_n GA_{n,l,g} \cdot gnls_{n,l} \quad 5.1.14$$

$$WANLS_g = \sum_l WA_{l,g} \cdot pwnls_l \quad 5.1.15$$

in which the variables for total N losses (kg, in sub-region $_g$) from $CANLS_g$ = cropping land, $FANLS_g$ = fruit land, $GANLS_g$ = sown grass land, and $WANLS_g$ = planted shrub-land. The coefficients for unit area N loss (kg ha^{-1}) of $nlha_{r,t,p,h,l}$ = cropping activities, $anls_l$ = fruit activities, $gnls_{n,l}$ = sown grass activities, and $pwnls_l$ = planted shrub activities.

5.1.4 Inputs of fertilizers, biocides and irrigation water

Fertilizer inputs

Total inputs of chemical fertilizers are calculated as the total requirements minus those applied from manure, assuming that the use efficiency of manure N (P and K) is identical to that of mineral N (P and K). For each sub-region, the following equations are used to calculate the total inputs of fertilizers.

1) Requirements of mineral fertilizers for crop production:

$$CAFERT_{g,f} = \sum_l \sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot nha_{r,t,p,h,c,l,f} - \sum_j \sum_s \sum_l \sum_c \sum_h CMN_{c,h,l,s,g,j} \cdot nc_{s,f} \quad 5.1.16$$

2) Requirements of mineral fertilizers for apple production:

$$FAFERT_{f,g} = \sum_l FA_{l,g} \cdot fnha_{l,f} - \sum_j \sum_s \sum_l FMN_{l,g,s,j} \cdot nc_{s,f} \quad 5.1.17$$

3) Requirements of mineral N ($_f$ = $_N$) for the sown grassland, calculated with Eqn 5.1.18a, in which $_n$ = $_{SGW}$, $_f$ = $_N$ and $_z$ = $_{SGS}$; and of P and K with Eqn 5.1.18b, where $_f$ = $_{P,K}$ and $_z$ = $_{SGS, SGN}$.

$$GAFERT_{f,g} = \sum_l GA_{n,l,g} \cdot gnha_{n,l,f} - \sum_j \sum_s \sum_l GMN_{l,g,s,j} \cdot nc_{s,f} - \sum_s GNU_{z,s,g} \quad 5.1.18a$$

$$GAFERT_{f,g} = \sum_l \sum_n GA_{n,l,g} \cdot gnha_{n,l,f} - \sum_j \sum_s \sum_l GMN_{l,g,s,j} \cdot nc_{s,f} - \sum_z \sum_s GPK_{z,s,f,g} \quad 5.1.18b$$

in which (for Eqns 5.1.16-18), the variables for total inputs (kg) of mineral nutrients (N, P and K) in $CAFERT_{f,g}$ = crop production, $FAFERT_{f,g}$ = fruit production and $GAFERT_{f,g}$ = grass production in sub-region $_g$; the variables for total amount (kg) of manure N from animal $_s$, as applied (labor requirement period $_j$) to $CMN_{c,h,l,g,s,j}$ = cropping activities, $FMN_{l,g,s,j}$ = fruit activities and $GMN_{l,g,s,j}$ = (sown) grass activities in land unit $_l$ in sub-region $_g$; and the variables $GNU_{z,s,g}$ = available N and $GPK_{z,s,f,g}$ = available P and K for grassland $_z$ in slurry excreted during grazing of animal $_s$ in sub-region $_g$ (see Eqns 5.2.25 and 5.2.28). The coefficients for unit area inputs (kg ha^{-1}) of nutrients (N, P or K) in $nha_{r,t,p,h,c,l,f}$ = cropping activities, $fnha_{l,f}$ = fruit activities and $gnha_{n,l,f}$ = sown grassland; and the coefficient $nc_{s,f}$ = concentration of N, P or K in manure (kg kg^{-1}) of animal type $_s$.

4) Per sub-region, the total nutrient requirements ($FERT_{f,g}$) is a summation over all land use activities, minus the available nutrients in the excreta passed by draught animals while working on the fields. For N ($_{f=N}$), it is calculated with Eqn 5.1.19a, and for P and K ($_{f=P,K}$) with Eqn 5.1.19b.

$$FERT_{f,g} = CAFERT_{f,g} + GAFERT_{f,g} + GAFERT_{f,g} - \sum_s WNU_{s,g} \qquad 5.1.19a$$

$$FERT_{f,g} = CAFERT_{f,g} + GAFERT_{f,g} + GAFERT_{f,g} - \sum_s WPK_{s,g} \qquad 5.1.19b$$

Per sub-region, total used amount of manure (from animal $_s$) should not exceed the total available amount for that sub-region, as described by an equation ($_{f=N}$)

$$MNU_{s,g} - OvMU_{s,g} = \left(\sum_j \sum_l \sum_c \sum_h CMN_{h,c,l,g,s,j} + \sum_j \sum_l FMN_{l,g,s,j} + \sum_j \sum_l GMN_{l,g,s,j} \right) \cdot nc_{s,f} \qquad 5.1.20$$

in which (Eqns 5.1.19-20), the variables (kg N) $WNU_{s,g}$ = total available amount of slurry N, $WPK_{s,g}$ = total available amount of P (K) excreted in the fields by draught animals ($_{s=OX,DK}$, see Table 5.3) while working, $MNU_{s,g}$ = total available manure N produced by animal $_s$ in sub-region $_g$, and $OvMU_{s,g}$ = amount of manure N from animal $_s$ not used for land-based agriculture in sub-region $_g$. The first three variables will be described in the next section.

Biocide inputs

Total biocide inputs for crop and fruit production per sub-region are computed with the following equations:

$$CABCD_g = \sum_l \sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot bha_{r,t,p,h,c,l} \qquad 5.1.21$$

$$FABCD_g = \sum_l FA_{l,g} \cdot fbha_l \qquad 5.1.22$$

in which (for Eqns 5.1.21-22), the variables for total inputs of biocides (kg, active ingredients, in sub-region $_g$) in $CABCD_g$ = crop production and $FABCD_g$ = fruit production. The coefficients for unit biocide input (kg ha^{-1}, active ingredient) of $bha_{r,t,p,h,c,l}$ = cropping activities and $fbha_l$ = fruit activities.

Water requirement

Irrigation water is only available for the flood plain. Total water requirement (WAT_g) for crop production per sub-region is cropping area multiplied by the unit water requirement ($wha_{r,t,p,h,c,l}$, t ha^{-1}) of the cropping activities, summed over all activities. For rainfed cropping activities, the coefficient *wha* is 0.

$$WAT_g = \sum_l \sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot wha_{r,t,p,h,c,l} \qquad 5.1.23$$

The fruit activity in the flood plain also needs irrigation. For other activities, water requirement, as indicated with the coefficient $fwha_l$ (t ha^{-1}) is 0. Total water requirement ($FAWAT_g$, ton) for fruit production per sub-region is calculated as:

$$FAWAT_g = \sum_l FA_{l,g} \cdot fwha_l \qquad 5.1.24$$

5.1.5 Labor inputs

Labor inputs are calculated for each of the five labor requirement periods, as defined for crop production in Chapter 4. Annual labor input is the summation over the five periods. It is assumed that manure can be applied for all land use activities in any period, and terraces are built in the fifth period.

Total labor inputs for crop production

Labor requirements for the cropping activities include those for farming operations, application of manure, and terracing. Labor required for manure transport and application depends on transport means (tractor or animals) and land conditions (slope steepness and the distance between homesteads and fields), i.e., it varies with mechanization levels and land units. Labor required for terrace construction depends on terracing methods (by bulldozers or by hand) and land units. Per sub-region, the total required labor for terrace construction, and total labor inputs for crop production can be described by Eqns 5.1.25a and 5.1.25b, respectively.

$$TRLB_{j,g} = \sum_l \sum_m \sum_{c=BT,ST} TRC_{c,m,l,g} \cdot tlab_{c,m,l,j} \qquad 5.1.25a$$

$$CALAB_{j,g} = \sum_l \sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot lab_{r,t,p,h,c,l,j} + TRLB_{j,g} + 0.001 \cdot \left(\sum_s \sum_l \sum_h \sum_c CMN_{c,h,l,g,s,j} \cdot mlab_{c,h,l} \right) \qquad 5.1.25b$$

in which the variables $TRLB_{j,g}$ = total labor requirement (man-days) for terrace construction in period $_j$, $CALAB_{j,g}$ = total labor inputs (man-days) for cropping activities in period $_j$; and $TRC_{c,m,l,g}$ = terracing activities ($_{c\,=\,ST,\,BT}$), i.e., construction area (ha) of terrace type $_c$ with terracing method $_m$ for land unit $_l$ in sub-region $_g$. The coefficients for unit labor requirement (man-days ha^{-1} in period $_j$) of $lab_{r,t,p,h,c,l}$ = cropping activities ($CA_{r,t,p,h,c,l}$) and $tlab_{c,m,l,j}$ = terracing activities ($TRC_{c,m,l}$). The coefficient $mlab_{c,h,l}$ = labor requirements (man-days t^{-1}) for transport and application of manure, as applied to all cropping activities with soil conservation measure $_c$ and mechanization level $_h$, practiced on land unit $_l$.

Labor inputs for fruit production

Total labor inputs for fruit production are a summation of labor required for routine orchard management and harvest, and for application of manure. Total labor inputs per period per sub-region are calculated as:

$$FALAB_{j,g} = \sum_l FA_{l,j,g} \cdot flbh_{l,j} + 0.001 \cdot \left(\sum_s \sum_l FMN_{l,g,s,j} \cdot fmlb_l \right) \qquad 5.1.26$$

in which the variable $FALAB_{j,g}$ = total labor requirements (man-days) for apple production in period $_j$ in sub-region $_g$. The coefficients $flbh_{j,l}$ = labor requirements (in period $_j$) of fruit activities practiced on land unit $_l$ (man-days ha^{-1}) and $fmlb_l$ = man-days required for one ton manure N applied to fruit activities (in land unit $_l$).

Labor inputs for (sown) grass production

For grass activities, labor inputs per period per sub-region are calculated with equation 5.27, in which $GALAB_{j,g}$ is total labor inputs (man-days) for period $_j$ in sub-region $_g$, and $glbh_{n,l,j}$ is labor requirement (man-days ha^{-1}) for normal operations, and $gmlb_l$ is labor requirements for applying manure (man-days t^{-1}).

$$GALAB_{j,g} = \sum_l \sum_n GA_{n,l,g} \cdot glbh_{n,l,j} + 0.001 \cdot \left(\sum_s \sum_l GMN_{l,g,s,j} \cdot gmlb_l \right) \qquad 5.1.27$$

Labor inputs for firewood production

Labor inputs for firewood production are calculated with the following equation:

$$WDLAB_{j,g} = \sum_l WA_{l,g} \cdot pslb_{l,j} + NWA_g \cdot nslb_j \qquad 5.1.28$$

in which the variable $WDLAB_{j,g}$ = total labor inputs for firewood production (man-days) in labor period $_j$, and the coefficients for labor requirements (man-days ha^{-1}) for harvest of firewood (period $_j$) of $pslb_{l,j}$ = planted shrub activities, and $nslb_j$ = the natural shrub-land.

5.1.6 Animal traction

Draught animals include oxen and donkeys. Oxen are used for ploughing, sowing and transport of agricultural products and manure, etc., and donkeys are used only for transportation. The unit of measurement for animal traction is an ox day or a (adult male) donkey day, i.e., the work that can be done by an ox or a male donkey during one day of 8 hours. Similar to labor inputs, total requirements for draught animals are computed per period per sub-region.

Inputs of draught animals in cropping activities

Total days required for oxen and donkeys per labor requirement period are calculated as:

$$CADA_{j,a,g} = \sum_{l}\sum_{c}\sum_{h}\sum_{p}\sum_{t}\sum_{r} CA_{r,t,p,h,c,l,g} \cdot daha_{r,t,p,h,c,l,j,a} + 0.001 \cdot \left(\sum_{s}\sum_{l}\sum_{h}\sum_{c} CMN_{c,h,l,g,s,j} \cdot dat_{c,h,l,a} \right) \tag{5.1.29}$$

in which the variable $CADA_{j,a,g}$ = total days required for draught animal $_a$ in period $_j$ in sub-region $_g$. The coefficients $daha_{r,t,p,h,c,l,j,a}$ = days required for draught animal $_a$ per hectare in period $_j$ for cropping activities $CA_{r,t,p,h,c,l}$, and $dat_{c,h,l,a}$ = days of draught animal $_a$ required for one ton manure, as applied to cropping activities (with soil conservation measure $_c$ and mechanization level $_h$, practiced in land unit $_l$).

Inputs of draught animals in fruit activities

Inputs of oxen and donkeys are calculated with functions similar to those used for cropping activities.

$$FADA_{j,a,g} = \sum_{l} FA_{l,g} \cdot fdha_{l,j,a} + 0.001 \cdot \left(\sum_{s}\sum_{l} FMN_{l,g,s,j} \cdot fdat_{l,a} \right) \tag{5.1.30}$$

in which the variable $FADA_{j,a,g}$ = total days required for draught animal $_a$ in period $_j$ in sub-region $_g$. The coefficients $fdha_{l,j,a}$ = required days of draught animal $_a$ per hectare for period $_j$; and $fat_{l,a}$ = days of draught animal $_a$ needed per ton application of manure.

Inputs of draught animals in grass activities

For sown grassland, only oxen are used for ploughing, sowing and application of fertilizers.

$$GADA_{j,a,g} = \sum_{l} GA_{l,g} \cdot gsda_{l,j,a} + 0.001 \cdot \left(\sum_{s}\sum_{l} GMN_{l,g,s,j} \cdot gdat_{l,a} \right) \tag{5.1.31}$$

in which the variable $GADA_{j,a,g}$ = total days required for draught animal $_a$ in period $_j$ in sub-region $_g$. The coefficients $gsda_{l,j,a}$ = days required for draught animal $_a$ per hectare in period $_j$, and $gdat_{l,a}$ = oxen days ($_a = _{OXN}$) required for applying one ton manure-N to sown grassland in land unit $_l$.

Inputs of draught animals in firewood production activities

For firewood production, only donkeys are used for transporting the harvested firewood to homesteads. Total days ($WDDA$, $_a = _{DNK}$) required for transport donkeys are computed as:

$$WDDA_{j,a,g} = \sum_{l} WA_{l,g} \cdot psda_{l,j,a} + NWA_g \cdot nsda_{j,a} \tag{5.1.32}$$

in which the variable $WDDA_{j,a,g}$ = total donkey days required in labor period $_j$ in sub-region $_g$. The coefficients for requirements (days ha^{-1}) of donkeys in period $_j$ for transporting firewood from $psda_{l,j,a}$ = planted shrubs on land unit $_l$ and $nsda_{j,a}$ = natural shrubs.

5.1.7 Production costs and net return in agriculture

Total monetary inputs for crop production

Production costs include those for: 1) farm equipment and machinery use, 2) fertilizers and biocides, 3) seeds; 4) irrigation water, 5) terracing, 6) draught animals and 7) labor. Costs for farm equipment and machinery use is specified for each cropping activity. Seed costs depend on rotations, i.e., type and frequency of crops in a rotation, and production levels (higher seed requirements are assumed for higher production levels because of higher plant density). Other items can be calculated using the price multiplied by the total required amount or days for each sub-region.

$$\begin{aligned} CACOST_g = & \sum_l \sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot cstha_{r,t,p,h,c,l} \\ & + \sum_l \sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot seed_{r,p} \\ & + \sum_f CAFERT_{g,f} \cdot nprc_f + WAT_g \cdot wprc + CABCD_g \cdot bprc \\ & + \sum_a \sum_j CADA_{a,j,g} \cdot daprc_a + \sum_l \sum_m \sum_c TRC_{c,m,l,g} \cdot tcst_{c,m,l} \\ & + \sum_j CALAB_{j,g} \cdot lprc + \sum_j \sum_s \sum_l \sum_h \sum_c CMN_{c,h,l,g,s,j} \cdot mcst_{c,h,l} \end{aligned} \quad 5.1.33$$

in which the variable $CACOST_g$ = total costs of cropping activities (yuan). The coefficients (yuan ha^{-1}) $cstha_{r,t,p,h,c,l}$ = monetary inputs for farm equipment and machinery use in cropping activities $CA_{r,t,p,h,c,l}$, $seed_{r,p}$ = cost of seeds for crop rotation $_r$ at production level $_p$, and $tcst_{c,m,l}$ = terracing costs for terrace type $_c$, built with method $_m$ in land unit $_l$ ($_{l}$ = GSL, MSL, STL, VST). The coefficients for prices (yuan kg^{-1}) of $nprc_f$ = elementary nutrients and $bprc$ = biocides (active ingredient); and the coefficients $wprc$ = price of irrigation water (yuan t^{-1}), $daprc_a$ = cost for use of draught animal $_a$ (yuan d^{-1}), and $lprc$ = labor price (yuan per man-day). The coefficient $mcst_{c,h,l}$ = costs for transport of manure (yuan t^{-1}), as applied to cropping activities with soil conservation measure $_c$ and mechanization level $_h$, practiced in land unit $_l$.

Total monetary inputs for fruit production

Production costs ($FACOST_g$, yuan) for each sub-region are calculated with equation:

$$\begin{aligned} FACOST_g = & \sum_l FA_{l,g} \cdot fcst_l + \sum_f FAFERT_{g,f} \cdot nprc_f \\ & + FWAT_g \cdot wprc + \sum_j \sum_s \sum_l FMN_{l,g,s,j} \cdot fmcst_l + FBCD_g \cdot bprc \\ & + \sum_a \sum_j FADA_{a,j,g} \cdot daprc_a + \sum_j FALAB_{j,g} \cdot lprc \end{aligned} \quad 5.1.34$$

in which the coefficients $fcst_l$ = monetary inputs for building orchard terrace, young apple trees, farm equipment, etc. (yuan ha^{-1}), and $fmcst_l$ = cost for transport and application of manure (yuan t^{-1}), as applied to fruit activities in land unit $_l$.

Total monetary inputs for sown grassland

Production costs (*GACOST*, yuan) of sown grassland equal the costs for seeds and small equipment, mineral fertilizers, labor and animals. Per sub-region, the total production costs are calculated as:

$$\begin{aligned} GACOST_g &= \sum_l \sum_n GA_{n,l,g} \cdot gcst_{n,l} + \sum_f GFERT_{f,g} \cdot nprc_f \\ &+ \sum_j \sum_s \sum_l GMN_{l,g,s,j} \cdot gmcst_l \\ &+ \sum_j GALAB_{j,g} \cdot lprc + \sum_a \sum_j GADA_{j,a,g} \cdot daprc_a \end{aligned} \quad 5.1.35$$

in which the coefficients $gcst_{n,l}$ = costs for seeds and small equipment (yuan ha^{-1}) for grass activities $GA_{n,l}$, and $gmcst_l$ = costs for transport/application of manure (yuan t^{-1}), as applied to grass activities on land unit $_l$.

Total monetary input for firewood production

For firewood production activities, fertilizers and biocides are not applied; therefore, the costs per sub-region are those for small equipment ($wcst_l$), labor and draught animal use. Eqn 5.1.36 is applied for calculation of the total costs ($WACOST_g$):

$$WACOST_g = \sum_l WA_{l,g} \cdot wcst_l + \sum_j WDLAB_{j,g} \cdot lprc + \sum_j \sum_a WDDA_{j,a,g} \cdot daprc_a \quad 5.1.36$$

Net (agricultural) return

Net agricultural return is the difference between gross production value (total production of marketable products multiplied by their price) and total production costs. For crop and fruit production, the total annual net return for each sub-region is calculated with equations:

$$CARTN_g = \sum_i CAPRD_{i,g} \cdot prc_i - CACOST_g \quad 5.1.37$$

$$FARTN_g = FCPRD_g \cdot aprc - FACOST_g \quad 5.1.38$$

$$WARTN_g = WOOD_g \cdot wdprc - WACOST_g \quad 5.1.39$$

in which the variables (all in yuan) for total net return from $CARTN_g$ = cropping activities, $FARTN_g$ = fruit activities, and $WARTN_g$ = firewood production activities. The coefficients for price (yuan kg^{-1}) of prc_i = main (marketable) crop product $_i$ (dry weight), *aprc* = apple (fresh weight) and *wdprc* = firewood (dry weight).

5.2 Animal activities

Animal activities are defined on the basis of animal types and production aims. The outputs include meat, wool/cashmere, draught animals and manure, and the inputs comprise feed, capital and labor. For each animal activity, the input-output coefficients are quantified per animal unit (AU) on an annual basis. In this subsection, mathematical definitions of the animal activities and functions for the inputs and outputs are presented.

5.2.1 Definition of animal activities

Eight animal activities are defined, i.e., four activities, including goats, fine-wool sheep, small-tail sheep and pigs, that are mainly for producing meats; a cattle and donkey activity for producing draught oxen and transport donkeys; and draught oxen and transport donkey activities for supplying animal traction.

A livestock activity ($LSTA_{s,g}$) is defined by animal types and sub-regions, as indicated by subscripts $_s$ and $_g$, respectively. Each animal can be fed with various feed types, as grouped into four categories, i.e., grasses, agricultural by-products (grain husks and cakes of oil crops), main crop products and crop residues. For each feed category, an index is selected to indicate the feed types, e.g., subscript $_z$ is used to index the grass types (Table 5.3). In addition, an abbreviation is given for each animal activity and each feed type.

Table 5.3 Lists of indexes and abbreviations used for defining the animal activities, and for the feed types in the MGLP model

Index and types		Animal and feed types and their abbreviations
s	Animal activities	*GOT*: cashmere goat; *FSH*: fine-wool sheep; *TSH*: small-tail sheep; *CAT*: cattle; *DKY*: donkey; and *PIG*: pig; OX: draught oxen; DK: transport donkey
z	Grass types	*NGS*: natural grass; *SGS*: sown grass with N input; *SGN*: sown grass without N input
k	Agricultural by-products	*WHK*: wheat bran; *MHK*: millet husk; *SYP*: cake of soybean from irrigated and rainfed production activities; *SYN*: cake of soybean from N-limited production; *FXP*: cake of seed flax from irrigated and rainfed production; *FXN*: cake of seed flax from N-limited production
i	Crop products	Including only corn (*CRN*), autumn potato (*POT*), summer potato (*SPT*) and alfalfa (*ALF*)
u	Crop residues	All crop residues in Table 5.1 except for flax residues (*FLX*)

5.2.2 Physical livestock production

Animal products include meat, wool, cashmere, draught/transport animals, and manure. Per sub-region, total amount of an animal product is the production per AU multiplied by the total number of AU for an animal activity. For instance, total meat production can be calculated with equation:

$$MEAT_{s,g} = LSTA_{s,g} \cdot met_s \qquad 5.2.1$$

in which the variable $MEAT_{s,g}$ = total meat production (kg, carcass) from animal type $_s$ ($LSTA_{s,g}$, animal units) in sub-region $_g$, and the coefficient met_s = annual meat (kg AU^{-1}, carcass) production of animal type $_s$.

For manure production, a different procedure is applied (Subsection 5.2.4). For other animal products (wool and cashmere), equations are similar to Eqn 5.2.1, and therefore not presented here.

5.2.3 Determination of feed requirements and supplies

General considerations

- Requirements and supply of feed are expressed in DE (digestible energy) and DCP (digestible crude protein). Requirements of DE and DCP can be met by four feed types: 1) grass, 2) crop residues; 3) grain husk; and 4) main crop products, as given in Table 5.3.
- Grass is only used for grazing and it is consumed outdoors. Other feed sources that are either by-products (grain husks and cakes) or can be used for other purposes as well (main crop products and crop residues) are only consumed indoors, as feedstuff. Thus constraints are included in the model, such that all grass produced in a sub-region is consumed by the ruminants in that sub-region (Eqn 5.2.6).
- Pigs consume no grass or crop residues; other animals (ruminants) eat from all four sources (excluding potatoes) but with limitations (Eqns 5.2.7-11).
- The LP model determines how the animals are fed, taking into account the previous conditions. The model uses the following calculation procedure to determine the feed regime:
  (1) Calculating the number of animals for which DE requirements can be met by grass, taking into account that energy intake from grass is limited (Eqns 5.2.4-6); since grass is relatively DCP rich, there is an over intake of DCP.
  (2) Based on (1), we know the feed requirements from other feed sources; although grass is relatively DCP rich, we assume no compensation by lower DCP intake from other feed sources.

Total feed intake

Total feed intake is determined by the DE requirement, assuming that the total supply of DE, including from grazing grassland, should equal the total requirement, as described by:

$$\begin{aligned} FDE_{s,g} &= LSTA_{s,g} \cdot de_s \\ &= \sum_p \sum_i FEDC_{p,i,s,g} \cdot cde_{i,s} + \sum_p \sum_u FEDR_{p,u,s,g} \cdot rde_{u,s} \\ &+ \sum_k FEDH_{k,s,g} \cdot hde_{k,s} + \sum_z FEDG_{z,s,g} \cdot gde_{z,s} \end{aligned} \qquad 5.2.2$$

in which the variable $FED_{s,g}$ = total intake of DE (MJ) for animal $_s$ in sub-region $_g$; and variables for feed intake (kg, by animal $_s$ in sub-region $_g$) of $FEDC_{p,i,s,g}$ = main crop product $_{p,i}$, $FEDR_{p,i,s,g}$ = crop residue $_{p,u}$, $FEDH_{k,s,g}$ = agricultural by-product $_k$, and $FEDG_{z,s,g}$ = grassland type $_z$. The coefficients de_s = annual DE requirement (MJ per AU) of animal activity $_s$; and coefficients for DE concentration in (MJ kg^{-1} DM for animal $_s$) $cde_{i,s}$ = marketable crop product $_i$, $rde_{u,s}$ = crop residue $_u$, $hde_{i,s}$ = agricultural by-product $_k$, and $gde_{z,s}$ = grass type $_z$.

Different N-concentrations in crop products are used to determine the N input for cropping activities without and with N limitation in Chapter 4, i.e., lower N-concentrations are assumed for cropping activities with limited N input. This consideration results in lower protein concentrations in the crop products from the N-limited cropping activities. This difference in CP concentration has been taken into account. The index $_p$, the production level (defined by water availability and N input level), one of the factors used to define the cropping activities, is used to indicate the production level, under which crop product $_i$ or crop residue $_u$ have been produced. In the MGLP model, the amount of products used for animal feeding can be related to the total production by following two inequalities:

$$\sum_s FEDC_{p,i,s,g} \leq \sum_l \sum_c \sum_h \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot yld_{r,t,p,h,c,l,i} \cdot nyld_i \qquad 5.2.3a$$

$$\sum_s FEDR_{p,u,s,g} \leq \sum_l \sum_c \sum_h \sum_t \sum_r CA_{r,t,p,h,c,l,g} \cdot rsh_{r,t,p,h,c,l,u} \cdot nrsh_u \cdot acf_u \qquad 5.2.3b$$

in which the indices $_i$ = $_{CRN, POT, SPT, ALF}$ (Tables 5.1 and 5.3), and $_u$ = $_{RCRN, RWHT, RSOY, RMLT}$ (Table 5.3), and the coefficient acf_u = fraction of crop residue $_u$ available for feeding animals. Other coefficients and variables refer to Eqns 5.1.3 and 5.1.4.

Feed intake from grazing grassland

Feed intake from grazing grass is defined as a fraction of the DE requirement for an animal type, i.e., the amount of feed (dry matter) covered from grazing grassland is determined only by the requirement of DE. Using $f_{z,s}$ to present the fraction of DE intake from grazing grass type $_z$ for animal $_s$, the total intake of DE from grazing grass can be expressed as:

$$LSTA_{s,g}' \cdot f_{z,s} \cdot de_s = FEDG_{z,s,g} \cdot gde_{z,s} \qquad 5.2.4a$$

Let $LSTA_{s,g} \cdot f_{z,s} = FDGF_{z,s,g}$, then Eqn 5.2.4a can be transformed into Eqn 5.2.4b by dividing the equation with de_s, the annual requirement of DE (MJ per AU) for animal type $_s$:

$$FDGF_{z,s,g} = \frac{FEDG_{z,s,g} \cdot gde_{z,s}}{de_s} \qquad 5.2.4b$$

in which $FDGF_{z,s,g}$ represents the number of animal units fed from grassland type $_z$ for animal type $_s$ in sub-region $_g$, assuming that daily DE intake for an animal is identical.

For each animal activity, upper limits of feed intake from grassland, defined as a fraction of total DE intake, were given in Table 4.10 in Subsection 4.6.2 (Chapter 4). Those limits can be described with Eqn 5.2.5, in which the index $_s \neq _{PIG}$ and $glmt_s$ = upper fraction of the total DE intake from grassland for animal $_s$.

$$\sum_z FEDG_{z,s,g} \cdot gde_{z,s} \leq FDE_{s,g} \cdot glmt_s \qquad 5.2.5$$

For each grassland type, the grass production available for animals is assumed to be fully consumed. For the sown grassland, i.e., for $_n$ = $_{SGW, SGN}$ and $_z$ = $_{SGS, SGN}$, and for the natural grassland, i.e., for $_z$ = $_{NGS}$, these balances can be described with Eqns 5.2.6a and 5.2.6b, respectively.

$$\sum_s FEDG_{z,s,g} = \sum_l GA_{n,l,g} \cdot sgyld_{n,l} \tag{5.2.6a}$$

$$\sum_s FEDG_{z,s,g} = NGA_g \cdot ngyld_g \tag{5.2.6b}$$

Feed intake from feedstuffs

It is assume that feedstuffs can be selected to meet the requirements of both DE and DCP. Since the intake and requirements of DE and DCP may not be balanced simultaneously for an animal type, it is assumed that the intake of DE exactly equals the requirement (Eqn 5.2.2), and that the DCP intake can be equal to the requirement or slightly higher. A factor (*fe*, slightly >1.0 with a value of 1.05 used for the MGLP model) is introduced in Eqn 5.2.7b to account for this slight over-supply of DCP.

Per animal activity, the required DCP from indoor feeding equals the number of animal units fed in stables, i.e., $LSTA_{s,g} - \sum_z FDGF_{z,s,g}$ (total number of animal units minus the number fed from grassland), multiplied by the annual requirement of DCP (kg per AU). The total intake of DCP from the feedstuffs, as determined by Eqn 5.2.7a, should meet the requirement as defined by Eqn 5.2.7b:

$$\begin{aligned} FDCP_{s,g} &= \sum_p \sum_i FEDC_{p,i,s,g} \cdot cpc_{p,i} \cdot digc_{i,s} \\ &+ \sum_p \sum_u FEDR_{p,u,s,g} \cdot cpr_{p,u} \cdot digc_{u,s} + \sum_k FEDH_{k,s,g} \cdot cph_k \cdot digh_{k,s} \end{aligned} \tag{5.2.7a}$$

$$\begin{aligned} \left(LSTA_{s,g} - \sum_z FDGF_{z,s,g}\right) \cdot dcp_s &\le FDCP_{s,g} \\ &\le \left(LSTA_{s,g} - \sum_z FDGF_{z,s,g}\right) \cdot dcp_s \cdot fe \end{aligned} \tag{5.2.7b}$$

in which the variable $FDCP_{s,g}$ = total DCP intake (kg) of animal type $_s$ from feedstuffs in subregion $_g$. The coefficient dcp_s = DCP requirement (kg per AU per year) of animal $_s$ from feedstuffs; and the coefficients for CP content (kg kg^{-1} dry matter) in $cpc_{p,i}$ = main (marketable) crop product $_{p,i}$, $cpr_{p,i}$ = crop residue $_{p,u}$, cph_k = agricultural by-product $_k$, and cpg_z = grass type $_z$; and for the digestibility (kg kg^{-1}, for animal $_s$) of CP in $digc_{i,s}$ = main crop product $_i$, $digr_{i,s}$ = crop residue $_u$, $digh_{k,s}$ = agricultural by-product $_k$, and $dig_{z,s}$ = grass type $_z$.

For each animal activity, the upper intake limit of DE from main crop products (coefficient $flmt_{i,s}$), as given in Table 4.10 in Chapter 4, can be described with an equation:

$$\sum_p FEDC_{p,i,s,g} \cdot cde_{i,s} \le FDE_{s,g} \cdot flmt_{i,s} \tag{5.2.8}$$

In Chapter 4, it was assumed that small-sized potatoes amounting to 5% of the total production should be used for pig feeding. This consumption is described with Eqn 5.2.9, in which the subscript $_i$ = $_{POT, SPT}$ and $_s$ = $_{PIG}$

$$FEDC_{p,i,s,g} = 0.05 \cdot CAPRD_{p,i,g} \qquad 5.2.9$$

Crop residues are used not only for feeding animals, but also for firewood. The total available amount of crop residues and its allocation between the two purposes can be described with Eqn 5.2.10, in which $FWR_{p,u,g}$ = amount of crop residue $_{p,u}$ used for firewood (kg DM) in sub-region $_g$.

$$\sum_s FEDR_{p,u,s,g} + FWR_{p,u,g} \le RSP_{p,u,g} \qquad 5.2.10$$

Total available husks (from millet and wheat), soybean and flax cakes are related to the amount of millet and wheat, and soybean and seed flax (as food oil) consumed by the population within each sub-region. The part sold at markets or exported outside the sub-region is not considered to be available as feed sources. The total available husks or cakes per sub-region are fully consumed by the animals in that sub-region, presented as:

For husks, i.e., $_{k = WHK, MLK}$: $\sum_s FEDH_{k,s,g} = \sum_p FOOD_{p,i,g} \cdot hsk_i$ 5.2.11a

For soybean cakes, i.e., $_{k = SYP, SYN}$: $\sum_s FEDH_{k,s,g} = OSOY_{p,g} \cdot (1 - osoy)$ 5.2.11b

For soybean cakes, i.e., $_{k = FXP, FXN}$: $\sum_s FEDH_{k,s,g} = FLX_{p,g} \cdot (1 - oflx)$ 5.2.11c

in which the variable $FOOD_{p,i,g}$ = total amount (kg) of crop product $_{p,i}$ ($_{i}$ = $_{MLT, WHT}$) consumed by the local people in sub-region $_g$; and the variables for amount (kg DM) of oil-bearing crops used for producing food oil (in sub-region $_g$) FLX = seed flax and $OSOY$ = soybean (see Subsection 5.4.1). The coefficients (kg kg^{-1} DM) hsk_i = husk fraction of the crop product $_{i=WHK, MLK}$; $oflx$ = oil content in seed flax, and $osoy$ = oil content in soybean.

5.2.4 Determination of manure

Nitrogen output from animal production systems is estimated using different procedure for the pig activity from ruminant animal activities. In this subsection, the calculation procedure for slurry N (total N in excreta), and manure N (collectable slurry N) is presented.

Determination of slurry and manure N from pigs

Pigs are fed in stables with a diet that is much less variable than that of ruminants, and thus a fixed quality of the manure is assumed, i.e., a fixed amount of slurry N is produced per pig unit (= two pigs per year with a total liveweight of 180 kg). Per sub-region, the total slurry N produced from pig activities ($_s$ = $_{PIG}$) can be determined by the number of pig units multiplied by the slurry N produced (kg N) per pig unit. The manure N from pigs can then be obtained by multiplying the result by the fraction of slurry N that can be collected. A general equation is applied:

$$MNU_{s,g} = LSTA_{s,g} \cdot srn \cdot rc \qquad 5.2.12$$

in which $MNU_{s,g}$ = total manure N (kg) produced from pigs in sub-region $_g$, srn = slurry N produced per pig unit per year (kg), and rc = fraction of slurry N (kg kg^{-1}) that can be collected, set at 0.7 in this study

Determination of slurry N from ruminants

The ruminant animals ($_{s \neq PIG}$) can graze on grassland or be fed in stables with feedstuffs, of which the feed quality is variable in terms of digestibility and protein content. As the LP model calculates the amount of intake for a feed type, this may cause variable contents of N in the slurry when different feed types are selected. In this study, the faeces and urine N are calculated separately for the ruminant animals with following assumptions:

- Digestibility of protein in each feed is fixed for an animal type; thus, the faeces N from the animal type is calculated as a summation of indigestible N over all consumed types of feed.
- The intake of DCP from feedstuffs equals the requirement (for calculation purposes, a value slightly over intake is allowed. See Eqn 5.2.7b); therefore, the total urine N, (i.e., the digestible N that is not incorporated in animal products) from indoor feeding can be determined by the number of animal units fed from feedstuffs and urine N excreted per animal unit.
- During grazing, the animal can only eat grass, so, DCP from grazing grass is oversupplied; considering this over intake of DCP, urine N is calculated as total N in the consumed DCP minus that retained in animal products.
- The slurry N is excreted in stables, in grassland while grazing or in the field while working (for draught animals). The slurry N excreted in stables can be collected and applied for agricultural uses; the slurry N in a grazed grassland type can be directly used by the grass plants, and the slurry N deposited in fields while working is considered to be available for plants (crops, fruits or grass).

The general procedure used to calculate the faeces, urine, slurry and manure N from ruminant animals is presented in Fig. 5.2.

Determination of faeces N

Faeces N is the indigestible N excreted with faeces, which can be simply estimated on the basis of feed intake, and the content and digestibility of crude protein (CP), with a general equation: $FN_y = \sum_x FD_{x,y} \cdot cp_x \cdot \left(1 - d_{x,y}\right)$ in which FN_y is total faeces N excreted and $FD_{x,y}$ the amount of feed $_x$ consumed by animal $_y$; and cp_x is the content and $d_{x,y}$ the digestibility of CP in feed $_x$ for animal $_y$.

For each of the four feed categories (Table 5.3), given the content and digestibility (animal specific) of CP in each feed type, the total faeces N (indigestible N) produced by animal type $_s$ in sub-region $_g$ can be determined on the basis of the intake amount, as presented with Eqns 5.2.13-16, in which the constant 6.25 is the conversion coefficient of protein into N, and the variables and coefficients refer to Eqn 5.2.7.

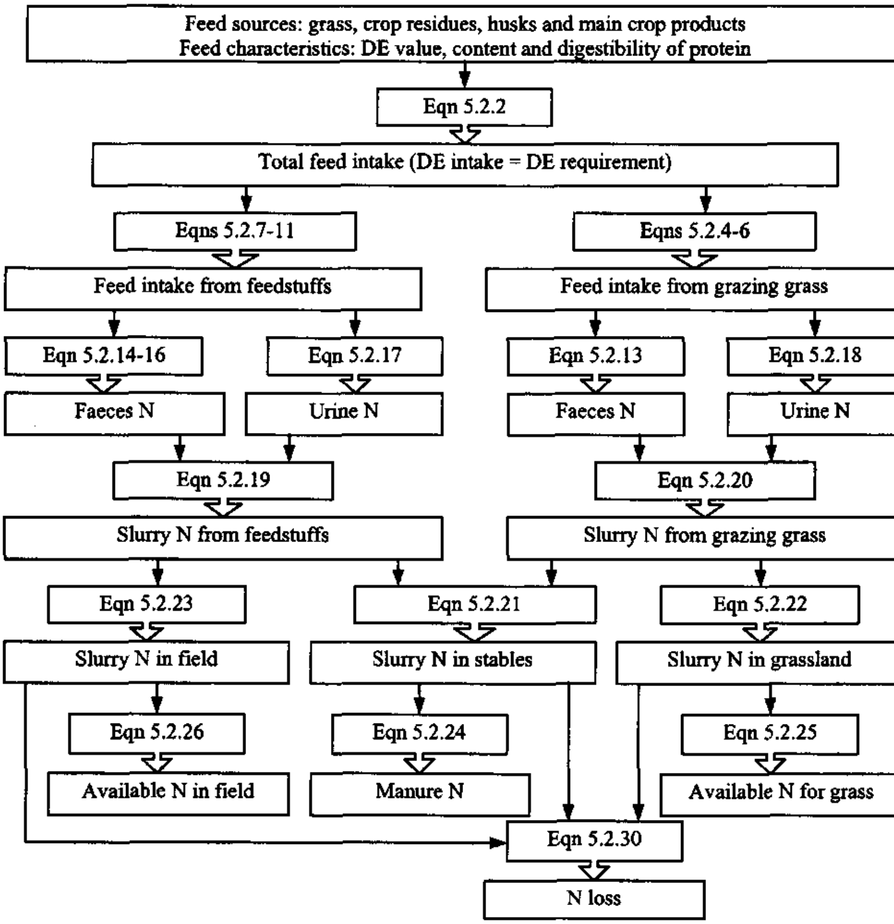


Figure 5.2 A illustration of the calculation procedure for determining manure N and N loss

1) Indigestible N of (grazing) grass type $_z$ ($FNG_{z,s,g}$) excreted with faeces by animal $_s$

$$FNG_{z,s,g} = \frac{1}{6.25} \cdot \left[FEDG_{z,s,g} \cdot cpg_z \cdot \left(1 - dig_{z,s}\right)\right] \qquad 5.2.13$$

2) Total indigestible N of grain husks and cakes of oil crops ($FNH_{s,g}$) excreted with faeces by animal $_s$

$$FNH_{s,g} = \frac{1}{6.25} \cdot \sum_k FEDH_{k,s,g} \cdot cph_k \cdot \left(1 - digh_{k,s}\right) \qquad 5.2.14$$

3) Total indigestible N of crop products ($FNC_{s,g}$) excreted with faeces by animal $_s$

$$FNC_{s,g} = \frac{1}{6.25} \cdot \sum_i \sum_p FEDC_{p,i,s,g} \cdot cpc_{p,i} \cdot (1 - digc_{i,s}) \qquad 5.2.15$$

4) Total indigestible N of crop residues ($FNR_{s,g}$) excreted with faeces by animal $_s$

$$FNR_{s,g} = \frac{1}{6.25} \cdot \sum_u \sum_p FEDR_{p,u,s,g} \cdot cpr_{p,u} \cdot (1 - digr_{u,s}) \qquad 5.2.16$$

Determination of urine N

Urine N is the difference of nitrogen in total consumed DCP and in the animal products. For each animal activity, the requirement of DCP per animal unit (AU) as given in Table A5.6 in Appendix 5 is determined on the basis of the target production. Per sub-region, the total urine N excreted by an animal type from indoor feeding can be obtained on the basis of those data, assuming that average DCP content in the selected types of feed (by the LP model) equals that in the defined diet.

$$URNF_{s,g} = \left(LSTA_{s,g} - \sum_z FDGF_{z,s,g} \right) \cdot \left(\frac{dcp_s}{6.25} - pn_s \right) \qquad 5.2.17$$

in which $URNF_{s,g}$ = total urine N (kg) excreted by animal $_s$ from feedstuffs in sub-region $_g$, and pn_s = amount of N (kg per AU) exported by the products of animal type $_s$.

This is true as long as animals are fed with feedstuffs, but as mentioned before, intake of DCP from grazing grassland is higher than the required DCP. This over-intake of DCP results in higher content of N in urine, since only a small part of N in the consumed DCP is retained in the animal products, and the largest part is excreted with urine. For a grass type consumed during grazing, the N excreted with urine ($URNG_{z,s,g}$ in kg) can be computed as total N in the consumed DCP minus that removed in the animal products, expressed with Eqn 5.2.18.

$$URNG_{z,s,g} = \frac{1}{6.25} \cdot FEDG_{z,s,g} \cdot cpg_z \cdot dig_{z,s} - FDGF_{z,s,g} \cdot pn_s \qquad 5.2.18$$

Determination of slurry N

Per sub-region, total slurry N produced by an animal $_s$ from feedstuffs is a summation of the faeces N and urine N excreted during indoor feeding, as calculated with Eqn 5.2.19; and total slurry N produced by an animal $_s$ from grazing grass type $_z$ is computed with Eqn 5.2.20.

$$SLNF_{s,g} = FNC_{s,g} + FNR_{s,g} + FNH_{s,g} + URNF_{s,g} \qquad 5.2.19$$

$$SLNG_{z,s,g} = URNG_{z,s,g} + FNG_{z,s,g} \qquad 5.2.20$$

in which the variables (kg) $SLNF_{s,g}$ = total slurry N from feedstuffs and $SLNG_{z,s,g}$ = total slurry N from grazing gassland $_z$.

It is assumed that 60% of the slurry N from grazed grass is excreted in that grassland during daytime grazing and 40% in stables at night, and that all slurry N from feedstuffs (indoor feeding) is excreted in stables, with the exception of oxen and transport donkeys, which excrete 60% in stables and 40% in other places while working. Thus the total slurry N excreted in stables can be computed with Eqn 5.2.21, and slurry N excreted by a grazing grassland type of animal is calculated with Eqn 5.2.22. The slurry N excreted in the field by a draught animal is calculated per sub-region with Eqn 5.2.23 (for simplicity of calculation, it is not related to the land use types.).

$$SLNS_{s,g} = SLNF_{s,g} \cdot pc_s + 0.4 \cdot \sum_z SLNG_{z,s,g} \quad 5.2.21$$

$$SLNGL_{z,s,g} = 0.6 \cdot SLNG_{z,s,g} \quad 5.2.22$$

$$SLNW_{s,g} = SLNF_{s,g} \cdot (1 - pc_s) \quad 5.2.23$$

in which (Eqns 5.2.21-23), the variables (kg) $SLNS_{s,g}$ = total slurry N excreted in stables by animal $_s$ in sub-region $_g$, $SLNGL_{z,s,g}$ = total slurry N excreted in grassland type $_z$ by animal $_s$ in sub-region $_g$, and $SLNW_{s,g}$ = total slurry N excreted in field while working by animal $_s$ ($_{OXN,}$ $_{DNK}$) in sub-region $_g$. The coefficient pc_s = fraction of slurry N excreted in stables, and for indoor feeding, i.e., for all feed types excluding grasses, and for $_s$ = $_{GOT,\ FSH,\ TSH,\ CAT,\ DKY}$, pc_s = 1.0; and for $_s$ = $_{OX,\ DK}$, pc_s = 0.6. The constants 0.4 and 0.6 indicate that 40% of the slurry N from grazed grass is excreted in stables, and 60% in grassland.

Determination of manure N

Not all slurry N excreted in stables by the ruminants is available for manure, as part is lost due to volatilization and denitrification during storage. Total collectable slurry N in stables for an animal activity in a sub-region is calculated with the equation:

$$MNU_{s,g} = SLNS_{s,g} \cdot rc \quad 5.2.24$$

in which the variable $MNU_{s,g}$ = available slurry N (kg) from animal activity $_s$ in sub-region $_g$, and the coefficient rc = fraction of slurry N in stables that can be collected (a value of 0.7 is used in this study).

Slurry N excreted in a grassland is available for the grass plants, which equals the total slurry N excreted in that grassland, multiplied by the fraction that can be used by the grass, as calculated:

$$GNU_{z,s,g} = SLNGL_{z,s,g} \cdot rg \quad 5.2.25$$

in which the variable $GNU_{z,s,g}$ = slurry N (kg) from animal $_s$, available for the grassland $_z$, and the coefficient rg = fraction (kg kg^{-1}) of slurry N available for the grassland (excluding loss due to volatilization), with an average value of 0.7 used in this study.

Slurry N excreted in fields while working (oxen and donkeys) can be used by the crops, apples or grasses. Assuming that the draught animals, if they work, are fed in stables, the available slurry N produced per animal type per sub-region is estimated with:

$$WNU_{s,g} = SLNW_{s,g} \cdot rw_s \quad 5.2.26$$

in which the variable $WNU_{s,g}$ = available slurry N (kg) for the plants, excreted by oxen or donkeys while working, and the coefficient rw_s = availability of the slurry N, set to 0.7 for $_s$ = $_{OX}$, and 0.4 for $_s$ = $_{DK}$, taking into account that (draught) oxen spend more time on the field than (transport) donkeys.

Determination of available P and K in manure

Available P and K in manure are simply calculated using the contents of P and K estimated for each animal type on the basis of information from literature. As the manure is expressed in slurry N, the amount of available P and K can be estimated with equations:

$$MPK_{s,f,g} = MNU_{s,g} \cdot nc_{s,f} \qquad 5.2.27$$

$$GPK_{z,s,f,g} = GNU_{z,s,g} \cdot nc_{s,f} \qquad 5.2.28$$

$$WPK_{s,f,g} = WNU_{s,g} \cdot nc_{s,f} \qquad 5.2.29$$

in which the index $_f$ = $_P$ or $_K$, and the variables (kg) for available P or K excreted with slurry (for animal $_s$ in sub-region $_g$) during $MPK_{s,f,g}$ = indoor feeding, $GPK_{s,f,g}$ = grazing and $ARPK_{s,f,g}$ = working. The coefficient $nc_{s,f}$ = content (kg kg^{-1}, related to N) of P or K in the excretion of animal $_s$.

N-losses

For an animal activity, the N loss ($LSTNLS_{s,g}$) equals the total slurry N produced minus the total N available for all land use activities, plus part of manure N ($OvMU_{s,g}$) that is not used for agricultural production, calculated as:

$$\begin{aligned} LSTNLS_{s,g} = SLNF_{s,g} + \sum_z SLNG_{z,s,g} - MNU_{s,g} - \sum_z GNU_{z,s,g} \\ - WNU_{s,g} + OvMU_{s,g} \end{aligned} \qquad 5.2.30$$

5.2.5 Total labor inputs for livestock production

Labor requirements for livestock production are defined for the same periods as distinguished for crop production. Total labor inputs are the total of labor required for grazing, indoor feeding, and other management.

Labor inputs for grazing are total units (AU) of animals grazing on grassland, multiplied by the required man-days per AU, as calculated:

$$GRLAB_{s,j,g} = \sum_z FDGF_{z,s,g} \cdot gralab_{s,j} \qquad 5.2.31$$

in which the variables $GRLAB_{s,j,g}$ = total labor inputs (man-days) for the grazing of animal $_s$ during period $_j$ in sub-region $_g$, and $FDGF_{z,s,g}$ = animal units on grazing for animal activity $_s$ (see Eqn 5.2.4). The coefficient $gralab_{s,j}$ = labor requirements (man-days per AU) for grazing of animal $_s$ for period $_j$.

The total of labor inputs for indoor feeding equals total animal units fed in stables multiplied by the labor requirements per AU:

$$FDLAB_{s,j,g} = \left(LSTA_{s,g} - \sum_{z} FDGF_{z,s,g} \right) \cdot fdalab_{s,j} \qquad 5.2.32$$

in which the variable $FDLAB_{s,j,g}$ = total labor input (man-days) for indoor feeding of animal $_s$ in period $_j$ in sub-region $_g$. The coefficient $fdalab_{s,j}$ = labor requirements (man-days per AU) for indoor feeding of animal $_s$ in period $_j$.

The total labor inputs ($LSTLAB_{j,g}$ in man-days) for animal activities are the total labor required for grazing (*GRLAB*) and for indoor feeding (*FDLAB*), as computed with:

$$LSTLAB_{j,g} = \sum_{s} \left(GRLAB_{s,j,g} + FDLAB_{s,j,g} \right) \qquad 5.2.33$$

5.2.6 Total monetary inputs and net return

Total monetary inputs

Costs for animal activities include those for feed, labor and other inputs (corrals, salts and veterinary care, etc.), plus the cost for management of grazing grassland ($GACOST_g$). For the feed, only main crop products are priced. For grass, crop residues and industrial by-products (husks, cakes), no price is given.

$$\begin{aligned} LSTCOST_g = & \sum_{s} LSTA_{s,g} \cdot acst_s + \sum_{j} LSTLAB_{j,g} \cdot lprc \\ & + \sum_{p} \sum_{s} \sum_{i} FEDC_{p,i,s,g} \cdot prc_i + GACOST_g \end{aligned} \qquad 5.2.34$$

in which the variables $LSTCOST_g$ = total costs of livestock production (yuan) in sub-region $_g$, and $FEDC_{p,i,s,g}$ = amount (kg DM) of main crop product $_{p,i}$ (= $_{CRN,\ POT,\ SPT}$) consumed by animal type $_s$ in sub-region $_g$. The coefficients $acst_s$ = monetary inputs (yuan) for corrals, salt and veterinary care per AU, and prc_i = price (yuan kg^{-1}) of main crop product $_i$.

Total net return

Net return is gross value of livestock products including meat, wool, cashmere and draught animals, minus the total costs. Draught animals are priced, as they can be sold at market. The cost of using draught animals is taken into account for all land use activities. For draught animal activities, the economic return is assumed to equal the total days used for agriculture, multiplied by the cost per daily use. In other words, the draught animals used for agricultural production can have a benefit only when they are working. The return is calculated as:

$$DARTN_{a,g} = \sum_{j} \left(CADA_{a,j,g} + FADA_{a,j,g} + WADA_{a,j,g} + GADA_{a,j,g} \right) \cdot daprc_a \qquad 5.2.35$$

in which $DARTN_{a,g}$ = total benefit of draught animal $_a$ from uses for agricultural production in sub-region $_g$, and $daprc_a$ = price (yuan d^{-1}) per day use of draught animal $_s$.

For each period, the available animal days should be equal to or greater than the total required animal days. This relationship can be described as:

$$DAN_{a,g} \cdot pad_j \geq CADA_{a,j,g} + FADA_{a,j,g} + WADA_{a,j,g} + GADA_{a,j,g} \qquad 5.3.36a$$

$$\sum_j DAN_{a,g} \cdot pad_j \geq DAN_{a,g} \cdot wrk_a \qquad 5.3.36b$$

$$DAN_{a,g} \leq 0.25 \cdot Pop_g \qquad 5.3.36c$$

in which $DAN_{a,g}$ = total number of draught animal $_a$ required for sub-region $_g$ and pad_j = duration (days) of labor period $_j$.

Eqn 5.3.36a does not give upper limit for the number of draught animals to be maintained, which may lead to a large number of draught animals, further resulting in low use efficiency of the draught animals. To overcome this problem, a constraint described by Inequality 5.3.36b is given, which implies that annual days of working for draught animal $_a$ should be equal to or greater than the given days of wrk_a for that animal. Here, a value of 90 days for the draught oxen ($wrk_{a=OXN}$) is assumed, and a lower value of 60 days for the transport donkeys ($wrk_{a=DNK}$) is used, as the donkeys can also be used for non-agricultural purposes (riding, power for traditional food processing). An additional restriction described by Eqn 5.3.36c is assumed, i.e., that the total number of draught oxen or transport donkeys should not exceed one-fourth of the total rural population (Pop_g) per sub-region.

The required draught animals should be maintained by feeding and other necessary inputs. Therefore, an equivalent number of draught animal activities ($LSTA_{s,g}$, indicated by the index $_{s\,(=\,OX,\,DK)}$, see Table 5.3) is needed, i.e., $DAN_{a,g} = LSTA_{s,g}$.

For cattle and donkey activities ($_s$ = $_{CAT,\,DKY}$), defined only for producing draught animals, the number of animals (oxen or transport donkeys) produced per sub-region can be used for agricultural production in the sub-region or sold at market. Also, the draught animals can be bought at market. The active life for oxen, either produced from cattle activity or bought, is assumed to be 10 years, and for transport donkeys, either produced by donkey activities or bought, it is assumed to be 12 years. Under these assumptions, the number of draught animals ($_a$ = $_{OXN,\,DNK}$) that can be sold or should be bought per year equals the number newly produced from the activity of cattle ($_s$ = $_{CAT}$) or donkeys ($_s$ = $_{DKY}$), minus the number of draught animals ($=\frac{DAN_{a,g}}{ap_a}$) that should be replaced per year, as calculated with:

$$DAIE_{a,g} = LSTA_{s,g} \cdot dan_s - \frac{DAN_{a,g}}{ap_a} \qquad 5.3.37$$

in which the index: $_s$ = $_{CAT,\,DKY}$ and $_a$ = $_{OXN,\,DNK}$. The variable $DAIE_{a,g}$ = number of draught animal type $_a$ that can be sold (positive value) or should be bought (negative value) per year in sub-region $_g$. The coefficients dan_s = number of draught animals (per year) produced from animal activity $_s$, and ap_a = active life (years) of draught animal $_a$.

Assuming that the draught animals can be sold or bought at the same price, the return from selling the surplus of newly produced draught animals or the cost of buying the shortage of draught animals can be described as:

$$DASLD_{a,g} = DAIE_{a,g} \cdot danprc_s \qquad 5.2.38$$

in which the index $_s$ = $_{CAT,\ DKY}$, the variable $DASLD_{a,g}$ = total return (yuan, positive value) or cost (yuan, negative value) for selling or buying draught animal $_a$ in sub-region $_g$, and the coefficient $danprc_a$ = price (yuan) of draught animal $_a$.

The net return from meat, wool and cashmere is the total production multiplied by the prices, minus the total costs. Adding the benefit from draught animals, the total economic return from all animal activities can be calculated as:

$$\begin{aligned} LSTRTN_g = & \sum_{s=all} MEAT_{s,g} \cdot mprc_s + \sum_{s=GOT,FSH,TSH} LSTA_{s,g} \cdot wool_s \cdot wlprc_s \\ & + \sum_{s=GOT} LSTA_{s,g} \cdot csm_s \cdot csmprc_s + \sum_{a=OXN,DNK} DARTN_{a,g} \\ & + \sum_{a=OXN,DNK} DASLD_{a,g} - LSTCOST_g \end{aligned} \qquad 5.2.39$$

in which the coefficients for marketable products from animal activity $_s$ (yuan kg^{-1}) $wool_s$ = wool production ($_s$ = $_{GOT,\ FSH,\ TSH}$) and csm_s = cashmere production ($_s$ = $_{GOT}$); and for the price of the marketable products (yuan kg^{-1}) from animal activity $_s$ $wlprc_s$ = wool, $csmprc_s$ = cashmere (yuan kg^{-1}), and $mprc_s$ = meat.

5.3 Objective functions

Based on the land use problems discussed in Chapters 1 and 2, ten objectives are defined, as related to environmental, social and economic aspects of sustainable land use and regional development in Ansai. These objective variables (Table 5.4) include minimization of total cropping area (*AC*), total soil loss (*TSLS*), total N loss (*TNLS*), total mineral (fertilizer) N use (*TNUS*), total biocide use (*TBCD*) and total production costs (*TCST*); and maximization of total crop production (*TCPRD*), total employment in agriculture (*TEMP*), total net agricultural return (*TRTN*) and labor productivity (*URTN*). In addition, four other objective variables (Table 5.4) are defined, such as minimization of soil loss per ha that is optimized via the variable *USLS*, minimization of food deficit (*TIXP*), etc.[1] Objective functions regarding areas allocated to different land use groups, such as the area allocated to mixed cropping (with alfalfa) activities, to irrigated, rainfed or N-limited cropping activities, etc. are not given here, but they are included in the model program for specific model optimizations.

This section presents the general forms of all objective functions used in the MGLP model. Further details, i.e., equations for the variables (Table 5.4) used in the objective func-

[1] The objective variable *TIXP* has been used as a constraint in the current version of the MGLP model, as food self-sufficiency can be fully met under the given assumptions (Chapters 6-7). A preliminary analysis for the effect of the objective variables of *USLS*, *USLN* and *UBCD* has been conducted, but the optimization results for those objective variables has not been presented in the final report (Chapters 6-7).

tions, can be found in Sections 5.1-2 and 5.4.

5.3.1 Environmental objective variables

Environmental problems, especially severe land degradation, are major concerns for the regional development in Ansai and the Loess Plateau. Eight objective variables are defined to explore the environmental aspects of future land use: minimization of cropping area, minimization of total and per ha soil loss, minimization of mineral N use, minimization of total and per ha N loss, and minimization of total and per hectare biocide use.

Table 5.4 Objective variables and definition of the variables used for the objective functions

Objective Variable and Description		Unit
Environmental objective variables		
AC	*Minimization of total area used for crops*	ha
TSLS	*Minimization of total soil loss* from cropping activities (*CASLS*), fruit activities (*FASLS*), sown grass activities (*GASLS*) and firewood activities (*WASLS*)	ton
USLS	A variable as used to minimize soil loss per ha, with a reference factor *Sref*	ton
TNLS	*Minimization of total N loss* from cropping activities (*CANLS*), fruit activities (*FANLS*), sown grass activities (*GANLS*) and firewood activities (*WANLS*)	kg
TNUS	*Minimization of total mineral N* used for cropping activities (*CAFERT*), fruit activities (*FAFERT*) and sown grass activities (*GAFERT*)	kg N
UNLS	A variable as used to minimize N loss per ha, with a reference factor *Nref*	kg N
TBCD	*Minimization of total biocides* used for cropping activities (*CABCD*) and fruit activities (*FABCD*)	kg a.i.
UBCD	A variable as used to optimize per hectare biocide use, with a reference factor *Bref*	kg a.i
Social objective variables		
TIXP	*Minimization of total deficit of crop products*, calculated as the difference between the total food requirements (*FOOD*) for human consumption plus those used for feeding animals (*FEED*) and total marketable crop production (*CPRD*)	ton GE
TEMP	*Maximization of total employment in agriculture*, calculated as the total labor engaged in cropping activities (*CALAB*), fruit activities (*FALAB*), firewood activities (*WALAB*), grass activities (*GALAB*) and animal activities (*LSTLAB*);	man-years
Economic objective variables		
TCPRD	*Maximization of total crop production*	kg GE
TCOST	*Minimization of total production costs* Ansai (*TCOST*) for cropping activities (*CACOST*), fruit activities (*FACOST*), grass activities (*GACOST*), firewood activities (*WACOST*) and animal activities (*LSTCOST*)	yuan
TRTN	*Maximization of total net agricultural return* from cropping activities (*CARTN*), fruit activities (*FARTN*), grass activities (*GACRTN*), firewood activities (*WARTN*) and animal activities (*LSTRTN*)	yuan
URTN	A variable as used to maximize labor productivity, with a reference factor *Iref*	yuan

Total area for arable farming

The land degradation is largely caused by over-cultivation in Ansai. Therefore, the most efficient way in mitigating the severe soil erosion may be transformation of the slope cultivation into more sustainable land uses, such as grass or shrubs. Minimization of total cropping area under different target values for other objectives, explores the scope for reducing the arable land area. Eqn 5.3.1 is applied, where *CA* is cropping activities, the index $_g$ is sub-region, and other indices are defining factors for cropping activities (Table 5.4).

$$AC = \sum_g \sum_l \sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} \qquad 5.3.1$$

Soil losses

Only soil losses from crop, fruit, sown grass and planted shrubs are taken into account, and soil losses from natural grass, shrub and forest (preserved) land are excluded. Two objective functions are formulated: total soil loss and unit soil loss (per hectare). Total soil loss is the sum of those from all cropping, fruit, sown grass and planted shrub activities.

$$TSLS = \sum_g \left(CASLS_g + FASLS_g + GASLS_g + WASLS_g \right) \qquad 5.3.2$$

Average soil loss per hectare cannot be minimized in a linear model, as both soil loss and total agricultural area are variables in the LP model. However, it can be optimized in a transformed way, in which the soil loss per hectare is approximated by a linear function (Eqn 5.3.3a). This equation is based on Bessembinder (1997), in which *Sref* is a reference value for soil loss (t ha^{-1}). After minimization of *USLS*, the minimal soil loss (*SLSha*) per hectare can be calculated using Eqn 5.3.3b.

$$USLS = TSLS - Sref \cdot \sum_g \left(AC_g + AF_g + AG_g + AW_g \right) \qquad 5.3.3a^2$$

$$SLSha = TSLS \Big/ \sum_g \left(AC_g + AF_g + AG_g + AW_g \right) \qquad 5.3.3b$$

Total mineral (fertilizer) N use

Total mineral N use is the sum of N use from all land use activities. The total fertilizer N use for the county (*TNUS*) and per sub-region (*GNUS*) is described with Eqn 5.3.4:

$$TNUS = \sum_g GNUS_g \qquad 5.3.4a$$

$$GNUS_g = CAFERT_{f,g} + FAFERT_{f,g} + GAFERT_{f,g}, \quad \text{For }_{f=N} \qquad 5.3.4b$$

[2] The soil loss per hectare = $\frac{TSLS}{AREA}$, where $AREA = \sum_g \left(AC_g + AF_g + AG_g + AW_g \right)$; the reference variable *USLS* is related to the *TSLS* by the reference factor *Sref* (> 0): $\frac{USLS}{AREA} = \frac{TSLS}{AREA} - Sref$; Multiplying *AREA*, the equation is transformed as: $USLS = TSLS - Sref \cdot AREA$. As *Sref* is a constant, minimization of soil loss per unit area, $\frac{TSLS}{AREA}$ equals minimization of $\frac{USLS}{AREA}$, and therefore also equals minimization of *USLS*.

N loss

Total N loss (*TNLS*) is the sum of those from all production activities, as presented:

$$TNLS = \sum_g \left(CANLS_g + FANLS_g + GANLS_g + WANLS_g\right) + \sum_g \sum_s LSTNLS_{s,g} \qquad 5.3.5$$

N loss per hectare is optimized using a similar function as for soil loss, with a reference factor for N loss, *Nref* (kg ha^{-1}).

$$UNLS = TNLS - Nref \cdot \sum_g \left(AC_g + AF_g + AG_g + AW_g\right) \qquad 5.3.6a$$

$$NLSha = TNLS \Big/ \sum_g \left(AC_g + AF_g + AG_g + AW_g\right) \qquad 5.3.6b$$

Biocide use

Biocide use in the county is the total amount of biocides applied for crop and fruit production, as computed:

$$TBCD = \sum_g \left(CABCD_g + FABCD_g\right) \qquad 5.3.7$$

Except for total biocide use, the objective for minimal use of biocides per hectare can be attained by minimizing the objective variable, *UBCD*, as presented by Eqn 5.3.8a, in which *Bref* is a reference value of biocide use per hectare. After minimization of reference variable (*UBCD*), the minimal use of biocides per hectare can be obtained by dividing the total use (*TBCD*) by the total area of cropping and fruit activities (Eqn 5.3.8b).

$$UBCD = TBCD - Bref \cdot \sum_g \left(AC_g + AF_g\right) \qquad 5.3.8a$$

$$BCDha = TBCD \Big/ \sum_g \left(AC_g + AF_g\right) \qquad 5.3.8b$$

5.3.2 Social objective variables

The social development goals are expressed in two objective variables: minimum food deficit (food security) and maximum employment. Income (net agricultural return) is considered to be an economic goal.

Food security

Food security or food self-sufficiency is defined as a minimum deficit for food grains, calculated for the county (*TIXPF*) and for each sub-region ($IXPFG_g$). Total amount of food deficit (positive value) or surplus (negative value) is expressed as grain equivalent (GE), calculated with Eqn 5.3.9, in which the coefficient *eq* is energy value of GE (heat of combustion, 16 MJ kg^{-1}), as used to transfer the energy into kilograms of GE.

$$TIXPF = \sum_{g} IXPFG_g \qquad 5.3.9a$$

$$IXPFG_g = \frac{1}{eq} \cdot \sum_{p} \sum_{i} IXPF_{p,i,g} \cdot efd_i \qquad 5.3.9b$$

in which $_i$ = consumable crop products ($_{i \neq ALF}$), $IXPF_{p,i,g}$ = deficit or surplus amount of crop product $_{p,i}$ in sub-region $_g$ (it is further discussed in Section 5.4.1), and efd_i = energy value (heat of combustion, MJ kg^{-1} DM) of crop product $_i$.

Total employment in agriculture

Total employment is the sum of labor involved in all agricultural production activities. For each production activity, five labor demand periods (subscript $_j$) are distinguished, so, annual employment is a sum of the total required labor for each of the five periods. Total annual employment (*TEMP*, man-years) in the county is the total employment per sub-region (EMP_g, man-years), as calculated with Eqn 5.3.10, in which the constant 240 represents the number of working days per year.

$$TEMP = \sum_{g} EMP_g \qquad 5.3.10a$$

$$EMP_g = \frac{1}{240} \cdot \sum_{j} \left(CALAB_{j,g} + FALAB_{j,g} + LSTLAB_{j,g} + GALAB_{j,g} + WALAB_{j,g} \right) \qquad 5.3.10b$$

5.3.3 Economic objective variables

Three objective variables are used to optimize the economic goals: total crop production, total costs of agricultural production and total net return of agricultural production. Total crop production is selected as an objective variable because: 1) the farmers and the local government are concerned with the total production; and 2) total crop production is a more stable indicator than net return, as the price of crop products and inputs often varies from year to year. For the two other objective variables, the calculation is based on present prices.

Crop production

As with food self-sufficiency, total crop production (marketable or consumable) for the county (*TCPRD*) and each sub-region ($CPRD_g$) is expressed as a grain equivalent (GE). Total crop production (kg GE) equals a summation of the total marketable production of the food crops (corn, millet, wheat, soybean, autumn and summer potatoes, and flax) multiplied by the energy content (efd_i), divided by the energy value of GE.

$$TCPRD = \sum_{g} CPRD_g \qquad 5.3.11a$$

$$CPRD_g = \frac{1}{eq} \cdot \sum_{i} CAPRD_{i,g} \cdot efd_i \qquad 5.3.11b$$

Total costs of agricultural production

Per sub-region, the total costs are calculated as a summation of cropping, fruit, livestock, firewood and grass production activities. For the whole county, the total costs (*TCOST*) are a summation of all sub-regions ($COST_g$). As the available nutrients in the excreta of draught animals deposited while working are considered per sub-region, the total costs for agricultural production including the cost for fertilizer, should be reduced by an amount that is equal to the value of available slurry nutrients excreted in the field.

$$TCOST = \sum_{g} COST_g \qquad 5.3.12a$$

$$\begin{aligned} COST_g &= CACOST_g + FACOST_g + LSTCOST_g + GACOST_g \\ &+ WACOST_g - WNU_g \cdot nprc_{f(=N)} - \sum_{f=P,K} WPK_{f,g} \cdot nprc_f \end{aligned} \qquad 5.3.12b$$

Total net return of agricultural production

Net agricultural return is the sum of returns from crop, fruit and livestock production. Grassland can only be used for animal grazing within a sub-region. Transferring crop residues among the sub-regions is not allowed, because it is not beneficial to transport such a bulky volume of plant material. Thus, crop residues are not priced either as output (product) of cropping activities or input for animal activities or for firewood. Per sub-region, annual economic return is the total from crop, fruit and livestock production, minus the cost for firewood production and grassland. For each sub-region, the available slurry nutrients excreted in the field by the draught animals while working should be subtracted from the total inputs of mineral nutrients. This benefit from the reduced amount of fertilizer inputs should be added.

$$TRTN = \sum_{g} RTN_g \qquad 5.3.13a$$

$$\begin{aligned} RTN_g &= CARTN_g + FARTN_g + LSTRTN_g + WARTN_g \\ &+ WNU_g \cdot nprc_{f(=N)} + \sum_{f=P,K} WPK_{f,g} \cdot nprc_f \end{aligned} \qquad 5.3.13b$$

Net return per laborer can be optimized in a transformed way using Eqn 5.3.14, in which *URTN* is a reference variable, *Iref* (yuan per laborer per year) is a reference factor, and *INCOM* is average maximum labor productivity (yuan per laborer per man-year).

$$URTN = TRTN - Iref \cdot TEMP \qquad 5.3.14a$$

$$INCOM = TRTN / TEMP \qquad 5.3.14b$$

5.4 Constraints

Land use options are affected and restricted by many constraints, such as available land area, labor, fertilizers, and capital, and they are driven by food security objectives. Some constraints are unambiguous, e.g., area of different land units, and, to some extent, labor availability, which is strongly related to the population in Ansai. Import of labor from outside Ansai is not feasible, because of its geographic isolation. Other constraints are not ambiguous and should be used as fixed constraints in an exploration, e.g., fertilizers and capital availability. The total use of such resources is a result of the exploration, and normative, *a priori* assumptions of their availability should not obscure the biophysical opportunities for agricultural land use.

Finally, several relationships between components of the system are implemented as constraints in the model, i.e., those related to plant-animal relationships: availability and maximum use of manure, available number of draught animals to be used for farm operations. In this section two types of constraints are described: 1) food and firewood requirements, to a large extent, based on the assumption that Ansai should be self-sufficient in its food and firewood production, and 2) land and labor constraints. The constraints related to plant-animal relationships are described in Sections 5.2-5.3.

For trade-off and scenario analyses, additional constraints could be required, such as those for a more detailed definition of food security. These aspects are included in the model program for a specific model optimization.

5.4.1 Food and firewood demands

Total requirements for food and firewood are estimated according to the requirement per capita and projected population in the year 2020.

Food demand constraints

Food requirements are determined by population size and dietary structures. The total food consumption in terms of energy should equal the total supplied by foods (consumable crop products, vegetable oil, apple and meats). For protein, the total consumption is assumed to be equal to or slightly higher than the demand determined by the defined diet and population size. These food demand constraints are described by the following equations or inequalities:

$$FODE_g = 365 \cdot Pop_g \cdot edmd = FODE_g \cdot of + \sum_i \sum_p FOOD_{p,i,g} \cdot (1 - hsk_i) \cdot efd_i + FRUT_g \cdot eft + \sum_s HMET_{s,g} \cdot emt_s \qquad 5.4.1$$

$$FODP_g = \sum_p \sum_i FOOD_{p,i,g} \cdot pfd_{p,i} + FRUT_g \cdot pft + \sum_s HMET_{s,g} \cdot pmt_s \qquad 5.4.2$$

$$365 \cdot Pop_g \cdot pdmd \leq FODP_g \geq 365 \cdot Pop_g \cdot pdmd \cdot pf \qquad 5.4.3$$

in which the variable (MJ per year for sub-region $_g$) $FODE_g$ = total food energy requirement; the variables (kg per year for sub-region $_g$) $FODP_g$ = total protein requirement, $HMET_g$ = total consumed meat of animal $_s$, and $FRUT_g$ = total apple (fresh weight) consumption. The coefficients Pop_g = rural population size, pf = upper limit for total protein consumption, of =

vegetable oil fraction in total food energy intake, and *osoy* = oil content in soybean (kg kg^{-1}). The coefficients for average requirement per person of *edmd* = energy (MJ d^{-1}), and *pdmd* = protein (kg d^{-1}); and *apdmd* = animal protein (kg d^{-1}); for energy content (MJ kg^{-1}) of efd_i = crop product $_i$ (dry matter), emt_s = meat of animal $_s$, and *eft* = apple (fresh weight); and for content (kg kg^{-1}) of protein in $pfd_{p,i}$ = crop product $_{p,i}$, pmt_s = meat of animal $_s$, and *pft* = apple (in fresh weight).

In the diet, the requirements for fruit, meat or vegetable oil are defined by a given fraction of food energy or protein. For apple, a constant fraction in the diet is defined, as presented by Eqn 5.4.4. The protein from meat should equal the total requirements of animal protein per sub-region, as given by Eqn 5.4.5a. In addition, a minimum fraction of the total food energy requirement is assumed to be from animal meat (Eqn 5.4.5b). Vegetable oil can be imported or produced from oil crops of seed flax and soybean, the total required amount of which is determined by Eqn 5.4.6. For wheat and potatoes, a lower limit in the total food intake is given, while for other crops, an upper limit is assumed, both of which are described by Eqns 5.4.7-8.

$$FRUT_g \cdot pft = FODE_g \cdot fap \qquad 5.4.4$$

$$\sum_s HMET_{s,g} \cdot pmt_s = 365 \cdot Pop_g \cdot apdmd \qquad 5.4.5a$$

$$\sum_s HMET_{s,g} \cdot emt_s \geq FODE_g \cdot fmde \qquad 5.4.5b$$

$$\left(OIMP + \sum_p OSOY_{p,g} \cdot osoy + \sum_p FLX_{p,g} \cdot oflx\right) \cdot oil = FODE_g \cdot of \qquad 5.4.6$$

$$\sum_i \sum_p FOOD_{p,i,g} \cdot (1 - hsk_i) \cdot efd_i \geq FODE_g \cdot fcmt_i, \text{ For } i = \textit{WHT, POT, SPT} \qquad 5.4.7$$

$$\sum_i \sum_p FOOD_{p,i,g} \cdot (1 - hsk_i) \cdot efd_i \leq FODE_g \cdot fcmt_i, \text{ For } i = \textit{CRN, MLT, SOY} \qquad 5.4.8$$

in which the variable OIL_g = import of vegetable oil (kg per year) in sub-region $_g$, and the variables for amount used for producing vegetable oil of $OFLX_{p,g}$ = seed flax and $OSOY_{p,g}$ = soybean. The coefficients *osoy* = oil content in soybean (kg kg^{-1}), *oflx* = oil content in seed flax (kg kg^{-1}), and *oil* = energy content in vegetable oil (= 39 MJ kg^{-1}); and the coefficients for fraction of the food energy intake from *fap* = apple, *fmde* = meat, and $fclm_i$ = food crop $_i$.

Import and export of agricultural products

In a sub-region or the county, total production can be more or less than the total consumption for each of the agricultural products. The surplus or deficit of the production in a sub-region can be exported or imported, as indicated with a single variable for each product in Eqns 5.4.9-15: $IXPF_{p,i,g}$ = amount (kg) of import (positive value) or exports (negative value) of crop product $_{p,i}$ in sub-region $_g$; $IXPF_{p,i,g}$ = amount (kg) of import or exports of apple in sub-region $_g$; and $IXPM_{s,g}$ = amount (kg) of import or exports of meat of animal $_s$ in sub-region $_g$.

For soybean ($_{i=SOY}$): $IXPF_{p,i,g} = FOOD_{p,i,g} + OSOY_{p,g} - CAPRD_{p,i,g}$ 5.4.9

For seed flax ($_{i=FLX}$): $IXPF_{p,i,g} = FLX_{p,g} - CAPRD_{p,i,g}$ 5.4.10

For corn and potatoes ($_{i=CRN, POT, SPT}$):

$$IXPF_{p,i,g} = FOOD_{p,i,g} + \sum_s FEDC_{p,i,s,g} - CAPRD_{p,i,g} \quad 5.4.11$$

For wheat and millet ($_{i=WHT, MLT}$): $IXPF_{p,i,g} = FOOD_{p,i,g} - CAPRD_{p,i,g}$ 5.4.12

For alfalfa ($_{i=ALF}$): $IXPF_{p,i,g} = \sum_s FEDC_{p,i,g,s} - CAPRD_{p,i,g}$ 5.4.13

For fruit: $IXPA_g = FRUT_g - FAPRD_g$ 5.4.14

For meat: $IXPM_{s,g} = HMET_{s,g} - MEAT_{s,g}$ 5.4.15

Firewood demand constraints

Firewood requirements are expressed in terms of standard coal equivalent (SCE, heat of combustion = 29.7 MJ kg^{-1}). Sources of firewood include crop residues and shrubs that are transferred into a standard coal. The requirement and supply of firewood is presented as Eqn 5.4.16, in which the variable of STW_g is the amount (kg SCE) of firewood that should be imported (positive value) or exported (negative value) in a sub-region. Per sub-region, total requirement of crop residues for firewood and for feeding animals should not exceed the total available amount (Eqn 5.4.17), and total firewood covered from shrubs should not exceed the total supply (Eqn 5.4.18).

$$\sum_u \sum_p FWR_{p,u,g} \cdot wer_u + FWD_g \cdot wes + STW_g = Pop_g \cdot wdmd \quad 5.4.16$$

$$FWR_{p,u,g} + \sum_s FEDR_{p,u,s,g} \leq RSP_{p,u,g} \quad 5.4.17$$

$$FWD_g \leq WOOD_g \quad 5.4.18$$

in which the variables (kg DM) FWR = annual amount of crop residue $_{p,u}$ used as firewood, and FWD = annual amount of shrubs used as firewood. The coefficients wer = standard coal equivalent of crop residues (kg kg^{-1} DM), wes = standard coal equivalent of shrubs (kg kg^{-1} DM), and $wdmd$ = annual firewood requirement per capita (kg SCE).

5.4.2 Resource constraints

Resource constraints include available land area, irrigation water and labor. In this study, only the flood plain is accessible for irrigation. As area of the flood plain is very limited, occupying only 1.74% of the total area of Ansai, available water is not considered as a constraint.

Available land

The suitable land units can be used for crop, fruit, grass, and firewood production. For each land unit within a sub-region, the land area used for these activities should not exceed the available area. Therefore, the following inequalities exists:

$$\sum_c \sum_h \sum_p \sum_t \sum_r CA_{r,t,p,h,c,l,g} + FA_{l,g} + WA_{l,g} + \sum_n GA_{n,l,g} \le Suit_{l,g} \qquad 5.4.19$$

Terracing area

In Section 5.1.1, the relationships between the terracing and cropping activities are described by Eqn 5.1.2. A sloping land unit may not be fully terraced, due to possible limitation of accessibility. This restriction can be described by Eqn 5.4.20, in which $LRTC_{l,g}$ is the total terraced area for land unit $_l$ in sub-region $_g$, and aT_l is the fraction of land unit $_l$ that can be terraced.

$$LRCT_{l,g} = \sum_m \sum_{c=BT,ST} TRC_{c,m,l,g} \le aT_l \cdot Suit_{l,g} \qquad 5.4.20$$

Terracing requires high labor (by hand) and capital (by machinery) inputs. The effect of terracing on the land use, soil loss control, and agricultural production may need to be analyzed in more detail, to be more informative to the stakeholders. Thus, Eqns 5.4.21 are formulated to help analyze the effect by giving a restriction to total terracing area. For spaced terracing, the part not terraced is excluded by a factor (tf_l) that gives a fraction of the terraced part.

$$GRCT_{g,l} = \sum_{c=BT} \sum_m TRC_{c,m,l,g} + \sum_{c=ST} \sum_m TRC_{c,m,l,g} \cdot tf_l \qquad 5.4.21a$$

$$TRCT = \sum_l \sum_g GRTG_{g,l} \le TrL \qquad 5.4.21b$$

in which the variables (ha) $GRCT_{g,l}$ = total terracing area on land unit $_l$ in sub-region $_g$, $TRCT$ = total terracing area, and $TRC_{c,m,l,g}$ = terracing activities (refers to Eqn 5.1.2). TrL = total terracing area (ha), which can be given according to preference for a policy scenario.

Available labor

Total available labor for agriculture per sub-region (Lab_g) is calculated with equation:

$$Lab_g = Pop_g \cdot talab_g \qquad 5.4.22$$

in which Pop_g = total projected rural population in sub-region $_g$, and $talab_g$ = fraction of economically active population in sub-region $_g$.

Per sub-region, it is assumed that total labor requirement should not exceed the total available labor (Lab), i.e., labor cannot be transferred from one sub-region to another. Per labor period per sub-region, the labor requirement is related to labor supply with Inequality 5.4.23, where Lab_g is the amount of total labor in sub-region $_g$.

$$CALAB_{j,g} + FALAB_{j,g} + GALAB_{j,g} + WALAB_{j,g} + LSTLAB_{j,g} \leq Lab_g \cdot pad_j \qquad 5.4.23$$

Chapter 6 Presentation of the Optimization Results: 1. Extreme Values and Trade-off Analysis

6.1 Introduction

Before generating specific land use scenarios, the solution space should be identified, which is determined by the extreme values of different objective variables (Table 6.1) that are related to the key land use issues discussed in Chapters 1 and 2. These extreme values of the objective variables are calculated individually by various base runs of the MGLP model under a set of basic constraints and food self-sufficiency requirements.

Section 6.2 of this chapter describes the objective variables and basic constraints incorporated in the model and the criteria of self-sufficiency requirements for agricultural products. Section 6.3 presents the optimization results and trade-offs, with a focus on crop production, soil loss, net agricultural return and employment in agriculture. Next, the effect of changing food requirements as determined by a change of diet and population growth is discussed in Section 6.4. Finally, conclusions are drawn in Section 6.5.

6.2 Objective variables and constraints for base runs

6.2.1 Objective variables

Agricultural development in Ansai comprises many specific issues, such as food security, soil and nitrogen loss, capital availability, agricultural productivity, employment, and improvement of income for the rural people. In the MGLP model, these issues have been translated into ten objective variables, each of which represents a specific aspect of regional development. These ten objective variables are shown in Table 6.1.

6.2.2 Requirements of agricultural products

Two categories of agricultural products are considered, i.e., food and firewood. Agricultural production policies for Ansai primarily aim at self-sufficiency level for the rural population that covered 94% of the total population in 1990; therefore, total food and firewood requirement is based on the projected rural population in 2020, using the mean population growth rate between 1982 and 1990. For the base runs, total food requirement in each of the six sub-regions (Table 6.2) is determined by the projected rural population in 2020, and an assumed diet. Other food requirement options specified using different population growth rates and dietary patterns, and their consequences on land use allocations are discussed in Section 6.3.

Table 6.1 Optimization and abbreviation of the selected objective variables (GE = grain equivalent, a.i. = active ingredient)

Aspects	Objective Variables and the Optimization	Abbreviation	Unit
Crop production	minimization of total cropping area (maximization of land productivity)	MnCA	ha
	maximization of total crop production	MxCP	kg (GE)
Soil and N loss	minimization of total soil loss	MnSL	t
	minimization of total N loss	MnNL	kg N
Employment	maximization of total employment in agriculture	MxEM	man-year
Net return	maximization of total net agricultural return	MxNT	yuan
	maximization of labor productivity (maximization of the reference variable *URTN* in Chapter 5)	MxLP	yuan
Production inputs	minimization of total cost for agricultural production	MnCT	yuan
	minimization of total use of mineral (fertilizer) N	MnFN	kg N
	minimization of total use of biocides	MnBC	kg a.i.

Table 6.2 Rural population (persons) in Ansai, based on the 1990 and 1982 censuses

Sub-region	Rural population, 1990 Total persons	% of the total population	Economically active population (aged 20-60, %)	Mean population growth rate (%), 1982-1990	Projected rural population in 2020
WP	15980	98.1	44.6	1.80	25727
LH	21742	98.4	43.9	2.34	41037
TH	15661	98.4	45.1	2.25	28788
WZ	22588	97.3	46.1	1.66	34892
ZY	33344	84.5	45.9	1.97[(1)]	53209
XL	28056	94.1	43.9	2.11[(2)]	48912
Total	137371	93.6	45.0	2.34[(3)]	232564

[(1), (2)] The growth rate excludes the effect of population immigration to the towns of Zhenwudong (in ZY) and Zhuanyaowan (in XL) from other areas, respectively; and thus is lower than the mean value of 3.27% (ZY) and 2.24% (XL). [(3)] Mean growth rate of the total population of Ansai.

Projection of the rural population

Per sub-region, the rural population in the year 2020 (RP_g, persons) is estimated with Eqn 6.1, based on the rural population in 1990 (PO_g, persons), mean relative growth rate (r_g, fraction) of population (1982-90), and relative population migration rate from rural to urban areas (im_g), expressed as fraction of the rural population per year. In Eqn 6.1, n is number of years, i.e., 30 years from 1990 to 2020.

$$RP_g = PO_g \cdot \left(1 + r_g - im_g\right)^n \qquad 6.1$$

Based on the census data of 1982 and 1990, the mean relative population growth rate in the different sub-regions (Table 6.2) is 1.8-2.34%, and the mean population migration rate from rural to urban areas in Ansai is estimated at 0.17% per year. In this study, the relative migration rate of population is set to 0.2% per year for the first four sub-regions (Table 6.2). For the sub-region XL, a value of 20% higher (0.24%) is used, as more members of the rural population may migrate to the town of Zhuanyaowan in this sub-region. For sub-region ZY, the population migration rate is assumed to be 0.4%, since Zhenwudong, the capital of Ansai, could supply more opportunities to absorb the rural population.

Defined diet

Human diet is expressed in terms of requirements for energy and protein. According to Peng *et al.* (1991), daily food consumption per capita varies largely between poorer and richer parts of the population: from 5.5 to 15.5 kJ for energy; and from 37.7 to 91.7 g for protein with 85.2-96.6% of the protein covered by plant foods in 1983 in the Loess Plateau.

Based on the Sanitation Research Institute, Chinese Academy of Physics (cited by ACTER 1986), a diet with daily food energy of 11 kJ and protein of 75 g per capita has been defined. In this diet, it is assumed that 15% of the food protein and less than 7.5% of the food energy is from animal meat; and at least 35% of the food energy is from wheat. In addition, requirements for vegetable oil, potatoes and apple in the diet are specified, and set to 14.5%, 15-20% and 1.3% of the total energy, respectively, which are derived from the data of Luyten (1995).

Firewood requirement

Firewood requirements are expressed in terms of standard coal equivalent (SCE, heat of combustion = 29.7 MJ kg^{-1}). According to Peng *et al.* (1991), average annual home consumption per person in 1985 was 396 kg SCE in the rural areas of the Loess Plateau, similar to the average consumption of 400 kg SCE in China as a whole. In this study, the annual firewood requirement is set to 400 kg SCE per capita.

6.2.3 Constraints for the base runs

Assumptions and mathematical descriptions of the agricultural production activities, constraints and objective variables in the MGLP model have been given in Chapter 5. A summary description of the main assumptions and constraints for the base runs of MGLP model is presented in this subsection.

Limitation for the land resources

Land available for agriculture includes suitable land, natural grassland and natural shrubland. The suitable land comprises 6 land units, and the limit of each land unit that can be used for the major types of production activities is shown in Table 6.3.

Limits for irrigated/mechanized farming, and terracing are given per land unit, as not all land is accessible to irrigation/mechanization due to poor infrastructure and small size of land parcels. For the flood plain, the area suitable for irrigated/mechanized farming is set to 80% of the land area; for gently and moderately sloping land units, the area suitable for mechanized farming is set to 80%; for each of the sloping land units, not more than 60% of the land can be terraced. Considering the limited markets and poor road systems, an upper limit, i.e., 10% of the sloping land units and 15% of the flood plain, can be used for growing apples in each sub-region.

Table 6.3 Upper limit (fraction) of each land unit used for the major types of production activities (FLP-VSL is land unit, 'N' is not suitable or not considered)

Major types of production activities	FLP	TRL	GSL	MSL	STL	VSL
Irrigated cropping activities	≤ 0.8	N	N	N	N	N
Semi-mechanized cropping activities	≤ 0.8	N	≤ 0.8	≤ 0.8	N	N
Manual cropping activities	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
Fruit activities	≤ 0.15	≤ 0.1	≤ 0.1	≤ 0.1	≤ 0.1	≤ 0.1
Sown grass production activities	N	N	≤ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
Firewood production activities	N	N	N	N	≤ 1.0	≤ 1.0

The area of natural grassland (or natural shrub-land) used for animal grazing (or firewood collection) should be less than the available area per sub-region. No limit is given for water availability because of limited land area accessible to irrigation.

Restrictions for agricultural products

Corn can be used as food and for feeding animals, and soybean can be used for food and for producing vegetable oil. Wheat and millet can only be used for food, and seed flax only for vegetable oil. Potatoes are mainly for food, but 5% (small sized) of the potato production is assumed for feeding animals. For Ansai, it is assumed that each of the marketable crop products should not be deficit, but for each sub-region, the deficit is allowed.

Crop residues are consumed by animals or used as firewood within each sub-region (Table 6.4), as transport of residues among the sub-regions may not be economical due to their bulky volume. Shrub-wood production from the natural and planted shrub-land in a sub-region is fully determined by the requirement in that sub-region, i.e., the produced amount equals the requirement of shrub-wood. Per sub-region, the total requirement of crop residues including those used for feeding animals and for firewood should not exceed the total production; and production of alfalfa is fully consumed by animals within each sub-region.

Agricultural by-products including grain husks, cakes and small part (the small-sized potatoes) of potatoes are consumed by animals per sub-region, i.e., the requirement is equal to or less than the available amount. Manure produced by animals in a sub-region can only be used for crop, fruit and (sown) grass production in that sub-region, and it is considered as a loss if it is not fully used. Table 6.4 presents the limit for use of crop residues, alfalfa and shrubs.

Table 6.4 Limitation of crop residues, alfalfa and shrubs used for feed or firewood. 'N' means that the product cannot be used for feed or firewood. The figures are percentages of the available amount of the product in the column heading and the signs '≤' and '=' are the limit for that product that can be used for feedstuffs or firewood in each sub-region.

Item	Corn	Wheat	Millet	Seed flax	Soybean	Alfalfa	Shrub-wood
For feed	≤ 60%	≤ 60%	≤ 75%	N	≤ 50%	= 100%	N
For firewood	≤ 100%	≤ 100%	≤ 100%	≤ 100%	≤ 100%	N	= 100%

Draught animals

Draught animals can be sold or bought at markets. For each sub-region, an upper limit is given for the total number of oxen or donkeys that can be maintained for agricultural production. This limit is set to one-fourth of the total rural population, with the assumption that one family can have a maximum of one ox and one donkey. Meat from the obsolete draught animals is consumable, and consumed only within each sub-region.

Net return

Per sub-region, the net return (the gross production value minus the total production costs) should be non-negative, i.e., the gross value of agricultural production should be higher than the total production costs. The gross production value is the summation of all agricultural products (crops, meat, apples and firewood) multiplied by their prices. The production costs comprises all inputs such as production materials (fertilizers, irrigation water, biocides and seeds), feed (for animals), machinery, small farm tools, soil conservation, draught animals, and labor. Costs of land and capital (interest) are not considered.

Labor availability

Available labor for agricultural production is calculated as the product of the estimated rural population in 2020 and the fraction of the population that is economically active (aged 20-60), as shown in Table 6.2, assuming that the age structure will not change. Per sub-region, the labor requirement should not exceed the total available labor, i.e., there is no labor import from other sub-regions.

Self-sufficiency

Food crops are classified into three categories: food grains (corn, wheat and millet), tuber crops (summer and autumn potatoes) and oil crops (soybean and seed flax). Per sub-region, the total requirement for each of these food categories should be self-supplied in terms of grain equivalent (GE). Per sub-region, the meat production in terms of pork equivalent (PE) should meet the requirement; and for the county as a whole, there is no deficit for goat meat, sheep meat and pork, respectively. Apple is self-supplied per sub-region. Further, it is assumed that at least 50% of the requirement for vegetable oil is produced from soybean and flax, and the remaining part is from markets.

6.3 Optimization results for the base runs: optimum values and trade-offs

This section presents the optimum objective values and the trade-offs among objectives. First, the extreme values calculated by the MGLP model without imposing restrictions on other objective variables are given, and next, land use, crop production, net return, employment and soil loss are discussed in more detail using a trade-off analysis. Finally, a summary of the results is given.

6.3.1 The extreme objective values

The extreme value for each of the objective variables is calculated individually without imposing restrictions on other objectives, under the given constraints of self-sufficiency for each sub-region. The optimization results are summarized in Table 6.5, in which the values in each column are from separate model optimizations; and the optimal results are not achieved simultaneously. All values are for Ansai county as a whole, and calculated with the constraints as discussed in Section 6.2. The total crop production is expressed in grain equivalent (GE, equals 16 MJ per kg), biocide use in active ingredient (a.i.), and monetary objectives in Chinese yuan (1 US$ equals 8.3 yuan in current exchange rate, 1999).

6.3.2 Land use allocation

Agricultural land use varies with the different objective optimizations (Fig. 6.1). When maximizing the total crop production, total net return or total employment, all of the suitable land is used, of which more than 90% is allocated to crops and the remainder is allocated to apples. For other objective optimizations, only part of the suitable land is used. For example, when minimizing the total soil loss, 4.5 10^4 ha (about two-fifths of the suitable land) is used, of which 90% is allocated to crops[1].

In minimizing total cropping area and, alternatively, total agricultural production costs, rather similar land use structure is obtained: about 60% of the suitable land is used, of which around one-third is allocated to crops; the remainder is mostly allocated to shrubs for producing firewood. The reason for the similarity of these two objectives is that when minimizing the cropping area, i.e., maximizing land productivity, priority should always be given to the most productive land use activities, which are often cost-effective.

The minimum cropping area required for the rural population to meet the self-sufficiency requirements in 2020 is 2.1 10^4 ha, or 17% of the cultivated area surveyed in the late 1980s (Chen *et al.* 1988a). Except for the maximization of total crop production, total employment and total net return, the area allocated to crops for the optimization of other objective variables ranges from 2.3 10^4 to 4.1 10^4 ha.

Apple production is attractive for achieving the maximum labor productivity and total net return. When maximizing both objectives, a total of 1.1 10^4 ha (i.e., the maximum area assumed to be available for apple production) is allocated to apple. When maximizing total employment, a slightly lower area, i.e., 9.2 10^3 ha is allocated for growing apples. When optimizing other objective variables, the area allocated to apple is between 138 ha and 327 ha.

An area of 1.8 10^4 and 9.6 10^3 ha allocated to the sown grass activities, respectively, when minimizing total use of mineral N and biocides. When mineral N input is limited, the livestock systems are emphasized, in order to supply more manure N, which results in an in-

[1] In this minimization, the sloping land units selected for crop production are all terraced. As it is assumed that the defined grass and shrub activities are practiced only on sloping land, the soil loss for such activities is normally higher than the terraced (bench terrace) cropland. That is why no sown grass and very limited planted shrub-land use are selected when minimizing the total soil loss.

crease of the sown grass area. As no biocides are applied for the defined sown grass activities, the MGLP model shifts to use grassland instead of cropland to produce the required feed (grazing grass, residues and alfalfa, etc.) when the biocide use is limited. When minimizing the total cropping area and total production costs, a limited area is allocated to sown grasses. For other objective optimizations, the sown grasses are not selected.

When maximizing total crop production or total net return, no planted shrubs are selected; when minimizing total soil loss and maximizing total employment, the area allocated to shrubs is 4.1 10^3 and 0.3 10^3 ha, respectively. When optimizing other objectives, a much larger area is allocated to shrubs, ranging from 2.8 10^4 to 4.0 10^4 ha.

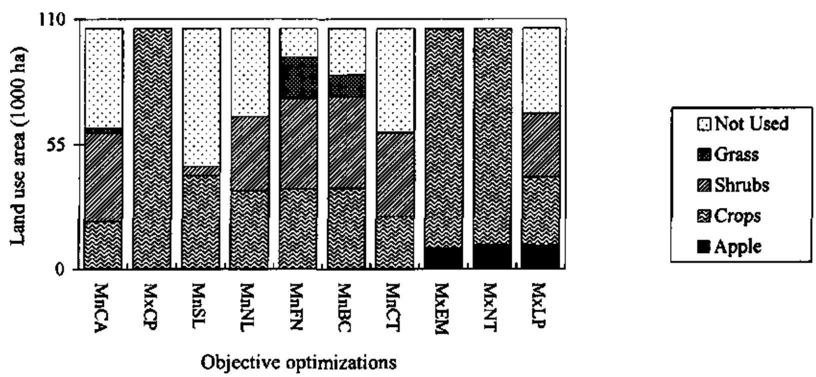


Figure 6.1 Land allocations under different optimizations of the selected objective variables (Abbreviations MnCA - MxLP are defined in Table 6.1).

Table 6.5 Extreme values of the objective variables optimized (**bold**) and the associated values of other objective variables. The abbreviations MnCA-MxLP are defined in Table 6.1. The values in each column are from separate model optimizations, and thus the optimal results are not achieved simultaneously.

Objective variable	MnCA	MxCP	MnSL	MnNL	MxEM	MxNT	MxLP	MnCT	MnFN	MnBC
Total cropping area [CA, 10^3 ha]	**20.8**	105.7	41.1	34.2	96.3	95.3	30.0	23.1	35.0	35.5
Total crop production [CP, 10^3 t GE]	114	**541**	220	110	328	394	136	109	131	123
Per unit area soil loss [SL, t km^{-2}]	188	441	**52**	434	906	653	270	237	660	567
Total N loss [NL, t N]	1313	3586	1751	**815**	5398	4426	2616	1164	2501	2396
Total employment [EM, 10^3 man-years]	13.5	54.5	22.3	18.1	**88.2**	63.7	23.4	12.7	29.3	23.4
Total net return [NT, 10^6 yuan]	*130*	*388*	*181*	*111*	*555*	***781***	487	144	*147*	109
Labor productivity [LP, yuan per man-year]	9690	7121	8128	6160	6293	12249	**20809**	11388	5009	4636
Total production costs [CT, 10^6 yuan]	165	543	267	200	933	705	242	**151**	332	252
Total mineral N use [FN, t N]	2326	12094	5160	1315	4311	8529	5243	2029	**394**	1990
Total biocide use [BC, t a.i.]	52	158	77	56	230	279	151	61	63	**28**

6.3.3 Agricultural production

Maximizing the total crop production

The maximum crop production is 541 10^3 t GE, about 9 times the total crop production (59.0 10^3 t) of Ansai in 1992. Divided by the total cropping area, the average crop production (excluding alfalfa) is 5.1 t GE ha^{-1}, lower than the value of 5.5 t GE ha^{-1} obtained by minimizing the total cropping area. Since no restriction is imposed on the land area used for each cropping activity, this leads to most land allocated to corn or corn-included rotations (because the yield of corn is high). In the total crop production, corn covers 92%, millet 1%, wheat 2%, soybean 3%, and potatoes 2%. This is much different from current crop production structure in Ansai, in which corn production occupies about 30%, millet 25%, wheat 14%, potatoes 11%, and soybean, flax and other minor crops about 20% of the total crop production.

In this maximization, the suitable land is not allocated to land use activities of planted shrubs and sown grasses. The energy required for cooking and basic heating is covered by crop residues and shrubs from the natural shrub-land. The self-sufficiency requirement for meat is mainly supplied by pork, with a small amount from the slaughtered draught animals (oxen and donkey) when they are old. The total pork production is 7438 t, and sheep and goat activities are not selected in this optimisation.

When other objectives are optimized, total crop production is much lower. In minimizing the total cropping area, N losses or production costs, the total crop production is slightly higher than one-fifth of this extreme value. In maximizing the total agricultural employment and total net return, the total crop production is 61% and 73% of the maximum value.

The effect of available inputs

At the maximum crop production, the associated inputs such as production costs, mineral N use, biocide use, and labor input (employment) are presented in Table 6.5. Currently in Ansai, the availability of capital, fertilizers and biocides is often limited and the maximum crop production may not be achievable due to their limited availability. By limiting the production inputs, their effect on the total crop production can be analyzed in an iterative procedure with the MGLP model.

The procedure, the so-called trade-off analysis, is used to investigate the trade-off relationships between two objectives, i.e., to find the optimal value of the first objective variable under different restrictions imposed on the second one. In this case, the first objective variable is the total crop production (to be maximized), and the second objective variable can be the total production costs, employment, mineral N use, biocide use, or total terracing area. For a trade-off analysis, several optimization runs are needed. Per run, the restriction value for the second objective variable (RV) can be given with Eqn 6.2.

$$RV = MRV + f \cdot (ORV - MRV) \qquad 6.2$$

in which MRV is the minimum value of the second objective variable obtained without imposing restrictions on other objective variables, ORV is the value of the second objective variable for achieving the optimum value of the first objective variable, and *f* is a factor value (0-1). For each objective variable, its *MRV* and *ORV* value can be read from Table 6.5. For the second objective variable that is to be maximized in the model, an additional minimization run is required to obtain its *MRV*. For example, the *MRV* of total employment can be obtained by minimizing the total employment without imposing restrictions on other objective variables.

The procedure can be illustrated with an example of the trade-offs between total crop production and total production costs. The total production costs are 151 10^6 yuan (*MRV*) at its minimum, and 543 10^6 yuan (*ORV*) at the maximum total crop production (Table 6.5). For the first optimization run, we give *f* a value of 0.1, and thus the restriction value (*RV*) for the total production costs are 190.2 10^3 yuan, as calculated with Eqn 6.2. If we set the total production costs at $\leq$ 190.2 10^3 yuan in the MGLP model, the total crop production can be maximized. For the next run, we give *f* a different value (e.g., 0.2), and thus *RV* is obtained, and the total crop production is maximized again. Following the same procedure, various runs can be conducted by giving different restriction values (*RV*) via *f*.

The restriction for the second objective and optimization results for the first objective are normalized with Eqn 6.3, in which *rsv* is the restriction value (*RV*), expressed as a percentage of the *ORV* in a run, and *obv* is the optimized value (*OV*) of the first objective variable in a run, expressed as a percentage of its maximum value (*MOV*).

$$rsv = \frac{RV}{ORV} \cdot 100 \qquad 6.3a$$

$$obv = \frac{OV}{MOV} \cdot 100 \qquad 6.3b$$

The trade-off results between the total crop production and the various inputs are presented in Fig. 6.2, in which the Y-axis is the total crop production determined by the restricted values shown on the X-axis.

To achieve the maximum crop production, the associated production costs are 543 10^6 yuan. By reducing this cost value by 10%, the total crop production decreases about 2%. Further limiting the total production costs, the total crop production decreases rapidly. If total cost is limited to 80%, the total crop production decreases about 8%. By reducing the total cost by 50%, the total crop production is reduced by about 40%. At the minimum total cost of 151 10^6 yuan, only 20% of the maximum total crop production can be achieved.

The total mineral N required to achieve the maximum crop production is 1.2 10^4 t (about 7 times 1725 t, the total use of mineral N of 1992 in Ansai). When the input of mineral N is reduced by 20%, 50% and 90%, the optimized crop production decrease 4%, 13% and 27%, respectively. If the total mineral N input is set to 394 t, the minimum value determined by minimizing the total mineral N use (Table 6.5), the total crop production[2] can approach 360 10^3 t, about two-thirds of the extreme value.

The total use of biocides for achieving the maximum crop production is 158 t a.i., which is considerably higher than the total biocide use of 1992 in Ansai (22.3 t, commercial formulation of biocides). This biocide use can be reduced by one-third at a decrease of 6% of the total crop production. When the biocide use is further reduced, marked decrease in the total crop production occurs, e.g., by limiting the biocide use to 50%, 30% and 20% of the optimal value (158 t), the total crop production is reduced by 17%, 41% and 70%, respectively.

To achieve the maximum crop production, the required labor is 5.4 10^4 man-years. By decreasing the labor input, the total crop production decreases almost linearly (Fig. 6.2). If the total employment is reduced by 15%, 61% and 75%, the maximum crop production decreases by 5%, 50% and 70%, respectively.

At the maximum total crop production, the total terraced area is 5.9 10^4 ha, the maximum area that can be terraced in Ansai. If this terraced area is reduced by 50%, total crop production can approach 96% of its maximum value. Without terracing, the maximum crop production is 478 10^3 t, 12% lower than the maximum value.

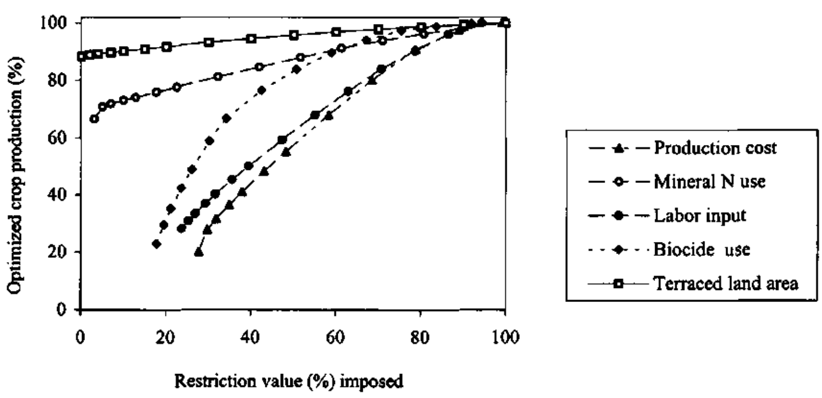


Figure 6.2 Effect on total crop production of restrictions imposed on each of the objective variables (total production costs, mineral N use, biocide use, employment, and terraced area). The value of each variable on the X-axis is expressed as % of its value for achieving the maximum crop production (Table 6.5), based on Eqn 6.3a. The total crop production optimized under different restrictions is expressed as % of the maximum value (Eqn 6.3b).

[2] In Table 6.5, a total crop production of 131 10^3 t is presented for the run in which total mineral N is minimized. The fact that 360 10^3 t can be produced at the same N use level points at a non-pareto optimal solution in Table 6.5. In the case of maximizing the total crop production (360 10^3 t), the increased N requirements due to the increased crop production are covered by manure and bio-fixation: the area allocated to cropping activities is 1.0 10^5 ha, of which more than 40% is under mixed crop rotations with alfalfa, and the total manure N produced from the livestock systems is 7137 t, of which 7109 t is applied to crops. In the run of minimizing the total mineral N use, as presented in Table 6.5, the area allocated to cropping activities is 3.5 10^4 ha, of which one-fourth is planted with mixed crop rotations, and total manure N is 2638 t, in which 2592 t is applied to crops, averaging 74 kg ha^{-1}.

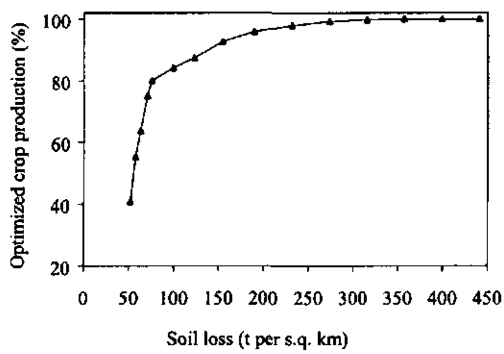


Figure 6.3 Effect on total crop production of restrictions imposed on the total soil loss (expressed as soil loss per km^2). The optimized crop production under different restrictions imposed on total soil loss is expressed as % of the maximum (Eqn 6.3b).

The effect of limiting total soil loss

From the trade-off values as presented in Fig. 6.3, it can be seen that up to a certain level, restricting the total soil loss has a very limited effect on the total crop production. At the maximum crop production (541 10^3 t), the total soil loss is 4.7 10^5 t, averaging 441 t km^{-2} by the agricultural land area (allocated). If this soil loss is reduced by 40%, i.e., to an average soil loss of about 270 t km^{-2}, total crop production decreases only about 1%. When this soil loss is further reduced, up to an average value of around 200 t km^{-2}, total crop production decreases obviously (Fig. 6.3). At the minimum total soil loss of 2.4 10^4 t (52 t km^{-2}), the total crop production is 220 10^3 t, 40% of the maximum value.

The tightened restriction for soil loss greatly reduces the land area, especially of sloping land allocated to crops. When soil loss is more than 300 t km^{-2}, the same area of 10.6 10^4 ha (i.e., the total suitable area) is allocated to crops. From this to the point at which the mean soil loss is 75 t km^{-2}, the area allocated to crops markedly decreases to 8.8 10^4 ha. When the soil loss is reduced further to its minimum value, the area allocated to crops becomes only 3.8 10^4 ha, i.e., a large area with a steep slope is excluded for cropping.

6.3.4 Net agricultural return

Maximizing total net return

Total net agricultural return can approach 781 10^6 yuan, about ten times the net agricultural production value of Ansai in 1992. Corresponding to this extreme value, the average labor productivity is 12.2 10^3 yuan per man-year, and the average net return per capita of rural population is 3358 yuan per year, about 8 times the annual net return of 1992 in Ansai (438 yuan per capita).

Compared to the results of maximizing total crop production, this optimization of total net return focuses less on crop production, but shifts more towards apple and animal production. The total crop production is 394 10^3 t GE, 72% of its maximum (541 10^3 t GE). In the total crop production, corn covers 71.0%, wheat 14.0%, soybean 6.4%, summer potato 7.0%, millet 1.4% and seed flax 0.2%. Apple (fresh weight) production is 170 10^3 t, pork 30.0 10^3 t and mutton 1.6 10^3 t, which is much higher than the values obtained when maximizing total crop production. In addition, total 47 10^3 t DM of alfalfa is produced from crop rotations with alfalfa.

As no land is allocated to sown grasses and planted shrubs, the required feed for animals is mainly from crop residues, alfalfa, corn and the natural grassland. The firewood is covered by crop residues and shrubs from the natural shrub-land.

The effect of restricted inputs

To achieve the maximum total net return, the total production costs are 705 10^6 yuan, biocide use 279 t a.i., mineral N use 8529 t N, and terracing area 5.9 10^4 ha. From the results presented in Fig. 6.4, these required inputs could be greatly reduced without sacrificing the total net return too much. At a reduction of about 35% for the total production costs, 50% for the total mineral N use, 30% for the total use biocide use, or 60% for the total terraced area (imposed individually in the MGLP model), 95% of the maximum net return can be achieved.

At the minimum production costs (151 10^6 yuan), the total net return optimized is 18.5% of the extreme value (781 10^6 yuan). When the capital input increases, the total net return rapidly increases, and then the increase slows down. At about 50% of the required total production costs, 88% of the maximum net return can be obtained.

The minimum use of biocides is 28 t a.i. (Table 6.5), 10% of the biocides (279 t) required to attain the maximum net return. When this minimum value is used as the upper limit of biocide use, the total net return optimized is 114 10^6 yuan, about 15% of its extreme value. When this restriction for biocide use is relaxed, the total net return rapidly increases; this increase slows down at around 70% of the required biocides (Fig. 6.4). For instance, the total net return can approach 25%, 50% and 90% of the extreme value when total biocide use is limited to 12%, 28% and 64% of the value associated with the maximized net return. The total biocide use can be reduced by 10% with a very limited reduction (about 0.2%) of the maximum net return. If the total net return is 2% lower than the maximum, the total biocide use can be reduced by 20%.

When the total mineral N input is limited, the shortage of N can be partly compensated by growing crops in alfalfa-based rotations and by using organic N from the animal production systems. This leads to a limited reduction of the total net return, e.g., with a decrease of 20% and 50% of the total N use, the total net return can be reduced by only about 1% and 5%. At the minimum use of mineral N (394 t), the total net return can approach 586 10^6 yuan[3], 75% of the extreme value.

[3] Compared to the value associated with the maximum total mineral N use (Table 6.5), this value is much higher. The reason is the same as that for the total crop production (refers to footnote 2).

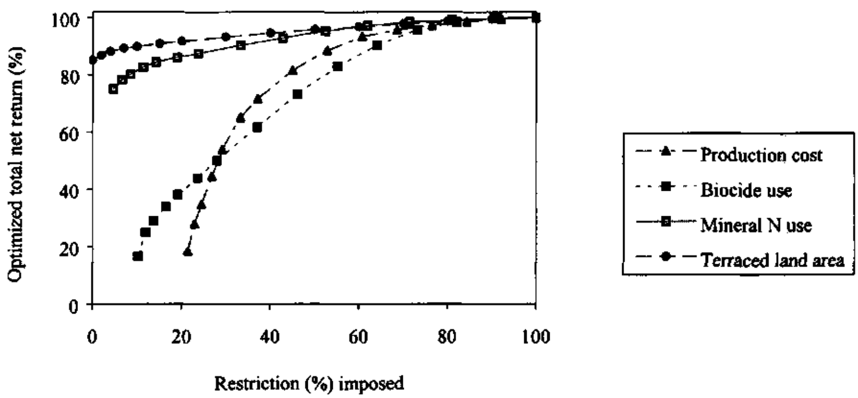


Figure 6.4 Effect on total net return of restrictions imposed on each of the objective variables (total production costs, mineral N use, biocide use, and terraced area). The value of each variable on the X-axis is expressed as % of its value for achieving the maximum net return (Table 6.5), based on Eqn 6.3a. The total net return optimized under different restrictions is expressed as a percentage of the maximum value (Eqn 6.3b).

The effect of terracing area on the total net return is similar to that on the total crop production. If no terrace is built, the total net return is 15% lower than its extreme value. When terracing area is limited to 10% and 50% of the maximum terracing area (5.9 10^4 ha), 90% and 96% of the maximum total net return can be achieved.

The effects of restricted soil and N losses

Total soil loss at the maximum total net return is 6.9 10^5 t, averaging 653 t km^{-2} for the agricultural area (excluding the natural grass and shrubs). This value can decrease to 211 t km^{-2} with a slight decrease (1%) of the maximum total net return. When the average soil loss is limited to 120 t km^{-2}, the total net return is reduced by 4%. Further tightening the restriction for total soil loss causes a rapid decrease of the net return, as it greatly limits the area used for agricultural production. From Fig. 6.5A, it can be seen that from the point at which the soil loss is about 100 t km^{-2} to the point of minimum soil loss (52 t km^{-2}), the total net return rapidly decreases from 94% to only 23% of its maximum. The reasons for this abrupt change are similar to those that cause the abrupt change of the total crop production (see Subsection 6.3.3). More explanations will be given in the next section.

The total N loss associated with the maximum net return is 4.4 10^3 t. By lowering this total N loss by 10%, 25% and 50%, the total net return can be reduced by about 1%, 5% and 20% (Fig. 6.5B). If the total N loss is limited to the minimum value (815 t), the total net return approaches only 14% of the maximum value.

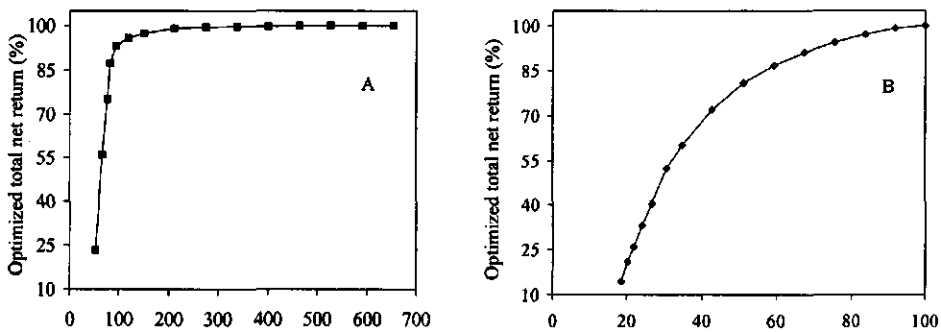


Figure 6.5 Effect on total net return of restrictions imposed on the total soil loss (A) and total N loss (B). The value of total N loss (B) on the X-axis is expressed as a percentage of its value for achieving the maximum net return (Table 6.5), based on Eqn 6.3a. The soil loss is expressed as a ratio of total soil loss to the agricultural area. The total net return optimized under different restrictions is expressed as a percentage of its maximum value (Eqn 6.3b).

6.3.5 Soil losses

Minimizing the soil loss

The total soil loss is the summation over all agricultural land use, excluding the natural grass, natural shrubs, forests and unusable land. When targeting the minimization of total soil loss under a given restriction of self-sufficiency requirement for the agricultural products, the minimum value is 2.4 10^5 t, averaging 52 t km^{-2} by the agricultural land area. This value is slightly higher than 46 t km^{-2}, the value obtained by minimizing the soil loss per unit agricultural area (via the reference variable *USLS*, see Eqn 5.3.3a, Section 5.3, Chapter 5). This optimized soil loss is less than 1% of the mean soil loss at present in Ansai.

The soil loss in optimizing other objectives

In minimizing total cropping area and total production costs, and maximizing net return per employment, the average soil loss of agricultural land is 188, 237 and 270 t km^{-2}, respectively. These values are 4-6 times the minimum soil loss, but much lower than those obtained when other objective variables are optimized (Table 6.5). These figures reveal that the objective of achieving a minimum soil loss per unit area does not conflict very much with the objectives of maximizing the crop productivity (minimizing the total cropping area), minimizing the production costs, and maximizing the labor productivity. Under these objectives aiming at maximizing the agricultural productivity per unit land area or per laborer, priorities are given to the cost-effective production systems that often have low soil loss. At the maximum total net return and total employment, the associated soil loss is 653 and 906 t km^{-2}, respectively. These higher soil losses are due to the use of sloping land (without terracing) for agricultural production.

When total use of biocides and chemical N is minimized, the soil loss is 567 and 660 t km^{-2}, respectively. These rather high soil losses are the result of lower plant coverage of the selected land use activities. To approach the minimum total inputs of biocides (or mineral N), priority could always be given to the land use activities that need lowest inputs of biocide (or mineral N), but they normally have lower yields and therefore lower plant coverage.

Total soil loss under restricted inputs

The trade-off values of total soil loss as determined by restrictions imposed on the selected four variables, i.e., the total production costs, total mineral N use, total biocide use and total terracing area are presented in Fig. 6.6. The total production costs, total use of mineral N and biocides, and total terraced area (X-axis) are presented as a percentage of the values (267 10^6 yuan, 5.2 10^3 t, 28 t a.i and 3.3 10^4 ha, respectively) associated with the minimum total soil loss.

Fig. 6.6 shows that the total production costs, mineral N use and biocide use, and terracing area required for achieving the minimum total soil loss can be greatly reduced if the mean soil loss increases to about 60 t km^{-2} from the minimum. Corresponding to this soil loss, the total production costs can be reduced by 40%; total mineral N use by 90%; biocide use by 60%; and the total terrace area by 75%, respectively. After these points, increasing the total input, mineral N use, biocide use or terraced land area can cause limited reduction of the soil loss.

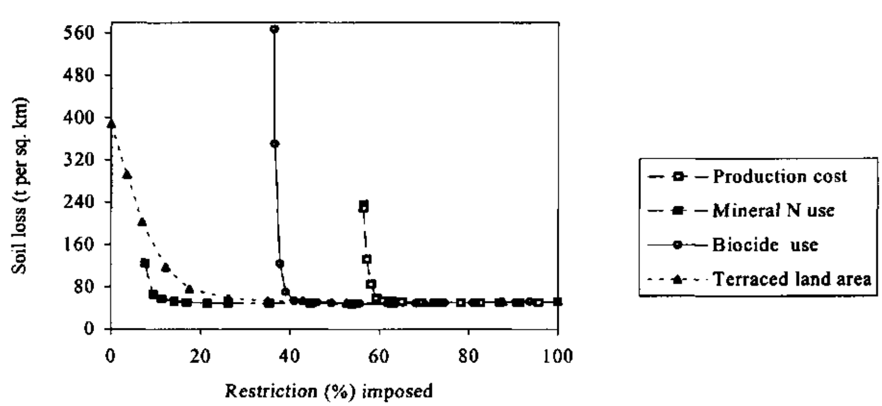


Figure 6.6 Effect on total soil loss of restrictions imposed on each of the objective variables (total production costs, mineral N use, biocide use, and terraced area). The value of each variable on the X-axis is expressed as a percentage of its value for achieving the minimum total soil loss (Table 6.5), based on Eqn 6.3a. The total soil loss optimized under different restrictions is expressed as soil loss per unit agricultural area.

This abrupt change is due to 1) the great differences of soil loss among the cropping activities when different soil conservation measures, such as terracing, residue mulching, furrow-ridging and contouring are adopted; 2) the similarity in soil loss for the land use activities that are identical in soil conservation measures, production levels and land conditions; and 3) very low soil loss for the cropping activities on flat or terraced land compared to those on sloping land with low level conservation (e.g., contouring). When the total inputs in monetary terms (N or biocide) is highly limited, some land use types are selected that need low (N or biocide) inputs, but normally with much higher soil loss. When the limitation is less restricted, up to a certain level, the soil losses of the selected land use types are very similar; if the limitations are relaxed further, the MGLP model can choose the land use activities that need higher (N or biocide) inputs, and have slightly lower soil loss. This adjustment actually can make a very limited reduction in the total soil loss.

6.3.6 Employment and labor productivity

Maximum total employment is 8.8 10^4 man-years, 84% of the total available labor projected in the year 2020. The average labor productivity corresponding to this extreme value is 6.3 10^3 yuan per man-year (Table 6.5). Without employment restrictions, the maximum labor productivity is 20.8 10^3 yuan per man-year, as calculated by maximizing the reference variable *URTN* (Eqn 5.3.14a, Section 5.3 in Chapter 5).

Total employment is greatly affected by total inputs (total production costs), i.e., it decreases with decreasing total production costs. When the total inputs including labor in monetary terms are restricted, the MGLP model gives priority to production activities that are most labor-intensive, to achieve the maximum employment. The trade-offs among total employment and total production costs are shown in Fig. 6.7A. At the maximum total employment, the total production costs are 932 10^6 yuan. If these production costs are reduced by about 20% and 50%, the total employment is reduced by 5% and 23%, respectively. At the minimum total production costs (151 10^6 yuan), only 15% of the maximum employment can be attained.

Increasing employment results in a great increase of total production costs, and it therefore leads to a decrease of labor productivity in terms of net return per man-year. At the maximum labor productivity, the total employment is 2.3 10^4 man-years. When this employment increases to the maximum of 8.8 10^4 man-years, the labor productivity almost linearly decreases (Fig. 6.7B), i.e., it is largely determined by a single factor of total labor input. This trade-off is much different from the trade-off between total employment and total production costs (Fig. 6.7B), because the maximization of labor productivity under a given restriction on total employed labor seeks a maximum ratio of the total net return to total labor input, i.e., the model gives priority to activities with high net return per laborer. Maximization of total employment seeks a point at which the labor employment is maximal, and the total production costs are at the given limit. In this optimization, the priority is given to the production activities that have the highest labor requirement.

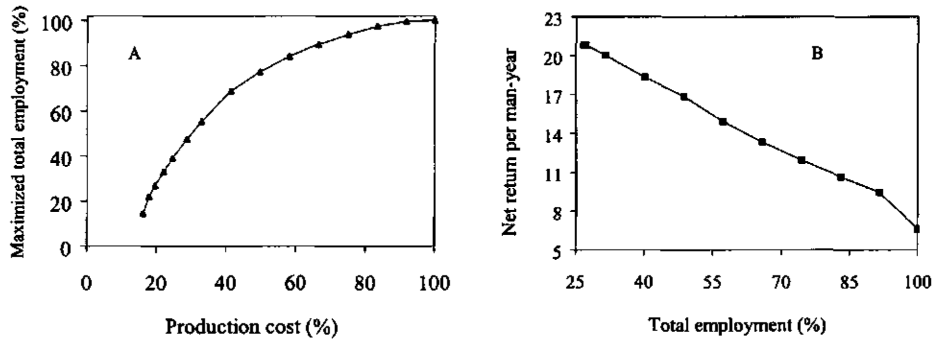


Figure 6.7 A. Effect on total employment of restriction imposed on total production costs. The production costs are expressed as a percentage of their value for achieving the maximum total employment (Table 6.5), based on Eqn 6.3a. The total employment optimized under different restrictions is expressed as a percentage of the maximum value (Eqn 6.3b). B. Effect on net return per laborer (1000 yuan per man-year) of restriction imposed on total employment. The employment on the X-axis is a percentage of the maximum employment (8.8 10^5 man-years).

6.3.7 A brief summary of extreme objective values and trade-offs

Without restrictions on the total production costs, fertilizer N and biocide use, and on other objective variables, total crop production and total net return can approach 541 10^3 t GE and 781 10^6 yuan. These values are about ten times the total crop production and the total net agricultural return of Ansai in 1992, respectively. The total soil losses can be decreased to an average of 52 t km^{-2} for the total agricultural area, as required for meeting the self-requirements of food and firewood. This minimum soil loss causes a great decrease of other objectives, such as total crop production and net return.

At maximum total net return, the mean soil loss is 653 t km^{-2}. The trade-off results show that reduction of this soil loss to 200 t km^{-2} weakly affects the total net return. In other words, below this soil loss, the total net return is strongly affected, because it results in a great decrease of the area (sloping land) used for agriculture. When the mean soil loss is at about 60 t km^{-2}, increasing the total production inputs, mineral N use, total biocide use, or terracing area can lead to a very limited decrease of the soil loss (Fig. 6.6).

To obtain maximum crop production and net return, the required labor input is about 50% and 60% of the total available labor, respectively. To achieve the maximum labor productivity (net agricultural return per laborer), the total employment is 2.3 10^4 man-years (about 20% of the available labor). By increasing total employment, the labor productivity almost linearly decreases. Evidently, labor availability is not a limiting factor for crop production in Ansai.

Total inputs have an apparent effect on total crop production, total net return and total employment. When the total input in monetary terms is limited, these three objective variables are markedly reduced (Fig. 6.2, 6.4 and 6.7B). Since biocide input is required for all cropping and fruit activities, limiting the total biocide use results in a decrease of the area used for agricultural production, and consequently, causes an obvious reduction in total crop production and total net agricultural return (Figs. 6.2-3). There is large potential to reduce the mineral N use, since its requirement can be largely covered by manure and biologically fixed-N (alfalfa and soybean fixations).

6.4 Analysis of changing food requirements

In the base runs, ten objectives are evaluated, subject to the restriction of the self-sufficiency requirement as determined by the average population growth rate and an assumed diet in the year 2020. In this section, additional options for food requirements based on different population growth rates and dietary patterns are defined and their consequences on land use allocations are examined.

6.4.1 Options for food requirement

The growth rates (Table 6.2) as used for the population projection in the base runs are rather high. As these high population growth rates strongly conflict with the population policy of China, the local government could make more efforts to decrease the population growth. Therefore, two additional population growth rates are assumed, i.e., 60% and 80% of the average value in 1982-1990. Thus, three population scenarios are identified, i.e., low, moderate and high population growth, corresponding to 60%, 80% and 100% of the average growth rates of 1982-1990 (Table 6.2). The projected total rural population based on the low and moderate growth rates is 1.8 10^5 and 2.1 10^5 persons, 78.6% and 88.7% of that used in the base runs, respectively.

In addition to the base diet used in the base runs, a moderate diet is defined with the identical daily food energy (11 MJ) as the base diet, but with higher protein intake of 81 g (Luyten 1995). In this moderate diet, it is assumed that 15-30% of the food energy and 30% of the protein is from animal meat, and the composition of wheat, potatoes, vegetable oil and apple in the diet is the same as for the base diet. Combining the two diets (i.e., the base and moderate diets), and the three population growth scenarios, six options (including the combination as used in the base runs) are identified for the food requirements.

6.4.2 Optimization results for different food requirement options

The optimization results for these six food requirement options are given in Table 6.6, and the comparative values for those obtained in the base runs are presented in Fig. 6.8. For the options A and B, in addition to the self-sufficiency requirements for agricultural products, the total available labor also differs from the base runs (the total available labor is lower). For the option C_m, the difference from the base runs (C_b) is only the food requirements.

Table 6.6 Optimal values of the objectives under the six food requirement options. Each value in the table is obtained by a separate model optimization; the values are not achieved simultaneously. A-C represents the low, moderate and high population growth scenarios; subscript b is the base diet and subscript m is the moderate diet.

Objective variables	Unit	Base Diet			Moderate Diet		
		A_b	B_b	C_b	A_m	B_m	C_m
Min. total cropping area	10^3 ha	13.4	16.5	20.8	17.7	21.4	26.1
Min. mean soil loss*	t km^{-2}	40	43	46	41	44	47
Min. total mineral N use	ton	0	56	394	0	60	411
Min. total N loss	ton	551	665	815	1203	1411	1656
Min. total biocide use	ton a.i.	18.6	22.4	28.2	19.3	23.6	30.0
Min. total production costs	10^6 yuan	105	125	151	178	208	247
Max. total crop production	10^6 kg GE	543	543	541	530	529	524
Max. total net return	10^6 yuan	788	788	781	784	781	771
Max. net return per man-year	10^3 yuan	24.3	22.7	20.8	20.0	18.7	17.1
Max. total employment	10^3 man-years	75.9	82.3	88.2	75.3	81.7	87.1

* The value is obtained by minimizing the soil loss per unit agricultural area (via the reference variable *USLS*); this is different from that in Table 6.5, which is obtained by minimizing the total soil loss.

The objective variables

Total cropping area and total production costs increase with the increased food requirement. For the lower food requirement options A_b and B_b, the minimum cropping area is 35% and 25%, and the minimum production costs are 30% and 17% lower than the base run values. If more meat is consumed (in the moderate diet), the minimum values increase markedly, e.g., for food requirement C_m, the minimum cropping area is 25% and the minimum production costs are 64% higher than the base run values. These marked increases are caused by the increased requirement for feed (corn, alfalfa and crop residues) that should be produced from the cropland, and the higher cost of producing meat compared to that of producing food crops.

For the total crop production and total net return, the optimized values slightly decrease with an increase of food requirement. This small variation is mainly due to the different requirements of cereals, potatoes and oil crops, and also of feed that are assumed to be fully met. The yield or benefit, e.g., of oil crops, is relatively lower, so, when the requirement for those products increases, the MGLP model has to allocate more land to the relevant cropping activities. For all food requirement options, the required labor is lower than the available labor, so, the labor availability has no effect on the optimal values of both objectives.

The food requirements have a marked impact on the labor productivity. The maximum labor productivity decreases with increased food requirements. For the low food requirement A_b, the maximum labor productivity is 24.3 10^3 yuan per man-year, while for the high food requirement C_m, it decreases to 17.1 10^3 yuan per man-year. This decrease in labor productivity is mainly due to the increased requirements for meat (higher cost and low benefit), oil crops (low yield, so, relatively low benefit) and feed.

The optimal value of the soil loss is very similar for all food requirement options. The values as shown in Table 6.6 are obtained by minimizing soil loss per unit agricultural area (via the reference variable *USLS*). For all food requirement options including the one used in the base runs, the minimum soil loss per unit area can be reduced to less than 50 t km^{-2}.

The total mineral N use can be reduced to zero for the food requirement options A_b and A_m (low population size), i.e., the required N can be met by manure and biological N-fixation. For the food requirement options of B_b, B_m, C_b and C_m, the minimum mineral N use is 56-411 t, and it increases with the increased requirement of food grains and meat (or feed).

The minimum total N loss is not related to the minimum total mineral N use, as the total N loss is calculated as the summation over all land use and animal activities. All N, including mineral and manure N applied to the land use systems and biologically fixed-N, are subject to losses. From Table 6.6 and Fig. 6.8, the minimum total N loss increases from 551 t for food requirement A_b, to 1656 t for C_m. This large increase is due to the increased land requirement for agriculture, and also largely due to the increased N loss from the animal production systems (increased meat requirement).

Increased requirements, especially for food grains, lead to an increase of the minimum biocide use. Compared to option A_b (or A_m), the minimum biocide use for option B_b (or B_m) increases considerably (Table 6.6 and Fig. 6.8). Comparing the values for the options A_b and A_m (or B_b and B_m), which have the same population size but different meat requirements, the total biocide use is very similar, i.e., increasing meat consumption has only a small effect on the optimal value.

The maximum total employment in agriculture ranges from 75.3 to 88.2 10^3 man-years for the six food requirement options. This variation is mainly caused by the total available labor related to population size. Comparing the values for the options A_b and A_m (or B_b and B_m), the total employment increases with increased population size (Table 6.6).

Land use allocation

Land use allocation varies with different food requirements. In the maximization of total crop production, total net return and total employment, available land for agriculture is all used for the six food requirement options. For the other objective optimizations, the available land is not limiting, i.e., part of the suitable land is not used. For instance, at maximum labor productivity, the total area used for agricultural production is 5.4-8.4 10^4 ha, 50-80% of the total suitable land. When maximizing the crop productivity (minimizing total cropping area), 50-70% of the total suitable land is used for agriculture.

The effect of food requirements on the land use allocation depends on the objectives to be optimized. In the maximization of total crop production, the land use allocation is hardly affected by the food requirements, i.e., all suitable land is used for crop production, except for a very limited area allocated to apple (108-138 ha, increasing with the population size). In maximizing the total net return and total employment, the land allocation is rather similar, with an emphasis on crop and apple production.

In maximizing labor productivity, the area allocated to apple is at the upper limit given for growing apple in all food requirement options, because of the high benefit of apple production, while the area allocated to crops and shrubs varies (Table 6.6). For the food requirement options with the base diet, sown grass is not selected; but for the options with the moderate diet (more animal meat), some land is allocated to grass for animal grazing. In minimizing the total mineral N use, the area allocated for agricultural production is 70-95% of the suitable land area, varying with the different options for food requirements. Unlike other optimizations, this minimization allocates much area to the sown grass activities. In minimizing total cropping area, the firewood requirement is mainly supplied by the planted shrubs; therefore, a large area is allocated to shrubs.

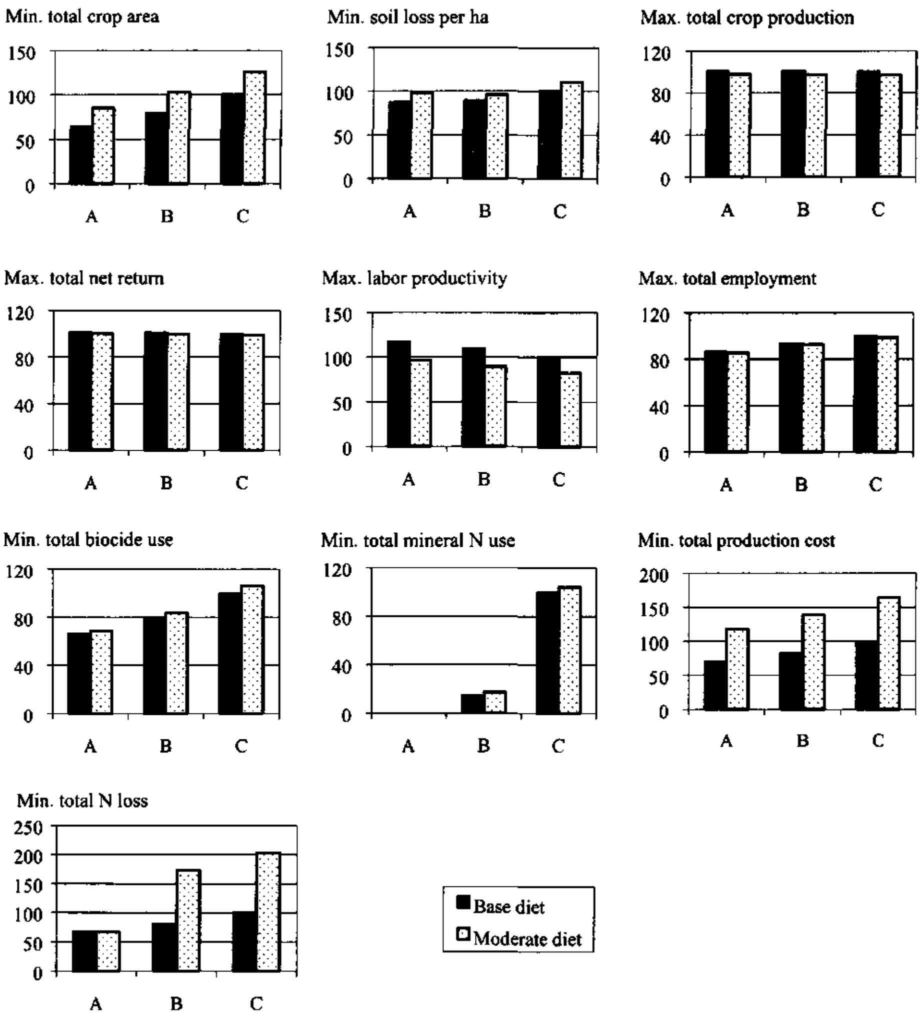


Figure 6.8 The objective values optimized under the six options of food requirements. A-C represent the low, moderate and high population growth scenarios. The objective value in the Y-axis is expressed as a percentage of the base run value of that objective.

6.5 Conclusions

Large technical potentials exist for reducing the soil loss, and increasing the crop production, net agricultural return and agricultural employment in Ansai. In general, the soil loss can be reduced to a very low level at a small sacrifice to the optimal values of other objectives (Fig. 6.3 and 6.5A). The soil loss control is largely in line with the goals of increasing the crop productivity and labor productivity (net agricultural return per laborer). Employment has marked impacts on most objectives, i.e., increasing agricultural employment can considerably increase the total production costs, cropping area, use of chemicals and soil loss, and greatly decrease the labor productivity (Fig. 6.7B). Great potential exists for reducing the mineral (fertilizer) N use without decreasing the maximum crop production much. Most of the mineral N use can be replaced by manure and biologically fixed-N, at a sacrifice of about one-third of the minimum total crop production (Fig. 6.2), or one-fourth of the maximum total net return (Fig. 6.3).

A large potential exists to produce the food requirement for the rural population using a limited cropping area. By limiting the cropping area to the most productive land types, the soil and N losses, the use of biocide and fertilizers, and the total production costs can be greatly reduced. And a rather good net return per laborer can be obtained, but this tremendously decreases the total agricultural employment (see Table 6.5).

The calculated production costs and biocide use are very high compared to current conditions. Restricting the total production costs and biocide use results in a great decrease of total net agricultural return, total crop production, and total agricultural employment.

The effect of changing food requirements varies among the objectives (Table 6.6 and Fig. 6.8). Increasing food requirements slightly affects the maximum total crop production, total net return and total employment, but it has marked (negative) impacts on the minimum total production costs, total cropping area, total biocide use and total N loss.

Chapter 7 Presentation of the Optimization Results: 2. Scenario Analysis

7.1 Introduction

In Chapter 6, we calculated the extreme values of ten objectives and the trade-offs among objectives under a set of basic constraints as defined for the base runs. The extreme value provides the upper or lower limit of a specific objective that can be achieved without imposing restrictions on other objectives. Each trade-off presents the conflict between two particular objectives and the possibility of improving one objective by allowing a given sacrifice of another. These analyses give much, but not sufficient, information to stakeholders, since several objectives are normally involved simultaneously in a policy making process, i.e., many factors are often considered by stakeholders in decision making.

In this chapter, the focus is on different policy views, in each of which several objectives are involved simultaneously, but with differing priorities regarding various strategies of the regional agricultural development. According to the key issues in relation to land use, socio-economic development and environmental protection, four scenarios are defined, i.e., soil conservation, agricultural employment, economic development and environmental protection.

These four scenarios have been formulated on the basis of the regional problems and possible development directions. The main aims are to deal with the problems concerning soil loss, population pressure and unemployment, low agricultural income, limited off-farm income generating opportunities, and the potential impacts of increasing the use of chemicals on the environment. Because terracing needs high labor and capital inputs, each scenario will be discussed with two options, with and without terracing.

7.2 Policy scenarios and the generation procedure

Policymakers seldom pursue a single goal such as minimum soil loss, but they also consider other objectives like economic return, production costs and employment. Therefore, policy scenarios are defined, in which several objectives are considered simultaneously. Each scenario represents a different priority setting with regard to objectives. With the MGLP model, a policy scenario can be evaluated by optimizing each of the objective variables that are closely related to the policy goals under given restrictions of another objective. In this section, the definitions of policy scenario and constraints are given, followed by a description of the generation procedure and restrictions assumed for the objective variables.

7.2.1 Definition of the four policy scenarios

A policy scenario regarding future land use represents a particular development choice preferred by stakeholders of the rural community or the government. Each of the four policy scenarios is defined by different priority setting of particular objectives and by the same assumptions regarding exogenous variables (i.e., population growth and requirement of agricultural products). The four policy scenarios related to the key issues of land use in Ansai are described below.

Scenario SA: Soil conservation

This scenario concentrates on soil loss control. For this aim, arable farming would be practiced with the most efficient techniques regarding soil loss control and crop productivity, and it would be restricted to the most productive land units, to increase the area available for other land use purposes (grass, shrubs or nature conservation). This scenario deals with the problem of serious soil loss and the destruction of natural vegetation, which is mainly caused by slope cultivation.

Scenario SB: Agricultural employment

Under this scenario, the primary aim is to maintain a high employment in agriculture for the large rural population. In addition, a great effort is made to increase crop production. Traditionally in Ansai, and in China as a whole, both farmers and the government always pay the greatest attention to crop production in agriculture, due to limited arable land available and the problem of food security. This scenario favors the continuation of the current labor-intensive and cropping-based type of agriculture.

Scenario SC: Economic development

Under this scenario, the greatest effort is made to increase the profit of agricultural production, i.e., to obtain a high ratio of total net return to total inputs in monetary terms. This is a common economic goal for regional development.

Scenario SD: Environmental protection

The major aim of this scenario is to protect the environment by keeping the input of biocides and mineral (fertilizer) N low; this is made possible through an integrated use of the land resources. In this scenario, the use of manual labor has a higher priority than the use of machinery, because of the high labor resource and because mechanized farming may have adverse effects on the environment, such as soil compaction and air pollution by fuel combustion. This scenario uses elements of the concepts of organic or ecological agriculture that emphasize low fertilizer N and biocide use.

7.2.2 Additional constraints incorporated in the policy scenarios

The basic constraints and self-sufficiency for agricultural products have been described in Section 6.2 of Chapter 6. For the four policy scenarios, more restrictions are considered, which are given in this subsection.

Food security

In the base runs, food security was indicated by food self-sufficiency, i.e., the production of food crops and meat should equal or exceed the requirements of the rural population. Considering the annual variability of crop production due to climatic variation, and the importance of food crops for survival, it is assumed that per sub-region, the total crop production (in GE) should be at least 150% of the total food requirement for self-sufficiency plus the feed requirement. For each specific crop (e.g., corn, wheat, potato), the deficit (total import) is assumed not to exceed 50% of the total requirement (including food and feed) for that crop per sub-region.

Land use and soil loss

In the base runs, all land use activities defined in Chapter 4 are included. In the scenario analyses of this section, the land use activities with a soil loss exceeding 15 t ha^{-1} are excluded. This criterion is still rather high, but could be acceptable compared to the current situation, in which the soil loss of cropland is normally more than 40 t ha^{-1}, and of some steep sloping cropland even more than 100 t ha^{-1}.

Area for apple growing

In the base runs, it is assumed that the apple-growing area should not exceed 10% (or 15%) of the area for each of the suitable land units, i.e., totaling 1.1 10^4 ha. This value may be too high, compared to the apple area of 420 ha in 1992. In recent years, apple farming has been promoted by the local government, because of the high profit. However, further development may be restricted by the markets, since Ansai is rather far from an urban area, and the current apple production in Shaanxi Province is mainly distributed in the counties south of Ansai. Therefore, it is assumed that the apple growing area is limited to 1000 ha, about 2.5 times that of 1992. This assumption is rather arbitrary. The optimization results can be compared with the base run values that use a larger area for growing apple, to analyze the consequences of this arbitrary limit.

Available terracing land

Terrace construction needs high labor and capital inputs; therefore, the terrace area that can be built in the future may be restricted. According to the land use survey data (Chen 1988a), up to the late 1980s the total terraced area in Ansai was only 3186 ha (this terraced area is treated as a land unit in the MGLP model), even though terracing was promoted by the government via financial support. In the future, terrace construction may be limited by the high cost, or other problems such as the land tenure systems and the small farm size. Therefore, it could be helpful to the stakeholders to show the consequences of terracing on the soil loss control, agricultural production and regional development. For the scenario analyses, two extreme 'what-if' options are considered, i.e., 'what' can be expected 'if' terracing is not limited, or 'if' no additional terraces are constructed in the future. These two options are named as 'With-Terracing' and 'Non-Terracing' options, and applied to each scenario. For the 'With-Terracing' option, maximum 60% of the area for each sloping land unit can be terraced (i.e., the same area as in the base runs), while for the 'Non-Terracing' option, a minimum terracing area[1] of 200 ha (excluding the existing terraces) is applied to meet the constraints of Subsection 7.2.2, i.e., to get a feasible solution of the MGLP model.

7.2.3 Generation procedure of the policy scenarios

General description of the procedure

Several objective variables are selected for the generation of each scenario. When not optimized, the objective variable is treated as a constraint with a goal value that is in line with the policy priorities.

An iterative procedure is defined for the scenario generation. For each of the objectives concerned in a policy scenario, a priority order is given according to policy preferences, with an assumed deviation from the optimum of that objective. The objective variable with the highest priority (major goal) is firstly optimized without imposing restrictions on other objectives. The optimized value plus (for minimization objective) or minus (for maximization objective) the assumed deviation ('sacrifice') is given for the first objective variable, and then the second objective variable is optimized. The optimized value plus or minus the given deviation is imposed on the second objective variable. In the next run, the third objective variable is optimized, with the restrictions imposed on the first two objectives. With the same procedure, the remaining objectives are optimized sequentially.

With this procedure, some solution space released by a small sacrifice of the optimal value of the higher priority objective is left for the lower priority objective to improve the value. This procedure can be mathematically described as below:

Let n = total number of objectives considered in a scenario, $_i$ = priority order of an objective, e.g., $_i$ = 1, the objective with the highest priority; O_i = the optimization value of objective $_i$ under restrictions imposed on the first $(i-1)$ objectives, G_i = the goal value of objective $_i$, and α_i = deviation (fraction) from the optimum value of objective $_i$.

When $_i$ = 1, optimal value ($O_{i=1}$) of the first objective variable can be obtained by minimization or maximization without imposing restrictions on other objectives.

When $_i$ = 2 to n, the optimal value (O_i) of objective $_i$ can be obtained by minimization or maximization, along with the first $_{i-1}$ objectives as constraints with the following upper or

[1] This terraced area refers to 'real' area that is terraced, i.e., for the spaced terracing, only the terraced part is considered, and the inter-terrace slope is treated as slope land.

lower bounds:

$G_{i-1} \leq (1+\alpha_{i-1}) \cdot O_{i-1}$, if the O_{i-1} is a minimized value; or 7.1

$G_{i-1} \geq (1-\alpha_{i-1}) \cdot O_{i-1}$, if the O_{i-1} is a maximized value. 7.2

For the last objective, i.e., $i = n$, the goal value $G_i = O_i$.

Priority setting and generation of the policy scenarios

Scenario SA: Soil conservation

In this scenario, seven objective variables are selected, and the assumed deviation values (α_i) are given in Table 7.1. The major aim of this scenario is to reduce soil loss and cropping area, therefore, total soil loss is firstly minimized under the restrictions of self-sufficiency requirements for agricultural products. Next, total cropping area is minimized, by assuming that the total soil loss should not be increased by more than 20% ($\alpha_1 = 0.2$) of the minimized value.

After the optimization of the first two objectives for this scenario, the goal values ($G_{i=1,2}$, the minimized value minus the deviation) are added to the MGLP model as constraints for optimizing other objectives. From the base run results, the objective minimization of both total soil loss and total cropping area resulted in a great sacrifice of employment in agriculture, so, the total employment is maximized in the third run ($i = 3$). In the next four runs, the total net return is maximized, and the total (agricultural) production costs, total mineral N use and total biocide use are minimized sequentially with restrictions imposed on the higher priority objectives, to improve the values. No additional (compared to self-sufficiency defined in Subsection 7.2.2) objective with regard to crop production is included.

Table 7.1 Selected objectives, optimization procedure and restrictions as imposed for scenario SA. The various rows represent subsequent runs of the model. Min. = Minimization and Max. = Maximization.

Priority setting (i) and optimization of the selected objectives	The objective optimized and the deviation value (α_i) in different runs						
	Soil loss	Cropping area	Employment	Net return	Production costs	Mineral N use	Biocide use
1. Min. total soil loss	***O_1***						
2. Min. total cropping area	0.2	***O_2***					
3. Max. total employment	0.2	0.15	***O_3***				
4. Max. total net return	0.2	0.15	0.15	***O_4***			
5. Min. total production costs	0.2	0.15	0.15	0.1	***O_5***		
6. Min. mineral N use	0.2	0.15	0.15	0.1	0.1	***O_6***	
7. Min. biocide use	0.2	0.15	0.15	0.1	0.1	0.05	***O_7***

Scenario SB: Agricultural employment

The primary goals of this scenario are to increase employment in agriculture and crop production. From the optimization results of the base runs, maximizing employment can result in very high production costs and low labor productivity (net return per laborer) because of an increased requirement for agricultural land, and increased inputs of labor and draught animals. So, after the total employment is maximized, the total production costs are minimized to exclude land use activities that require high labor input but provide low benefit, such as some activities on very steep land. The next run is to maximize total crop production with the restrictions imposed on employment and production costs (Table 7.2). With these three objective optimizations, the goals for agricultural employment and crop production can be guaranteed.

Other goals such as reducing chemical use and soil loss, and increasing net agricultural return are considered to be less important. In the next four runs, the remaining four objectives selected for this scenario are optimized sequentially. These optimizations can result in a small improvement of the objectives of total net return, total mineral N and biocide use, and total soil loss. The priority setting, optimization and assumed deviations of the selected objectives are given in Table 7.2.

Scenario SC: Economic development

The aim of this scenario is to maximize the profit of agricultural production, i.e., to obtain a high ratio of total net return to total inputs. The total net return is firstly maximized, and then the total production costs, total use of fertilizer N and biocides are minimized sequentially (Table 7.3). In the last two runs, the objective of employment is maximized and total soil loss is minimized. Employment and soil erosion control are less emphasized in this scenario.

Table 7.2 Selected objectives, optimization procedure and restrictions as imposed for scenario SB (refer to the description of Table 7.1)

Priority ($_i$) and optimization of the selected objectives	The objective optimized and the deviation value (α_i) in different runs						
	Employment	Production costs	Crop production	Net return	Mineral N use	Biocide use	Soil loss
1. Max. employment	O_1						
2. Min. total production costs	0.2	O_2					
3. Max. crop production	0.2	0.15	O_3				
4. Max. total net return	0.2	0.15	0.15	O_4			
5. Min. mineral N use	0.2	0.15	0.15	0.1	O_5		
6. Min. biocide use	0.2	0.15	0.15	0.1	0.1	O_6	
7. Min. total soil loss	0.2	0.15	0.15	0.1	0.1	0.05	O_7

Table 7.3 Selected objectives, optimization procedure and restrictions imposed for scenario SC (refers to the description of Table 7.1)

Priority ($_i$) and optimization of the selected objectives	The objective optimized and the deviation value (α_i) in different runs					
	Net return	Production costs	Mineral N use	Biocide use	Employment	Soil loss
1. Max. total net return	O_1					
2. Min. total production costs	0.2	O_2				
3. Min. total mineral N use	0.2	0.15	O_3			
4. Min. total biocide use	0.2	0.15	0.15	O_4		
5. Max. total employment	0.2	0.15	0.15	0.1	O_5	
6. Min. total soil loss	0.2	0.15	0.15	0.1	0.05	O_6

Scenario SD: Environmental protection

The major aim of this scenario is to keep a low use of biocides and mineral N either in total or per unit agricultural area. For this target, three primary objectives, i.e., total biocide use, total employment and total mineral N use are selected (Table 7.4). First, the total biocide use is minimized without imposing any restriction on other objectives. In the second run, the total employment is maximized under the restriction for the total biocide use not more than 120% of the minimized value. Except the purpose of increasing the total employment, this maximization is to reduce the biocide use per ha by increasing the area for agricultural use as a result of the increased employment. The third run is to minimize total mineral N use.

After the optimization of these three objectives, the total soil loss, total net return, total production costs and total N losses are optimized sequentially with the restrictions imposed on the higher priority objectives. Because the low chemical use can increase soil loss as discussed in section 6.2 of Chapter 6, a higher priority is given to the soil loss control for this scenario than the SB and SC scenarios. The seven selected objective variables and the assumed deviations are presented in Table 7.4. No additional (compared to self-sufficiency defined in Subsection 7.2.2) objective with regard to crop production is included.

Table 7.4 Selected objectives, optimization procedure and restrictions as imposed for scenario SD (refers to the description of Table 7.1)

Priority ($_i$) and optimization of the selected objectives	The objective optimized and the deviation value (α_i) in different runs						
	Biocide use	Employment	Mineral N use	Soil loss	Net return	Production costs	N loss
1. Min. total biocide use	O_1						
2. Max. total employment	0.2	O_2					
3. Min. total mineral N use	0.2	0.15	O_3				
4. Min. total soil loss	0.2	0.15	0.15	O_4			
5. Max. total net return	0.2	0.15	0.15	0.1	O_5		
6. Min. total production costs	0.2	0.15	0.15	0.1	0.1	O_6	
7. Min. total N loss	0.2	0.15	0.15	0.1	0.1	0.05	O_7

7.3 Optimization results of the scenarios

The results (Table 7.5) are presented for the four scenarios in relation to the two terracing options: 'With-Terracing' and 'Non-Terracing'.

7.3.1 Land use and agricultural production

The land use area presented in Table 7.5 only concerns the suitable land for arable farming, not including the natural grass- and shrub-land, and other types of land are assumed to be preserved or not usable.

The area used for agriculture is 56.4 10^3 ha in the scenario SA_t, and increases to 78.6 10^3 ha in the scenario SA_0. In the two SB scenarios aimed at obtaining high employment and high crop production, all suitable land is used, of which more than 90% is allocated to crops (cropping activities), and the smallest area is allocated to shrubs compared to other scenarios. Due to the high requirement of N and biocides, the area allocated to apple is the minimum required for producing the self-sufficiency requirement of apple in the SD scenarios, which aim at low chemical inputs. For other scenarios except SA_t, the area for apple production approaches the assumed upper limit of 1000 ha. The area allocated to sown grass for animal grazing is 5.7 10^3 and 2.4 10^3 ha in the scenarios SC_t and SC_0, but in other scenarios, no or only very limited area is used for sown grass (Table 7.5).

Table 7.5 Optimization results for the four scenarios in relation to the two terracing options (The subscript t = 'With-Terracing', and 0 = 'Non-Terracing'. The **bold** figures are the primary goal values of the corresponding scenario in the same column.)

	'With-Terracing'				'Non-Terracing'			
	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
Area under Agriculture [10^3 ha]	56.4	105.8	105.8	93.8	78.6	105.8	105.8	105.8
Crops	**26.7**	97.8	74.0	50.8	**29.3**	97.6	62.2	58.2
Apples	0.51	1.0	1.0	0.14	1.0	1.0	1.0	0.14
Sown grasses			5.4		2.7		1.4	
Planted shrubs	29.2	7.0	25.4	42.9	45.7	7.2	41.3	47.5
Crop Production								
Total [10^3 t GE]	127.6	**440.2**	282.2	139.1	115.6	**367.7**	244.4	174.2
Mean [t GE ha^{-1}]	4.8	4.5	3.8	2.7	3.9	3.8	3.9	3.0
Meat and Apple Production [10^3 t]								
Pork (Carcass)	8.0	21.8	8.5	6.8	4.8	24.7	13.3	8.2
Mutton (Carcass)	2.3	1.0	4.0	7.1	4.0	1.7	2.3	6.3
Apple (Fresh Weight)	18.3	25.6	25.6	4.9	23.5	23.5	23.5	4.9
Surplus of Agricultural Production [10^3 t]								
Food crops (GE)	33.6	305.7	190.4	31.3	42.5	211.8	136.6	45.3
Pork (Carcass)	2.2	15.4	4.8	3.9	0.7	19.2	7.9	4.1
Mutton (Carcass)				2.3	0.3			2.9
Apple (Fresh Weight)	13.4	20.7	20.7		18.5	18.5	18.5	
Net Return								
Total [10^6 yuan]	183.0	462.3	442.8	125.6	205.1	382.4	349.1	163.1
Mean [10^3 yuan per man-year]	8.2	6.7	**9.9**	2.9	10.0	6.5	**10.3**	4.5
Total net return to cost [yuan $yuan^{-1}$]	0.86	0.79	**1.19**	0.32	0.99	0.62	**1.0**	0.40
Total Production costs [10^6 yuan]	211.7	582.1	372.1	386.7	206.2	614.6	349.8	407.0
Employment								
Total [10^3 man-years]	22.3	**69.3**	44.9	44.0	20.6	**58.7**	34.0	36.3
% of total available labor	21	66	43	42	20	56	33	35
Mean Soil Loss of Agricultural Area [t km^{-2}]	**51**	271	237	74	**199**	696	365	250
N Loss								
Total [t]	1379	3867	2903	2323	1697	3877	2716	2795
Mean (crop+apple+sown grass) [kg N ha^{-1}]	24	37	27	25	22	37	26	26
Total Fertilizer Use [t]								
N	2449	7981	5873	**618**	1767	5645	4502	**1281**
P	1392	4284	3165	1872	1506	3986	2587	2197
K	2561	6098	5419	4063	3186	6425	3834	4264
Biocide Use								
Total [t a.i.]	61	137	153	**33**	56	124	128	**44**
Mean [kg a.i. ha^{-1}]	2.2	1.4	2.0	**0.7**	1.9	1.3	2.0	**0.8**

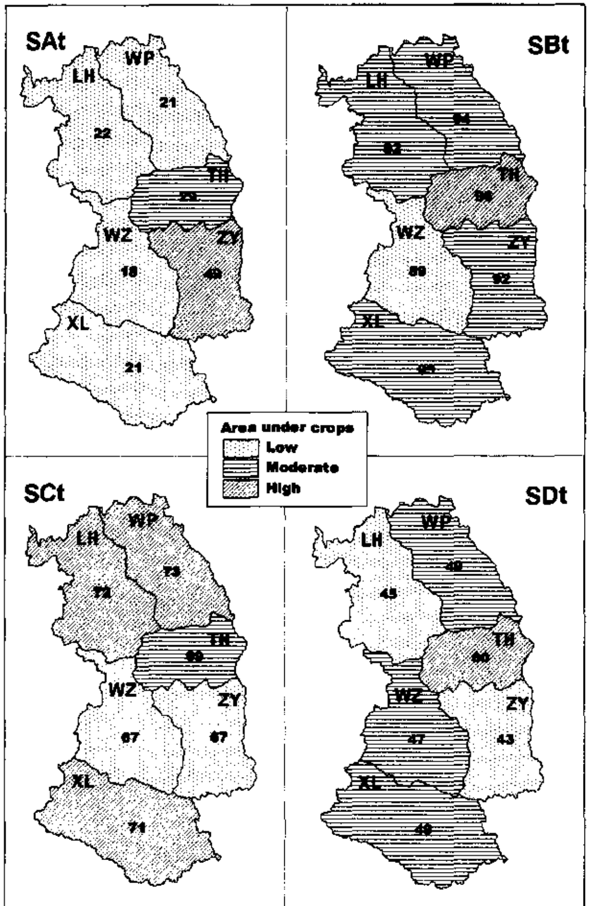
In the SA and SD scenarios, the total area under crops is lower for the scenarios with terracing than for the scenarios without terracing (Table 7.5). This increase of agricultural area in the later scenarios is due to the lower crop yield, because no terraces are allowed. Similar cropping area has been found for the SB scenarios. In contrast to these scenarios, the area allocated to crops is higher in the scenario SC_t than SC_0, probably due to the aim of high net return. The cropping area of Ansai in 1992 was estimated at 56 10^3 ha[2], based on the government reported data and the land use survey data collected in the late 1980s.

The area allocated to crops varies greatly, ranging from 26.7 10^3 ha in the scenario SA_t, to 97.8 10^3 ha in the SB_t (Table 7.5, Fig. 7.1). Maps 7.1A and 7.1B present a percentage of the suitable land area allocated to crops in each sub-region in all scenarios. In the SA scenarios, the percentage of suitable land used for crops is much higher in the sub-region ZY than in other sub-regions, due to the limited suitable land area and higher requirement of food crops for the larger population. In the scenario SB_0, the area used for crop production in the sub-region ZY is markedly lower than other sub-regions, mainly due to the restrictions imposed on soil loss and the higher total firewood requirement (larger population, see Table 6.2). Without terracing, cropping on steep sloping land causes severe soil loss problems, and thus a rather big area is allocated to shrubs for producing the required firewood (to reduce the requirement of crop residues for firewood). For other scenarios, less variation in the area allocated to crops has been found among the sub-regions.

Total crop production ranges from 115.6 10^3 t GE in the scenario SA_0 to 440.2 10^3 t GE in the SB_t (Table 7.5, Fig. 7.1). These production volumes are about 2-7.5 times that of Ansai in 1992 (59 10^3 t). Maps 7.2A and 7.2B present the spatial distribution of crop production among the sub-regions. In SA and SD scenarios aimed at soil loss control and environmental protection, respectively, crop production is largely determined by the constraint of food requirement. For instance, the total crop production in the sub-region ZY is the highest among the sub-regions, because of its high food requirement determined by its large population size. For the SB and SC scenarios, the total crop production in each sub-region is largely dependent on the availability of suitable land and labor.

The total crop production is not linearly related to the cropping area, because of differences in crop yield of the selected cropping activities. Table 7.6 presents that the cropping area under the three yield levels, i.e., N-limited, attainable rainfed and attainable irrigated production levels, varies among the scenarios. In the SD scenarios, the N-limited cropping activities dominate, but in other scenarios, the attainable rainfed cropping activities are most often selected. Attainable irrigated production can only be practiced on the flood plain, with a total suitable area of 4354 ha (= 85% of the flood plain area) in Ansai. This area is not fully used in the SD scenarios, as the irrigated crop production needs higher N and biocide input, but it is used entirely in the other scenarios.

[2] For unclear reasons, the cropping area reported by the government is in general much lower than the actual cropped area. The data used here is adjusted by a factor of 150%. This adjusted cropping area is rather conservative, i.e., it may be still lower than the actual cropped area.

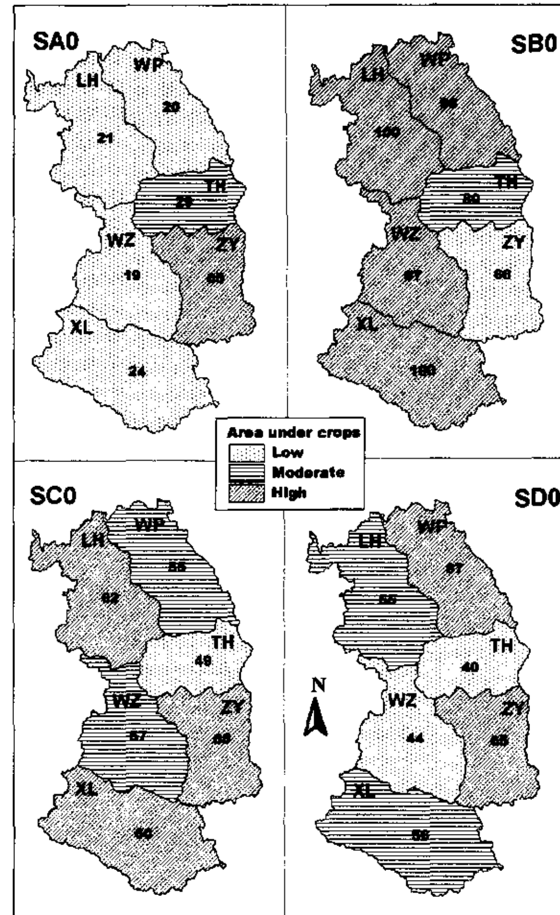


Map 7.1A Percentage of the suitable land area allocated to crops per sub-region in the four 'With-Terracing' scenarios

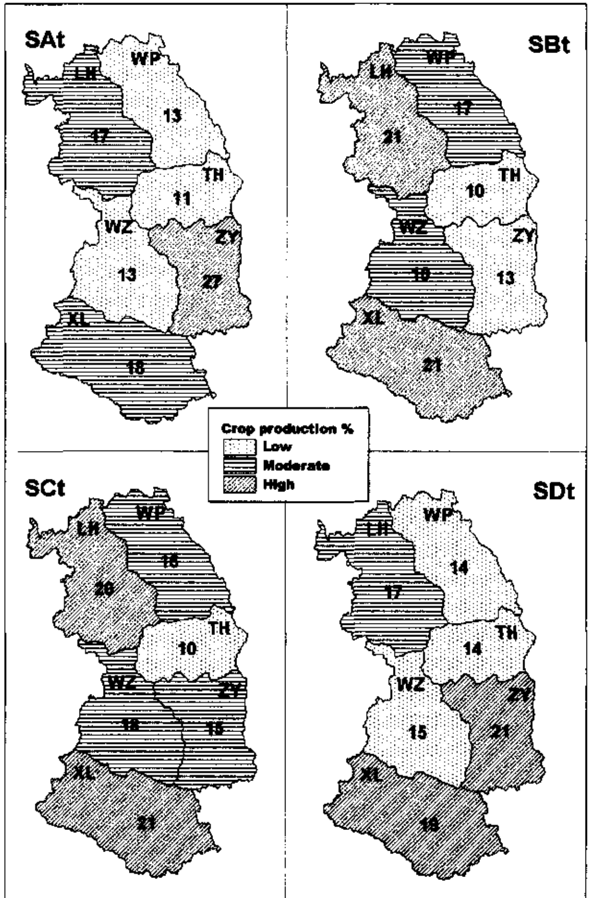
N

Townships

WP: Wangjiawan
Pingqiao
LH: Liandaowan
Huaziping
TH: Tanjiawan
Haojiaping
WZ: Wangyao
Zhao'an
ZY: Zhenwudong
Yanhewan
ZL: Xihekou
Zhuanyaowan
Gaoqiao
Louping



Map 7.1B Percentage of the suitable land area allocated to crops per sub-region in the four 'Non-Terracing' scenarios



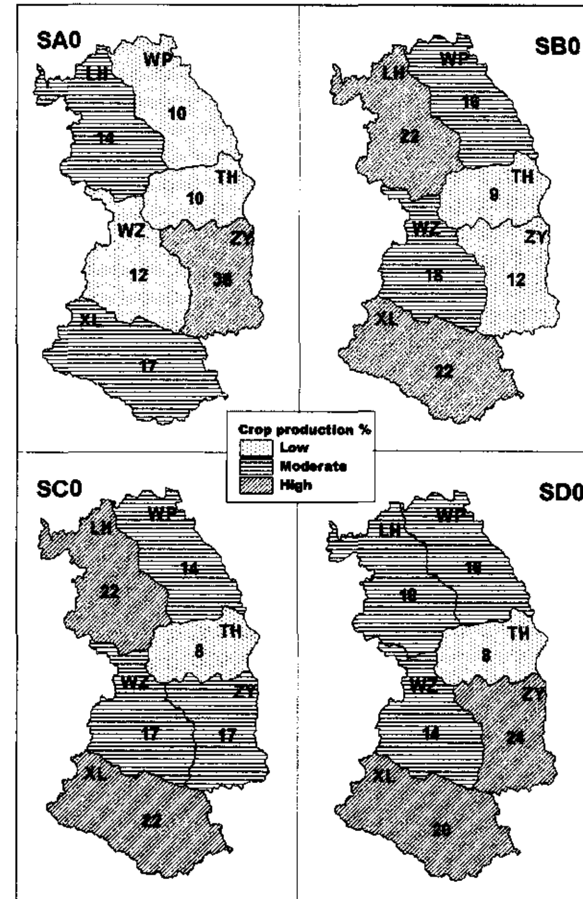
Map 7.2A Regional distribution of crop production in the four 'With-Terracing' scenarios

N

Townships

WP: Wangjiawan
Pingqiao
LH: Liandaowan
Huaziping
TH: Tanjiawan
Haojiaping
WZ: Wangyao
Zhao'an
ZY: Zhenwudong
Yanhewan
ZL: Xihekou
Zhuanyaowan
Gaoqiao
Louping

Note: Crop production per sub-region is expressed as a percentage of the total crop production of Ansai



Map 7.2B Regional distribution of crop production in the four 'Non-Terracing' scenarios

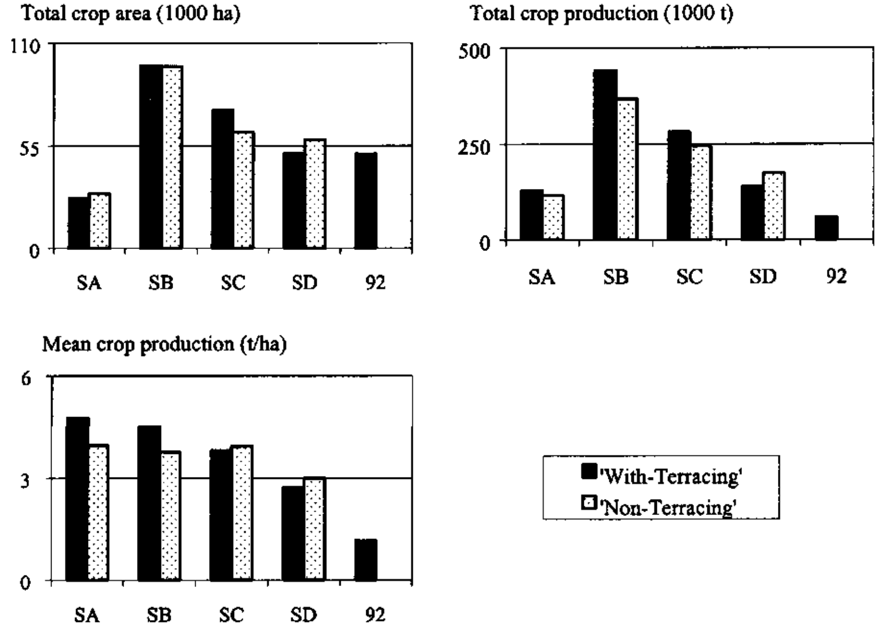


Figure 7.1 Total cropping area, total and average crop production (GE). The figure 92 refers to the data in 1992.

Comparing figures in Table 7.6, the area allocated to N-limited cropping activities in scenarios SA_t-SC_t is lower than in SA_0-SC_0, but higher in the scenario SD_t than SD_0, which results in a different mean crop production (excluding alfalfa) per ha (Table 7.5, Fig. 7.1). This difference in the mean crop production is also caused by terracing and the area under the mixed crop rotations with alfalfa, as the yield on terraced land is higher than on sloping land, and the alfalfa is not taken into account in the mean crop production.

For all scenarios, the total net crop production (excluding the losses during harvesting and post-harvest processing) is mainly from corn, with a total amounting to 65.4-353.2 10^3 t DM (Table 7.7). Wheat production[3] is also strongly addressed, especially in the SC scenarios that aim at obtaining a high agricultural profit. For all scenarios, the amount of potatoes produced equals the self-sufficiency requirement of potatoes as defined. This indicates that potato production is not attractive for all scenarios, as consequences of high seed cost, high biocide inputs, and high labor inputs for transport of the potatoes to homestead, thus leading to a low profit. The total net production for other crops has a range of 0.4-28.8 10^3 t DM. In addition, a total of 16.2-92.5 10^3 t DM of alfalfa is produced in the different scenarios.

The selected crop activities mainly include mono-cropping corn and wheat, and a few corn- or alfalfa-included crop rotations (Fig. 7.2). In the SA and SB scenarios, the selected

[3] The selection of wheat could be due mainly to the fact that winter wheat can make the requirement of labor and draught animals more evenly distributed in a year. The growing season is long and the harvest time (in early July) does not conflict with that of the autumn crops (corn, millet, soybean and autumn potatoes).

cropping activities mainly comprise the 3-year rotation of corn-soybean-corn (CSC) and the mono-cropping of corn, with a total area of 43-74% of the total cropping area. For the SC scenarios, the CSC (44-56%) and winter wheat (21-45%) dominate. Unlike in the SA-SC scenarios, in the SD scenarios more crop rotations are selected, i.e., crop production is less concentrated on a certain crop rotation. Due to the restriction of mineral N input, a rather large area is allocated to mixed crop rotations, i.e., flax-alfalfa (growing 5 years)-millet-corn (FA5MC), and alfalfa (growing 3 years)-corn-millet (A3CM).

For livestock production, except the draught animals oxen and (transport) donkeys, only pigs and small-tail sheep are selected in all scenarios. Due to low productivity and limited grazing land, the goats and fine-wool sheep are not selected. Because of corn's high yield, a great surplus of the corn production is obtained in all scenarios. This surplus production is partly used for feeding pigs, leading to a high pork production (carcass) totaling 4.8-24.7 10^3 t, of which 0.7-19.2 10^3 t can be sold or exported (Table 7.5). The total mutton production (carcass) is 1.0-7.1 10^3 t for the different scenarios; and the production is all consumed by the rural population in the scenarios SA_t-SC_t and SB_0. The pork production was 2497 t and mutton was 807 t in Ansai in 1992.

Table 7.6 Land area allocated to different yield levels

	'With-Terracing'				'Non-Terracing'			
	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
Total area [10^3 ha]								
Nitrogen-limited yield level	1.8	14.4	3.1	44.7	7.8	38.7	3.7	45.6
Attainable rainfed yield level	20.6	79.1	66.5	4.6	17.1	54.6	54.2	8.5
Attainable irrigated yield level	4.4	4.4	4.4	1.6	4.4	4.4	4.4	4.0
% of total cropping area								
Nitrogen-limited yield level	6.8	14.7	4.2	87.9	26.7	39.6	5.9	78.5
Attainable rainfed yield level	76.9	80.8	89.9	9.0	58.5	55.9	87.1	14.7
Attainable irrigated yield level	16.3	4.5	5.9	3.1	14.9	4.5	7.0	6.9

Table 7.7 Total net production (10^3 t DM) of the crops in the different scenarios

Crop	'With-Terracing'				'Non-Terracing'			
	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
Corn	75.3	353.2	137.3	77.8	65.4	292.4	160.9	104.5
Millet	13.2	5.3	2.2	23.7	14.5	9.2	4.9	28.8
Wheat	12.2	23.1	104.4	12.2	12.2	12.2	36.1	12.2
Soy	8.3	21.8	17.8	4.1	5.0	19.8	18.6	6.3
Potato	9.6	9.6	9.6	9.6	9.6	9.6	9.6	9.6
Flax	1.7	0.6	0.4	3.5	2.5	1.5	0.8	2.5
Alfalfa	16.2	42.1	19.5	94.5	41.5	73.7	22.8	88.5

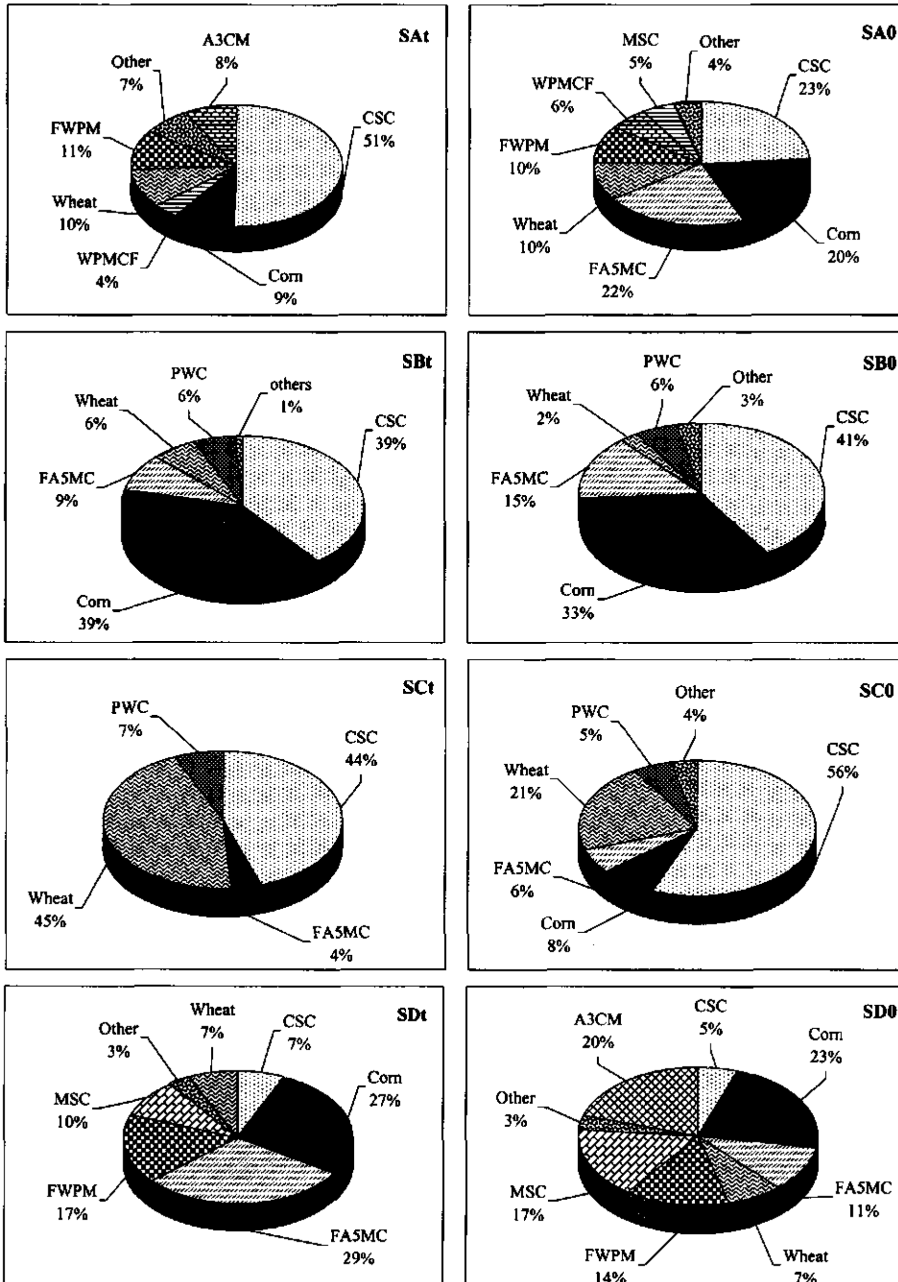


Figure 7.2 Main crop rotations selected and the area (% of the total cropping area) in the different scenarios. Mono-cropping: corn and winter wheat; 3-year rotations: CSC = corn-soybean-corn, MSC = millet-soybean-corn, CMP = corn-millet-autumn potato, and PWC = summer potato-wheat-corn; 4-year rotations: FWPM = flax-wheat-autumn potato-millet; 5-year rotation: A3CM = alfalfa (3 years)-corn-millet; 8-year rotation: FA5MC = flax-alfalfa (5 years)-millet-corn.

7.3.2 Soil loss and soil conservation

The mean soil loss per unit agricultural area is 51-271 t km^{-2} in the scenarios SA_t-SD_t, and increases to 199-696 t km^{-2} in the scenarios SA_0-SD_0 without terracing. These soil losses are much lower than those at present (Fig. 7.3). For the SA_t-SD_t scenarios, the terracing is most often selected because of its high efficiency in soil loss control, e.g., 71% and 83% of the cropland is terraced (bench terrace) in the scenarios SA_t and SD_t. Since most sloping land is terraced in both scenarios, crop residues are mostly removed and used for firewood and feeding animals, rather than left on the field for the purpose of soil conservation. In the scenarios SB_t and SC_t, about half of the total cropland is cultivated with crop residue mulching; and 23% and 34% of the cropping area are terraced with spaced terracing, respectively. Spaced terracing needs much lower labor input, and therefore provides a higher benefit.

Unlike in the scenarios SA_t-SD_t, the most frequently selected soil conservation measure (73-95% of the cropping area) in the scenarios SA_0-SD_0 is furrow-ridging (Table 7.8), since furrow-ridging can meet the goal of soil loss control and also save crop residues for feed and firewood. Another reason is that furrow-ridging can meet the goal of employment (furrow-ridging preparation needs a high labor input). The next most frequently used measure is crop residue mulching, but with an exception for SA_0 (this could be due to the restriction of cropping area and the requirement of crop residues for firewood and feed.). The selection of crop rotations with alfalfa seems to be strongly determined by the restriction of mineral N use, because the allocated area is much higher in the SD scenarios than in other scenarios.

Table 7.8 Cropping area with specific soil conservation measures in the scenarios. The figures in each column cannot be added up, as some measures are applied simultaneously, e.g., furrow-ridging and residue mulching.

	'With-Terracing'				'Non-Terracing'			
	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
Area allocated to different soil conservation measures [10^3 ha]								
Alfalfa-based crop rotations	2.8	8.5	3.1	15.8	6.8	15.0	4.1	18.6
Residue mulching	2.6	47.4	42.1	4.5	3.8	42.8	37.2	36.7
Furrow-ridging	2.8	31.8	4.9	4.6	21.2	89.5	48.0	50.4
Bench terracing	19.0	35.8	33.5	42.4				
Spaced terracing	0.0	22.7	25.0	1.0	0.5	0.5	0.5	0.5
Area allocated to different soil conservation measures [% of the total cropping area]								
Alfalfa-based crop rotations	10.5	8.7	4.2	31.1	23.1	15.3	6.5	32.0
Residue mulching	9.5	48.4	56.9	8.9	12.8	43.9	59.9	63.2
Furrow-ridging	10.5	32.5	6.6	9.1	72.5	91.7	77.2	86.6
Bench terracing	71.0	36.6	45.3	83.4				
Spaced terracing		23.2	33.8	2.0	1.8	0.5	0.8	0.9

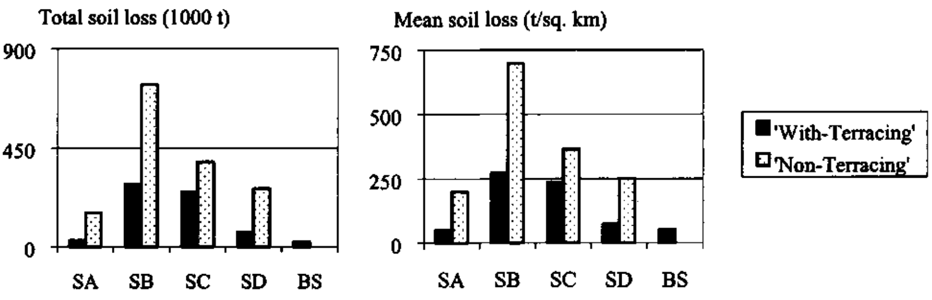


Figure 7.3 Total and average soil loss of agricultural land use for the different scenarios. BS is the minimized total soil loss in the base run.

7.3.3 Employment and requirement of draught animals

Employment

The total employment in agriculture is the lowest for the SA scenarios, with a value of 22.3 10^3 man-years for SA_t and 20.6 10^3 man-years for SA_0, which is less than one-fourth of the total available labor. The highest agricultural employment can be achieved in the scenarios SB_t and SB_0, with an employment totaling 69.3 10^3 and 58.7 10^3 man-years, 66% and 56% of the total available labor, respectively. In the SC and SD scenarios, the total employment is within a range of 38.3-44.9 10^3 man-years (Table 7.5, Fig. 7.4). Compared to the labor involved in agricultural production in 1992 (estimated at 28 10^3 man-years), the total employment is higher in all but the SA scenarios. Currently in Ansai, the rural labor is mostly involved in agricultural production, and the actual employment is estimated at a range of 40 to 55% of the total rural labor force, i.e., 45-60% of the labor force is unemployed.

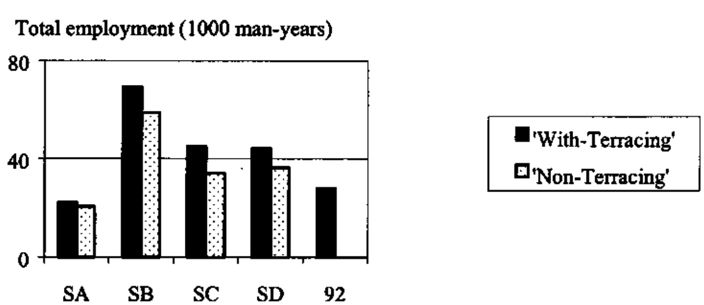
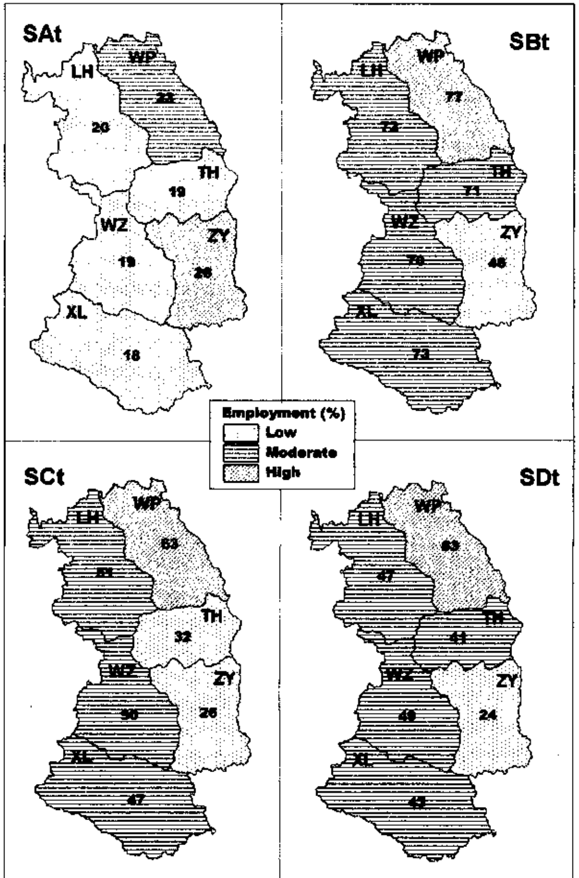


Figure 7.4 Total employment in the different scenarios. The figure 92 refers to the estimated agricultural employment in 1992.

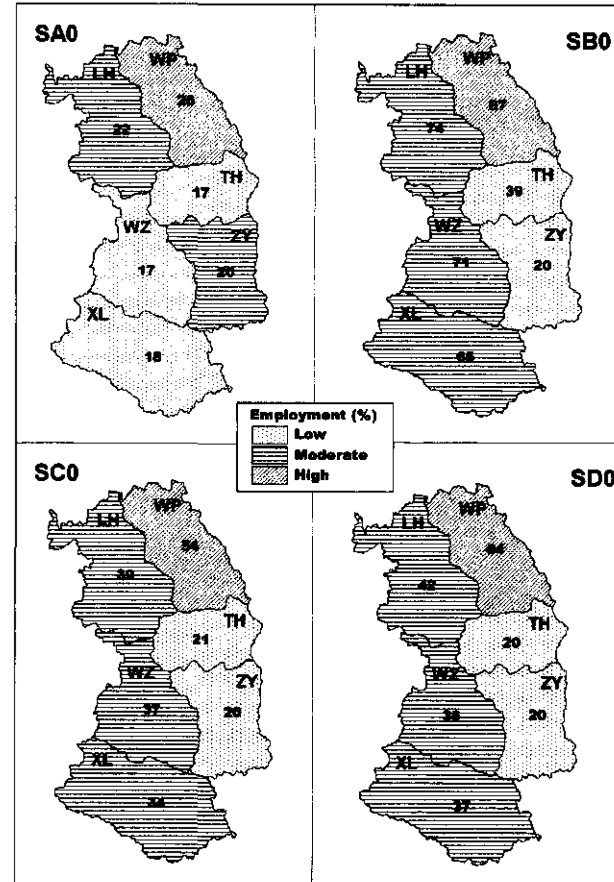


Map 7.3A Percentage of total rural labor employed in agriculture per sub-region in the four 'With-Terracing' scenarios

N

Townships

WP: Wangjiawan
Pingqiao
LH: Liandaowan
Huaziping
TH: Tanjiawan
Haojiaping
WZ: Wangyao
Zhao'an
ZY: Zhenwudong
Yanhewan
ZL: Xihekou
Zhuanyaowan
Gaoqiao
Louping



Map 7.3B Percentage of total rural labor employed in agriculture per sub-region in the four 'Non-Terracing' scenarios

From the regional data presented in Maps 7.3A and 7.3B, employment is very limited in the sub-region ZY, especially for the 'Non-Terracing' scenarios, under which only 20% of the available labor can be employed in agriculture. In the sub-region TH, employment is also rather low due to its limited land area. For other sub-regions, more than 70% of the available labor can be employed (scenarios SB_t), because of their relatively rich land resources.

The total employment in the SA_t-SD_t scenarios is higher than in the SA_0-SD_0 scenarios, because of the labor requirement of terrace construction. As shown in Table 7.9, 16-27% of the total employment is used for terracing in the four scenarios with terracing. The total terraced area per year (assuming the terrace is used for 10 years) is 1898-4409 ha, and the mean labor input is 2.4-2.6 man-years per ha.

For terracing, two construction techniques are defined, i.e., by hand and by machinery (see Chapter 4). In the scenarios SA_t and SD_t, only manual terracing is selected, and in SB_t and SC_t, the manually terraced area occupies 95% and 92%, respectively. Mechanical terracing is almost not selected in all scenarios, because of the high available labor force.

In Chapter 4, five labor requirement periods are distinguished. For the 'With-Terracing' scenarios, the peak labor requirement occurs in the period 5, which is assumed to be available for terracing. For the no terracing scenarios, the peak labor requirement occurs in the period 4, i.e., the harvest time for autumn crops. But, labor is not a binding factor for all scenarios, i.e., the available labor is more than the requirement even in peak labor demanding periods.

The total suitable land area for semi-mechanized farming is 14.7 10^3 ha in Ansai. Because of low labor input, the net return of the semi-mechanized cropping activities is higher than the labor-intensive (manual) ones. Of this suitable land area, 100% and 80% are used in the scenarios SC_t and SC_0; and 6.4 10^3 ha and 4.9 10^3 ha in the scenarios SA_t and SA_0, respectively. In the scenarios SB_t, SD_t and SD_0, the area allocated to semi-mechanized cropping activities is less than 2000 ha. But, for the scenario SB_0, a much larger area (9.2 10^3 ha) is allocated to semi-mechanized cropping activities, due to the restriction of available oxen. In this scenario, a very large number of oxen, totaling 40.7 10^3 oxen units (male adult cattle equivalent) are required (Table 7.10), which is much higher than in other scenarios.

Table 7.9 Total terraced area per year, the average and total labor input for terracing (as % of the total employment) for the four scenarios. Note that the terrace area refers to land area actually terraced, i.e., for the spaced terracing, only the terraced part is taken into account.

	SA_t	SB_t	SC_t	SD_t
Terraced area per year [ha]	1898	4409	4275	4266
Mean labor input for terracing [man-year ha^{-1}]	2.3	2.5	2.4	2.8
Total labor input for terracing [%]	19	16	23	27

Requirement of draught animals

The total required number of oxen and donkeys (for transport) is given in Table 7.10. In 1992, the total number of cattle and donkeys including young animals was 18.7 10^3 and 18.4 10^3 heads, of which about 75% was used for agricultural production in Ansai. The total number of animals in 1992 was estimated at 10.5 10^3 oxen units and 10.4 10^3 donkey units, assuming that one ox or donkey equals 0.75 units. In the scenarios SB_t and SB_0-SD_0, the required oxen are higher than the number reported in 1992. For donkeys, the required number is higher only in the SB scenarios.

Different from the labor employment, the required oxen input is much lower in the SA_t-SD_t scenarios than in the SA_0-SD_0 scenarios. This increased requirement in the $_0$ scenarios is due to the high requirement for land preparation. Without terracing, furrow-ridging is the most often selected soil conservation measure, to reduce the soil loss (see Table 7.8). Preparation of furrow-ridges needs high oxen input, therefore, the total requirement is high.

The donkey is a major means of transport in Ansai. In this study, it is used only for transportation of manure and agricultural products. The total required number of donkeys depends to a large extent on the total amount of agricultural production (marketable crop product, crop residues, apple, alfalfa and shrubs). The total required number of donkeys varies between 5.8 10^3 and 19.4 10^3 donkey units (male adult donkey equivalent) for all scenarios (Table 7.10). The variation in the donkey requirement can be explained by the different production volumes of agricultural products as shown in Tables 7.5 and 7.7.

The required number of each type of draught animals is determined by the peak requirement period, i.e., crop sowing period for oxen and harvest period for donkeys. Compared to these two periods, the requirement for oxen and donkeys is much lower in the other four periods, which results in a rather low use rate for both animals. The actual working time, expressed as ratio of the days worked to total days per year, is 25-35% for oxen and 19-33% for donkeys. This causes a large waste of feed to keep this large number of draught animals. Since the labor resource in the rural area is high, it may be necessary to include cropping activities that are fully based on manual labor without using any draught animals and machinery. This labor-intensive arable farming is currently practiced in Ansai, and it could be considered when the MGLP model is revised in the future.

Table 7.10 Total number of oxen and transport donkeys, and their actual working time expressed as percentage of 365 days per year assuming 8 hours a day. Current draught animals are estimated, based on data of 1992 Ansai Yearbook.

	Current	'With-Terracing'				'Non-Terracing'			
	(1992)	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
Total oxen [10^3 oxen unit]	10.5	4.8	29.0	10.9	13.3	11.1	40.7	20.0	26.5
Total donkey [10^3 donkey unit]	10.4	5.8	23.2	14.7	13.0	7.0	19.4	9.8	12.6
Actual working time of oxen [%]		28.3	24.9	33.4	34.8	27.0	24.9	33.5	26.2
Actual working time of donkey [%]		26.4	19.0	17.9	33.3	27.1	19.2	23.7	29.9

7.3.4 Chemical inputs and N losses

N use and losses

The total fertilizer use varies with the different scenarios (Table 7.5). The total fertilizer N use is 618 t for the scenario SD_t and 1281 t for the scenario SD_0, which is much lower than the other scenarios, and the fertilizer N use (1750 t N) of Ansai in 1992 (Fig. 7.5). When high crop productivity is targeted (SA scenarios), the total fertilizer N use increases to 2449 (SA_t) and 1767 t (SA_0), although the area under crops is much lower than in the SD scenarios. If crop production (SB scenarios) or net return (SC scenarios) is the main aim, the total fertilizer N use greatly increases.

The average total N use for the agricultural land use including the arable land, orchard (apple) and sown grassland is 58-128 kg ha^{-1}. Excluding the manure N, the average input of fertilizer N decreases to 12-90 kg N ha^{-1}. For all scenarios, rather a large amount totaling 1185-3390 t N (Table 7.11) is covered from manure. In the low chemical input scenarios SD_t and SD_0, 81% and 68%, respectively, of the total requirement can be supplied by manure N, which leads to very low input of mineral N, with an average value of 12 and 22 kg N ha^{-1}, respectively. For other scenarios, the proportion of manure N in the total N use ranges from 25 to 46%. At present, manure is still a very important source of nutrients, but no data are available for the current manure use.

Table 7.11 Available manure N, total N loss and average use of N per ha agricultural area (excluding shrubs for which no fertilizer N is used).

	'With-Terracing'				'Non-Terracing'			
	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
Available manure N (all used)								
Total [t N]	1185	2799	1951	2686	1526	3390	1983	2764
% of total N use	33	26	25	81	46	38	31	68
Average N use per unit agricultural area								
Mean total N use [kg N ha^{-1}]	128	107	96	58	94	90	97	63
Mean mineral N use [kg N ha^{-1}]	90	81	73	12	54	57	70	22
Total N loss [t N]	1379	3867	2903	2323	1697	3877	2716	2795
From agricultural land use	724	2276	1708	622	800	2021	1601	963
From livestock	655	1591	1195	1701	897	1856	1115	1832
Mean N loss (crop + apple + sown grass) [kg N ha^{-1}]	24	37	27	25	22	37	26	26

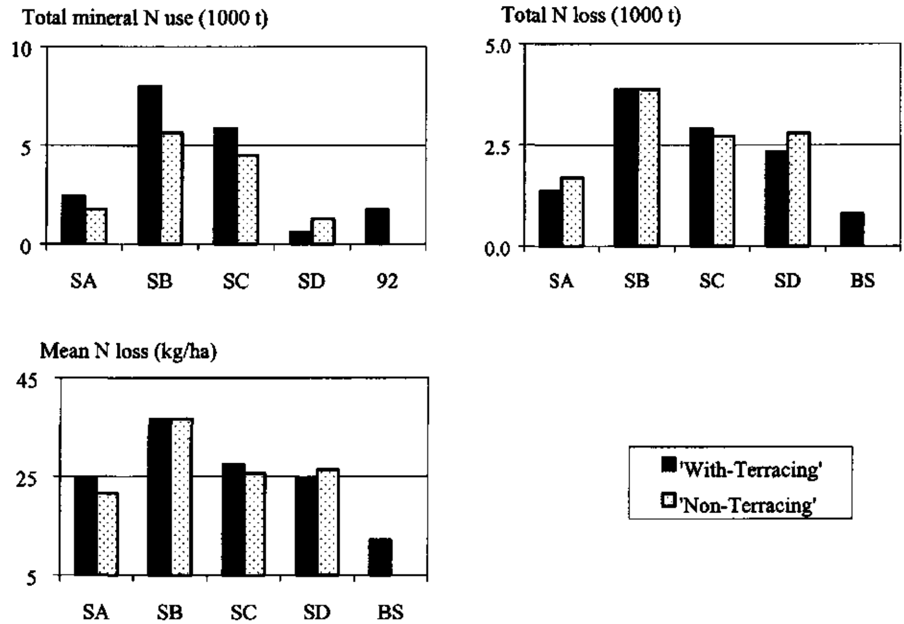


Figure 7.5 Total mineral N use, total and average N loss in the different scenarios. The figure 92 refers to the total mineral N use in 1992, and BS is the extreme value obtained at the minimization of total N loss in the base runs.

The total N loss is the summation over all land use activities and animal production systems. The N loss from animal excretion is calculated as the total slurry N minus the used part[4] of the manure N (collectable slurry N), and the N available for grass (natural and sown grasses) and crops that is excreted during grazing or working (of the draught animals). The total N losses from both agricultural land use and animal excretion are rather high, ranging from 1379 to 3877 t (Table 7.11, Fig. 7.5), compared to the total use of mineral N (Table 7.5). This high N loss is largely from slurry N loss (Table 7.11) that covers 41-53% of the total N losses in the SA-SC scenarios, and 73% and 66% in the scenarios SD_t and SD_0. The total N loss from agricultural land use is between 622 and 2276 t (Table 7.11), apparently related to the total area under agriculture and total N use in the different scenarios. Due to the larger number of pigs and sheep, and the higher requirement of draught animals, slurry N loss (Table 7.11) is much higher in the SB and SD scenarios.

[4] In all scenarios, the manure N is fully used.

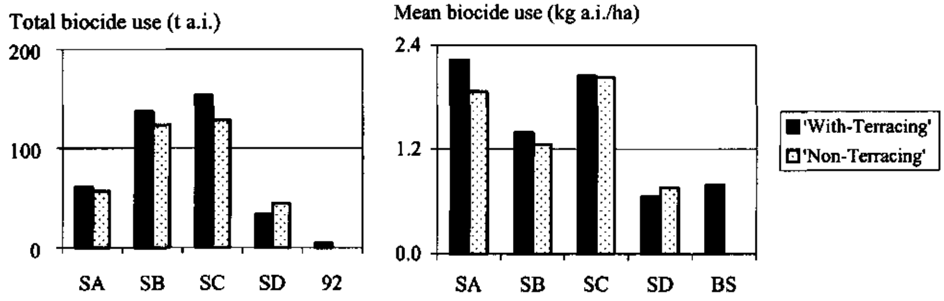


Figure 7.6 Total and average biocide use for crop and apple production. The figure 92 refers to the total biocide use (in commercial formulation) in 1992, and BS is the mean biocide use at the minimization of total biocide use in the base run.

P and K use

Total P and K use seems very high in comparison with current use in Ansai. The reported amount in 1992 totaled 620 t P and only 66 t K. In this area, shortage of P in the soil is an important limitation for increasing crop yield; but for K, it may not be very important, as leaching seldom occurs in the calcareous loess soils. For this study, a balanced situation for all nutrients is assumed, i.e., the nutrient removal from soils should be covered by input.

Biocide use

A rather high use of biocides is required for all scenarios, ranging from 33 to 153 t a.i. (Table 7.5, Fig. 7.6), compared to the present situation in Ansai (22.3 t in commercial formulation in 1992). The average input of crop and apple growing area is 0.7-2.2 kg a.i. ha^{-1}. Similar to the mineral N use, much higher biocide use is required when aiming at a high crop yield (SA scenarios), or agricultural profit (SC scenarios).

7.3.5 Agricultural production costs

The agricultural area, total employment and total number of draught animals to be maintained heavily affect the total costs of agricultural production. In the scenarios SA_t and SA_0, the total production costs are 211.7 10^6 and 206.2 10^6 yuan, while in the scenarios SB_t and SB_0, they increase to 582.1 10^6 and 614.6 10^6 yuan due to the increased requirement for agricultural land and labor. The total agricultural costs of Ansai in 1992 are estimated at about 55 10^6 yuan (based on price in 1992), taking into account the cost for labor input[5]. Compared to this value, the calculated total production costs are much higher for all scenarios (Fig. 7.7). Divided by the total agricultural land area, the average cost is at a range of 2.6-5.8 10^3 yuan ha^{-1} for the different scenarios. If the planted shrub land that needs very low input is excluded, the

[5] The production costs in the Yearbook of Ansai did not include the cost of labor. Here, the cost for labor is roughly estimated on the basis of labor inputs and the labor price in that year. The net return in the Yearbook did not exclude the labor cost. The net return in 1992 used in the next subsection (7.3.6) excludes this labor cost.

average production costs increase to 4.6-7.8 10^3 yuan ha^{-1}. These average values just give a rough indication of the production costs that include the costs for livestock production, as the animal (especially pig) production is indirectly related to agricultural land area.

For all scenarios, labor cost covers a big part of the total costs of agricultural production, ranging from 32 to 43% (Table 7.12). The proportion of the total costs covered by fertilizers and biocides is low, from 8 and 9% in the scenarios SD_t and SD_0, to 16 and 13% in the scenarios SC_t and SC_0, respectively. Other costs associated with draught animals, seeds, irrigation, feed, small farm equipment, and machinery cover 40-59% of the total production costs.

Table 7.12 Cost composition (% of the total production costs) of agricultural production

	'With-Terracing'				'Non-Terracing'			
	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
Cost of fertilizers and biocides	12.9	13.2	16.4	8.3	14.1	11.4	13.2	9.0
Cost of labor	37.9	42.9	43.4	41.0	36.0	34.4	35.0	32.1
Cost of other inputs	49.2	43.9	40.2	50.8	50.0	54.3	51.8	58.9

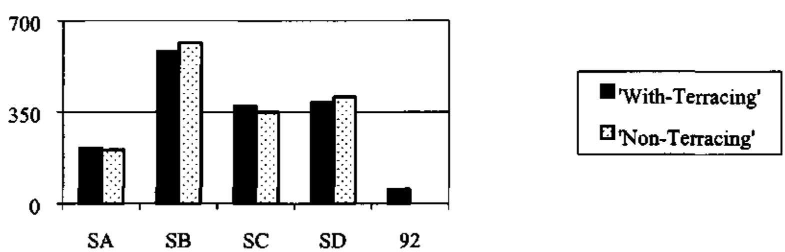


Figure 7.7 Total agricultural production costs. The figure 92 refers to total costs in1992. Note that the cost of 1992 from the 1992 Yearbook of Ansai was based on the prices of that year.

7.3.6 Net return and labor productivity

The total net return differs among the scenarios, ranging from the lowest of 163.1 10^6 yuan in the scenario SD_t to the highest of 462.3 10^6 yuan in the scenario SB_t. Comparing the average value per laborer, the net return per man-year in the SC scenarios is higher than in other scenarios (Fig. 7.8). The availability of terraces has small effects on the average return for the SB and SC scenarios; but for the SA and SD scenarios, increasing the terrace area results in much lower net return per laborer. This reflects that aiming at reducing soil loss (SA scenarios) or chemical use (SD scenarios) decreases labor productivity (net return per laborer) when a large area of sloping land is terraced. When the external input of chemicals is limited, labor productivity is greatly reduced, i.e., the average net return per laborer is only 2.9 10^3 and 4.5 10^3 yuan per man-year in the scenarios SD_t and SD_0.

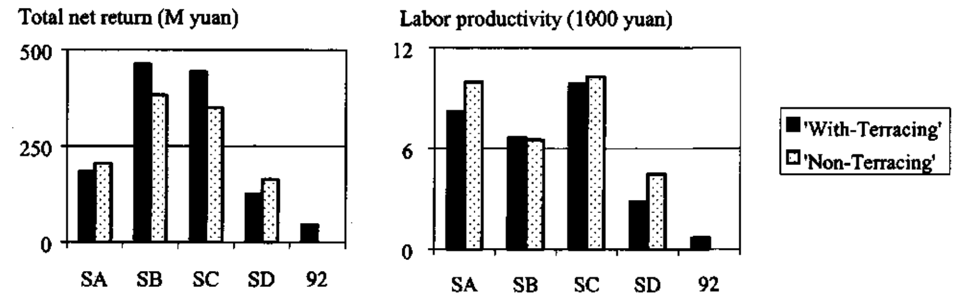


Figure 7.8 Total net return and average labor productivity (net return per man-year). The figure 92 refers to the total net return and labor productivity in 1992, estimated on the basis of the 1992 Yearbook and prices of that year, taking into account the labor cost (see footnote 2). In the model, the net return is based on 1997-1998 prices.

For all scenarios, the net return is mainly from the arable farming, occupying 50-71% of the total value (Table 7.13). Due to restricted input of biocides and N, the apple production is greatly limited in the SD scenarios. In the SA scenarios, both soil loss and cropland area are heavily restricted, which results in low employment and low total crop production. Limited area for arable farming also reduces the available amount of feed, leading to low livestock production. As consequences, the proportion of apple production in the total net return is increased.

The net return from animal production is calculated as the total production value minus the total costs. The total production value includes meat, wool and cashmere, selling of draught animals, and benefit from use of draught animals (equal to the total cost for animal use in the arable farming, grass, and apple production, and firewood collection). The total costs include feed, labor, routine care, corrals, the purchase price of draught animals and piglets, and the costs for sown grasses. The total net return of livestock covers 20-42% of the total agricultural return, varying among the different scenarios (Table 7.13). Except in the SD scenarios, the proportion of livestock production in the total agricultural production value increases in the non-terracing scenarios.

Table 7.13 Contribution (%) of crop, apple and livestock production to the total net return

	'With-Terracing'				'Non-Terracing'			
	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
Arable farming	57.2	65.4	68.3	48.2	50.2	59.8	59.9	71.1
Apple	20.0	10.8	11.3	7.8	22.4	12.0	13.1	6.0
Livestock	21.6	23.6	20.1	41.8	26.0	28.0	26.4	21.2
Shrubs	1.2	0.2	0.4	2.2	1.4	0.2	0.6	1.7

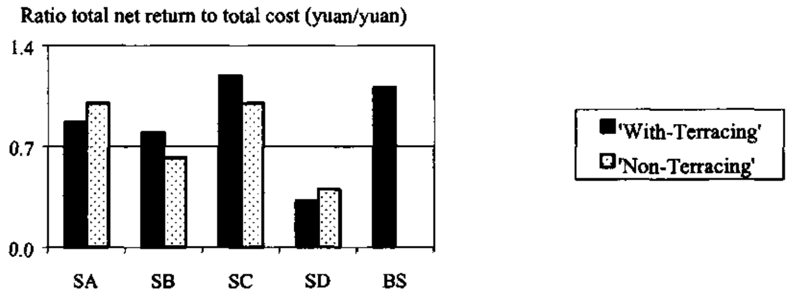


Figure 7.9 Ratio of total net return to total production costs. BS is calculated using the data obtained by maximizing the total net return in the base runs (Chapter 6).

Fig. 7.9 presents the ratio of total net return to total agricultural production costs for different scenarios. For the total agricultural inputs (total production costs), one yuan input can produce an output from 0.3 yuan in SD_t to 1.2 yuan in SC_t. The net return in the SD scenarios is very low in terms of unit production costs, due to the restriction of fertilizer N and biocide use. In the SB and SC scenarios, the net return per unit total inputs is higher for the 'With-Terracing' option than that in the 'Non-Terracing' option; while in the SA and SD scenarios, it is lower. These could be caused by the higher inputs for soil conservation by use of bench terracing in SA_t, than that in SA_0. In SD scenarios, the total net return is low due to limited inputs of chemicals to meet the goal of environmental protection (low use of chemical use and low emission). Use of terracing in SD_t increases the total costs, but has a limited increase of total net return due to restriction of chemical use.

7.4 Sensitivity of model results

The model results can be analyzed by examining their sensitivity to the parameter values or the variation of land use allocations obtained when a small change is given for the objective values. LP model has standard analyses, e.g., shadow prices or reduced costs, to examine sensitivity for changing parameter values. The disadvantage of these analyses is that they are partial analyses valid for only a limited range of the parameter values, whereas the sensitivity of the model to changes in many parameter values simultaneously is very relevant as well. Therefore, in this section, other methods are used to analyze the model's sensitivity to parameter values and the inclusion of particular constraints. Sensitivity for three important aspects related to the labor input (agricultural employment), firewood requirement, and soil loss control are studied. First the effects of changing the labor price on the scenario results are evaluated; second the effect of removing the constraint of firewood requirement is analyzed; and third the model's sensitivity to changes in measures for soil loss control and production technologies is examined by analyzing the consequences when slightly different target values for objective are used. These analyses should be regarded as examples of numerous sensitivity analyses that can, and in fact must be, carried out with this type of model. In Chapter 8, other aspects of the model that deserves a sensitivity analysis are discussed.

7.4.1 Effect of changing labor price

Currently in Ansai, official data are not available for the rural labor cost, because the labor involved in agricultural production is mostly from the family members. According to interviews conducted in 1997 among farmers and the local officers, the labor price in Ansai was around 15 yuan per man-day. This labor price is used for the base runs and for the scenarios. From the scenario results, a rather large part of the production costs is covered by labor; therefore, this sensitivity analysis takes labor price as an example.

The consequences of increasing the labor price by 10% and 50% are evaluated. For all scenarios, the selected objectives are optimized using the same procedure as for the scenario generations (Section 7.2), but with a 10% (or 50%) increase of the labor price. From the optimization results, the main points found are summarized below:

Increasing the labor price has a marked adverse effect on the total net return and total production costs, but a limited effect on other objective variables in the SA, SB and SD scenarios.

At the 10% and 50% increase of the labor price, the total net return is reduced by 3-5% (Fig. 7.10), and 16-25% in the SA-SC scenarios; 11% and 55% in scenario SD_t; and 7% and 35% in scenario SD_0, respectively. This higher relative decrease in the SD scenarios is because of the low total net return, as a result of the restricted input of biocides and mineral nitrogen. In the scenarios of SA, SB and SD, an apparent increase of total production costs has been found, with an increase of 4-5% (Fig. 7.10) and 16-25% for the 10% and 50% increase of the labor price, respectively. This results in a decrease of 3-11% and 16-55% respectively for the labor productivity (net return per laborer), because of the fact that no change[6] has been found for the total labor employment in these scenarios. The effect on the other objective variables (e.g., total cropping area, total N and soil losses) is very limited, with a change of mostly less than 3% of the scenario values in all scenarios except SC.

For the SC scenarios mainly aimed at increasing the net return per unit input (production costs), marked changes are also found for the objectives, such as the total cropping area, employment, mineral N use and soil losses (Table 7.14). The results show that a 10% and 50% increase of the labor price results in a decrease of the total employment by 6% and 29% in SC_t, and 4% and 21% in SC_0, respectively. For the total soil loss, a large increase of 36% and 7% is found for the scenario SC_t at an increase of the labor price by 10% and 50%, respectively. This large increase in soil loss is due to the decreased terrace area, which is decreased to reduce the labor cost for terracing (Table 7.15). The relative lower increase in total soil losses at the 50% increase of labor price is because of the larger decrease of cropping area (Table 7.15), compared to that at the10% increase. Because of the large decrease of labor inputs as a result of the reduced terracing area, the labor productivity is increased in SC_t.

[6] The total employment decreases 0.4% in SD_t and 0.6% in SD_0 at a 50% increase of labor price.

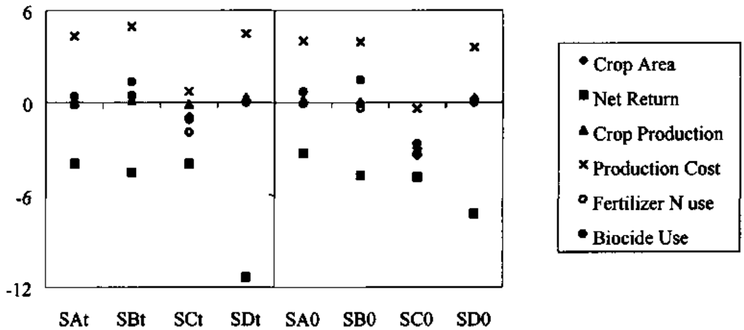


Figure 7.10 Relative change in the objective variables caused by 10% increase of labor price in different scenarios. The relative change is defined as $v = (V - V_0) \div V_0 \cdot 100$, where V = the objective value determined by the increased labor price, and V_0 is the value of that objective obtained in the scenarios presented in Section 7.3 by using default labor price.

Table 7.14 Effects of increasing the labor price by 10% and 50% in the SC scenarios. The figure is expressed as a percentage of the objective value from its scenario value.

	10% increase of labor price		50% increase of labor price	
Objective variable	SC_t	SC_0	SC_t	SC_0
Total soil loss	35.8	1.0	7.2	-1.4
Total N Loss	5.7	0.0	-2.7	-1.3
Total mineral N use	-1.9	-3.3	-14.1	-28.3
Total biocide use	-1.1	-2.7	-8.9	-17.7
Total crop production	-0.1	-2.8	-10.3	-22.3
Total production costs	0.7	-0.4	2.6	-4.6
Total net return	-4.0	-4.8	-19.6	-23.9
Total employment	-6.2	-4.5	-28.6	-21.3
Labor productivity	2.4	-0.4	12.5	-3.3

Table 7.15 Effect on the land use allocations of increasing the labor price by 10% and 50% in the SC scenarios. The figure is expressed as a percentage of the objective value from its scenario value. The scenario value in the table is that obtained for default labor price (Section 7.3).

Cropping activities with different	Scenario value (10^3 ha)		10% increase		50% increase	
production technologies	SC_t	SC_0	SC_t	SC_0	SC_t	SC_0
Total cropping area	74.0	62.2	-0.9	-3.4	-9.9	-20.7
Mixed crop rotations with alfalfa	3.1	4.1	17.0	10.4	22.7	69.8
Crop rotations without alfalfa	70.9	58.1	-1.7	-4.4	-11.4	-27.0
Contoured tillage	6.3	9.3	7.9	-6.3	14.0	6.6
Furrow-ridging	4.9	48.0	-24.2	-3.2	-36.1	-28.0
Bench terracing	33.5	0.0	-27.0	0.0	-33.4	0.0
Spaced terracing	25.0	0.5	36.2	0.0	19.0	0.0
Crop residue mulching	42.1	37.2	-17.4	-6.7	-26.6	-32.4
No crop residue mulching	31.9	25.0	20.9	1.4	12.1	-3.2
Semi-mechanized	14.7	13.4	0.0	7.6	0.0	9.6
Manual labor/animal traction	59.3	48.8	-1.2	-6.5	-12.4	-29.0
N-limited yield level	3.1	3.7	5.2	11.5	22.7	77.2
Attainable rainfed yield level	4.4	4.4	0.0	0.0	0.0	0.0
Attainable irrigated yield level	66.5	54.2	-1.3	-4.7	-12.1	-30.0

The land use allocations are markedly affected by the labor price increase in the SC scenarios, but not in the other scenarios

In the SC scenarios, a marked decrease of total cropping area is found, when the labor price is increased by 50% (Table 7.15). This decreased cropping area is mainly allocated to sown grassland, the area of which increases from the scenario value of 5.4 10^3 ha (or 1.4 10^3 ha) to 8.7 10^3 ha (or 9.5 10^3 ha) in SC_t (or SC_0). For both 10% and 50% increases of the labor price, the area allocated to mixed crop rotations with alfalfa is apparently increased, and the use of crop residues for field mulching is markedly decreased (Table 7.15), e.g., at the 50% increase of labor price, the area allocated to the mixed crop rotations increases 70%, and the area allocated to the cropping activities with residue mulching decreases 32% in SC_0. These changes are strongly driven by the increased forage requirement for feeding animals, because the livestock production largely shifts from pigs to sheep. In SC_t (or SC_0), total pork production is decreased by 16% (or 11%) and 34% (or 47%), but, mutton is increased by 25% (or 30%) and 35% (or 149%), when the labor price is increased by 10% and 50%, respectively.

Another change due to the labor price changes is that bench terracing is largely replaced by spaced terracing, which requires less labor and capital inputs; and the area allocated to the cropping activities with furrow-ridging, which requires high labor inputs, is markedly reduced (Table 7.15). The area allocated to the N-limited cropping activities is increased, associated with a decrease of the area allocated to the attainable rainfed cropping activities. The change of the land use allocations caused by the increased labor prices is not apparent for the scenarios of SA, SB[7] and SD, and is mostly less than 5%.

7.4.2 Effect of exclusion of firewood requirements

Crop residues and shrubs used for cooking and heating in the rural area may be replaced by fossil energy (coal and oil) in the future. From Table 7.5, it can be seen that there is a large area of 7.0-47.5 10^3 ha allocated to shrubs in the different scenarios for producing firewood. This subsection presents the optimization results (Tables 7.16-17) without the constraint of firewood requirement. The same procedure and restrictions imposed on the objectives (Tables 7.1-7.4) as for that of the scenarios are applied to these optimizations. Based on the optimization results, the following three points are highlighted:

1) *An improvement of the main objective values has been found for all scenarios.* In the SA scenarios for soil conservation, the scenario value (Table 7.5) of the total soil loss can be reduced by 75% (SA_t) and 84% (SA_0), and total cropping area is reduced by 17% (because no residue requirement for firewood). Associated with the improvement of both objectives, the total employment, total net return and total crop production decrease, but for other objectives, the value is markedly improved (Table 7.16). The value of total biocide use (the primary objective of SD scenarios) is reduced by 15% for SD_t and 32% for SD_0. In the SB and SC sce-

[7] For the SB scenarios, a rather apparent change of the land use allocation is found at the 50% increase of labor price. The area allocated to the semi-mechanized, to attainable rainfed cropping activities, and to spaced terracing is increased; and the area allocated to bench terracing and to N-limited cropping activities is decreased.

narios, the main objectives are less affected (Table 7.16). Because crop residues are not required for firewood, a great increase (19-55%) of mutton production has been found for all scenarios, with the exception of the SB scenarios (with a very limited increase of less than 2%) that aim at maintaining high employment and crop production.

2) *Firewood requirement has an apparent effect on the selection of production technologies*. Except for SA scenarios aimed at soil conservation, an increase of the total cropping area of 5-18% (Table 7.16) is found for the SB-SD scenarios, because no land for growing shrubs is required. The area allocated to N-limited cropping activities (low chemical inputs) is apparently increased for all scenarios (Table 7.17), probably due to the goal constraints as given to the total use of N and biocides, and labor employment (see Tables 7.1-4). The areas allocated to the attainable irrigated and rainfed cropping activities are markedly decreased in all scenarios but for SC aimed at obtaining a high economic return, which has no change (SC_t) or a small increase of 2.3 10^3 ha (SC_0).

3) *Total use of mineral N is markedly decreased for most scenarios*. In the SD scenarios, mineral N (100% reduction) is not required for meeting the constraints (Section 7.2). In other scenarios, the mineral N use can be reduced by 6-56% of the scenario values. This great decrease in fertilizer N use is due to the increased area allocated to N-limited cropping activities, and increased use of crop residues for field mulching (Table 7.17). Except in the scenario SD_0[8], the area cropped with residue mulching is substantially increased.

Table 7.16 The optimization results for the objective variables without the constraint of firewood requirement. The figures are expressed as the relative difference (%) compared to the scenario values shown in Table 7.5. The **bold** figures are the optimum values of the objective variable with the highest priority in each scenario.

Objective variable	'With-Terracing'				'Non-Terracing'			
	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
Total cropping area	-17	6	5	11	-17	7	18	7
Total soil loss	**-75**	-6	16	-49	**-84**	-17	32	-17
Total N Loss	-13	-6	8	11	-27	3	9	2
Total mineral N use	-56	-22	-18	-100	-34	-30	-6	-100
Total biocide use	-24	-5	0	**-15**	-9	3	10	**-32**
Total crop production	-24	-1	-1	-1	-16	3	7	-14
Total production costs	-24	1	-3	5	-25	8	10	2
Total net return	-4	4	**5**	-3	-12	12	**12**	-19
Total employment	-23	**2**	-6	-1	-34	**10**	10	-7
Labor productivity	24	2	11	-3	34	2	2	-13

[8] Because protein content in alfalfa is high, the model needs crop residues of low protein to maintain a balanced protein content in the animal diets. In this scenario SD_0, the alfalfa production is high as a result of large area allocated to the mixed crop rotations with alfalfa (Table 7.17). In this scenario, crop residues are mostly used for feeding animals.

Table 7.17 Area (10^3 ha) and the difference (%) from the scenario values for the cropping activities with different technologies

	'With-Terracing'				'Non-Terracing'			
	SA_t	SB_t	SC_t	SD_t	SA_0	SB_0	SC_0	SD_0
The area (10^3 ha) allocated to the cropping activities with different technologies								
Total cropping area	22.1	103.5	77.9	56.4	24.2	104.0	73.3	62.3
Attainable irrigated & rainfed	18.0	72.3	70.9	1.9	16.7	49.3	67.3	1.1
N-limited	4.1	31.1	7.0	54.4	7.6	54.8	6.0	61.2
Mixed crop rotations with alfalfa	5.1	11.7	7.0	20.4	5.7	13.2	6.0	23.7
Crop rotations without alfalfa	17.1	91.8	70.9	35.9	18.5	90.8	67.3	38.7
Crop residue mulching	13.1	98.4	63.8	5.1	16.1	77.1	61.0	35.8
No crop residue mulching	9.0	5.1	14.1	51.3	8.1	26.9	12.2	26.5
The area difference (%) from the scenario values								
Attainable irrigated & rainfed	-28	-13	0	-69	-16	-16	15	-91
N-limited	125	116	124	22	42	42	62	34
Mixed crop rotations with alfalfa	81	37	124	29	-15	-12	47	27
Crop rotations without alfalfa	-29	3	0	3	-18	10	16	-2
Crop residue mulching	414	108	52	12	329	80	64	-2
No crop residue mulching	-63	-90	-56	11	-68	-51	-51	24

7.4.3 Variation of land use allocation caused by a small change in goal values

This subsection analyzes how the land use allocations can change by maximizing or minimizing land area under a group of cropping activities with a specific production technique, given a tolerated deviation for the goal value. This analysis particularly focuses on analyzing the substitutability of different measures for soil conservation at a small sacrifice of the goal values. For this analysis, a method is adopted that is based on an approach to study the 'nearly optimal solution', as described by Makowski *et al.* (2000).

Defined land use groups

The main criteria used to define the cropping activities include production level, mechanization level, soil conservation measures (tillage and residue management), and terracing (see Chapter 2). For this analysis, the focus is mainly on the criteria that are closely related to soil loss control. Twelve land use groups are defined, which include 11 groups for cropping activities and a group for sown grass activities (Table 7.18). Each of the land use groups will be minimized/maximized with the MGLP model, under the restrictions defined in Table 7.19.

For each scenario, a deviation of 0.05 is given for two main objectives and the last optimized objective that gave the final scenario results. The purpose is to investigate the potential of replacing one soil conservation measure or production technology by another in each scenario, without decreasing or increasing the goal value of the major objectives by more than 5%. By minimizing or maximizing each of the arable land use groups, variation range of a specific technology selected in each scenario can be determined.

Table 7.18 Defined land use groups and their optimizations

Aspects	Defined land use groups	Optimization
Rotation type	Mixed crop rotations with alfalfa (AL)	Maximization
	Crop rotations without alfalfa (CR)	Maximization
Soil conservation	Cropping activities with furrow-ridging (FR)	Minimization
	Cropping activities with contoured tillage (CT)	Minimization
	Cropping activities with residue mulching (RM)	Minimization
	Cropping activities without crop residue mulching (NM)	Minimization
	Cropping activities with bench terracing (BT)	Minimization
	Cropping activities with spaced terracing (ST)	Maximization
Production level	N-limited cropping activities (NL)	Minimization
	Attainable irrigated and rainfed cropping activities (PW)	Minimization
Others	Labor-intensive (non-machinery use) cropping activities (HD)	Minimization
	Sown grassland activities (GR)	Maximization

Table 7.19 Criteria for determining the restrictions of objectives in optimizing the area allocated to each of the land use groups (Table 7.18). The sign of inequalities means that the objective value in the first column should (or should not) exceed the product of the figure with the objective value in a particular scenario. For instance, the first objective of total cropping area should have a value not exceeding 1.05 times the goal value of scenario SA_i/SA_0, as presented in Table 7.5.

Objectives	SA_i/SA_0	SB_i/SB_0	SC_i/SC_0	SD_i/SD_0
Total cropping area	**≤ 1.05**	No bound	No bound	No bound
Total soil loss	**≤ 1.05**	**≤ 1.05**	**≤ 1.05**	≤ 1.0
Total N loss	No bound	No bound	No bound	**≤ 1.05**
Total crop production	No bound	≥ 1.0	No bound	No bound
Total net return	≥ 1.0	≥ 1.0	**≥ 0.95**	≥ 1.0
Total production costs	≤ 1.0	**≤ 1.05**	**≤ 1.05**	**≤ 1.05**
Total employment	≥ 1.0	**≥ 0.95**	≥ 1.0	≥ 1.0
Total fertilizer N use	≥ 1.0	≤ 1.0	≤ 1.0	≤ 1.0
Total biocide use	**≤ 1.05**	≤ 1.0	≤ 1.0	**≤ 1.05**

Method for presenting the results

The area allocated to each arable land use group as determined by these optimizations (i.e., minimization or maximization of the area allocated to each land use group) is expressed as a difference from the allocated area under each scenario. This difference (R_j) is presented as a percentage of the total area allocated to cropping activities in the different scenarios (SA-SD), calculated with an equation:

$$R_j = \frac{(NR_j - SR_j)}{SA} \cdot 100 \qquad 7.3$$

in which, NR_j is area (ha) allocated to land use group $_j$, when minimizing or maximizing the area of an arable land use group (e.g., AL) shown in Table 7.18, SR_j is the area (ha) allocated to arable land use group $_j$ in a scenario (scenario value), and SA is the total area (ha) allocated to crops in a scenario (scenario value).

Major results

For each scenario, the defined variables in Table 7.18 are optimized individually under the constraints in Table 7.19. The optimization results (*R* values, Eqn 7.3) are summarized in Fig. 7.11. From these figures, it can be seen that the land allocation obtained by optimizing the area allocated to different land use groups shown in Table 7.18, is quite different from the scenario values. The major points found with this analysis are given below:

1) *The soil conservation measure of furrow-ridging, which is highly labor-demanding, can be largely replaced by using crop residue mulching for all scenarios.* For instance, the cropping area (the scenario value) with furrow-ridging (FR) can be reduced by 32%, associated with an increase of 32% for the area cropped with residue mulching (RM) in SA_0.

2) A *large potential exists for reducing the bench terracing area by using spaced terracing, which requires less input of labor and capital.* In the scenario SA_t (or SB_t), the bench terracing area (the scenario value) can be reduced by 23% (or 21%), associated with an increase of 27% (or 21%) for the spaced terracing. In the scenario SC_t, a maximum reduction of 44% for the bench terracing area is found, associated with an increase of 32% for the spaced terracing and of 16% for the furrow-ridging. The required area for bench terracing can decrease 50% of the scenario value in SD_t.

3) *Use of crop residues for field mulching can be markedly reduced.* The area of the land use group with residue mulching (RM) in SB_t can be reduced by 35%, with an area increase of 10% for mixed crop rotations with alfalfa, and 5% for FR. The area of RM can be 16% lower than the scenario value in SB_0; and it can be reduced by 43%, associated with an increase of 12% for mixed crop rotations and of 11% for FR in SC_0. The area cropped with residue mulching can decrease to zero in SC_t, and in the SD scenarios.

4) *Apparent land use changes are found.* When the area allocated to N-limited cropping activities is maximized, the area allocated to the attainable irrigated and rainfed cropping activities (PW) can be reduced by 49% and 39% for the scenarios SC_t and SC_0, respectively. The area under the mixed crop rotations can increase 33% (SC_t) and 22% (SC_0), respectively, compared to the scenario values.

The area under mixed crop rotations can increase 14%, with an associated decrease of 12% for the bench terracing area in SD_t. Increasing the area of PW is increased by 43%, it can reduce the total cropping area by 13% and the bench terracing area by 11% in the scenario SD_t. In the scenario SD_0, a 11% decrease of the cropping area is found, when the area of PW increases 47%, associated with a large decrease of 47% for the land use group RM, and of 13% for the land use group FR.

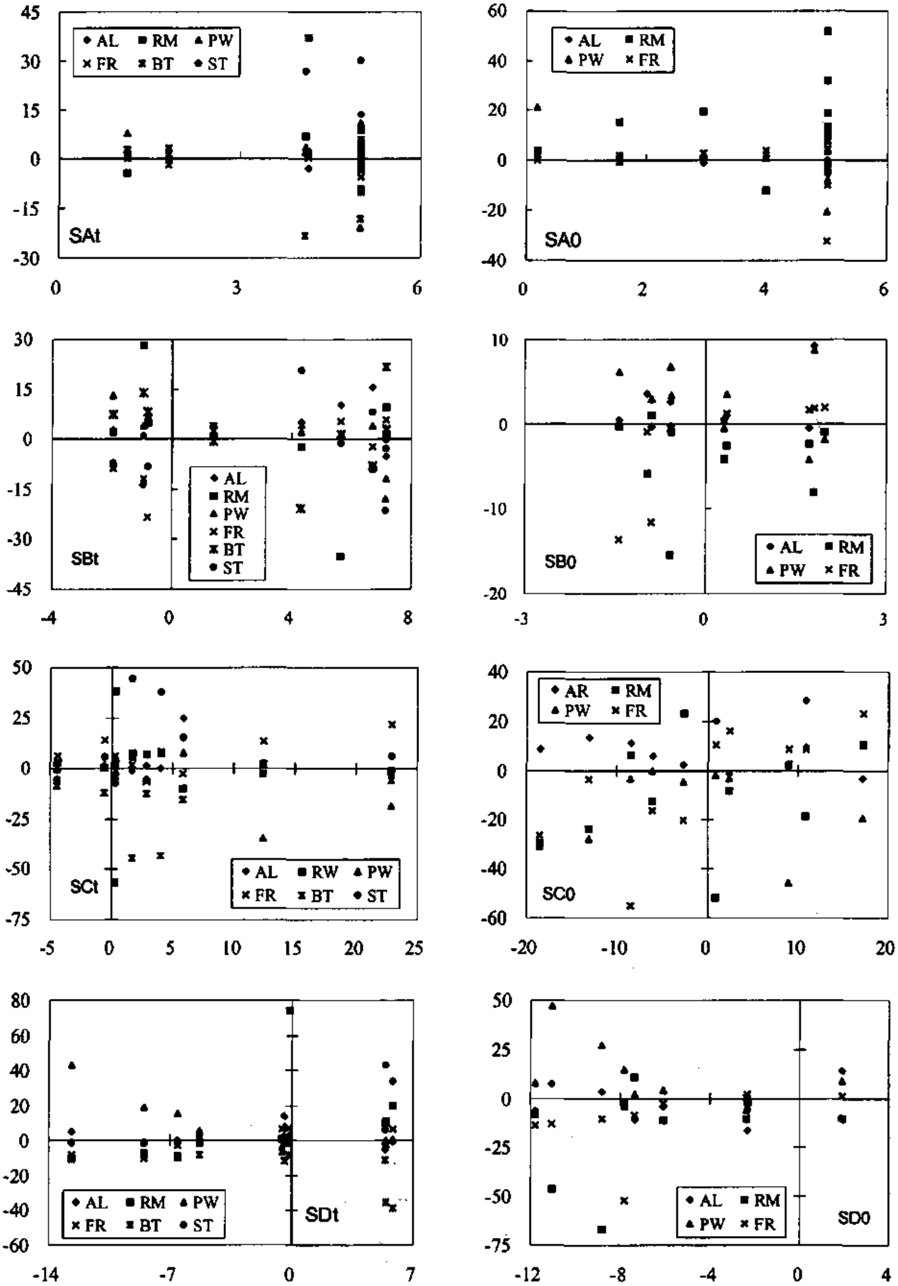


Figure 7.11 Variation (%) of the area allocated to selected land use groups in the four scenarios (SA-SD) and the two options of 'With-Terracing' (indicated by 't') and 'Non-Terracing' (indicated by '0'). The figures are calculated with Eqn 7.3. The X-axis presents the relative change of total area allocated to cropping activities, and the Y-axis is variation of the area allocated to the different land use groups (see Table 7.16), based on Eqn 7.3.

7.5 Conclusions

The scenario results presented in this chapter give the technical potentials for future agricultural development, which does not mean that these goals will be certainly achieved in the assumed time horizon. The results are generated for explicit assumptions with respect to, e.g., the self-sufficient requirement of agricultural products and prices. Results may be severely affected when any of these assumptions is changed. The methodology presented in Section 7.4 enables to explicitly analyze the consequences of these assumptions.

The scenarios presented here are considered to be relevant to the main problems as perceived by the local government and rural communities, based on current knowledge and understanding of the regional developments. However, these scenarios should not be considered as final only solutions, as numerous other possibilities can be formulated according to the preferences of stakeholders. Different scenarios can be easily generated with the MGLP model when different priorities and goal values are given (by a specific stakeholder). The results of this chapter provide stakeholders with the following perspectives:

1) Food security can be easily guaranteed from a biophysical point of view.

Food security, i.e., the food requirement for self-sufficiency, can be guaranteed in Ansai. There is a large potential to reduce the area (currently) used for crop production. To meet the estimated food requirement of the rural population with the base diet in the year 2020, the required cropping area (SA scenarios) would be about one-fourth of the cultivated area (the surveyed data) or 60% of the officially reported crop sowing area in 1992. If the target is to achieve a high crop production (SB scenarios), at least three times the food (crops) requirement of the rural population in 2020 can be produced.

2) Soil loss from the cultivated land can be controlled.

Soil loss from the cultivated land can be reduced to a very low level. For all scenarios, the average soil loss from the agricultural land uses (cropland, orchard, sown grass and planted shrubs) can be reduced to below 7.0 t ha^{-1}. When the cropping area is highly restricted to most suitable land units, the mean soil loss of the agriculture land use can be reduced to 0.5 t ha^{-1} (SA_t) and 2.0 t ha^{-1} (SA_0). In the long-term, terracing could be the best choice for soil conservation and also for agricultural production, not only because of the high efficiency in soil loss control, but also because terracing can increase crop yield and utilize the high rural labor resource. The furrow-ridging cultivation that was implemented in Ansai in the late 1970s, and strongly promoted by the local government in the last two decades, seems to be not very promising, as the furrow-ridging preparation (normally done in spring) needs high oxen input. Due to the low requirement of oxen in the crop-growing period, this results in a limited use of the oxen. It is not economically attractive to maintain a large number of oxen primarily for land preparation, because the farmers with very limited available land cannot afford this cost, and it puts heavy pressure on the feed resources. The mixed crop rotations with alfalfa are a promising alternative for the sustainable land use, as they are efficient in controlling soil losses with low labor, fertilizer N and capital inputs. Also, the high root production of alfalfa can improve the soil fertility.

3) High agricultural employment can be guaranteed, but this causes marked adverse effects on the net return per laborer.

Abundant rural labor and marginal land resources are major restrictions for increasing the labor productivity. The results of the trade-off analysis (Section 6.3) and the scenarios all show a decrease of labor productivity, when the employment increases. Based on prices of 1997-98, the maximum net return per laborer can approach 20.1 10^3 yuan per man-year (the base run value in Table 6.5). If the employment (ratio of the employed labor to the total available labor) is maintained to a level similar to the current conditions (the scenario SC_t), the possible net return per laborer is 10 10^3 yuan per man-year.

A potential for increasing agricultural employment exists. Of the total estimated rural labor available in the year 2020, 56-85% can be employed in agriculture (SB scenarios and the base run value in Chapter 6), which is much higher than the current employment rate. With this employment rate, an average net agricultural return per laborer of 6.7 10^3 yuan per man-year (SB_t) and 6.5 10^3 yuan per man-year (SB_0) can be expected, but this net return is much lower than that of the base runs and of the SC scenarios (Table 7.5).

4) A potential exists for increasing the livestock production.

This study reveals a high technical possibility for reducing the cropping area while still guaranteeing food security (SA scenarios), associated with a limited agricultural employment (about one-fifth of the total available labor). This reduced cropland can be used for growing shrubs to produce firewood or for growing grasses. Due to the high rural labor resource, and limited land availability, the scenario results indicate that the future development of animal husbandry should focus on pig production and indoor feeding of sheep in combination with summer grazing. Possible options are to expand the growing area of corn to produce the feed requirement for pigs; and to grow crops in rotations with alfalfa to produce high quality feed (alfalfa), and to promote the use of crop residues for ruminants. Soil loss can be simultaneously achieved by growing crops in the mixed rotations with alfalfa. The sensitivity analyses (Subsection 7.4.2) reveal that the firewood requirement has an adverse effect on the development of ruminant animal husbandry, due to the required crop residues for firewood. Increasing the labor price can promote a shift in livestock from pig to mutton production, when the main objective is to obtain a high net return (Section 7.4.1).

5) High external inputs are required to achieve the goals defined for the scenarios

All scenarios show a high requirement of external inputs (fertilizers, biocides, labor, draught animals, seeds, feed and others) in monetary terms. This might be a very important limitation. Agricultural development is slow at present precisely because of the very limited benefit gained from limited input (except for labor) and marginal land conditions.

6) A potential exists to adopt labor-intensive agriculture with a low input of chemicals

Considering the area's high labor resource, rugged terrain, and limited accessibility, labor-intensive agriculture with restricted input of fertilizer N and biocides (the SD scenarios) may be adopted in the future in Ansai. In this agricultural system, the input of chemicals (biocides and N) can be greatly reduced by an integrated use of natural resources, such as growing more leguminous food and forage crops and raising animals. This agricultural production system is environment-friendly (low chemical emission to the environment), and labor resource-based. The problem is that the net return per laborer is much lower than that in other scenarios, although it is 2.5-4 times higher than that in 1992.

7) There are various options available for policymakers to choose from in planning future agricultural development

Finally, there are many options for policymakers or farmers in Ansai (and maybe also in the Loess Plateau) to choose from in planning future land use and agricultural development. To implement these scenarios, appropriate policies related to the land tenure system, soil conservation, and infrastructure construction, and probably government support could play essential roles. These aspects will be further discussed in Chapter 8.

Chapter 8 General Discussion and Conclusions

8.1 Introduction

Soil loss control, food security, employment (in agriculture) and improvement of income for the rural population are most important issues for achieving sustainable land use in the Loess Plateau. Debates on these issues are often based on incomplete (qualitative) information. Opinions on the policy choices differ among scientists, governments and the rural communities, because of the different priorities given to objectives, and the unclear consequences of policy choices due to the lack of quantitative information and understanding of the system. Measures are often directed towards one aspect, e.g., soil loss control, by focusing on reforestation and construction of terraces; they seldom consider other aspects at the same time, such as the economic return and potential unemployment problem.

The exploratory land use study presented in this thesis offers a systems approach, for the quantitative evaluation of the consequences of different policy choices and trade-offs between different objectives in Ansai. The results from this systematic study are helpful for understanding of the regional problems and agricultural development potentials.

This study should be considered as a synthesis of fragmented agronomic data and several other knowledge sources intended to explore options for reversing the unsustainability spiral in the Loess Plateau. At least three types of results have been obtained:

- synthesis of knowledge about basic processes, crop and animal production, and a systematic analysis of problems in regional development for the Loess Plateau;
- identification of knowledge gaps and contribution to a research agenda;
- exploration of future land use options, and their possible consequences in the case area of Ansai.

Section 8.2 of this chapter discusses the production activities, objective variables and basic constraints incorporated in the MGLP model, followed by a discussion of methods for data collection, data gaps and research priorities in Section 8.3. Next, the methods for model analyses (including calculation of extreme objective values, trade-off analysis, scenario analysis and sensitivity analysis) and the presentation of model results are discussed in Section 8.4. Finally, highlights of the scenario results, and policy and research implications are given in Section 8.5.

8.2 Choices of production activities and constraints

8.2.1 Alternative production systems

This study aims at long-term exploration of land use options by showing the ultimate possibilities for the end of a development path considering the socio-economic and environmental goals and restrictions imposed. In other words, this study aims at exploring the biophysical and agro-technical possibilities to meet various socio-economic and environmental goals, assuming that the socio-economic conditions and agricultural infrastructure have no limitations for adopting new production systems. The current agricultural systems in Ansai cannot meet the sustainability aims, because they are generally subsistence-based with low inputs, and associated with serious soil loss problems. Therefore, in this study production activities have been defined based on knowledge of alternative, future-oriented agricultural systems, and only those that are technically efficient and helpful in resolving the regional problems have been considered, according to current knowledge and presently known techniques.

In principle, production activities should serve the primary aims of production determined by the long-term objectives for the regional development. Such aims comprise high productivity per unit area or per laborer, high profit, soil conservation, low chemical emission to the environment, or maintenance of employment.

Impact of a production system on the environment in terms of inputs and emission of chemicals should be minimum. These environmental aims can be realized by optimal use of inputs and appropriate management, i.e., the best technical means. In other words, the input of each resource is minimized to the point that other inputs can be used to their best effect (De Wit 1992, Van Ittersum & Rabbinge 1997). The aim of low fertilizer (particular N) inputs, and maintenance of soil fertility and productivity can be attained by using manure, incorporating crop residues, and growing legumes.

Alleviation of soil erosion problems requires appropriate land use systems and use of soil conservation measures. There are many possible options for water and soil conservation, such as rotational cropping of annual crops with closely seeded perennial forage crops, contoured tillage, crop residue mulching, furrow-ridging, and terracing.

Crop productivity per unit area can be maximized to serve various aims, such as helping to convert slope cultivation into other use purposes (e.g., grass, or preservation), produce enough food, or make economic profit. However, the realization of maximum productivity per unit area may be constrained by limited markets, restricted regional demand for agricultural products, and availability of other resources such as fertilizers and capital. Thus, alternatives with less intensive land use, i.e., lower yield level and inputs must also be considered.

The above mentioned aspects have been considered in the various alternative production activities. With respect to the main production purpose, five forms of agricultural systems have been distinguished for Ansai, i.e., cropping, fruit, grass, livestock and firewood production. This study focuses on food crop production to meet the increasing food requirement by ever-growing population; therefore cropping activities are defined in more detail than others, considering that the soil losses are mainly caused by slope cultivation and destruction of natural vegetation for the sake of food production.

The cropping activities have been defined on a rotation basis, and thus various interactions among crops in a rotation can be taken into account, such as incidence of diseases and pests, nutrient and water use, and soil loss control. Growing crops in narrow rotations may increase incidence of diseases, pests, nematodes, and weeds, especially soilborne pathogens, and therefore lead to a yield loss. Relatively less or even no external nitrogen is required when legumes are included in a rotation. Soil losses can be reduced by rational arrangement of crops (e.g., row crops rotated with small grains or perennial forage crops) in rotations. The use efficiency of soil water and nutrients can be increased. For instance, nutrients in the deep soil that cannot be used by a crop (e.g., potato) due to its shallow rooting zone can be used by a following crop, such as corn, which has a deep rooting depth. In this semi-arid area, a better yield of a rainfed crop can be attained when it is grown after a crop that has low water requirement (e.g., seed flax).

Seven food crops (corn, millet, winter wheat, soybean, autumn and summer potatoes and seed flax) and one forage crop (alfalfa) have been selected, which are combined into a limited number (17) of representative crop rotations. Each rotation has been further differentiated into various cropping activities, based on predefined criteria or techniques that are currently used (e.g., furrow-ridging, terracing) or potentially feasible (e.g., crop residue mulching), and land units. This resulted in a large number totaling 2006 cropping activities identified.

In the MGLP model, each production activity is treated as a decision variable. The model has a flexible structure, and therefore additional production activities can be easily incorporated. Since this study focuses on food security and soil loss control, vegetable and tobacco production, and fully hand labor-based arable farming are not considered. This limitation can be improved in a later study by considering more activities.

8.2.2 Objective variables and constraints at sub-regional and regional levels

In relation to the land use problems and regional development, various objective variables (Table 5.4 in Chapter 5) has been defined, such as total and per ha soil loss, total cropping area, total crop production, total production cost, and total and per laborer net return. Each of these objectives represents a policy issue in relation to the future agricultural development in Ansai.

Various constraints with respect to food security (self-sufficiency), available labor and agricultural land are incorporated in the MGLP model. The food requirement is calculated as a function of population size, per capita requirement of food energy and protein, and a dietary structure; and the food security is described by a food supply-demand relationship of various agricultural products (food crops, meat, apple, etc.). This offers a flexible way to analyze the effect of exogenous driving factors such as population growth and changes in diets.

In this extremely hilly landscape of Ansai, different areas are severely isolated due to the steep terrain and the poor infrastructure, and the land conditions regarding the relief vary greatly. Two factors related to spatial variation are incorporated into the MGLP model, i.e., land units and sub-regions. Land units affect performance of land use activities and the associated inputs, which have been considered in this study. Sub-regions were divided according to administrative units, and did not affect the performance (inputs and outputs) of production activities. However, sub-regions have differences in several aspects such as land area, population, labor force and requirement of agricultural products. An increasing number of sub-regions results in a tremendous increase of computing time, and therefore a limited number of six sub-regions is incorporated in the current model. The model provides the possibility to consider more sub-regions.

Each sub-region is treated as 'a big farm' that is specified by various objective variables and constraints in the model. Per sub-region, the land use, agricultural production and the associated inputs and environmental impact are driven by the sub-region's requirements and the objectives to be achieved at the county level. All objective variables defined for the county as a whole are also applied to each sub-region, but the objectives at sub-regional level are not used for optimization. Considering the isolated conditions, food (in grain equivalent) and firewood (in standard coal equivalent) requirements should be self-supplied per sub-region. Labor force, crop residues, shrub-wood production, alfalfa, manure, and industry by-products (husks and cakes from oil crops) can only be used within a sub-region. Except for the activity-specific costs (i.e., small equipment, machinery and seeds) that are given for each production activity, other costs (e.g., fertilizers, labor) and the net return are calculated per sub-region, according to crop, fruit, firewood and livestock (including grasslands) production (see Chapter 5). Per sub-region, a non-negative constraint is imposed on its total net return.

By skipping the constraints, such as labor and food self-sufficiency at sub-regional level, the effect of those constraints imposed per sub-region can be investigated with the model. For instance, the effect of labor force or manure in one sub-region becoming available for others can then be analyzed.

8.3 Data collection and data gaps

Wide-range information covering biophysical, agro-technical and socio-economic aspects have been collected from meteorological observations, land resource surveys, censuses, yearbooks and literature. The data were generally fragmented and insufficient, particularly the agro-technical data that were mostly estimated from literature published outside of Ansai; and most data could not be directly used for the quantification of production activities. Therefore, methods have been adopted to integrate and derive more information from these incomplete data, and to make the data comparable. A summary discussion for the data collection, data gaps and the priorities for research agenda are given in this section.

8.3.1 Land evaluation

Land evaluation is to determine suitable land area and to quantify land suitability for different land use types based on crop simulation models. In this thesis, the suitable land for arable farming (Chapter 2) is simply determined using the land survey data of the late 1980s (Chen 1988a). The quantitative land evaluation (Chapter 3) is based on the EPIC simulation model (Mitchell *et al.* 1997).

The EPIC model is capable of simulating crop growth, hydrology, soil erosion, and nutrient cycling, and has been validated with experimental data from the USA and many other countries in the world. For use of this model in the Loess Plateau, some of the crop-specific parameters were collected from literatures and published experimental data in and outside of the region (see Appendix 1). For this study, a simple model has been developed for estimating water storage of the contoured furrow-ridging (Appendix 2).

All defined crop rotations in Chapter 2 are simulated for the potential, water-limited and N-limited situations, taking into account the different measures used for water and soil conservation, and land conditions (land units). This results in a total of 816 simulations for all defined land use systems (Chapter 3). Small programs have been prepared for generating the input data sets, model simulations, and processing the output results. The simulated results formed the basis for determining the target outputs of economic yield and crop residues, inputs of nutrients (N, P and K) and irrigation, and losses of soil and N for the cropping activities (Chapter 4).

The use of the EPIC model for the land evaluation offers the same basis of quantifying crop yields, N and soil losses for all crop and management variants. The consequences of preceding crops (due to difference in water and nutrient use) on the following crops, and measures for water and soil conservation are also evaluated with the model. Although the simulated results cannot be validated currently by experimental data, the reliability has been extensively examined using empirical data (Chapter 3).

8.3.2 Technical coefficients

The input and output coefficients of production activities are determined using a 'target-oriented approach', i.e., the minimum inputs are calculated on the basis of the given target outputs, assuming that 'best technical means' are applied. Differences in the know-how of farmers, market conditions and agro-infrastructure are not taken into account, assuming that these limitations will be eliminated in the time horizon considered. All production activities are quantified in a similar way, and thus comparisons among the activities are possible.

Technical coefficients of cropping activities

Crop yield, soil and N losses, and fertilizer requirements are derived from the EPIC-simulated results, taking into account possible yield reductions due to the unavoidable growth-reducing factors (climatic hazards; soil-borne diseases and pests; and imperfect management). Biocide inputs are derived from literature data, taking into account effect of crop rotations and yield levels.

Labor requirements are estimated with the task-time approach, which is based on time needed for each farm operation, taking into account the distance between fields and homestead, land slope, and farming equipment and powers used (Chapter 4). The approach offers the same estimation basis of labor requirements, which is useful particularly in hilly areas where cropping often takes place on various sloping land types. This study also provides a method of estimating labor requirements for transportation of agricultural products and manure. Section A3.3 of Appendix 3, presents a method for calculating the earthwork and labor input of terracing and building hillside ditches. The labor requirement for terracing is based on earthwork movement that is calculated as a function of land slope steepness and terrace width.

Technical coefficients of animal activities

A simple model has been developed to calculate the production of meat, wool/cashmere, manure and the feed requirement, assuming that the herd structure is stable and the daily feed requirement is identical for indoor and outdoor (grazing) feeding (Appendix 5). The herd structure is modeled using factors of fecundity and mortality rates, sex ratio and culling age of the animals, based on the method of Van Duivenbooden *et al.* (1991) and Hengsdijk *et al.* (1996). For each activity, the inputs and outputs, and other production parameters are assumed to be identical each year. Feed requirements are expressed in terms of digestible energy (DE) and digestible crude protein (DCP), and calculated as a function of the metabolic weight.

8.3.3 Identification of data gaps and its contribution to a research agenda

The study presented in this thesis can be regarded as a synthesis of fragmented knowledge, data and information about agricultural land use and resources in Ansai. A lot of research, mainly at plot level, and land resource surveys have been conducted for this county. In this study much information is used and integrated with (expert) knowledge from elsewhere and with knowledge generalized in simulation models (EPIC). In this way, alternative land use options are quantified. As such an explorative study is a very effective way of not only integrating knowledge, but also identifying knowledge and data gaps. This study can be effectively used to identify a research agenda, either to fill data gaps or to validate alternative land use systems as quantified in this thesis.

Spatial variation

The land use activities are quantitatively defined per land unit, based on the mean characteristics (e.g., land slope steepness, soil texture) of each land unit. For the quantitative land evaluation, a single climatic data set (1971-1993) is applied for Ansai. Physical and climatic characteristics may vary considerably within and between land units. Within each land unit, for instance, slope steepness and land shape is not uniform. As several relationships (e.g. between water erosion and slope gradient) are not linear, coefficients can be estimated more accurately at disaggregated level.

Possible spatial variation in temperature and soil moisture regimes (due to slope directions, slope steepness and elevation) and their effects on crop yields have been discussed (see footnote 2, Chapter 3), based on published experimental data. A systematic characterization and analysis of the spatial variation in physical conditions, its effect on climate (radiation, wind speed, temperature, and relative humidity) and the quantified implications for, e.g., soil moisture regimes and plant growth is required. This information can then be used to carry out land use explorations, using the presented methodology, at Ansai or more disaggregated level, e.g. watershed level.

In this hilly region, the rugged terrain and land slope are two most important factors that affect efficiency in the resource use, labor requirement, particularly for transportation, and soil conservation. This study offers a method (Chapter 4) to estimate labor requirement and other inputs. This method may be used as a basis for systematic assessment of economic performance of different agricultural systems in this hilly area, taking into account inputs for soil conservation, and the effect of slope steepness and land accessibility. The required data can be obtained by detailed farm surveys or by experiments. Again, the presented methodology for land use exploration can then be applied to e.g. farm or watershed level.

Soil losses

The EPIC model offers six options including the USLE of Wischmeier & Smith (1978) and five other modified USLE equations for predicting water erosion. In general, much different soil losses are simulated by the different equations. Up to now, no systematic work has been done to check the reliability of the USLE and its modified equations in predicting soil loss in the Loess Plateau. In this study, a modified USLE equation, the so-called MUST (Mitchell *et al.* 1997) is used, which has been developed recently for the EPIC model. This equation uses runoff variables to simulate erosion and sediment yield, and thus eliminated the need for a delivery ratio (used in the USLE to estimate sediment yield) (Mitchell *et al.* 1997). The modified SCS curve number method of the EPIC model is selected to calculate surface runoff, which relates runoff to soil type, land use, and management practices. The parameter values for runoff and water erosion, e.g., the hydrology curve numbers (CN) and management practice factor (PE), were obtained from the SCS hydrology handbooks (SCS 1972) and from Wischmeier & Smith (1978). The simulated results have been roughly examined with experimental data in the Loess Plateau, and seem plausible (see Subsection 3.3.3). The results indicate that the mixed crop rotations with alfalfa are efficient in controlling soil loss, which might be of interest to the regional planners and agronomists.

This study has demonstrated that the procedure for land evaluation would be a useful tool for an integrated assessment of crop production and soil losses in the Loess Plateau, because the EPIC model closely relates soil losses to the plant growth and management. It can also be used to evaluate new land use systems, and thus may be helpful for agronomists in designing experiments. However, further work should be conducted such as the calibration of the model and its parameters, based on conditions of the Loess Plateau.

Nutrient management

The results of the quantitative land evaluation have indicated that N losses are mainly from volatilization, surface runoff and soil sediment, whereas leaching and denitrification hardly occur in this region (Chapter 3). This implies that high N use efficiency can be expected if nitrate N is used, and water and soil losses are well prevented. The simulation results have also indicated that low losses from organic N can be attained, but can be very high from ammonia N if surface fertilization is applied. These results need to be confirmed by experiments. In this region, phosphorus shortage and high fixation by calcareous soils might be an important problem for crop production, but potassium is relatively rich in the soils, because of low soil leaching. The results of this study may be used for designing experiments of fertilizer use.

Rainfed arable farming and crop management

In this hilly region, irrigation is not feasible for most land, and thus rainfed farming is very important for producing the food requirement for self-sufficiency. The results of quantitative land evaluation revealed a high yield potential for the annual crops, particularly corn, millet, potato and soybean (see Table 3.7, Chapter 3). These results are generally in line with empirical and experimental data, and the conclusions of many Chinese agronomists. This high rainfed yield potential is largely owing to the well-matched growing and rainy seasons, deep soil and high water holding capacity (400 mm can be stored in a rooting zone of 150 cm at field capacity).

The sowing date may be delayed to late May and early June for autumn crops, so that the period of drought stress can be reduced before the rainy season (normally starting in mid-June). But this late sowing may increase the risk of frost damage in October and November. Another finding is that furrow-ridging and crop residue mulching is not evident in increasing the yield for the autumn crops (see Table 3.8, Chapter 3). It may be useful to examine these findings and operationalize an optimal sowing strategy by experiments in combination with crop simulation models.

Effects of crop rotations

Soil water available for a crop grown in a rotation is affected by its preceding crop under rainfed condition in this semi-arid region. There is a proven contribution of legumes to soil fertility and therefore to subsequent crops in a rotation. A properly arranged crop rotation can favor soil and water use, and reduce soil losses. These conclusions are also revealed by the results of quantitative land evaluation. However, many other factors operating in the crop rotations are poorly understood in this semi-arid region, such as their effects on the incidence of diseases and pests. This information should be obtained through experiments, and could help make more useful crop rotations for sustainable agriculture.

Refinement of the animal model

The current animal model does not consider the effects of temperature, relief and animal movement, etc. This simplification may result in an under-estimation of the feed requirements during grazing, particularly in this hilly region. Calculation of feed requirements for animal growth is rather simplified. The digestibility for a feed type is fixed, and thus it may under-estimate the feeding value, as the feeding value (digestibility and digestible energy), particularly of poor feedstuffs such as crop residues, can be improved by other high quality feed types in a diet. Thus, further refinement of this animal model could be required.

8.4 Analysis and presentation of model results

There are many ways to conduct the model analysis. Four types of model analysis have been done, which include the calculation of extreme objective values, trade-off analysis, scenario analysis and sensitivity analysis.

8.4.1 Extreme values and trade-off analysis

In the base runs of the MGLP model, the extreme value for ten objective variables related to the policy issues are calculated under a set of basic constraints and food self-sufficiency requirements for the rural population. The results are presented in Table 6.5 in Chapter 6, from which it can be found that the objective to maintain high employment in agriculture strongly conflicts with other objectives, such as soil loss control, labor productivity (net return per laborer). In other words, maximum agricultural employment is obtained at the heavy cost of other objectives. For instance, when total agricultural employment is maximized (88.3 10^3 man-years), the average soil loss per hectare agricultural area is 9.1 t (906 t km^{-2}), 16 times that (52 t km^{-2}) obtained by minimizing total soil losses.

To reveal more information, various trade-off analyses among the selected objectives have been conducted, through which conflicting relationships between two objectives have been evaluated. The trade-offs are investigated using an iterative procedure, in which the first objective variable is optimized with the MGLP model by imposing different restrictions on the second one, under non-binding conditions for other objective variables. The results are graphically presented in Figs. 6.2-6.7 (Chapter 6). From the results, it can be found that there is plenty of room for an objective to improve its value at a small cost of another. For instance, at a decrease of 5% from the maximum value for total net return, the total mineral N use is reduced by 50%. When a small increase of total soil loss is given, i.e., from its optimal value 0.52 t ha^{-1} (52 t km^{-2}) to 0.6 t ha^{-1} (60 t km^{-2}), the total production cost can be reduced by 40%. But, labor productivity decreases almost linearly with an increase of the total employment (see Fig. 6.7B, Chapter 6).

These trade-off results reveal valuable information, however, its usefulness may be limited, as it only considers the trade-offs between two objectives. This trade-off method can be expanded to three objectives[1], such as among the objectives of total soil loss (or total cropping area), total production cost (or total employment) and total net return (or total crop production). Such an analysis requires extensive computation time for the MGLP model running with a PC computer. Therefore, it has currently not been conducted, and can be done in a later study.

8.4.2 Scenario analysis

Scenario analysis considers several objectives simultaneously, by giving a different priority or goal value for the objectives, according to policy preferences. This study offers a procedure (see Section 7.2) of scenario analysis, in which four scenarios are evaluated with the MGLP model. For each scenario, several objectives are selected and specified by their priority (optimization order) and deviation from the optimum. Based on the priority order, the objective variables have been optimized sequentially by imposing restrictions on the higher priority objective variables.

An advantage of this procedure is that it eliminates the need to give a concrete value for different objectives involved in a scenario, and thus it is particularly useful when an explicit goal value is not available from stakeholders. In general, the goal value is difficult to determine, because the explorative study is future-oriented, and the optimized results are very different from the current conditions. For example, the total production cost and total biocide use obtained at various objective optimizations are considerably higher than the current inputs, because of considerations of labor cost, food requirement for the increased population with the assumed (improved) diet, and biocide inputs required for all cropping activities to achieve the target yield.

The scenarios presented here are considered to be important to the main problems and to the stakeholders of the local government and rural community, based on the current knowledge and understanding of regional developments. No interactive communications with stakeholders have been conducted. Preferences of stakeholders such as policymakers and rural communities may not be fully reflected in this study. Hence, these scenarios should not be considered as final solutions, as other, maybe numerous, possibilities can be formulated according to the preferences of stakeholders. Additional analyses can be carried out when in-

[1] Trade-off analysis among three objective variables can be conducted with the following procedure:

(1) Give a restriction value for the third objective variable (TOV), then optimize the first objective variable (FOV) without imposing a restriction on the second objective variable (SOV); and in the second run, optimize SOV without imposing a restriction on FOV. From those two runs, the range of value for the SOV under the given restriction of the TOV can be obtained, i.e., between the optimal value and the value obtained at optimizing the FOV, without imposing restrictions on other objective variables.

(2) Under the same restriction for the TOV as (1), optimize the FOV by imposing different restrictions on the SOV with the value within the range determined in (1).

(3) Given another restriction value for the TOV, repeat the same calculations of (1) and (2). By applying this calculation procedure [(1)-(3)] several times, the trade-off values among these three objectives can be obtained. The results can be presented graphically (in a three dimensional graph).

formation is available from different stakeholders, which may help to generate more meaningful results.

8.4.3 Uncertainty and sensitivity analysis

Due to insufficient information, the lack of process knowledge and the adopted assumptions, uncertainty is involved in the technical coefficients. Some parameters are estimated using incomplete information, such as yield reductions, and biocide requirement that is based on literature data from mostly outside of the region. Prices for agricultural products and production inputs vary with changing market conditions, and variation in their demand and supply. The population is projected according to a greatly simplified exponential equation, and labor is estimated according to the age structure of 1990. Food requirements also include uncertainty due to changes in population growth and migrations, and dietary structure. Firewood may not be required at all in the region, because other possible energy sources (e.g., coals) may become available in the future.

These uncertainty problems can be evaluated by sensitivity analysis. In Section 6.4, the effect of changing the food requirements (population growth and diets) was analyzed. In Section 7.4, three analyses were presented, i.e., the effect of increasing the labor price on the scenario solutions and the effect of removing the constraints for firewood requirement. A third sensitivity analysis is based on a methodology to study nearly optimum solutions of LP models as developed by Makowski *et al.* (2000). Mutual substitutability of different soil conservation measures was systematically analysed while allowing a 5% deviation in objective values. This analysis yields information on the model's sensitivity for changing soil conservation measures. More analyses can be conducted regarding the effect of yield reductions, fertilizer use efficiency, and biocide use in additional studies.

The technical coefficient generator that has been developed using EXCEL can be used to generate the input-output coefficients and analyze the sensitivity. This generator includes all EPIC-simulated results and basic information, such as yield reduction factors, nutrient (N, P and K) concentrations in crop storage organ and residues, task-time per farm operation, prices of crop products, fertilizers and biocides. By changing parameters such as reduction factors, or time needed per farm operation, the coefficients are easily re-generated, and thus the regenerated results can be used as an input of the MGLP model to further analyze the effect on the optimization solutions. This generator can be used alone to analyze sensitivity of a specific parameter. For instance, we can change the value for yield reduction, and then its effect on fertilizer inputs, production cost and net return can be calculated for various cropping activities. A similar analysis can also be easily applied to other factors, such as prices of labor, fertilizer, biocides and crop products; inputs of labor and chemicals; and even the amount of crop residues used for field mulching.

The MGLP model is well structured, and thus the sensitivity of some coefficients can be directly conducted with the model by a small change in the relevant linear functions. For instance, if we want to know the effect of a 10% decrease in biocide input for each cropping activity, this reduction can be directly added to the function for calculating biocide use in the model, and then the optimizations can be conducted with the MGLP model.

There is a proved positive effect of soil organic matter content on maintenance of soil fertility and sustainable productivity. In general, soil organic matter content can be improved by returning crop residues to fields, by growing alfalfa, and by increasing use of manure. The MGLP model offers a possibility to analyze the effect of these factors by introducing the criteria related to this agronomic matter.

8.4.4 Presentation of results

The type of study presented in this thesis yields an enormous amount of results, with respect to agro-technical, socio-economic and environmental objectives, and land use allocations of various types (e.g., crop rotations, cropping activities with different technologies, grass, apple). Thus, approaches are needed to explicitly present the model results. This study has paid much attention to this aspect, such as the use of graphic figures, tables, and maps to present the spatial distribution of optimization results for different policy scenarios. This is considered particularly important because many results (assumptions with respect to base run constraints, priorities for objectives in scenarios, objective values, selected land use systems and production techniques) are highly interacting. Moreover, results of LP models are typically discontinuous.

8.5 Highlights of results and their implications

8.5.1 Highlights of scenario results

There is a large potential to reduce the area used for crop production while still achieving guaranteed food self-sufficiency in Ansai (SA scenarios). To meet the self-sufficient food requirement for the rural population with the defined base diet in the year 2020, the required crop area can be reduced to 60% of the officially reported sowing area in 1992. Corresponding to this value, the average soil loss from agricultural land use can be reduced to 0.5 t ha^{-1} (51 t km^{-2}). If no terraces are further constructed, the soil loss can be reduced to 2.0 t ha^{-1} (199 t km^{-2}). These soil losses are very low compared to the current condition (normally more than 40 t ha^{-1} on sloping croplands).

It should be noted that the mean soil loss is calculated as an average of the suitable land that is allocated to cropping, apple, sown grass and planted shrubs for a certain optimization, assuming that the soil conservation measures are well maintained. Potential destruction of terraces by rainstorms, which has happened several times in the past decades, has not been considered. Soil losses from the natural grasslands, natural shrub-lands, extremely steep lands and gullies have not been taken into account.

The big rural population and high employment pressure on agriculture have a marked adverse effect on income improvement for the rural population. Increasing the total employment in agriculture can lead to an apparent decrease of labor productivity in terms of net return per laborer. However, there is potential for the maintenance of high agricultural employment and simultaneously ensuring a reasonable income for the rural population. In the scenarios SB_t and SB_0, 66% and 56% of the rural labor in 2020 can be employed in agriculture, with a mean net return per laborer of 6.7 10^3 yuan and 6.5 10^3 yuan per man-year, respectively. At an employment level (in terms of a percentage of employment to total available labor) similar to the present level (the scenario SC_t), the net return per laborer based on prices of 1997-1998, can approach 10 10^3 yuan per man-year, more than 10 times that of Ansai in 1992. Much higher external inputs (compared to the current) are needed to achieve this net return. This implies that low profit of the current agriculture due to the lack of inputs and extensive cultivation in this region can be greatly improved by efficient use of resources and appropriate inputs.

The results of the SD scenarios show that the use of chemicals can be greatly reduced compared to other scenarios, but this leads to a much lower net return per laborer. The feasibility of these scenarios in this region may depend very much on the labor prices. Sensitivity analysis indicates that the net return per laborer is markedly decreased, when the labor price is increased (Subsection 7.4.1).

In the long-term, terracing could be a promising choice for soil conservation and also for agricultural production. The high rural labor resource can be used for terrace construction. Furrow-ridging cultivation is also efficient in soil loss control when the land slope is not very steep, but the high oxen requirement for furrow-ridging preparation is a problem, because these oxen are only used during a very limited part of the year. This problem can be largely alleviated by using crop residue mulching that requires much lower inputs of draught animals (see Subsection 7.4.3). From an economic point of view, spaced terracing could be more promising than bench terracing, because of its lower inputs of labor and capital. The sensitivity analysis results presented in Subsection 7.4.3 have revealed a large possibility to replace bench terracing by spaced terracing at a small increase of total soil loss.

8.5.2 Policy implications

The results revealed from this study are based on the assumptions that the current restrictions of infrastructure, marketing and farmer knowledge have no adverse effect on the use efficiency of agricultural resources. From an agro-technical point of view, the problems with soil loss control, food security, maintenance of employment in agriculture and income improvements that were identified in Chapters 1 and 2 can be greatly alleviated, if the defined land use and techniques will be implemented in the future. As a general conclusion, soil loss control is, to a large extent, in accordance with the improvement of production efficiency in Ansai. In the long-term, investment in soil conservation can greatly improve the environmental conditions, and also increase crop production and the income of the rural population. To stimulate sustainable land use and agricultural production by reversing 'the unsustainability spiral', in addition to population control, policies should aim at promoting farmers' participation and investment in agriculture (particularly in soil conservation), and improvement of the infrastructure, marketing and educational systems. In this area, intensification of arable farming could be important, by which a large part of the sloping land can be converted into more sustainable forms of land use.

For policy interventions to be successful regarding sustainable land use of the region, participation of the local people is needed. Judging from past experience and current debates, appropriate policies towards the land tenure system seem to be crucial in promoting farmers' participation in soil conservation and investment in agriculture. Such policies should guarantee the long-term use of a piece of land, and the ownership or interest of a farmer's investment in agriculture. Considering that full privatization of land may not be possible, at least in the near future, for historical and political reasons, land can be 'partially privatized', i.e., 'the right to use land (wasteland)' could be sold to farmers for a period of 50-100 years. The feasibility of this policy is still being tested in government-selected areas. Another policy is the so-called 'stabilizing' and prolonging of 'the right to use land' (mainly farmland). Complete details and further improvements of this policy have also been discussed and tested in the selected demonstration regions of China in recent years. If these policies are finalized and strictly implemented, they should encourage farmers to invest in their land, and further stimulate the sustainable use of land resources.

Population control (family planning) is still a very important policy measure, with regard to the rapid population growth in this region. This policy should be combined with the policy measures for improving the social security and educational systems. As mentioned in Chapter 1, the lack of social security in the rural area may be the most important reason for the high birth rate. Currently, government attention is mainly focused on the construction of the social security system in the urban areas. Policies, e.g., related to insurance and the guarantee of minimum living standards (particularly for old people), are also urgently needed in the rural areas. Education is another important issue in this region, due to the lack of teachers and finance, and the isolation of villages by the steep terrain. An improvement of the education system will greatly depend on support from the government, private and state-owned companies, and other social communities (e.g., 'Hope Project'[2]) in the near future. Special attention should be paid to women and girls, because they have much less access to education.

Considering that soil conservation in the Loess Plateau is very important for the alleviation of flooding risk in the lower reaches of the Yellow River, and the backward economy in this region, special policies are required. Such policies may include subsidy of production inputs, exemption from agricultural tax, and investment (government) in soil conservation and infrastructure. The construction of infrastructure can promote the development of markets, and thus cash crops such as apple can be expanded, further improving the income of rural population. To reduce the pressure of employment on agriculture, development of non-agricultural production activities (e.g., rural enterprises) to absorb the large rural labor force should be emphasized.

In general, many possibilities exist for stakeholders to make choices for the future development, and the 'unsustainability spiral' can be successfully broken by efficient use of land

[2] A welfare organization aimed at collecting/distributing donations from individual persons and companies for supporting education in the poor areas of China.

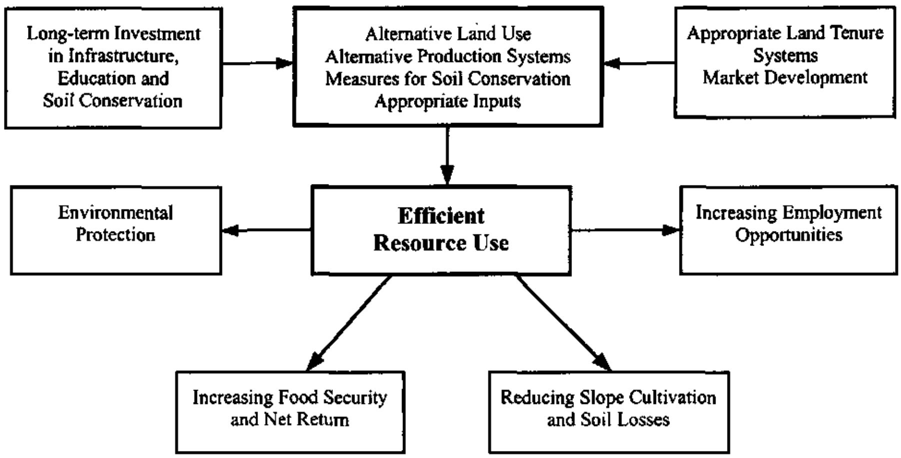


Figure 8.1 A schematic illustration of main agro-technical and policy measures to stimulate efficient resource use for breaking 'the unsustainability spiral' and meeting various goals of regional development in the Loess Plateau

resources and appropriate policy measures. Fig. 8.1 presents the key measures of promoting an efficient resource use, to meet various goals of the regional development. A prerequisite for adoption of alternative and innovative land use systems, and agro-technical and soil conservation measures such as those suggested in this thesis, is the development of appropriate policies that stimulate the land tenure systems and investment in infrastructure, soil conservation and education.

8.5.3 Research implications

Section 8.3.3 proposed some further research related to soil losses, and nutrient and crop management. The following research agenda focuses on the integrated use of resources, which is highly complementary to the study presented in this thesis.

Mixed farming systems

The optimization results indicate that food security can be easily guaranteed, and a potential exists for development of animal husbandry. Considering the high labor resource, soil erosion problems and restricted availability of fertilizers, mixed farming systems that integrate crop and animal production should be promising for regional development. Such mixed farming systems may include a type that integrates rotational cropping (corn, millet and alfalfa), grass (grazing) and sheep production; or one that integrates rotational cropping (corn, millet and alfalfa), and pig and sheep production. In these production systems, forage (alfalfa and corn) and crop residues can be used to feed sheep or pigs, while the manure is used for crop production. This research can be conducted at farm or village level.

Agroforestry

Agroforestry includes trees/shrubs in the cropping systems. Currently, no systematic work has been done in this region, and therefore it has not been considered in this study. This agricultural system may have potential in this region, where rich leguminous shrub species can be selected and grown as shelterbelts (ISWCYP 1997, Zhao *et al.* 1994). The advantage is that the shrub belts can prevent soil loss with low inputs, and also can be harvested for firewood every 4-6 years. A possible problem is that due to their high water requirement the trees/shrubs may have to face stiff competition for limited rainwater from crops grown between the shrub belts.

Catchment management and exploration of optimal land use

A small catchment is often used as the basic unit for integrated resource management and soil loss control, and therefore adoption of this MGLP model at catchment level could be very useful for catchment management. Taking into account the spatial variation of land conditions, this MGLP model can be used for exploring the optimal options for catchment management. At a small catchment level, more detailed information can be obtained using detailed maps and GIS technology. Some important factors such as slope steepness, elevation, accessibility of land parcels, distance to homesteads, and possible cost for construction of necessary infrastructure can be considered in more detail.

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Summary

Introduction

The Loess Plateau is located in the mid-reaches of the Yellow River in northern China (see Map 1, Chapter 1). Most of the area is dominated by loess hills. The mean population density ranges from 30 to 200 persons km^{-2} for most counties, and more than 90% of the population lives in rural areas and most rural labor is involved in agricultural production. Due to population pressure, slope cultivation is very common, resulting in serious soil erosion. For instance, in Ansai county, about 80% of the cultivated land has a slope gradient of more than 19%, and mean soil loss (sediment yield) of the county is 84 t ha^{-1} per year. This severe soil loss has caused massive siltation in the riverbed of the lower reaches of the Yellow River, and has consequently increased the flooding risk of the river.

Problems with soil loss, food insecurity, population pressure, and low income of the rural population are interrelated, and consequently result in an 'unsustainability spiral' in the Loess Plateau. Up to now, much research has been carried out for the Loess Plateau, but often of a fragmented and empirical nature. No systematic and quantitative research has been conducted for the entire regional land use system, resulting in a lack of quantitative information on opportunities at system level. This has partly led to the different opinions regarding future land use and agricultural development in the region.

This study uses Ansai County in the Loess Plateau as a case study, 1) to operationalize a methodology for land use exploration, with specific emphasis on soil conservation, food security and regional development objectives; and 2) to explore strategic land use options for Ansai that may break the unsustainability spiral, using a systems analysis of information with respect to the agricultural production, and the agro-ecological and socio-economic environment. This second aim can be specified in three sub-aims:

1) to reveal the crop production potentials, and identify feasible techniques to raise the land productivity and serve the aim of soil conservation;
2) to evaluate the consequences of different land use priorities, and the possibilities of satisfying various objectives and to reveal trade-offs;
3) to evaluate the possible consequences of a growing population and changing food requirements on the land use, agricultural production, and economic return and environment.

Method

The key of the methodology is that biophysical possibilities for land use are confronted with societal objectives and constraints, using an MGLP model that generates strategic land use options for different priorities with respect to the societal objectives and constraints. The methodology comprises three major steps: 1) quantification of possible future ('alternative') production activities; 2) development of an MGLP model with resource constraints, and societal objectives and constraints, which optimizes land use allocation; and finally 3) systematic analysis and representation of the model results.

Alternative production activities and their quantification

Definition of alternative production activities

Current production systems in Ansai are generally subsistence-based with low inputs, and associated with serious soil loss problems. In this study (Chapter 2), alternative production activities are defined based on the agro-ecological principles, taking into account the land conditions, problems with land use and regional development, and policy objectives as presented in Chapters 1 and 2. Five forms of production activities are distinguished, i.e., cropping, fruit, firewood, grass and livestock activities. As the focus of this explorative land use study is on food security and soil conservation, the cropping activities are defined in detail. Eight crops are selected including seven food crops, i.e., corn, millet, winter wheat, soybean, autumn and summer potatoes, and seed flax, and one forage crop, i.e., alfalfa. These crops have been combined into 17 crop rotations, comprising mono-cropping rotations, rotations without alfalfa and rotations with alfalfa. Each crop rotation is further differentiated into various cropping activities, taking into account aspects related to productivity (3 yield levels), soil conservation (4 measures) and labor use (2 mechanization levels). Considering 2 terracing options (bench and spaced terracing) and six suitable land units (flood plain, existing terraces, and four sloping land units with a slope of < 9%, 10-18%, 19-27% and 28-47%, respectively), a total of 2006 cropping activities has been defined. Other production activities include 6 fruit (apple) activities, 10 sown grass activities, 2 planted shrub activities, and 8 animal activities comprising goat, sheep, pig, cattle and donkey production.

Quantitative land evaluation

The quantitative land evaluation is conducted using the EPIC simulation model (Chapter 3). The 17 crop rotations are simulated for potential, water-limited and N-limited situations, taking into account the different measures used for water and soil conservation, and land conditions (land units). The simulation results formed the basis of determining the target outputs of yield and crop residues, soil and nitrogen losses, nutrient (N, P and K) inputs and irrigation requirement for cropping activities.

Technical coefficients of production activities

Production activities are quantified using a 'target-oriented approach', i.e., the set of minimum inputs to realize the target is calculated, assuming that the 'best technical means' are applied (Chapter 4). This implies that current socio-economic, infrastructure or local know-how limitations do not affect biophysical options and efficiency in the resource use. Thus, strategic options can be explored that are not obscured by current limitations. Basic information for quantifying the production activities is obtained from the quantitative land evaluation, and from experimental data, literature and expert knowledge.

The target yields of cropping activities are based on the EPIC simulation results, taking into account unavoidable yield-reductions, due to climatic hazards (hail, frost and rainstorms); soil-borne diseases and pests (due to narrow rotations and particular cropping sequences); and crop management imperfections (i.e., fertilizers, weeding, biocides, water irrigation may not always be timely and evenly applied).

Nutrient requirements (N, P and K) to realize the target yields are determined on a balanced basis, i.e., the inputs equal the harvested nutrients (i.e., the total removal by economic products and harvested crop residues) plus the losses. The same use efficiency has been assumed for nutrients from fertilizers and manure. Pesticide inputs are derived from literature data and expert knowledge, taking into account effect of crop rotations and yield levels.

Labor requirements are estimated with a task-time approach that is based on time needed for each farm operation, taking into account the distance between fields and homesteads, land slope, and farming equipment and traction used. Labor requirements for transportation of agricultural products and manure are estimated as a function of the amount and distance, and for terracing and building hillside ditches as a function of earthwork movement.

Production costs and net return are based on prices of production inputs (e.g., fertilizers, labor, biocides) and marketable crop products in 1997-98. Crop residues and manure are not priced, but costs for their transportation and application are considered. No price is given for grazing grasses, but costs for the inputs in the sown grassland (activities) are taken into account.

Technical coefficients of the sown grass activities are also based on EPIC-simulation results, and those of fruit and planted shrub activities are estimated using literature data. Animal production and feed requirements are estimated using an animal model that is based on a stable herd structure determined by fecundity and mortality rates, sex ratio and culling age of the animals. For each activity, the inputs and outputs, and other production parameters are assumed to be identical each year. Feed requirements are expressed in terms of digestible energy (DE) and digestible crude protein (DCP), and calculated as a function of the metabolic weight.

A technical coefficient generator that has been developed using EXCEL, is used to generate the input-output coefficients. This generator includes all EPIC-simulation results and basic information and parameters, such as yield reduction factors, task-time per farm operation, and prices of crop products, fertilizers and biocides. By changing parameters such as yield reduction factors and the time needed per farm operation, the coefficients can be easily re-generated.

Objectives and constraints of the MGLP model

Ten objective variables for the MGLP model have been defined based on the land use problems and policy issues in Ansai (Chapters 2 and 5), i.e., total and per ha soil loss, total cropping area, total crop production, total employment in agriculture, total production cost, total net return, labor productivity (net return per laborer), total mineral N use, total biocide use, and total N losses. These objectives can be optimized by the model, taking into account a number of constraints (Chapter 5).

The main constraints include the land resource, labor force, requirement of agricultural products, and feed requirements. In Ansai, not all land can be used for agriculture. Excluded areas are preserved and unusable land including forestland, extremely steep lands, residential areas and water bodies. These excluded areas are not part of the model optimization, and they always belong to the 'preservation' category. The available agricultural land includes suitable land (slope gradient < 47%), and natural grassland and shrub-land. The suitable land can be used for growing crops, apple, (sown) grass and (planted) shrubs. Natural grasslands can be used only for animal grazing and natural shrub-lands are used only for firewood collection.

The labor force for agricultural production is based on the projected rural population in 2020 and the fraction of the population that is economically active (aged 20-60). Labor requirements and labor force are calculated for each of five labor-demand periods. Food requirement and supply are expressed in grain equivalent. Food requirements are calculated as a function of rural population size, per capita requirement of food energy and protein, and a dietary structure. The food supply is the total food production minus the part used for feeding animals. Food self-sufficiency is defined by a food supply-demand relationship of various individual agricultural products (food crops, meat, apple, etc.).

Firewood requirement, expressed as standard coal equivalent (SCE), can be met by shrub-wood and crop residues, and is calculated as a product of the projected rural population size in 2020 and per capita SCE requirement. Feed requirements can be met by four feed types: 1) grass, 2) crop residues, 3) industrial by-products and 4) main crop products (corn, alfalfa and potatoes). Feed intake of an animal is based on its DE and DCP requirement.

Constraints are imposed at regional or sub-regional level. The county is divided into six sub-regions. Considering the rather isolated location in Ansai, labor force, crop residues (as feedstuffs or firewood), shrub-wood, alfalfa and manure are assumed to be used only within a sub-region. For Ansai as a whole, self-sufficient requirements for each of the marketable crop products, apple and meat must be met, but for individual sub-regions deficits are allowed. Per sub-region, total crop production should exceed the total requirement in terms of grain equivalent. Grassland (the natural and newly sown) is used for animal grazing within each sub-region. Available husks of wheat and millet, and cakes from seed flax and soybean are determined by the amount consumed as food and food oil. Functions are incorporated in the

MGLP model for determining indoor feeding and grazing for a ruminant animal and for calculating manure production.

Model analysis

Four approaches are applied for the model analysis, i.e., calculation of extreme objective values and trade-off analysis (Chapter 6), and scenario analysis and sensitivity analysis (Chapter 7). The objective variables are optimized in various base runs of the MGLP model under food self-sufficiency requirements. Based on optimization values of the objectives, trade-offs between selected pairs of objectives are evaluated using an iterative procedure, i.e., a first objective variable is optimized by imposing different restrictions on a second one, under non-binding conditions for other objective variables.

Four policy scenarios (Chapter 7) have been defined according to objective priority, i.e., soil conservation, agricultural employment, economic development, and environmental protection. The scenarios have been evaluated in such a way that each objective in a scenario is optimized sequentially with the MGLP model by imposing restrictions on the higher priority objective variables. The scenario results are examined by sensitivity analyses. Three important aspects related to the labor, firewood requirement and production techniques have been evaluated. First effects of increasing the labor price are analyzed, and next that of skipping the firewood requirement constraint. Finally effects on land use allocation (i.e., area allocated to the activities with different soil conservation measures or production technologies) are evaluated while allowing a small deviation of the objective values.

Results

Land unit level - quantitative land evaluation

Compared to current yield levels, high rainfed yields can be attained in Ansai, particularly for corn, millet, potatoes and soybean (Chapter 3). For instance, long-term mean (rainfed) yield of corn is 6.6-9.3 t DM ha^{-1}, millet 4.7-6.6 t DM ha^{-1}, and autumn potato 5.6-7.1 t DM ha^{-1}, varying mainly with land conditions. Furrow-ridging and crop residue mulching used for water and soil conservation have a limited contribution to the yield increase (less than 10%) of corn, millet, soybean and autumn potato, since their growing period is well matched to the rainy season. By contrast, the yield of winter wheat, summer potato and seed flax can be markedly improved by those measures, especially on sloping land units, because of the improvement of soil moisture conditions in the dry season (winter and spring). Without fertilizer N use, considerable yields can also be obtained by growing crops in the crop rotations with alfalfa, e.g., the mean yield of corn is 4.1-5.0 t DM ha^{-1}.

Efficiency of soil conservation measures in controlling soil loss varies, i.e., terracing is the best, with which water and soil losses can be controlled, and next is crop rotations with alfalfa. The efficiency of furrow-ridging in controlling soil loss is lower than crop residue mulching for steeply sloping lands. Soil loss of steep lands cannot be efficiently prevented using only furrow-ridging or residue mulching for crop rotations without alfalfa.

Low N losses may be achieved in the region. The simulation results show that N losses are mainly from volatilization, and from runoff and soil loss. Denitrification and leaching hardly occur because soils are rarely saturated and rainfall cannot leach out of the rooting zone. Long-term average of N losses can be limited to 25% of the applied N under a well management condition, i.e., runoff and soil loss are well controlled.

Ansai level - extreme objective values and trade-offs

The MGLP model reveals that under conditions of food self-sufficiency for the rural population in 2020, the mean soil loss from agricultural area (excluding natural grasslands and shrub-lands) can be reduced to 0.5 t ha^{-1} (Chapter 6). This is associated with a very low agricultural employment, due to restricted area used for agriculture. A very high potential exists for increasing the crop production, net return and agricultural employment. To achieve this potential, high inputs (compared to the current situation) are required. Other findings include:

The soil loss control is, to a large extent, in line with the goals of increasing crop productivity and labor productivity (net agricultural return per laborer). A great potential exists for reducing the use of mineral N, which can be mostly covered by manure and biologically fixation, at a sacrifice of about one-third of the maximum total crop production, or one-fourth of the maximum total net (agricultural) return.

Agricultural employment has marked impacts on most objectives, i.e., increasing agricultural employment can considerably increase the total production cost, cropping area, use of chemicals and soil loss, and greatly decrease the labor productivity. In other words, the goal for maintenance of employment in agriculture strongly conflicts with these objectives, i.e., it causes a large sacrifice of these objective goals.

Trade-offs among many objectives are initially weak: one objective can be improved a lot without much sacrificing of another. For instance, a decrease of the total net return with 5% compared to its maximum value, is associated with 35% reduction in the total production cost. A decrease of the crop production with 6% compared to its maximum value, is associated with a reduction in the biocide use of one-third. When the total soil loss is slightly increased from its minimum value 0.5 t ha^{-1} to 0.6 t ha^{-1}, the total production cost can be reduced by 40%. By contrast, the (negative) relationship between labor productivity and total employment is almost linear.

The effect of changing food requirements varies among the objectives. Increasing the food requirements can result in a marked increase of the total production cost, total cropping area, total biocide use and total N loss.

Possibilities and limitations for sustainable land use and regional development in Ansai

From the scenario results, it can be concluded that the goals of food security and soil conservation in Ansai can be easily achieved from a biophysical and agro-technical point of view. Current cropping area can be greatly reduced under guaranteed food security in Ansai in 2020, i.e., the required cropping area can be reduced to 60% of the officially reported crop sowing area in 1992, and the average of soil losses from agricultural land use can be reduced to 0.5 t ha^{-1}. If no additional (compared to the current area) terraces are constructed, the soil loss can be reduced to 2.0 t ha^{-1}. These soil losses are very low compared to the current values (normally more than 40 t ha^{-1} on sloping cropland).

The smaller area of cropland results in a larger area that can be used for growing shrubs to produce firewood or for growing grasses. This implies that there is a potential for livestock production. Due to limited available land and the high labor force, the scenario results indicate that the future development of animal husbandry should focus on pig production and sheep production (indoor feeding in combination with summer grazing). Possible options are to expand the area of corn to produce feed for pigs, and to grow crops in rotations with alfalfa to produce high quality feed (alfalfa), and to promote the use of crop residues for ruminants. The sensitivity analyses show that the firewood ('energy') requirement has an adverse effect on the development of ruminant animal husbandry, due to the required crop residues for energy. Increasing the labor price can promote a shift in livestock from pig to mutton production, when the main objective is to obtain a high net return.

In the long term, terracing and mixed crop rotations with alfalfa could be the best choices for soil conservation and also for agricultural production. The high rural labor force can be used for terrace construction. Alfalfa can fix nitrogen, and thus greatly reduce the demand for fertilizer N, and also improve soil fertility. Furrow-ridging cultivation is also efficient in soil loss control when the land slope is not very steep, but a problem is that furrow-ridging preparation has a high oxen requirement. The sensitivity analysis indicated that furrow-ridging can be largely replaced by crop residue mulching that requires much lower inputs of draught animals. From an economic point of view, spaced terracing could be more promising than bench terracing, because of its lower inputs of labor and capital. The sensitivity analysis revealed a large possibility for replacing bench terracing by spaced terracing at a small increase of total soil loss.

The large rural population and the lack of off-farm employment opportunities may be the most important factor affecting agricultural development in Ansai. This is evident from the trade-off results discussed in Chapter 6, i.e., increasing the total employment in agriculture leads to an apparent adverse effect on many other objectives. However, there is a potential for maintaining high agricultural employment at a reasonable income. For instance, in the agricultural employment scenario, 66% of the rural labor in 2020 can be employed in agriculture, which is higher than the current employment rate, and the mean net return per laborer is 6.7 10^3 yuan per man-year. At an employment level (the ratio of agricultural employment to the total rural labor) similar to the present level (economic development scenario), the net return per laborer based on prices of 1997-1998, can approach 10 10^3 yuan per man-year, more than 10 times that of Ansai in 1992 (this low net return in 1992 was because of the very limited external inputs and poor crop and soil management).

The environmental protection scenario requires low chemical inputs, and consequently low emissions to the environment, but low net return. Feasibility of implementing this scenario in Ansai depends very much on the prices of labor and chemicals. Based on prices in 1997-98, the possible net return per laborer can approach 4.5 10^3 yuan per man-year. This net return is much better than that in 1992; however, it is very sensitive to changes of the labor price.

Conclusions

This thesis presents a systematic analysis of future options for regional development for Ansai county in the Loess Plateau. Fragmented and empirical biophysical and agronomic information from the region is integrated with well-adopted production-ecological principles and other knowledge sources. This work contributes to the understanding of regional problems and agricultural development potentials. The results show agro-technical potentials for breaking the unsustainability spiral in the very fragile and poorly endowed regions of China. Problems related to soil conservation, food security, employment and income could be greatly alleviated if the defined land use, production systems and techniques are adopted in the future.

In general, soil loss control is largely in accordance with the improvement of production efficiency. In the long term, investment in soil conservation can greatly improve the environment, and also increase crop production and income of the rural population. In this area, intensification of the arable farming could be important, by which a large part of the sloping land can be converted into more sustainable forms of land use, e.g., forest and preservation.

To analyze socio-economic feasibility of the explored land use options and to promote actual development towards the identified options, appropriate policies must be developed. Policies for improving the land tenure system, controlling population growth, and improving infrastructure and educational systems should be enhanced or implemented. Special support from the government, such as through investments in education, infrastructure and soil conservation, are crucial for this region.

The systematic synthesis of knowledge in this exploration for Ansai also contributes to identifying knowledge gaps at lower levels of scale, e.g., land unit, slope aspect, field, crop or animal levels. In addition alternative, to some extent hypothetical, land use systems have been put forward that require testing and improvement in empirical settings. The presented results allow a much more targeted layout of empirical research, thus contributing to a research agenda for agronomy and soil, water and nutrient conservation.

Samenvatting

Inleiding

Het Lössplateau is gesitueerd in de middenstroom van de Gele rivier in Noord China (zie Kaart 1.1, Hoofdstuk 1) Het gebied wordt gedomineerd door lössheuvels. De gemiddelde bevolkingsdichtheid varieert van 30 tot 200 personen km^{-2} in de verschillende districten. Meer dan 90% van de bevolking leeft op het platteland en is nog actief in de landbouw. De hoge bevolkingsdruk veroorzaakt o.a. landbouwkundig gebruik van de hellingen, waardoor ernstige bodemerosie optreedt. In het district Ansai bijvoorbeeld heeft 80% van het bebouwde land een helling van meer dan 19% en bedraagt het gemiddelde bodemverlies (afzettingsopbrengst) 84 ton ha^{-1} per jaar. Dit zware bodemverlies heeft ernstige verzilting van de rivierbeddingen van de benedenstroom van de Gele rivier veroorzaakt en daarmee de kans op overstroming van de rivier vergroot.

Problemen van bodemverlies, voedselonzekerheid, bevolkingsdruk en lage inkomens van de plattelandsbevolking hangen samen en kunnen resulteren in een onduurzaamheidsspiraal. Tot nu toe is weliswaar veel onderzoek verricht voor het Lössplateau, doch dat is vaak fragmentarisch en sterk empirisch van karakter. Een systematisch kwantitatief onderzoek naar het gehele regionale landgebruikssysteem dat kan resulteren in kwantitatieve informatie over de potenties van het systeem ontbreekt. Dat heeft o.a. geleid tot zeer verschillende opvattingen over de toekomstige landgebruiksmogelijkheden en landbouwkundige ontwikkelingen in het gebied.

In deze studie wordt het Ansai district in het Lössplateau als een case studie gebruikt om:

1. een methodologie voor verkennende landgebruikstudies operationeel te maken;
2. de mogelijkheden te verkennen of er landgebruiksopties zijn waarmee de onduurzaamheidsspiraal kan worden doorbroken.

Daartoe wordt een systeembenadering toegepast die de agro-ecologische en sociaal-economische benadering integreert. Het tweede doel valt uiteen in 3 subdoelen:

1) het verkrijgen van inzicht in de productietechnieken die nodig zijn om productiviteitsverhoging en bodembescherming te realiseren;
2) het evalueren van de gevolgen van verschillende landgebruiksprioriteiten en de mogelijkheden om verschillende doelen en hun onderlinge uitruil (trade offs) na te gaan;
3) het evalueren van de gevolgen van een groeiende bevolking met andere voedselbehoeften voor het landgebruik en de economische en milieukundige prestaties.

Methode

De kern van de gebruikte methode is de confrontatie van de biofysische mogelijkheden met de maatschappelijke doelen en randvoorwaarden. Een meervoudig doelprogrammeringsmodel (MGLP model) is daarvoor ontwikkeld waarmee verschillende strategieën worden uitgewerkt. Dat gebeurde in 3 stappen: 1. kwantificering van de mogelijk toekomstige (alternatieve) productieactiviteiten; 2. ontwikkeling van een MGLP model met verschillende beperkingen voor de hulpbronnen, alsmede maatschappelijke doelen en beperkingen; en tenslotte 3. een systematische analyse en presentatie van de modeluitkomsten.

Alternatieve productieactiviteiten en hun kwantificering

Definitie van alternatieve productieactiviteiten

De huidige productieactiviteiten in Ansai zijn in het algemeen op het bestaansminimum met lage externe inputs en gaan doorgaans gepaard met serieuze problemen van bodemverlies. In deze studie (Hoofdstuk 2) zijn alternatieve productieactiviteiten gedefinieerd die zijn gebaseerd op agro-ecologische principes, waarbij de eigenschappen van de bodem, problemen met landgebruik en regionale ontwikkeling, en beleidsdoelen (Hoofdstuk 1 en 2) alle in acht zijn genomen. Er worden 5 typen activiteiten onderscheiden, i.e. akkerbouw, fruit, brandhout, gras en veehouderij. Aangezien deze studie in de eerste plaats gericht is op voedselzekerheid en bodembescherming zijn de (akkerbouw)gewasactiviteiten in detail omschreven. Acht gewassen worden beschouwd, waarvan 7 voedselgewassen: maïs, wintertarwe, sojaboon, zomer- en herfstaardappelen, gierst en zaadvlas, en daarnaast een veevoergewas luzerne.

Deze gewassen zijn gecombineerd tot 17 landbouwkundig zinvolle rotaties, waarin monocultures en rotaties zonder en met luzerne voorkomen. Iedere gewasrotatie is verder gedifferentieerd naar verschillende opbrengstniveau's (3 niveau's) bodembeschermingsstrategieën (4 typen) en arbeidsinzet (2 mechanisatieniveau's). Met inachtneming van 2 terrassystemen ('bench' en 'spaced' terrassen) en zes geschikte landeenheden (uiterwaarden, bestaande terrassen, en 4 niveau's van hellingen (<9, 10-18, 19-27 en 28-47%) ontstaan er in totaal 2006 verschillende gewasactiviteiten. De andere productie-activiteiten omvatten 6 fruit (appel) activiteiten, 10 ingezaaide graslandsystemen, 2 geplante struikgewas-systemen en 8 veehouderij activiteiten met productie van geiten, schapen, varkens, runderen en ezels.

Kwantitatieve landevaluatie

De kwantitatieve landevaluatie is uitgevoerd met het EPIC model (Hoofdstuk 3) De 17 gewasrotaties worden gesimuleerd voor potentiële, waterbeperkte, en N-beperkte groeiomstandigheden. Hierbij wordt rekening gehouden met verschillende maatregelen ten behoeve van water- en bodembeheersing. De simulatieresultaten vormen de basis voor het vaststellen van de mogelijke opbrengst van gewas en gewasresten, en voor het bepalen van de bodem en

N-verliezen, de input van plantenvoedingsstoffen (N, P en K) en de eventueel vereiste irrigatie.

Technische coëfficiënten

Productieactiviteiten worden gekwantificeerd met de 'doelgerichte benadering', hetgeen wil zeggen dat de minimale combinatie van inputs om het gestelde doel te bereiken wordt berekend, onder het principe 'best technical means' (Hoofdstuk 4) Dit houdt in dat heersende sociaal-economische, infrastructurele of kennisbeperkingen de biofysische opties en benuttingsefficiëntie van de hulpbronnen niet beïnvloeden. De basisinformatie om die productieactiviteiten te kwantificeren wordt verkregen uit de kwantitatieve landevaluatie, experimentele gegevens, literatuur en expert kennis.

De doelopbrengsten zijn gebaseerd op de EPIC simulaties, waarbij onvermijdbare verliezen als gevolg van klimaatsproblemen (hagel, vorst en regenbuien), bodemziekten en plagen (als gevolg van nauwe vruchtwisseling en bijzondere gewasvolgordes), en imperfecties in gewasmanagement (i.e. kunstmest, onkruidbestrijding, gewasbescherming, irrigatie die niet tijdig of ongelijkmatig wordt toegepast) worden meegenomen.

De nutriëntenbehoefte (N, P en K) om de doelopbrengsten te realiseren wordt berekend met behulp van een z.g. balans benadering: de inputs zijn gelijk aan de geoogste mineralen (de totale verwijdering van economische producten en gewasresten) plus de verliezen. Dezelfde gebruiksefficiëntie wordt verondersteld voor plantenvoedingsstoffen afkomstig uit kunstmest of dierlijke mest. De inzet van gewasbeschermingsmiddelen is gebaseerd op literatuur en expert kennis waarbij gewassrotaties en opbrengstniveau's in acht worden genomen.

De arbeidsinzet wordt gebaseerd op een aanpak met z.g. taaktijden. Deze omvatten de benodigde tijd per teelthandeling, met inachtneming van de gemiddelde afstand tussen veld en boerderij, helling en gebruikte apparatuur en trekkracht.

Productiekosten en netto-opbrengst zijn gebaseerd op prijzen van inputs (d.w.z. kunstmest, arbeid, gewasbeschermingsmiddelen) en vermarktbare gewasproducten in 1997-98. Aan gewasresten en dierlijke mest is geen prijs toegekend, maar kosten voor hun transport en toediening worden wel in rekening gebracht. Voor permanent grasland zijn ook geen kosten in rekening gebracht, maar inputkosten voor gezaaid grasland worden meegenomen.

Technische coëfficiënten van gezaaide graslandsystemen zijn gebaseerd op EPIC-simulaties; die van fruit -en brandhoutactiviteiten op literatuurgegevens. Dierlijke productie en veevoederbehoeften zijn geschat met behulp van een diermodel dat uitgaat van een stabiele kuddestructuur waarbij de vruchtbaarheid en sterfte, de geslachtsverhouding, en de vervangingsleeftijd van dieren in acht worden genomen. Er is aangenomen dat de inputs en outputs en andere productieparameters per activiteit van jaar tot jaar hetzelfde zijn. De veevoederbehoefte wordt uitgedrukt in termen van verteerbare energie (digestible energy, DE) en verteerbare ruwe eiwit (digestible crude protein, DCP), en berekend als functie van het metabolisch gewicht.

Een technische coëfficiënten generator, ontwikkeld in EXCEL, is gebruikt om input-output coëfficiënten te genereren. Deze generator bevat alle EPIC-simulatie resultaten, basisinformatie en parameters, zoals opbrengstreductiefactoren, taaktijden per teelthandeling, en prijzen van gewassen, kunstmest en gewasbeschermingsmiddelen. Door parameters te veranderen, zoals opbrengstreductiefactoren en de benodigde tijd per teelthandeling, kunnen de coëfficiënten ook eenvoudig worden aangepast.

Doelstellingen en beperkingen in het MGLP model

Voor het MGLP model zijn tien doelvariabelen gedefinieerd op basis van landgebruiksproblemen en beleidskwesties in Ansai (Hoofdstukken 2 en 5): bodemverlies totaal en per ha, totale gewasareaal, totale gewasproductie, totale werkgelegenheid in de landbouw, totale productiekosten, totale netto financiële opbrengst, arbeidsproductiviteit (netto-arbeidsopbrengst), totale gebruik van minerale N, totale N-verliezen en totale gewasbeschermingsmiddelengebruik. Deze doelstellingen kunnen door het model geoptimaliseerd worden met inachtneming van een aantal beperkingen (Hoofdstuk 5) De belangrijkste beperkingen zijn de beschikbare hoeveelheid land en arbeid, de vraag naar agrarische producten, en veevoederbehoeften. Niet al het land in Ansai kan worden gebruikt voor landbouw. Uitgesloten zijn beschermde of onbruikbare gebieden, waaronder bos, extreem steile gebieden, urbane gebieden en open watervlaktes. Deze gebieden worden in de model-optimalisatie buiten beschouwing gelaten en behoren altijd tot de 'behoud' categorie. Land beschikbaar voor landbouw omvat geschikt land (hellingen < 47%), natuurlijk grasland en natuurlijke struikvegetaties. Geschikt land kan gebruikt worden voor gewassen, appel, (gezaaid) grasland en (geplante) struiken. Natuurlijk grasland kan alleen gebruikt worden voor beweiding en natuurlijke struikvegetaties alleen voor brandhout.

De agrarische beroepsbevolking is gebaseerd op de geprojecteerde plattelandsbevolking in 2020 en de fractie van de bevolking die economisch actief is (leeftijd 20-60 jaar). De arbeidsbehoefte en het arbeidsaanbod worden berekend voor elk van de vijf onderscheiden arbeidsperioden. Voedselbehoefte en -aanbod worden uitgedrukt in graanequivalenten. Voedselbehoeften worden berekend als functie van de omvang van de plattelandsbevolking, de behoefte aan energie en eiwitten per hoofd, en de samenstelling van het dieet. Het voedselaanbod is de totale voedselproductie minus het deel dat gebruikt wordt voor het voeden van dieren. Voedselzelfvoorziening wordt gedefinieerd door de aanbod-vraag relaties van verschillende agrarische producten (voedselgewassen, vlees, appel, etc.).

De brandhoutbehoefte, uitgedrukt in standaard steenkool equivalenten (standard coal equivalent, SCE), kan worden gedekt door struiken en gewasresten en wordt berekend als product van de geprojecteerde plattelandsbevolking in 2020 en de SCE-behoefte per hoofd. In de veevoederbehoefte kan worden voorzien door vier typen veevoeder: 1) gras, 2) gewasresten, 3) restproducten na verwerking van gewasproducten en 4) primaire gewasproducten (maïs, luzerne en aardappels). De voederinname van een dier is gebaseerd op de behoefte aan de DE en DCP.

Beperkingen worden op regionaal (geheel Ansai) en sub-regionaal niveau opgelegd.

Ansai is verdeeld in zes sub-regio's. Gezien de geïsoleerde ligging van Ansai, wordt verondersteld dat arbeidskrachten, gewasresten, brandhout van struiken, luzerne en dierlijke mest uitsluitend binnen de sub-regio's worden gebruikt.

Voor het gehele Ansai moet aan de zelfvoorzieningsbehoefte worden voldaan en dit geldt eveneens voor appel en vlees, maar voor individuele sub-regio's zijn tekorten toegestaan. Per sub-regio moet de totale gewasproductie de totale behoefte in termen van graanequivalenten overschrijden. Grasland (natuurlijk en ingezaaid) wordt gebruikt voor beweiding binnen iedere sub-regio. Beschikbare restproducten na verwerking van tarwe en gierst (kaf), en veekoeken van zaadvlas en sojabonen worden bepaald door de consumptie van voedsel en plantaardige olie. In het MGLP-model zijn functies opgenomen die stalvoedering en beweiding door runderen beschrijven en de hoeveelheid dierlijke mest berekenen.

Model analyse

Vier benaderingen zijn toegepast om de modeluitkomsten te analyseren, te weten berekening van extreme doelstellingswaarden en uitruil (trade-off) analyse (Hoofdstuk 6), en scenario-analyse en gevoeligheidsanalyse (Hoofdstuk 7). De doelvariabelen zijn geoptimaliseerd in verschillende basis-runs van het MGLP model onder de eis van voedselzelfvoorziening. Op basis van optimale doelwaarden, wordt uitruil tussen geselecteerde paren van doelstellingen beoordeeld in een iteratieve procedure, d.w.z. een eerste doelvariabele wordt geoptimaliseerd door verschillende restricties op te leggen aan een tweede, terwijl aan de overige doelvariabelen geen beperkingen worden opgelegd.

Er zijn vier beleidsscenario's (Hoofdstuk 7) gedefinieerd op basis van verschillende prioriteiten voor doelstellingen, namelijk de scenario's bodembescherming, agrarische werkgelegenheid, economische ontwikkeling, en milieubescherming. De scenario's zijn geëvalueerd door een stapsgewijze optimalisatie van elk van de doelstellingen. Dit wordt gedaan door in het MGLP model op de doelvariabelen met een hogere prioriteit beperkingen te leggen. De scenarioresultaten zijn nader onderzocht met behulp van een gevoeligheids-analyse. Er zijn drie belangrijke aspecten geëvalueerd, n.l. arbeid, brandhoutbehoefte en productietechnieken. Ten eerste zijn effecten van hogere arbeidskosten geanalyseerd, en vervolgens het effect van het niet voorzien in de behoefte aan brandhout. Tenslotte zijn effecten op de toedeling van landgebruik (d.w.z. gebied toebedeeld aan activiteiten met verschillende bodembeschermingsmaatregelen of productietechnieken) geëvalueerd door middel van het toestaan van kleine afwijkingen van de doelwaarden.

Resultaten

Land eenheid niveau – kwalitatieve landevaluatie

In vergelijking met de huidige opbrengstniveau's kunnen hoge water-beperkte opbrengsten worden behaald in Ansai, in het bijzonder voor maïs, gierst, aardappelen en sojaboon

(Hoofdstuk 3). Zo is bijvoorbeeld het lange termijn gemiddelde (water-beperkte) opbrengst van maïs 6.6 - 9.3 t droge stof (ds) ha^{-1}, gierst 4.7 - 6.6 ds ha^{-1}, en herfstteelt van aardappel 5.7 - 7.1 t ds ha^{-1}, hoofdzakelijk variërend met de bodemcondities. Ruggenteelt en mulching met gewasresten ter bescherming van water en bodem dragen slechts in geringe mate bij aan de opbrengsttoename (minder dan 10%) van maïs, gierst, sojaboon en in de herfst geteelde aardappel omdat hun groeiseizoen goed is afgestemd op het regenseizoen. Dit in tegenstelling tot wintertarwe, in de zomer geteelde aardappel en zaadvlas waarvan de opbrengst aanzienlijk kunnen worden verhoogd door deze maatregelen, speciaal op landeenheden met hellingen door verbetering van de bodemvocht condities in het droge seizoen (winter en voorjaar). Zonder kunstmest-N kunnen aanzienlijke opbrengsten worden verkregen van gewassen geteeld in rotaties met luzerne. Onder zulke omstandigheden is de gemiddelde opbrengst van maïs bijvoorbeeld 4.1 - 5.0 t ds ha^{-1}.

De efficiëntie van bodembeschermingsmaatregelen om bodemverlies te beheersen varieert, d.w.z. terrassen zijn het best om zowel water- en bodemverliezen te beheersen, gevolgd door gewasrotaties met luzerne. Op steile hellingen zijn ruggen minder efficiënt voor het beheersen van bodemverlies dan mulching met gewasresten. In gewasrotaties zonder luzerne en op steile hellingen kan bodemverlies niet goed voorkomen worden door uitsluitend gebruik te maken van ruggen of mulching met gewasresten.

In de regio kunnen kleine N-verliezen worden bereikt. De simulaties tonen aan dat N-verliezen hoofdzakelijk onstaan door vervluchtiging, run-off en bodemverlies. Denitrificatie en uitspoeling treden nauwelijks op, omdat de bodems zelden verzadigd zijn en regenval niet uit de wortelzone kan spoelen. Gemiddelde lange termijn N verliezen kunnen worden beperkt tot 25% van de toegediende N onder goed management, d.w.z. management waaronder run-off en bodemverlies goed beheerst worden.

Ansai-niveau – Extreme doelwaarden en uitruil

De MGLP-resultaten tonen aan dat, onder de voorwaarden van zelfvoorziening van de plattelandsbevloking in 2020, het gemiddelde bodemverlies in landbouwgebieden (zonder natuurlijk grasland en struikvegetaties) kan worden gereduceerd tot 0.5 t ha^{-1} (Hoofdstuk 6). Dit gaat gepaard met een lage agrarische werkgelegenheid omdat het landbouwareaal beperkt is. Er bestaan zeer goede mogelijkheden om de gewasproductie, de netto financiële opbrengst en de agrarische werkgelegenheid te verhogen. Om deze mogelijkheden te benutten zijn veel inputs (vergeleken met de huidige situatie) nodig.

De beheersing van bodemverlies gaat, tot op zekere hoogte, samen met de doelen van een toenemende gewasproductiviteit en arbeidsproductiviteit. Er bestaan goede mogelijkheden om het gebruik van minerale N te verminderen. Deze kan voor het grootste deel worden vervangen door dierlijk mest en biologische stikstofbinding, ten koste van ongeveer eenderde van de maximale gewasproductie, of een vierde van de maximale netto (agrarische) financiële opbrengst. De agrarische werkgelegenheid heeft een duidelijke impact op de meeste doelstellingen d.w.z. met een toename in de agrarische werkgelegenheid stijgen de totale productiekosten, het gewasareaal, het gebruik van gewasbeschermingsmiddelen en bodemverlies aanzienlijk, en daalt de arbeidsproductiviteit sterk. Met andere woorden, het doel van handhaving van agrarische werkgelegenheid conflicteert sterk met deze doelstellingen. De uitruil tussen veel doelstellingen is in eerste instantie zwak: aan een doelstelling kan beter worden voldaan zonder dat dit veel ten koste gaat van een andere doelstelling. Zo gaat een afname in de totale netto financiële opbrengst met 5% in vergelijking met de maximale waarde, gepaard met een reductie van 35% in de totale productiekosten. Een afname van de gewasproductie met 6% vergeleken met de maximale waarde gaat gepaard met een reductie in gewasbeschermingsmiddelen met een derde. Wanneer het totale bodemverlies licht toeneemt van de minimale waarde (0.5 t ha^{-1}) tot 0.6 t ha^{-1}, kunnen de totale productiekosten met 40% worden gereduceerd. Een uitzondering vormt de (negatieve) relatie tussen arbeidsproductiviteit en werkgelegenheid die bijna lineair is. Het effect van veranderde voedselbehoeften varieert tussen de doelstellingen. Een toename in de voedselbehoefte kan resulteren in een aanmerkelijke toename van de productiekosten, het totale gewasareaal, het totale gewasbeschermingsmiddelengebruik en het totale N verlies.

Mogelijkheden en beperkingen van duurzaam landgebruik en regionale ontwikkeling in Ansai

Aan de hand van de scenario-resultaten kan worden geconcludeerd dat de doelstellingen van voedselzekerheid en bodembescherming in Ansai eenvoudig kunnen worden behaald vanuit een biofysisch en landbouw-technisch oogpunt. Het huidige gewasareaal kan aanzienlijk worden beperkt zonder dat dit ten koste gaat van de voedselzekerheid in Ansai in 2020, d.w.z. het benodigde gewasareaal kan tot 60% worden gereduceerd van het officieel gerapporteerde areaal in 1992, en het gemiddelde bodemverlies als gevolg van agrarisch landgebruik kan worden beperkt tot 0.5 t ha^{-1}. Wanneer geen additionele (t.o.v. het huidige areaal) terrassen worden aangelegd, kan het bodemverlies tot 2.0 t ha^{-1} worden beperkt. Deze bodemverliezen zijn erg laag ten opzichte van de huidige waarden (in het algemeen meer dan 40 t ha^{-1} bouwland op hellingen).

Het kleinere areaal bouwland resulteert in een groter areaal dat gebruikt kan worden voor het telen van struiken voor brandhout of voor grasland. Dit impliceert dat er mogelijkheden bestaan voor veehouderij. Door de beperkte hoeveelheid beschikbaar land en de grote beroepsbevolking zou de toekomstige ontwikkeling van de veehouderij zich moeten concentreren op varkens en schapen (stalvoedering gecombineerd met zomerbeweiding). Mogelijke opties zijn 1. uitbreiding van het maïsareaal om veevoeder te produceren voor varkens, 2. het telen van gewassen in rotaties met luzerne om hoogwaardig veevoer te produceren, en 3. het stimuleren van het gebruik van gewasresten als voer voor runderen.

De gevoeligheidsanalyses tonen aan dat de behoefte aan brandhout een negatief effect heeft op de ontwikkeling van de rundveehouderij, als gevolg van het gebruik van gewasresten om de energiebehoeften te dekken. Verhoging van de arbeidskosten kan een verschuiving van varkenshouderij naar schapenhouderij stimuleren, wanneer een hoge netto financiële opbrengst wordt nagestreefd.

Op de lange termijn zijn terrassen en gewasrotaties met luzerne de beste keuzes voor zowel bodembescherming als agrarische productie. De grote rurale beroepsbevolking kan gebruikt worden voor het aanleggen van terrassen. Luzerne kan stikstof vastleggen, en kan aldus de behoefte aan kunstmest-N sterk verminderen en bovendien de bodemvruchtbaarheid verbeteren. Ruggenteelt is efficiënt bij het beheersen van bodemverlies wanneer de hellingen niet bijzonder steil zijn. Een probleem is dat de aanleg van ruggen veel dierlijke trekkracht vergt. De gevoeligheidsanalyse toont aan dat ruggen grotendeels vervangen kunnen worden door mulching met gewasresten dat veel minder dierlijke trekkracht vergt. Vanuit economisch standpunt, zijn 'spaced' terrassen veel aantrekkelijker dan 'bench' terrassen vanwege de lagere arbeid en kapitaal-inzet. De gevoeligheidsanalyse toont aan dat er grote mogelijkheden bestaan om 'bench' terrassen te vervangen door 'spaced' terrassen ten koste van slechts een lichte toename in totaal bodemverlies.

De grote rurale bevolking en de afwezigheid van mogelijkheden om buiten het bedrijf te werken zijn wellicht de belangrijkste factoren die de agrarische ontwikkeling in Ansai bepalen. Dit blijkt duidelijk uit de uitruil tussen doelstellingen die in Hoofdstuk 6 is bediscussieerd, d.w.z. een toename van de werkgelegenheid in de landbouw resulteert in klaarblijkelijk negatieve effecten op vele andere doelstellingen. Er zijn echter mogelijkheden om een hoge agrarische werkgelegenheid te handhaven bij een redelijk inkomen. Zo kan in het agrarisch werkgelegenheidsscenario 66% van de plattelandsbevolking in 2020 in de landbouw werken. Dit is hoger dan het huidige werkgelegenheidscijfer, en de gemiddelde netto-arbeidsopbrengst is 6.7 10^3 yuan per man-jaar. Bij een werkgelegenheid (verhouding tussen agrarische werkgelegenheid en totale plattelandsarbeid) op het huidige niveau (economisch ontwikkelingsscenario), kan de netto-arbeidsopbrengst op basis van de prijzen in 1997-'98, 10 10^3 yuan bereiken, 10 keer zo hoog als in 1992 in Ansai (de lage netto-arbeidsopbrengst in 1992 is het gevolg van het zeer lage gebruik van externe inputs en slecht gewas- en bodemmanagement).

Het milieubeschermingsscenario vergt weinig chemische inputs, en heeft dientengevolge lage emissies, maar lage netto-arbeidsopbrengsten. De haalbaarheid van de implementatie van dit scenario in Ansai hangt zeer af van de kosten voor arbeid en chemische inputs. Bij het prijspeil van 1997-1998 benaderen de netto-arbeidsopbrengsten 4.5 10^3 yuan per man-jaar. Deze netto-arbeidsopbrengst is veel hoger dan in 1992. Zij is echter zeer gevoelig voor veranderingen in de arbeidskosten.

Conclusies

Dit proefschrift presenteert een systematische analyse van toekomstige opties voor regionale ontwikkeling van het Ansai district in het Lössplateau. Gefragmenteerde en empirische biofysische en agronomische informatie over de regio is geïntegreerd met breed-geaccepteerde productie-ecologische principes en kennis uit andere bronnen. Dit werk draagt bij aan het begrip van regionale problemen en agrarische ontwikkelingsmogelijkheden. De resultaten geven aan welke landbouwtechnische mogelijkheden er zijn om de onduurzaamheidsspiraal in de zeer fragiele en minderbedeelde regio's van China te doorbreken.

Problemen die verband houden met bodembescherming, voedselzekerheid, werkgelegenheid en inkomen kunnen sterk worden verlicht wanneer het landgebruik, de productiesystemen en de technieken zoals gedefinieerd in deze studie in de toekomst worden overgenomen.

In het algemeen, gaat de beheersing van bodemverlies gepaard met de verbetering van de productie-efficiëntie. Op de lange termijn kunnen investeringen in bodembescherming zeer voordelig zijn voor het milieu, en tevens de gewasproductie en het inkomen van de plattelandsbevolking doen stijgen. In dit gebied zou intensivering van akkerbouw belangrijk kunnen zijn, zodat een groot deel van het land met steile hellingen dat nu voor akkerbouw e.d. wordt gebruikt kan worden omgezet in meer duurzame vormen van landgebruik, bijvoorbeeld bosbouw en natuurbehoud.

Om de sociaal-economische haalbaarheid van de verkende landgebruiksopties te analyseren en om huidige ontwikkelingen te stimuleren in de richting van de geïdentificeerde opties, moet geschikt beleid worden ontwikkeld. Beleid voor verbetering van het pachtsysteem, de beheersing van de bevolkingsgroei, en verbetering van infrastructuur en onderwijs zou moeten worden versterkt of geïmplementeerd. Specifieke overheidssteun, zoals investeringen in onderwijs, infrastructuur en bodembescherming zijn cruciaal voor dit gebied. De systematische synthese van kennis in deze verkenning voor Ansai draagt ook bij aan de identificatie van kennistekorten op lagere schaalniveaus, bijvoorbeeld op het niveau van landeenheid, aspecten van landbouw op hellingen, veld, gewas of dier. Tevens zijn alternatieve, tot op zekere hoogte hypothetische, landgebruikssystemen, voorgesteld die empirisch getest en verbeterd dienen te worden. De gepresenteerde resultaten maken een veel gerichter ontwerp van empirisch onderzoek mogelijk, zodat wordt bijgedragen aan de onderzoeksagenda voor de agronomie, en het beheer van bodem, water en nutriënten.

摘 要

黄土高原是中国生态最脆弱的地区之一。由于人口密度高（多数县的平均人口密度在 30－200 人 km^{-2} 之间）、压力大，坡地耕垦非常普遍，致使水土流失严重。以安塞县为例，约 80%的耕地为陡坡地（坡度>19%），全县年均土壤流失量高达 84 t ha^{-1}。土壤侵蚀、粮食短缺、人口压力和农业人口的相对贫困是黄土高原面临的主要问题。

本研究以陕西安塞县为案例，采用系统分析方法和多目标线形规划（MGLP）技术，将区域农业系统、自然和社会经济条件，以及区域发展目标综合为一个系统分析模型。通过该模型，来探讨黄土高原地区，制约农业发展的主要障碍、发展潜力和长期发展战略（2020 年）。该模型包括 2032 个农业生产类型，超过 3000 个限制条件和 40 万个非零数据，用 XPRESS 软件写成。基本数据根据野外调查、气候、土壤和文献资料。数据获取和处理利用作物模拟模型、GIS 技术和专家知识。

研究方法及 MGLP 模型

1）农业生产类型及其投入—产出系数的确定

农业生产类型包括作物、水果、人工草场、人工灌丛（薪柴）和畜牧。由于本研究着重于粮食安全和水土保持，因此详细定义了作物生产类型。选择了 7 种粮食作物即玉米、谷子、冬小麦、大豆、秋土豆、夏土豆、胡麻，和饲料作物苜蓿。考虑作物病虫害、土壤水分和养分利用，将这些作物定义为三种轮作方式：连作、粮食作物轮作和草田轮作（即苜蓿—粮食作物轮作），共 17 种轮作类型。每种轮作根据生产水平、机械化程度、水土保持措施（沟垄耕作、秸秆覆盖、等高耕作等）、梯田（水平梯田和隔坡梯田）和土地适宜单元（洪积平原、现有梯田和 4 种坡地类型），进一步划分成不同的作物生产类型（共 2006 个作物生产类型）。

基本数据通过基于 EPIC 模拟模型的定量土地评价方法获取（第 3 章）。考虑不同的水土保持方法和土地条件（土地单元），对 17 种轮作类型模拟了其潜在、水分限制和养分（氮）限制条件下的产量、肥料需求量、氮和土壤流失量。模拟结果用于确定农业生产类型的投入—产出系数。第四章和附件 3 详细阐述了确定投入—产出的方法和基本数据，附件 4 给出了部分农业生产类型的投入—产出表。人工草场的投入—产出系数根据 EPIC 的模拟结果确定，而果园（苹果）和人工灌丛的投入—产出系数根据文献资料和专家知识估算。

畜牧生产类型的技术系数根据动物模型估计。该模型以畜群结构为基础，根据出栏

率、产羔率、死亡率等建立。此模型用于计算家畜（山羊、绵羊、耕畜）的产肉量、饲料需要量（可消化能量和蛋白）和厩肥产量。饲料的需求以可消化能（DE）和可消化粗蛋白（DCP）表示。

根据电子表格软件（EXCEL），开发了技术系数生成器，用于计算农业生产类型的投入—产出系数。该生成器包括所有的 EPIC 模拟结果和基本的参数，如减产因子、标准劳力投入，以及农产品、肥料和农药的价格等。通过改变参数，如减产因子、肥料价格，可以很容易生成新的投入—产出系数。利用该产生器可以确定每个农业生产类型的技术系数，如产量、氮损失量，以及实现此产量所需要的投入，如资金、灌溉、化肥（N、P 和 K）、劳力、耕牛（或机械）和农药等。

2）MGLP 模型的目标变量和约束条件

针对安塞县土地利用存在的问题和区域发展目标，定义了 10 个目标变量（第 2 章和第 5 章），即总的和单位面积的土壤流失量、作物种植面积、粮食总产量、农业就业总量、生产总成本、农业净收入、劳动生产率（单位劳动力的净收入）、矿物 N 的总投入量、农药总量和 N 的损失总量。考虑一系列的约束条件（第 5 章），这些目标可以通过模型优化。

主要的约束条件包括土地资源、劳动力、农产品需求和饲料需求。可利用农业土地包括适宜农耕的土地、天然草地和灌木林地，其面积根据土地调查资料确定。适宜土地可用于种植作物、果树、牧草和灌木。天然草地和天然灌木林地只用于放牧和提供薪柴。

农业劳动力根据预计的 2020 年农村人口计算。食物需求根据农村人口数、每人每天的食物能量和蛋白质需求、及食物结构（粮食、肉、油、水果等）计算。粮食供给量等于生产的生产总量减去饲料用粮。粮食供求关系按标准谷物当量计算。薪材来源包括灌木和作物秸杆，其供求关系按标准煤（SCE）计算。饲料包括 1）牧草；2）作物秸杆；3）农副产品；和 4）饲料用粮（玉米、苜蓿和土豆）。每头牲畜的饲料供求量根据 DE 和 DCP 计算。

该县划分为六个小区。劳动力、作物秸秆（作为饲料或燃料）、灌木、苜蓿和厩肥假定仅在同一小区内使用。每一小区，假定粮食、苹果和肉类自给，即作物总产量（谷物当量）和肉类总产量应超过总需求量。天然和人工草地仅限于小区放牧。谷物麸皮（小麦和谷子）和豆、麻饼（胡麻和大豆）由食物和食用油的消耗量确定。MGLP 模型提供了一个方法，用于确定牲畜圈养、放养，和计算厩肥产量。厩肥可用于农田、果园和人工草场。

主要结论

1）发展旱地农业具有很大潜力

EPIC 模拟结果显示（第三章），在安塞县可获得较高的雨养产量。例如，玉米的平均模拟（雨养）产量（干物质）为 6.6-9.3 t ha^{-1}，谷子 4.7-6.6 t ha^{-1}，秋土豆 5.6-7.1 t ha^{-1}。因为这些作物的生长季节与雨季完全匹配，模拟结果显示，用于水土保持的垄作和秸杆

覆盖对其产量的贡献是有限的。与此相反，这些措施可以显著提高冬小麦、夏土豆和胡麻的产量，对陡坡土地尤其如此。这主要是因为这些措施能减少降雨径流，间接改善了干旱季节（冬、春）土壤的水分条件。不施用 N 肥，通过作物与苜蓿轮作，也可以获得较高的产量（见第三章）。

除梯田外，作物与苜蓿轮作也可有效地控制水土流失。对陡坡地，沟垄耕作控制水土流失的效益不如作物秸杆覆盖。在该区域，N 损失可控制在一个很低的水平。模拟结果表明，N 损失主要是由于气化作用、地表径流和土壤流失。因为根层土壤水分很少饱和，降雨基本不产生土壤淋溶，氮的反硝化损失和淋失很低。在好的管理条件下，即地表径流和土壤流失等得到有效控制时，平均 N 损失量可控制在施 N 量的 25%以下。

2）从模型分析结果看，在安塞（也许整个黄土高原地区），粮食可实现自足有余

在有效管理和适当投入的条件下，粮食生产不但可满足 2020 年 23 万农业人口（作者计算）的需求并且还有富余。在保证安塞县 2020 年粮食安全的前提下，现有作物种植面积可以大幅度降低。考虑投入、食物安全（粮食生产的年际波动），最小耕地面积可控制在 3 万公顷左右，即，大致现有耕地面积（调查面积）的四分之一。如果食用高（动物）蛋白食物，最小耕地面积需要较大幅度提高（见第六章）。

3）农村剩余劳力是主要应解决的问题

农村人口多和缺乏非农业就业机会可能是影响安塞县农村发展的最重要的制约因素。从第六章的分析结果看这是明显的，即增加总的农业就业，会大幅度提高化肥、农药及资金投入，并需要维持高的作物种植面积。随农业就业人数的增加，人均劳力净产值几乎呈线性下降。然而，在适当农业投入的条件下，仍有一定潜力保持较高的农业就业率和较高的收入。从第七章的分析结果看，在基本维持现有耕地面积的前提下，农业就业率维持在农村劳动力的三分之二，人均劳力的年净产值（2020 年）为 6700 元（以 1997-1998 年的价格计）。如农业就业率维持在 40%左右，以 1997-1998 年的价格计，人均劳力的年净产值可达到 1 万元，高于 1992 年安塞县农村劳动力净产值的 10 倍。农业机械化在本地区发展潜力不大，一是受地形限制，不适宜机械作业，二是劳力充足，需求不大。

4）发展牲畜圈养有一定潜力

在满足粮食自给的前提下，坡耕地可以大幅度退耕。这些退耕土地可用于种草或种植灌木，但这会造成很低的农业就业量。在无其它（非农业）就业机会的情况下，退耕发展放牧畜牧业潜力不大。由于丰富的劳动力资源，模型分析结果表明，畜牧业应重点发展养猪和养羊（圈养为主，结合夏季适量放牧）。可能的选择是扩大玉米种植（养猪）、作物与苜蓿的轮作面积，以提供高质量的饲料（苜蓿），促进作物秸杆饲用（养羊）。这样既可解决农村剩余劳动力，也可增加收入，还可增加肥料，促进秸秆过腹还田。模型分析结果表明，解决农村能源，如用煤代替秸杆，可减少因秸杆用作薪柴对畜牧业发展造成的不利影响。

5）从长远考虑，应加强梯田建设，发展草田轮作

修建梯田和草田（作物与苜蓿）轮作是促进安塞水土保持和农业发展的有效措施。丰富的农村劳动力可用于修建梯田。苜蓿有固氮作用，因此可以大幅度降低 N 肥的需求，并能提高土壤肥力。当坡地不是很陡时，沟垄耕作可以有效地控制土壤流失，但问题是沟垄作需要大量耕牛。由于耕牛利用时间有限，造成饲料、资金浪费。此耕作法应作为权宜之计，从长远看还应发展梯田建设。从经济学的观点看，隔坡梯田优于水平梯田，因为前者需要的劳动力和资金投入较少。

6）只考虑耕作土地，通过修梯田、沟垄耕作、草田轮作和秸杆覆盖等，水土流失可基本控制（可控制在 7 t ha^{-1} 以下）

本模型未考虑沟壑、陡坡地和自然草场的水土流失。在很大程度上，土壤流失的控制与提高土地生产率和劳动生产率（单位劳动力的净农业产值）的目标一致。

7）提高粮食生产，除水土保持外，应增加化肥，特别是磷肥的投入

因为氮肥资源相对丰富，减少矿物 N 的投入有相当大的潜力。矿物氮肥可在很大程度上由有机肥和生物固氮替代。厩肥磷含量有限，加上磷肥利用率低（土壤固定），所以磷肥投入不足，可能会成为影响本地区粮食生产的主要制约因素。

8）要实现安塞县区域的可持续发展，需要大量的资金投入

从模型计算结果，所需投入一般要数倍于目前的农业投入（取决于要实现的目标）。因此，要实现长期的可持续发展目标，需要不断的自我积累或政府补贴。从目前来讲，重要的是充分调动农民的积极性，利用充足的劳力资源，发展基本农田建设。

9）实现区域可持续发展潜力很大

一般而言，土壤流失的控制与生产效益的提高是相一致的。从长远来看，投资水土保持可以改善环境，也可以增加作物产量和农村人口的收入。在该地区，应强化农业的集约化经营，这样，可促进坡地退耕，用于林地或作为保护用地。

为促进土地的可持续利用，必须有适当的政策。稳定土地使用权、控制人口增长、改进基础设施及教育系统；政府的特别支持，如加大对教育、基础设施和水土保持的投入，对该地区的农村发展是非常重要的。

10）应用前景

上述结果只是针对目前黄土高原地区存在的主要问题所做的分析。该模型结构开放，可根据决策者的需要进行各种优化分析，也可进行农业可持续发展的定量评估。该模型既可用于区域农业可持续发展的宏观分析，也可用于区域农业发展政策的预评估，即，可通过模型计算分析政策对土地利用、环境和社会经济（农业）的可能影响。

Appendix 1 The EPIC Model and its Parameter Values

This appendix presents the major modules for crop growth, water erosion, and nutrient (N) cycling, and calibration of the model parameters for the EPIC model.

A1.1 Plant growth module and its parameters

The plant growth module can simulate annual and perennial crops. Annual crops grow from planting date to harvest date or until the accumulated heat units equal the potential heat units (PHU) of a crop. Perennial crops maintain their root systems throughout the year, and start growing when average daily air temperature exceeds their base temperature. For fall planted crops, they become dormant in winter period. The dormant period is defined as the time when day length is within 1 h of the location's minimum day length. Crop phenological development is based on the heat unit index (HUI), the fraction of accumulated heat units of the PHU. The leaf area growth and senescence, nutrient uptake, and partitioning of dry matter among roots, shoots, and economic yield are all related to the HUI. A general plant growth module is used to simulate annual and perennial crops, by giving crop specific values for the model parameters. EPIC (version-5300) contains 46 crop-specific parameters for each of the most food crops, vegetables, forage crops, pasture and trees. The values of the major parameters are given in Table A1.1. Some of the crop parameters for the EPIC model have been modified based on literature data. The major parameters and modifications are described in this section.

BE and harvest index (HI)

BE is defined as the efficiency of intercepted radiation transformed to crop biomass. The default BE values for the EPIC model are used except for potato that is changed according to Spitters (1986). The default values of the base and optimal temperature for crop growth are used.

The economic yield is estimated using the harvest index concept. In EPIC, the HI is simulated with a non-linear function of HUI, assuming that the harvest index as a fraction of the potential HI is 0.1 when HUI = 0.5 and HI is 0.95 when HUI = 0.95 under no-stress of water shortage. Thus, if the growing season is shortened by frost or for other reasons, the potential HI is not attained. Effect of water shortage on the HI is nonlinearly related to water use ratio (WUR) of the actual to potential water use that is estimated at harvest. There is little reduction of the HI when WUR is greater than 0.5. For running the model, the potential HI should be supplied.

The HI of corn and soybean in the EPIC model is identical to that reported in Chinese literature (Feng *et al.* 1997, Wang *et al.* 1998, Yu *et al.* 1991, Wang & Huang 1995, SAC 1994). Reported HI of winter wheat is between 0.36-0.44 (Li & Lu 1991, Wang *et al.* 1998) in the Loess Plateau. A value of 0.42 is used for winter wheat. Harvest index of millet is normally 0.4-0.5, depending on the plant numbers per unit area and climatic condition, and is normally lower in high yield condition (SAAS 1987). A mean value of 0.45 is used. Harvest index of seed flax varies in a large range. In the field experiment of three years, Marshall *et al.* (1989) found that the harvest index was 0.57, 0.18 and 0.36, respectively. The harvest index in the EPIC model is 0.54, identical to that calculated on the basis of data by Van Heemst & Smid (1989). The harvest index from data of Du *et al.* (1993) is 0.27 in the Loess Plateau. A value of 0.4 has been used for seed flax in this study. Harvest index of potato is set to 0.76 according to Spitters (1986) and Boons-Prins *et al.* (1993).

Table A1.1 Values of major crop parameters used for the EPIC model*

Parameter	Soybean	Corn	Wheat	Autumn potato	Summer potato	Millet	Flax	Alfalfa
BE	25.0	40.0	30.0	27.0	27.0	35.0	25.0	25.0
HI	0.30	0.50	0.42	0.76	0.80	0.45	0.40	0.01
TG	25.0	25.0	15.0	18.0	18.0	24.0	22.5	25.0
TB	10.0	8.0	0.0	3.0	3.0	6.0	5.0	1.0
DMLA	5.0/6.0	5.0/6.0	5.0/6.0	5.0/5.5	4.5/5.0	4.0/5.0	2.5/3.0	5.0/6.0
DLAI	0.80	0.75	0.70	0.60	0.60	0.80	0.80	0.90
DLP1	15.03	10.05	5.01	10.10	10.10	15.05	15.02	15. 05
DLP2	60.95	50.95	50.95	40.95	35.95	60.95	50.95	50.95
BLAD	1.0	1.0	1.0	2.0	2.0	1.0	1.0	0.5
HMX	0.80	2.40	1.00	0.80	0.80	1.50	0.55	1.25
RDMX	1.0	2.0	2.0	0.7	0.7	1.5	1.3	2.0
CNY (%)	6.50	1.75	2.34	1.50	1.50	1.62	4.00	2.50
CPY (%)	0.91	0.25	0.33	0.14	0.14	0.26	0.33	0.35
BN1 (%)	5.24	4.40	6.00	5.50	5.50	4.40	4.82	5.00
BN2 (%)	2.65	1.64	2.31	2.00	2.00	3.00	2.94	3.00
BN3 (%)	2.58	1.12	1.06	1.78	1.78	1.20	1.85	2.00
RWPC1	0.40	0.40	0.40	0.20	0.20	0.40	0.40	0.40
RWPC2	0.26	0.26	0.25	0.20	0.20	0.32	0.20	0.20
PHU (°Cd)	1200	1600	1700	1900	1250	1800	1100	1300
GMHU	90	80	100	170	170	60	60	100

*Notes:

BE is radiation use efficiency (kg ha^{-1} MJ^{-1} m^2) and HI is potential harvest index

TG and TB are optimal and base temperature (°C) for crop growth, respectively.

DMLA is maximum LAI under potential growth condition. Numbers before slash are for rainfed conditions, and numbers after slash are for irrigated conditions; DLAI is fraction of growing period (in potential heat unit) when LAI begins to decline

DLP1,2 is two points on the optimal development curve of leaf area: i.e., DLP1 is the point on the curve early in the season and DLP2 is the point on the curve when LAI is near maximum. Numbers before decimal are percent of growing season (in potential heat unit) and numbers after decimal are fraction of maximum LAI.

BLAD is LAI decline parameter controlling rate of LAI decline and RBMD is BE decline parameter controlling the decline rate in radiation use efficiency

HMX is maximum crop height (m) and RDMX is maximum root depth (m)

CNY and CPY is normal N and P concentration in yield (% in DM); BN1, BN2 and BN3 is normal N concentration in crop biomass (% in DM) at emergence, mid-season and at maturity, respectively.

RWPC1 is fraction of root weight at emergence; RWPC2 is a factor controlling crop biomass partitioned to the roots.

PHU is potential heat units (temperature sum) required for maturity from crop emergence in degree-days (°Cd). GMHU is accumulated heat units required for germination (°Cd).

Leaf area index and the development

From emergence to the start of leaf decline, the potential growth rate of LAI is related to the heat unit factor (HUF) and the maximum LAI (DMLA). The HUF is non-linearly related to HUI with two crop parameters determined with the S curve function using the parameters of DLP (1,2), the two point values of leaf area on the optimal development curve. From the start of leaf decline to the end of the growing season, the LAI is estimated with equation: $LAI = [(1 - HUI) / (1 - HUI_0)]^{BLAD}$, where HUI_0 is the day expressed as HUI when LAI starts declining, and BLAD is the factor controlling decline rate of the LAI.

The DMLA is related to crop species and plant density. Crops are normally planted more densely under irrigated than rainfed conditions in semi-arid areas. So, lower DMLA values are used for rainfed than irrigated conditions. Parameters of DLAI and DLP have been modified according to literature data (Boons-Prins *et al.* 1993, HPRI-CAAS 1994, SAAS 1987, Van Heemst & Smid 1989), and simulated results of LAI development by WOFOST model (Van Diepen *et al.* 1989). A value of 1.0 is used for BLAD, i.e., the LAI is assumed to decline linearly.

Partitioning of crop biomass to roots and rooting depth

In the EPIC model, daily increased crop biomass partitioned to root is linearly related to the HUI by the two parameters of RWPC1 and RWPC2, i.e., root fraction = [RWPC1 − RWPC2·HUI]. The RWPC1 is the fraction of crop biomass partitioned to root at emergence, and RWPC2 is a factor controlling the crop biomass partition to root after emergence. A value of 0.4 for RWPC1 and 0.2 for RWPC2 is used for all crops in the EPIC model. With those two values, the simulated root weight for all crops always occupies about 20% of the total crop biomass at maturity. This may be too high, especially for potato. Therefore, the parameters have been modified.

In literature, root fraction as total crop biomass at maturity varies, even to a great range. For instance, root weight of wheat from only about 5% (Feng *et al.* 1997, Yu *et al.* 1991) to 25% (Miao *et al.* 1998). Root fraction of wheat reported by Du *et al.* (1993) is 18.8% of the crop biomass. For corn, millet and soybean, the root fractions reported by Miao *et al.* (1998) are 13.5%, 7.5% and 13.4%, and do not differ very much from those reported by other authors (Feng *et al.* 1997, Yu *et al.* 1991). The root fraction at maturity is set to 0.15 for wheat, 0.14 for soybean and corn, and 0.08 for millet, which can be ensured by the values of RWPC(1,2) used in Table A1.1. For potato, the RWPC1 is set to 0.2 according to Boons-Prins *et al.* (1993), and the original value for RWPC2 is used. For flax and alfalfa, the default values of the RWPC(1,2) for the EPIC model are used. The maximum crop height and rooting depth are modified by reviews of literature (Miao *et al.* 1998, SAAS 1987, Wang *et al.* 1995, IBP-CAAS 1993, HPRI-CAAS 1994, SAC 1994).

Nitrogen content

Crop N uptake in the EPIC model is based on a supply and demand approach (Mitchell *et al.* 1997). The daily crop N demand is the difference between the crop N content and the ideal N content for that day. In the EPIC model, the total N uptake is greatly determined by the parameter of BN3, the normal concentration of N in crop biomass at maturity.

The N concentration in storage organ (CNY) is set to 1.62% for millet (Dai 1991) and 1.50% for potato (de Koning *et al.* 1992). The CNY for other crops uses the default values for the EPIC model. The value of BN3 has been modified for winter wheat, millet, corn and flax, based on literature data (Suo *et al.* 1997, Chen *et al.* 1996, Van Duivenbooden *et al.* 1996, Dai *et al.* 1991, Yu *et al.* 1991 and De Koning *et al.* 1992). From my simulation results, the original EPIC values lead to too high concentration in the crop residues under ample N input. For instance, the EPIC-simulated N content in straw of winter wheat is 0.8% under irrigated (1.3% for rainfed) conditions, much higher than the maximum content of 0.69% reported by Van Duivenbooden *et al.* (1996). The default BN3-value is used for other crops. Under N-limited conditions, the original value of BN3 in the EPIC model is used for corn instead of the changed one, as the N content in straw simulated with this modified value was unrealistically low.

Potential heat unit (temperature sum)

The potential heat units from emergence to maturity (PHU) are set to 1600, 1800 and 1200 °Cd for corn, millet and soybean, respectively, based on Li (1997) and Boons-Prins *et al.* (1993), in combination with the calculated values according to days required for maturity from emergence. The PHU of autumn potato and winter wheat is set to 1900 °Cd and 1700 °Cd. For summer potato, the PHU is 1250 °Cd as estimated using the average length of growing period. The PHU of seed flax is 1100 °Cd at the base temperature of 5 °C, estimated according to data of Zhao *et al.* (1993). The PHU of alfalfa required for the maturity of seed is estimated with the experimental data of Guo & Zhang (1998).

The temperature sums required for germination (GMHU) of corn, potato and soybean are based on Boons-Prins *et al.* (1993). The GMHU of winter wheat and flax are roughly estimated according to the days required for germination, and alfalfa uses the original EPIC-value.

A1.2 Nutrient cycling and losses[1]

The N cycling module in EPIC simulates the processes of fertilization, crop uptake, transport by runoff and sediment, nutrient movement by soil evaporation, denitrification, ammonia nitrification and volatilization, mineralization, immobilization, bio-fixation, contribution of rainfall and irrigation, and NO_3-N leaching. Fig. A1.1 presents the parameters and the relationships between the major processes that determine soil supply and losses of nitrogen. The process of NO_3-N moving upward into the topsoil layer by mass flow due to soil evaporation is not included in Fig. A1.1.

The N-cycling model distinguished soil nitrogen into three types: mineral N, fresh organic N and humus N. The mineral N includes NO_3-N and NH_3-N, which can be taken up by crops. The NH_3-N is subjected to nitrification that transfers the NH_3-N into NO_3-N and volatilization that leads to the NH_3-N loss. NO_3-N is subjected to loss by denitrification, leaching, and runoff, or immobilized by soil micro-organisms during the mineralization of fresh organic N. The humus N in soil organic matter is divided into two types, active humus N that can be mineralized and added to the mineral N pool, and stable humus N that cannot be mineralized. Both types of humus N are in a balanced condition. 80% of the N from mineralization of the fresh organic N in crop roots and residue, micro-organisms, and manure, is added to the mineral N pool, and 20% is added to the active humus N pool. Humus N may be lost with sediment by soil erosion. N fixation of legumes is influenced by mineral N content in the soil.

Except for the factors included in Fig. A1.1, the N cycling is affected by fertilizer types, depth of fertilization, soil properties, water content, soil temperature, climate, and tillage operations. Those factors are inputted or simultaneously simulated by the related modules such as soil temperature, hydrology and tillage modules. The EPIC model offers a routine for the input of fertilizer types by giving the concentration of NO_3-N, NH_3-N and organic N. A similarly structured module for P cycling is included in EPIC.

Crop N uptake and sources of nitrogen

Crop use of N is estimated by using a supply and demand approach. The daily crop N demand is the difference between the crop N content and the ideal N content for that day. The optimal crop N concentration declines with increasing growth stage (Jones 1983) and is computed as a function of heat unit index (HUI).

Nitrogen inputs include N applied, N added by rainfall and irrigation water, and N fixed by leguminous crops. The applied N includes those in chemical fertilizers, manure and crop residues. The N in crop roots and stubble is used by following crops. N from rainwater and irrigation can be inputted into the model by giving the N concentrations. In this study, the concentration of 0.8 ppm in rainwater that is suggested by the EPIC model is used. No nitrogen from irrigation water is considered.

[1] This section is largely based on Mitchell *et al.* (1997).

Mineralization of organic N and immobilization of NO_3-N

Mineralization of organic N is based on the modified PAPRAN model (Seligman & Van Keulen, 1981). The model considers two sources of mineralization: fresh organic N pool, associated with crop residue and microbial biomass, and the stable organic N pool, associated with the soil humus. Mineralization from the fresh organic N pool is estimated as a product of the amount of fresh organic N and the decay rate. The decay rate is determined by soil water content, temperature, and ratios of C:N and C:P of crop residue. The mineralized N is 80% partitioned to the mineral N pool and 20% to the active humus N pool.

The active pool fraction in the plow layer depends on the number of years the soil has been cultivated, and is estimated on basis of the equation of Hobbs & Thompson (1971). Below the plow layer the active pool fraction is set at 40% of the plow layer value, based on work of Cassman & Munns (1980). Organic N flux between the active and stable pools is governed by an equilibrium equation. Mineralization from the active N pool is estimated as a function of soil moisture, temperature, and soil bulk density.

Daily amount of immobilization is proportional to amount of the mineralized crop residues and computed by subtracting the amount of N contained in the crop residues from the amount assimilated by the microorganisms. When N or P availability limits immobilization, the decay rate of residues is adjusted. The immobilized N is added to the fresh organic N pool and subtracted from the soil NO_3-N pool.

Losses of mineral nitrogen

Mineral N losses in EPIC include volatilization, denitrification, leaching, and runoff. Volatilization is estimated simultaneously with the nitrification using the first-order kinetic rate equation of Reddy *et al.* (1979). The combined nitrification and volatilization is related to amount of NH_3-N, nitrification factor and volatilization factor for the soil layer. The nitrification factor is a function of temperature, soil water content, and soil pH. The volatilization factor is estimated as a function of temperature and wind speed for surface-applied ammonia, and as a function of the depth of ammonia, the CEC, and soil temperature for below surface ammonia. Partition of the combined amount to nitrification and to volatilization is determined by the two factors.

Denitrification is a function of soil NO_3-N amount, soil temperature, and soil C content. The denitrification occurs only when the soil water content is at 95% or above of the soil field capacity. Amounts of NO_3-N lost through runoff and lateral flow are estimated as products of the water volume and the NO_3-N concentration. The leaching and runoff losses are calculated sequentially from layer to layer.

Loss of organic N

Organic N loss is estimated as the product of the sediment yield, concentration of organic N in the topsoil layer, and the enrichment ratio. The enrichment ratio is the concentration of organic N in the sediment divided by that in the soil. The enrichment ratio is logarithmically related to sediment concentration as described by Menzel (1980). Enrichment-sediment concentration relationship of an individual event was developed for EPIC by considering upper and lower bounds. The upper bound of enrichment ratio is the inverse of the sediment delivery ratio (sediment yield divided by gross sheet erosion). The lower limit of enrichment ratio is 1.0, i.e., the sediment particle size distribution is the same as that of the soil.

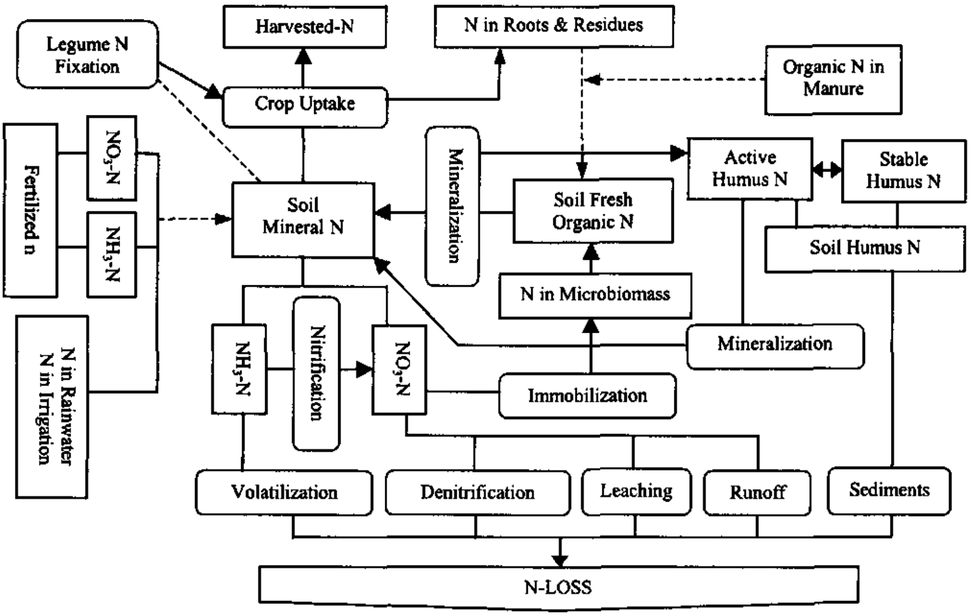

Figure A1.1 The factors and processes involved in the EPIC N-cycling module (After Mitchell *et al.* 1997)

A1.3 Water and soil loss

Equations for water erosion[2]

Fig. A1.2 presents the methodological diagram of predicting the water and soil losses with the EPIC model. The water and soil loss is simulated with a modified Universal Soil Loss Equation (USLE) of Wischmeier & Smith (1978), the so-called MUST, theoretically developed from sediment concentration bases, which uses only runoff variables to simulate erosion and sediment yield. Runoff variables increased the prediction accuracy, eliminated the need for a delivery ratio (used in the USLE to estimate sediment yield), and enables the equation to give single storm estimates of sediment yields. The equation is presented as:

$$Y = X \cdot K \cdot CE \cdot PE \cdot LS \cdot ROKF \qquad \text{A1.1}$$

in which, Y is the sediment yield in t ha^{-1} and X is the energy component, expressed as the number of rainfall and runoff erosion index units. K is the soil erodibility factor (valued 0-1), i.e., the soil loss rate per erosion index unit for a specified soil as measured on the standard unit plot, which is defined as a 72-ft length of uniform 9% slope continuously in clean-plowed fallow. CE is the crop cover and management factor, i.e., the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuos fallow (valued 0-1). PE is the erosion control practice factor (valued 0-1), i.e., the ratio of soil loss with a support practice like contouring or strip-cropping

[2] This section including all equations is largely based on the EPIC documentation (Mitchell *et al.* 1997).

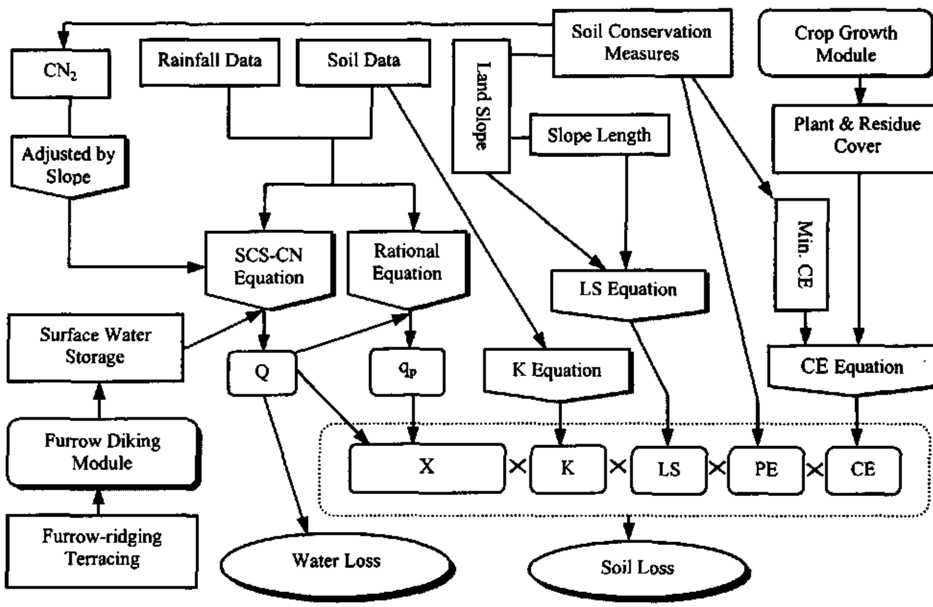

Figure A1.2 A diagram of the methodology used for predicting soil loss using the EPIC model (After Mitchell *et al.* 1997)

to that with straight-row farming up and down the slope. The factor of *LS* is the slope length and steepness factor, i.e., the ratio of soil loss from the field slope gradient and length to that from the standard unit plot under identical conditions. *ROKF* is coarse fragment factor, which is not used, as the soils have no coarse fragment in my study area. The *X* factor is calculated with equation:

$$X = 2.5 \cdot (Q \cdot q_p)^{0.5} \qquad \text{A1.2}$$

in which Q, is runoff volume (mm) and q_p is peak runoff rate (mm h^{-1}). The Q is simulated using a modification of the Soil Conservation Service (SCS) curve number method that relates runoff to soil type, land use, and management practices. Runoff (Q) is determined by rainfall (R in mm) and the retention parameter (S in mm) with the equation:

$$Q = \frac{(R - 0.2S)^2}{R + 0.8S} \qquad R \geq 0.2S \qquad \text{A1.3}$$

The parameter *S* defined as the rain not converted to runoff (SCS 1972) varies with soil moisture condition, soil field capacity, infiltration and transmission rate, land cover and land management. The value of S for different type of soil-cover complex was determined experimentally by SCS (1972) and transformed to CN by the SCS equation:

$$S = 254\left(\frac{100}{CN} - 1\right) \qquad (\text{S in mm}) \qquad \text{A1.4}$$

CN is a dimensionless, non-linear transformation of *S*, arranged to vary between 0 and 100 (Montgomery *et al.* 1983). The greater the CN is, the higher the runoff potential will be. The *S* is related to antecedent moisture conditions (AMC) and soil-cover complex. Three AMC levels were defined in SCS hydrology handbook (SCS 1972): AMC-1, the dry condition or upper limit of S, AMC-2, the average condition and AMC-3, the wet condition or lower limit of S. These three levels of AMC are determined by the total rainfall over 5 days preceding a storm. In consideration of more data available, CN_2, the curve number for AMC-2 is used for simulating daily runoff in the EPIC model. The CN values for AMC-1 and AMC-3 are related to CN_2 (see Mitchell *et al.* 1997). By assuming that the CN_2 from the SCS (1972) is appropriate for a 5% slope, an equation is included in the EPIC model for adjusting that value for other slopes.

EPIC offers a module of furrow diking to estimate the soil surface water storage. Runoff occurs only when the simulated Q exceeds the surface water storage estimated by the furrow-diking module. The q_p is computed with the modified Rational equation, as written in the form:

$$q_p = \frac{Q \cdot A}{360 \cdot \alpha \cdot t_c} \qquad \text{A1.5}$$

in which α is a dimensionless parameter that expresses the proportion of total (daily) rainfall during the watershed's time of concentration, t_c (hour). It ranges within the limits: $t_c/24 \le \alpha \le 1.0$. For a detailed mathematical description for the determination of t_c and α see the EPIC documentation. Q is the runoff (mm) computed with equation A1.3. A is the drainage area in ha. In this study, an assumed watershed area of 1 ha is used.

The K factor is computed as a function of contents of sand, silt, clay, and organic carbon, and evaluated for the topsoil layer at the start of each year of simulation. The LS factor is calculated using the equation of Wischmeier & Smith (1978). The CE factor is simulated in a daily step with an exponential equation of two factors, i.e., soil cover (aboveground biomass plus residue) and CVM, the minimum CE factor for water erosion. The soil cover factor is computed with the model, but the parameter CVM needs input. The PE factor should be inputted. Therefore, the EPIC module for water erosion needs inputs of climatic and soil data, PE, CVM, slope gradient (m m^{-1}) and slope length (m), and hydrology curve number (CN_2).

Factor values for soil erosion

Average slope steepness is used for each land unit. Slope length equals the interval of hillside ditches used for draining excess surface runoff. For terraced land, the slope length is set to 10 m and for flatland it is set to 60 m, since slope length hardly influences soil erosion under those conditions. The average slope gradients and slope lengths used for each land unit are shown in Table A1.2. For a specific practice such as contouring, the effectiveness of the support practice factor PE decreases with an increase of land slope gradient (Wischmeier & Smith 1978). Therefore, a higher PE value is used for the steeper slope land (Table A1.2).

The CE varies with changes in crop cover, residue mulching and tillage practice, and it has the lowest value, i.e., the CVM when the crop cover is at maximum. The CVM values (Table A1.3) are obtained or estimated based on the Table 5 and Figure 6-7 in the guidebook of *Predicting Rainfall Erosion Losses* (Wischmeier & Smith, 1978). Since no data are available for millet and flax, the CVM value of millet is based on data of wheat, but slightly higher due to a more open structure of millet. For flax that has low leaf area index and cover, the CVM may be more similar to row crops. A value of 80% of the corn-CVM is used for flax. The original value in the EPIC model is used for alfalfa. For crops farmed with furrow-ridges, the CVM is reduced by 50% to account for the benefit from furrow water storage, according to the suggestion by Wischmeier & Smith (1978).

Table A1.2 Gradient and length of slopes and the PE values used for different land units. All PE-values are based on Wischmeier & Smith (1978).

Items	Land Units					
	FLP	TRL	GSL	MSL	STL	VSL
Average slope gradient (m m^{-1})	0.01	0.01	0.07	0.132	0.222	0.364
Slope length (m)	60	10	60	35	15	10
PE for mixed crop rotations with alfalfa	0.3	0.3	0.25	0.35	0.45	0.59
PE for crop rotations without alfalfa	0.6	0.6	0.50	0.70	0.90	1.0

Table A1.3 Values of minimum CV factor for water conservation (CVM)

Management	Soybean	Corn	Wheat	Millet	Potato	Flax	Alfalfa
Residue removed	0.15	0.20	0.05	0.08	0.08	0.16	0.01
Residue mulch	0.08	0.14	0.04	0.06	0.04	0.11	
Furrow-ridge, residue removed	0.07	0.10	0.02	0.04	0.08	0.08	
Furrow-ridge, residue mulch	0.04	0.07	0.02	0.03	0.04	0.05	

CN value for the surface runoff

The CN-value is determined by soil-cover complex that consists of 4 components: soil, land use, rotation and tillage methods. In SCS hydrology handbook (SCS 1972), soils were distinguished into 4 hydrologic groups (A-D) based on their infiltration rate and water retention capacity. In Ansai, the loess soils with deep depth, silt loamy texture and well-drained condition are identical to the SCS hydrologic soil group B that has a moderate rate of water transmission, moderately well to well-drained with moderately fine to moderately coarse textures (SCS 1972). Therefore, the soils are treated as group B.

For cultivated land, four classes of land use (fallow, row crops, small grains and close-seeded legumes), two types of rotations (poor and good) and two tillage methods (straight row and contoured) were defined by SCS (1972) [3]. For each row crop or small grain, 4 combinations can be distinguished on basis of rotation and tillage methods. The combination determines the CN-value for a certain soil.

For a specific soil type, the retention parameter is related to the effectiveness of land use as a ground cover that varies with growing season and cover of crop residue on the field. In general, at planting or early growing stage, or if 2/3 soil is exposed, the fallow-CN applies (SCS 1972). In this study, fallow-CN is used for early growing season if the crop straw is removed, and a slightly lower value is used if the crop residue mulching is applied. From the end of early growing season to crop harvest, the average CN is applied. For mixed crop rotations, the fallow-CN is reduced by 3 to ac-

[3] **Land use classes**: 1) Fallow: the land is kept as bare as possible to conserve moisture for use by succeeding crop. It has highest potential for runoff; 2) Row crops: any field crops are planted in rows far enough apart that most of the soil surface is exposed to rainfall impact throughout the growing season. At planting time, it is equivalent to fallow and may be again after harvest. 3) Small grains: Crops planted in rows close enough that the soil surface is not exposed except during planting and shortly thereafter. And 4) Close-seeded legumes: included are alfalfa, sweet clover, timothy, etc., and combinations, planted in either close rows or broadcast.

Crop rotations: 1) Poor rotations: continuos cropping or combinations of row crops, small grain and fallow; and 2) Good rotations: they generally contain alfalfa or other close-seeded legumes or grass to improve tilth and increase infiltration;

Tillage methods: 1) Straight row: farmed in straight rows up and down or cross the slope; and 2) Contoured: contoured fields are those farmed as nearly as possible on the contour. The hydrologic effect is due to the surface storage.

count for the benefit from the increased infiltration due to the soil improvement by alfalfa (SCS 1972). The CN_2 values of the row crops (corn, soybean and potato) and small grains (winter wheat, millet and flax) under contoured cultivation, as used for this study are shown in Table A1.4. For alfalfa, an average value of 72 is used for the whole year.

Table A1.4 Differentiated types of land cover and the values of CN_2, based on SCS (1972). cR: crop rotations without alfalfa, aR: mixed crop rotations with alfalfa; R: crop residue removed, and M: crop residue mulching; ES: early growing stage, FP: fallowing period, EH: end of early growing stage to harvest, and WS: whole growing season.

Land treatment	Row crops	Small grains
cR-R-(ES & FP)	86	86
cR-R-EH	79	74
cR-M-FP	84	84
cR-M-WS	76	71
aR-R-(ES & FP); aR-M-FP	83	83
aR-R-EH; aR-M-WS	72	70

A1.4 Simulation years

The EPIC model simulates the crops sequentially in a rotation; so the individual crop actually is simulated with different weather data. Therefore, for a crop in different rotations, the simulated yield varies because of using different climatic data. To resolve this problem, 23 years daily rainfall and other monthly weather data are re-used by the EPIC model for several times (equal to the duration of crop rotations). This can be illustrated by a 3-year rotation of corn-millet-potato. The EPIC starts the simulation with corn using the weather data of first year, millet the second year and potato the third year, after 3 years (the rotation duration), corn again, then other two crops. After 23 years, the model re-loads the climate data, and millet is simulated with data of first year, then potato, corn; after 23 years, the model re-loads the data again, and potato is simulated with data of first year, then corn, millet. Thus, the weather data are used by three times, i.e., 69 years with simulations.

Appendix 2 A Simple Model for Estimating Surface Water Storage of Furrow-Ridges

This appendix presents a calculation method for estimating water storage of contoured furrow-ridges. The estimated water storage can be inputted into the EPIC model via the options of furrow diking and the efficiency factor in the EPIC control file.

A2.1 Approach

A furrow-ridge comprises furrows and ridges, and dikes may be built across the furrow. The water storage volume for furrow-ridging can be estimated by assuming that the furrow, the ridge, and the dike are trapezia, vertical to the land surface; the furrow and the ridge are on contour; both side slopes of the ridge/dike are at same steepness; and the slope is level along the furrow.

Furrow-ridging without dikes

Volume of the water storage depends on spacing of furrow-ridges (B), the bottom width between the toes of the furrow slopes (b), depth of the furrow (h), top width of the ridge (r), and steepness of land slope (S_l). Given the value of the above parameters, water storage depth (W_r) of the furrows can be computed with following equations:

$$W_r = f_r \cdot \frac{A}{B}; \quad A = A_1 + A_2 \qquad \text{A2.1}$$

$$A_1 = \frac{1}{2}(b + 2 \cdot h_m \cdot S_r)(h - h_m) \qquad \text{A2.2}$$

$$A_2 = (b + h_m \cdot S_r) \cdot h_m \qquad \text{A2.3}$$

$$h_m = h - \frac{(b + 2h \cdot S_r)}{S_r + S_l} \qquad \text{A2.4}$$

$$S_r = \frac{B - b - r}{2 \cdot h} \qquad \text{A2.5}$$

where S_l is *ctg*-value of land slope, S_r is the *ctg*-value of the side slope of the ridge/furrow, and h_m is the waterline on the upper furrow slope. f_r is a coefficient with a value of 0-1 given for adjusting the efficiency of the water storage, as the furrows and ridges may not be the same as the defined shape, and the land slope may not be uniform. A is the cross section area of water in the furrow, as calculated by dividing it into two parts: A_1, the triangular area above the line at height of h_m, and A_2, the trapezia area below the line. If water does not extend to the toe of the side slope of the upper ridge, i.e., $(b + h \cdot S_r) \geq (h \cdot S_l)$, the cross-section ($A$) is calculated with Eqn A2.6.

$$A = \frac{1}{2}\, h^2 \cdot (S_l - S_r) \qquad \text{A2.6}$$

Furrow-ridging with dikes across the furrows

The water storage is computed by dividing the furrow into three parts: between the slope toes of the two dikes, between the top and the toe of the left dike slope, and between the top and the toe of the right dike slope. With the assumption that the slope is level along the furrow, and steepness of side slopes of the dike is identical, the first two parts have equal water storage, and the total volume of water storage is assigned as V_2. The storage volume between the toes of the two dikes is assigned as V_1. V_1 and V_2 are calculated with the equations:

$$W_d = \frac{f_a \cdot (V_1 + V_2)}{B \cdot I} \quad \text{A2.7}$$

$$V_1 = A \cdot (I - 2 \cdot h \cdot S_d - d) \quad \text{A2.8}$$

$$V_2 = V_{21} + V_{22} + V_{23} \quad \text{A2.9}$$

$$V_{21} = \frac{1}{2} b \cdot S_d \cdot (h_1^{\,2} + h_2^{\,2}) \quad \text{A2.10}$$

$$V_{22} = \frac{1}{4} p \cdot S_d \cdot h \cdot h_1 \cdot (h_1 + h) \quad \text{A2.11}$$

$$V_{23} = \frac{1}{4} p \cdot S_d \cdot h_m \cdot h_2 \cdot (h_2 + h_m) \quad \text{A2.12}$$

$$h_1 = h - h \cdot \frac{S_r}{S_l} \quad \text{A2.13}$$

$$h_2 = h_1 - \frac{b}{S_l} \quad \text{A2.14}$$

in which A, B, b, h, h_m, S_l and S_r are the same as those in Eqns A2.1-2.5; h_1 and h_2 are water depth at the toe of the down slope and the toe of the upper slope of the furrow; S_d is *ctg*-value of the disk side slope; I and d are interval of dikes and top width of the dike; W_d is depth of water storage of the tied furrow ridges; and p is the ratio of $sin(90 - S_r)$ to $sin(S_r)$, where S_r is the side slope of the ridges (in degree); and f_d is a factor between 0-1 for adjusting the efficiency of water storage.

The V_1 is determined by the cross section area and the distance between the toes of the two dikes. V_2 is estimated in three parts: between the toes of the upper and down slopes of the furrow, between the toe and waterline of the furrow down slope, and between the toe and waterline on the upper furrow slope. Those three parts are calculated accordingly by formulae (A2.10-2.12). If $(b + h \cdot S_r) \geq (h \cdot S_l)$, the area, A in Eqn A2.8 is calculated with Eqn A2.6, and V_2 with Eqn A2.15.

$$V_2 = \frac{1}{4} h_1^{\,3} \cdot S_d \cdot S_l + V_{22} \quad \text{A2.15}$$

The W_r and W_d are on the sloping base and can be projected onto the level base by dividing them with $cos(S_l)$, where the land slope, S_l is in degree. Unit of the variables in all equations (A2.1-2.15), except for the slope variables can use mm, cm or m, and corresponding unit of area is mm^2, cm^2 or m^2 and volume is mm^3, cm^3 or m^3. The unit of W_r and W_d is in mm, cm or m, depending on the units as used by other variables.

The above methods can be used to estimate the water storage for any furrow-ridges with or without dikes on any steepness of land slope. If the width of the furrow bottom and top ridge/dike sets to 0, the furrow, ridge and dike are all in a shape of triangular; otherwise, they are in a shape of trapezia. When using this method, one should make sure that the steepness of the ridge side slope is not less than that of the land slope.

A2.2 Surface water storage of furrow-ridging and terraced lands

The effectiveness of the water storage depends on spacing of furrow-ridges, depth and bottom width of furrow, dike interval and steepness of land slope. The spacing of furrow-ridges is determined according to normal row spacing of crops and common practice of furrow-ridges in the Loess Plateau. To be effective in conserving water and soil erosion, spacing of furrow-ridges and depth of furrows should be at a reasonable level. Song *et al.* (1995) suggested that the spacing of furrow-ridges could be at least 40 cm and better 60-100 cm.

In this study, the spacing of furrow-ridges is set to 60 cm for all row-crops and small grains grown on sloping land. For small grains grown on flood plain or gentle sloping land, the spacing of furrow-ridges is set to 120 cm that is suitable for a 7-rows drill planter, commonly used for planting small grains in northern China. The dike interval all is set to 200 cm, and height of ridges or depth of furrows is 10-25 cm, increasing with land slope steepness, by considering that the effectiveness in water storage decreases with an increase of land slope. The top width of ridge and dike is set to 5 cm, and side slope of the dike is 1:1. Parameter values of the furrow-ridges and volume of the water storage estimated using the method are shown in Tables A2.1-A2.3.

For all crops except for potatoes, it is assumed that the furrow-ridges are well maintained during the growing season, and rebuilt just before the sowing date of next crop. During the fallow period, the volume of water storage is reduced and set to half of the water storage in the growing season. For potato cultivated with contoured tillage, it is assumed that the potato is ridged at the end of early growing stage. From then util the harvest, the surface water storage by the furrows is estimated using the approach for furrow-ridging without dikes, while for other crops, the approach for furrow-ridging with dikes is used.

Surface water storage of terraced lands

Terraces normally have a front ridge that bounds the terrace and can store excess rainwater. Height of the front ridge varies among areas. In this study, a normal height of 30 cm (Song *et al.* 1995) is used for front ridge of all terraces. The effective water storage is set to 75% of the ridge height; and thus the volume of water storage is 225 mm.

Table A2.1 Estimated surface water storage (mm) for row crops by furrow-ridges (Spacing of furrows: 60 cm, dike interval: 200 cm, bottom width of the furrow: 15 cm)

Item	FPL	GSL	MSL	SSL	VSL
Ridge height or furrow depth (mm)	150	150	200	200	250
Depth of surface water storage (mm)	56	48	57	46	37

Table A2.2 Estimated surface water storage (mm) for small grains by furrow-ridges (dike interval: 200 cm)

Item	FPL	GSL	MSL	SSL	VSL
Ridge height or furrow depth (mm)	100	150	200	200	200
Spacing of furrow-ridges (cm)	120	120	60	60	60
Bottom width of the furrow (cm)	105	105	30	30	30
Depth of surface water storage (mm)	57	67	72	61	45

Table A2.3 The estimated water storage (mm) for potato by the furrows (Ridge spacing: 60 cm, bottom width of the furrow: 15 cm)

Item	FPL	GSL	MSL	SSL	VSL
Ridge height/furrow depth (mm)	150	150	150	150	150
Depth of surface water storage (mm)	42	36	30	23	10

Appendix 3 Basic Data Used for Determining Technical Coefficients of Production Activities

A3.1 Reduction factors, and the major diseases and pests that may cause crop yield losses

The reduction factors are given in Table A3.1, and the major diseases and pests that may cause crop yield losses in Ansai are shown in Tables A3.2-3. All data in the three tables are based on ECPP (1996), HPRI-CAAS (1994), Hua & Wang (1996), Jiang (1998), Li *et al.* (1994), Liang *et al.* (1995), Qi *et al.* (1992), Sun *et al.* (1992a), SAAS (1987), Wang (1995), De Koning *et al.* (1992) and Rowe (1993).

Table A3.1 Yield reductions due to crop-specific diseases and pests (crop frequency and sequences)

Crop	Rotation	Reduction	Possible causes
Corn	Continuous	15%	Diseases: *Fusarium spp., Pythium spp., Gaeumannomyces graminis, Ustilago maydis;* Pest: *Ostrinia furnacalis*
Corn	After corn	8%	Diseases: *Fusarium spp., Pythium spp., Gaeumannomyces graminis, Ustilago maydis;* Pest: *Ostrinia furnacalis*
Corn	After millet	5%	Pest: *Chilo infuscatellus*
Millet	1 in 2	8%	Weed: *Setaria viridis;* Diseases: *Sclerospora graminicola* Nematode: *Aphelenchoides olyzae* Yokoo; Pest: *Chilo infuscatellus*
Millet	1 in 3	4%	Disease: *Sclerospora graminicola*
Millet	After corn	5%	Disease: *Gaeumannomyces graminis;* Pest: *Ostrinia furnacalis*
Soybean	1 in 3	8%	Nematode: *Heterodera glycines;* Weed: *Cuscuta*
Soybean	1 in 4	5%	Nematode: *Heterodera glycines;* Weed: *Cuscuta*
Flax	1 in 4	10%	Soil borne diseases: *Colletotricum linicolum, Rhizoctonia solani, Lereillula tourica* Arnan; Weed: *Cuscuta*
Flax	1 in 5	5%	Soil borne diseases: *Colletotricum linicolum, Rhizoctonia solani*
Wheat	Continuous	10%	Disease: *Gaeumannomyces graminis;*
Potato	1 in 3	15%	Diseases: *Rhizoctonia solani, Verticillium albo-atrum, V. Dahliea, Fusarium spp.;* Nematodes
Potato	1 in 4	10%	Diseases: *Rhizoctonia solani* Kuhn, *Verticillium albo-atrum, V. Dahliea;* Nematodes
Potato	1 in 5	5%	Diseases: *Rhizoctonia solani* Kuhn, *Verticillium albo-atrum, V. Dahliea;* Nematodes

Table A3.2 Main diseases and pathogens that may cause yield losses in Ansai

Diseases	*Pathogens*
Wheat rust	*Puccinia striiformis, Puccinia recondita*
Wheat flat smut	*Urocystis tritici*
Wheat powder mildew	*Erysiphe graminis*
Millet downy mildew	*Sclerospora graminicola*
Millet blast	*Piricularia setariae* Nishikado
Millet leaf rust	*Uromyces setariae-itaicae*
Potato late blight	*Phytophfhora infestans (Mont.)* De Bary
Potato early blight	*Alternaria Solani*
Potato bacterial ring rot	*Clavibacter michiganens subsp. Sepedonicum*
Potato soft rot	*Erwinia carotovora subsp. atroseptica, E. c. atroseptica*
Potato early dying	*Verticillium albo-atrum, V. dahliea*
Potato Rhizoctonia canker	*Rhizoctonia solani* Kuhn
Potato dry rot	*Fusarium spp.*
Corn northern leaf blight	*Helminthosporium turcicum*
Soybean grey speck	*Cercospora sojina*
Soybean brown spot	*Septoria glycines*
Soybean spot	*Pseudomonas glycinea*
Flax anthracnose	*Colletotricum linicolum*
Flax seedling blight	*Rhizoctonia solani* Kuhn
Flax Fusarium wilt	*Fusarium oxysposrum* var. *lini*
Flax rust	*Melampsora lini*
Alfalfa leaf rust	*Uromyces striatus* Schroet
Alfalfa	*Erysiphe polygoni* DC., *Leviellula taurica* (Lev.) Arn.

Table A3.3 Main crop pests that may cause crop yield losses in Ansai

English	Latin	Host crops
Greenbug, English grain aphid	*Schizaphis graminum, Sitobion avenae*	Wheat
Corn aphid	*Rhopalosiphum maidis*	Corn, millet
Peach potato aphid	*Myzus persicae* (Sulzer)	Potato (virus)
Soybean aphid	*Apbis glycines*	Soybean
Armyworm	*Leucania separata Walker*	Wheat, millet, corn
Millet borer	*Chilo infuscatellus*	Millet, corn
Asiatic corn borer	*Ostrinia furnacalis*	Corn, millet
Yellow-legged lema	*Qulema tristis*	Millet, wheat
Beet webworm	*Loxostege sticticalis*	Flax
Soybean pod borer	*Leguminivora glyniuorella*	Soybean
Lima bean pod borer	*Etiella zinekenella*	Soybean
Bean hawk moth	*Clanis bilineata tsingtauica*	Soybean
Bean bilster beetle	*Epicauta gorhami Marseul*	Soybean
Millet coried	*Liorchyssus hyalinus*	Millet, flax
Wheat mite	*Petrobia lateens*	Wheat
Cutworm	*Agrotis ypsilon*	Potato, wheat, corn, soybean, alfalfa
Wireworm	*Agriotes fuscicollis*	Corn, wheat, potato
Striated leafhopper	*Psammotettix striatus*	Wheat
Zokor	*Myospalax cansu*	Wheat, millet, alfalfa, potato

A3.2 Production Techniques and Labor Requirements

This section presents the definition of production techniques, and the basic data for determining the inputs of labor, machines, and draught animals.

A3.2.1 Production techniques

Production techniques determine labor requirements. In Chapter 2, three production levels, two mechanization levels, two tillage methods and two options for crop residue management are defined. Detailed descriptions related to labor requirement are needed. For the different production levels, operations related to applications of nutrients, biocides and weeding are given in Table A3.4. The two levels of mechanization are described in Table A3.5, mainly differentiated by power sources: using animal traction or power traction. Because of limitations by the rugged relief and small farm size, only light machinery and equipment is considered. The two options for tillage and residue management can be combined into four options.

Table A3.4 Application times of nutrients, biocides and weeding for the three yield levels and two mechanization levels. AIY = attainable irrigated yield level, ARY = attainable rainfed yield level, and NLY = N-limited yield level. L1-L5 are labor demand periods as defined in Subsection 4.2.4 of Chapter 4

Yield level	Fertilizer and biocide applications	Herbicide application and weeding
AIY, ARY	First fertilization in P1 or P2, and other two in P5 for non-legume crops; One fertilization applied for soybean and alfalfa in P2; Two biocide sprayings for soybean, seven for potato and one for other crops.	*Semi-mechanized*: One herbicide applied in P1 or P2, but for soybean, another additional herbicide sprayed in P5; *Hand Labor/animal traction*: First weeding and thinning in P2 for autumn crops, other two weedings in P5
NLY	Fertilizers applied during the land preparation (P1 or P2); Four biocide sprayings for potato and one for other crops;	*Hand Labor/animal traction:* First weeding and thinning in P2 for autumn crops, other two weedings in P5

Table A3.5 Production means for the two mechanization levels

Farm operations	Semi-Mechanized	Hand labor/Animal traction
Land preparation	Small scale tractor	Ox traction
Sowing	Tractor-driven planter	Ox-driven planter
Application of fertilizer	Small fertilizer distributor	Ox-driven fertilizer distributor
Fertilization at middle season	By hand	By hand
Irrigation	Sprinkler	Surface irrigation
Pesticide application	Knapsack power sprayer	Hand sprayer
Thinning	By hand	By hand
First weeding / Interrill tillage	Herbicides / machine	With oxen traction
Second/third weeding	Herbicides	By hand
Transport of manure/harvests	Small-scale tractor	Donkey- & oxen-drawn cart, donkeys
Cutting or digging	Power-driven cutter	By hand
Binding	By hand	By hand
Processing of crop residues	Shredders	By hand
Threshing / winnowing	Threshers	Ox traction / hand

A3.2.2 Labor requirements for field operations

Labor requirement is defined in terms of task-time, as calculated with Eqn 4.4 in Chapter 4. The time required per farm operation is presented in Tables A3.6 and A3.7, based on ECHATE (1983), ACTER (1986), CAAM (1992), HPRI-CAAS (1994) and Van Heemst (1981).

Table A3.6 Estimated actual labor hours per operation (*Ta*) carried out by an adult man with an oxen-drawn machine or by hand (for Eqn 4.4 in Chapter 4)

Operations	Unit	Corn	Millet	Wheat	Soybean	Potato	Flax	Alfalfa
Land preparation	$h\ ha^{-1}$	35	35	35	35	35	35	35
Sowing	$h\ ha^{-1}$	15	20	20	17	80	20	20
Thinning by hand	$h\ ha^{-1}$		50					
Fertilizer application	$h\ ha^{-1}$	10	12	12	11	10	12	4
Weeding / interrill tillage	$h\ ha^{-1}$	8	6	6	9	8	6	
Weeding by hand	$h\ ha^{-1}$	33	24	24	38	35	24	20
Biocide spraying	$h\ ha^{-1}$	6	4	4	4	4	4	4
Cutting / digging	$h\ t^{-1}$	11	22	25	20	2	25	3
Binding / collection	$h\ t^{-1}$	3	3	3	3	5	3	3
Residue process	$h\ t^{-1}$	15	12	12	12		12	
Application of manure	$h\ t^{-1}$	5	5	5	5	5	5	

Table A3.7 Estimated actual labor hours per operation (Ta) carried out by an adult man with a light power-driven machine or by hand (for Eqn 4.4 in Chapter 4)

Operations	Unit	Corn	Millet	Wheat	Soybean	Potato	Flax	Alfalfa
Land preparation	$h\ ha^{-1}$	4	4	4	4	4	4	4
Sowing	$h\ ha^{-1}$	2	2.5	2.5	2.2	3.0	2.5	2.5
Thinning by hand	$h\ ha^{-1}$		50					
Fertilization	$h\ ha^{-1}$	1.2	1.5	1.5	1.3	1.2	1.5	
Biocide spraying	$h\ ha^{-1}$	3	2	2	2	2	2	2
Cutting or digging	$h\ ha^{-1}$	3.0	2.5	2.5	2.5	3.0	2.5	1.5
Hand binding/collection	$h\ t^{-1}$	3	3	3	3	5	3	3
Crop residues processing	$h\ t^{-1}$	1	1	1	1	1	1	

Land preparation includes plowing, harrowing and seedbed preparation. If furrow-ridges are used, 50% more labor is needed for preparation of the furrow-ridges and probably additional plowing. In addition, 30 $h\ ha^{-1}$ is needed for building dikes across the furrows that can be carried out only by hand. All crops are sown with an ox-drawn or tractor-driven planter, with the exception that potato is planted by hand. For the non-mechanized farming with hand labor and draught animal traction, three weedings are needed, while for the semi-mechanized farming, herbicides are applied, and power-driven cutters are used for the harvests of wheat, millet, flax, soybean and alfalfa. Crop binding for all crops is carried out by hand. Crop thinning is needed only for millet and is carried out by hand. Currently, the thinning of millet is very time-consuming, at a range of 15 to 20 man-days per hectare. In this study, it is assumed that millet (coated seeds) is sown with an improved planter (Zhang *et al.* 1997), therefore, much lower labor for thinning is needed.

Task time for irrigation is related to the amount of water applied. At each irrigation operation with a sprinkler, the required time depends on the allowable intensity of irrigation that is mainly determined by soil infiltration, and applied amount of water. Maximum irrigation intensity for a loam soil is 12 $mm\ h^{-1}$ to avoid runoff loss (Song *et al* 1995). In this study, 15 mm of water per irrigation operation is supposed to be applied, requiring 2 hours per hectare. For surface irrigation, a minimum irrigation of 60 mm per operation is used, which is determined at pilot farms and field experiments in northern China (*ibid.*). Irrigation with a low-pressure pipe irrigation system needs 13-26 hours per hectare (*ibid.*). An average value of 20 $h\ ha^{-1}$ is used. The number of irrigation operations is based on the water requirement of the crops.

A3.2.3 Labor requirements for transportation

Labor requirement for transport is estimated with Eqn 4.5 in Chapter 4. The estimated labor requirements are shown in Table A3.8. The travel speed and carrying capacity for the donkey and ox are based on experimental data reported in literature (CADAC 1988, ACTER 1986).

For manure transport to the hilly land units with donkey, and donkey- and ox-cart, it is assumed that 20% more labor are needed than transport of crop products. Because homesteads are normally located at lower altitude or down slope areas, transportation of manure needs climbing hill slopes. For manure transportation with tractor, no-increase is considered.

Table A3.8 Labor needed for transport of crop products (for Eqn 4.5 in Chapter 4)

		Unit	Flood plain	Exiting Terraces	Hilly land units
	Distance (*d*)	km	0.5	1.0	1.5
Donkey	Carry weight (*C*)	t	0.07	0.05	0.05
	Travel speed (*v*)	km h^{-1}	4.0	3.0	3.0
	Labor needs (*Tlab*)	h t^{-1}	4.6	14.3	21.0
Donkey-cart	Carry weight	t	0.25	0.20	0.20
	Travel speed	km h^{-1}	4.0	3.0	3.0
	Labor needs	h t^{-1}	2.0	4.3	6.0
Ox-cart	Carry weight	t	0.6	0.4	0.4
	Travel speed	km h^{-1}	2.2	2.0	2.0
	Labor needs	h t^{-1}	1.9	3.5	4.8
Tractor	Carry weight	t	1.5	1.2	1.2
	Travel speed	km h^{-1}	18	15	15
	Labor needs	h t^{-1}	1.4	1.5	1.5

A3.2.4 Labor needs for on-farm process

On-farm processes include threshing, winnowing, drying and storage of grains, as well as sorting and storage of potato. For semi-mechanized crop activities, millet, corn, wheat, soybean and flax are processed with threshing machines. For non-mechanized crop activities, oxen are used to thresh the economic products of wheat, millet, soybean and flax, while corn is processed by hand. Other activities including drying, sorting (potato) and storage are done manually. Time needed for cutting of potato seed is 30 h t^{-1}. The labor requirements are shown in Table A3.9, which are estimated according to literature (ECHATE 1983, ACTER 1986, CAAM 1992, NAC 1993, CADAC 1988, HPRI-CAAS 1994, van Heemst 1981).

Table A3.9 Labor requirements (h t^{-1}) for on-farm processes

Operation	Corn	Millet	Wheat	Soybean	Potato	Flax	Alfalfa
By hand labor	50	45	52	40	4	45	2
By light machines	5	10	15	10	4	12	2

A3.3 Determination of labor requirements for terracing and hillside ditches

In Chapter 2, two terracing types, i.e., bench-terracing and spaced-terracing were defined. For the sloping land units without terracing, hillside ditches should be built to cut the slope shorter and to drain excess surface runoff. This appendix gives the quantification of these engineering measures.

A3.3.1 Parameters for terraces and hillside ditches

For cultivation purpose, terrace width should be at a reasonable width. Considering costs, stability of terrace, cultivatable area and facilitating cultivation, Shan & Chen (1993) suggested that the terrace width (*W* in meter) could be simply determined by land slope (α in degree) with Eqn A3.1.

$$W = 18.5 - 9.5 \cdot \log \alpha \qquad \text{A3.1}$$

Table A3.10 gives the terrace width and other parameters for different land units. For land units of STL and VTL, the terrace width is determined based on Eqn A3.1. For land units of GSL and MSL, higher terrace widths (than that calculated with Eqn A3.1) are used to facilitate cultivation by machinery, as terrace width should be at least 12 m for use of tractors (Sun *et al.* 1992b). For spaced terracing, ratios of terraced area to inter-terraced area suggested by Shan & Chen (1993) range from 1:1 to 1:3, depending on crop patterns and slope steepness. With these ratios, runoff can be well prevented when a rainfall process amounts to 100-150 mm if the terraces are well built and maintained (*ibid.*). In this study, the terrace interval is set to 45 m for the land unit of GSL, 30 m for MSL, 15 m for STL and 10 m for VST.

Hillside ditches built across a land slope are used to break the slope into segments, and to drain excess surface water. Required number of ditches depends on slope steepness, runoff coefficient and storm rainfall. In this study, the interval of hillside ditches is set to the same as the terrace interval of the spaced terracing. The parameters for the three measures are shown in Tables A3.10 and A3.11.

A3.3.2 Earthworks and labor requirement for terracing

Labor requirements for terracing are related to the amount of earthwork to be moved. The amount of earth movement is determined by steepness of land slope and terrace width, and calculated with Eqn A3.2a. When sloping land is terraced, a small part of the land occupied by the back slope and the front ridge is not available for cultivation. This non-cultivable land fraction is computed with Eqn A3.2b.

$$EV = 1250 \cdot H; \qquad H = \frac{W \cdot Ls \cdot Ts}{Ts - Ls} \qquad \text{A3.2a}$$

$$LF_t = \left(\frac{H}{Ts} + R\right) \Big/ \left(W + \frac{H}{Ts}\right) \qquad \text{A3.2b}$$

in which, *EV* is earth excavation in m^3 ha^{-1}, *W* and *H* are terrace width and height of terrace backslope in m, *Ls* is steepness of land slope and *Ts* of terrace back slope in m m^{-1}, LF_t is non-cultivable fraction of the land area, and *R* is width (bottom) of front ridge, for which a value of 0.6 m is used.

Labor requirement for manual terracing is about 900 man-days ha^{-1} for wider terraces and 300-450 man-days for narrower ones (Shan & Chen 1993) in the Loess Plateau. Mean labor requirements reported by Wang (1990) are 53.5 man-days per mu (equals 1/15 hectare) with an earth movement of 214 m^3 mu^{-1}, averaging 0.5 m^3 per man-hour, if a man-day is considered as 8 man-hours. Standard earthwork for a laborer at the government-managed farms was 2.5-4.0 m^3 d^{-1} at a moving distance of 20-10 m (ECHATE 1983). Based on this information, labor requirements (Table A3.10) for manual terracing are simply estimated by assuming that an adult man can carry out 0.45 m^3 earthworks in an hour for the land units of GSL and MSL. A higher value of 0.5 m^3 h^{-1} is used for land units of STL and VTL because the moving distance of the earth is shorter. For mechanical terracing, a bulldozer is used. The labor (or machinery) requirements are estimated according to experimental data of terracing by CGTM (1989) in the Loess Plateau.

After terrace construction, necessary maintenance for the front ridge and back slope of the terrace is needed, as rainstorms may lead to some damage on the terrace during rainy season. The labor required for terrace maintenance per year is assumed proportional to the total length of the terrace (10^4 m / terrace width) per hectare and terrace height. It is assumed that one man-hour is needed for the maintenance of 50 m terrace if the terrace height is 1 meter, and 10% more labor is needed per meter increase of terrace height. The estimated labor requirement for terrace maintenance is given in Table A3.10.

Table A3.10 Earthworks and labor requirements for building terraces *Ts* = 4.0 (76°) for GSL and MSL; *Ts* = 3.3 (73°) for STL and VST)

Items	Unit	GSL	MSL	STL	VST
Average land slope steepness	%	7.0	13.2	22.2	36.4
Bench Terracing					
Terrace width (*W*)	m	15	12	8	6
Height of terrace back-slope (*H*)	m	1.00	1.36	1.90	2.46
Earth excavation (*EV*)	$m^3\ ha^{-1}$	1334	2042	2378	3072
Non-cultivable fraction (LF_t)	fraction	0.06	0.08	0.14	0.20
Labor needs by hand	$h\ ha^{-1}$	2964	4538	4756	6144
Labor needs by machinery	$h\ ha^{-1}$	37	54	56	70
Maintenance by hand	$h\ ha^{-1}\ yr^{-1}$	13	17	25	38
Spaced Terracing					
Labor needs by hand	$h\ ha^{-1}$	784	1395	1867	2689
Labor needs by machinery	$h\ ha^{-1}$	10	17	22	31
Maintenance by hand	$h\ ha^{-1}\ yr^{-1}$	3	6	11	20

A3.3.3 Earthworks and labor requirement for hillside ditches

Labor requirements depend on how much amount of earthwork needs to be carried out. The earth excavation is simply estimated by assuming that the ditch and ridge are trapezoidal, and the side slopes (ratio of horizontal to vertical height) are all 1:1 (Fig. A3.1). The excavated earth is used to build the ridge. It is assumed that top width of the ridge is the same as the width of the ditch bottom (*b*). The following equations are used to calculate earth excavation and occupation fraction of hillside ditches:

$$EMd = \frac{2500}{I}\left[h \cdot b + (h+b)\frac{(h+2\cdot b)\cdot Ls + h}{1-Ls}\right] \qquad \text{A3.3a}$$

$$LF_d = \frac{2\cdot(h+b)}{I\cdot(1-Ls)} \qquad \text{A3.3b}$$

in which *EMd* is the earth excavation in $m^3\ ha^{-1}$, *b* the bottom width and *h* the depth of hillside ditches in meter, *I* the interval of hillside ditches in meter, and LF_d the non-cultivable fraction due to occupation by ditches.

In this study, the depth of the hillside ditches is set to 0.6 m, and the bottom width 5 cm. The estimated earthwork and labor requirements are shown in Table A3.11.

For excavation of hillside ditches, two labors and an ox are involved with earthwork of 4 m^3 per hour (2 m^3 per person per hour). If machinery is used, two workers are involved, and the earth excavation is 10 m^3 per person per hour. It is assumed that the hillside ditches have been used for three years, after which they are re-built.

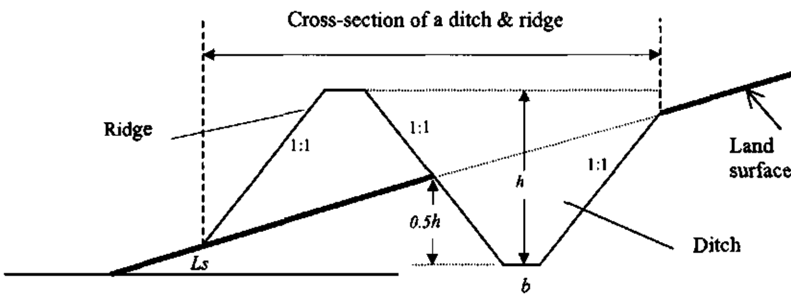

Figure A3.1 Cross-section and parameters of a hillside ditch

Table A3.11 Earthwork and labor requirement for building hillside ditches (h = 0.6 m)

Parameter	Unit	GSL	MSL	STL	VST
Interval of hillside ditches (I)	m	60	35	15	10
Earth excavation (ED)	m^3 ha^{-1}	25	42	102	209
Non-cultivable fraction (LF_d)	Fraction	0.03	0.05	0.11	0.20
Labor needs with animal traction	h ha^{-1} yr^{-1}	4	8	21	52
Labor needs with machine	h ha^{-1} yr^{-1}	1	2	-	-

A3.4 Prices of crop products and fertilizers

The basic data used to calculate the costs and net return are shown in Table A3.12, which are prices of 1997-1998. The price of autumn potato is 0.6 yuan kg^{-1}. A value of 50% higher than the price of autumn potato is used for summer potato, considering that production costs of summer potato are higher, due to the lower yield and dry climate during its growing season in Spring and early summer. This resulted in a limited supply in Ansai, and consequently a higher price (in 1997, the price of summer potato was twice of autumn potato). The price of fertilizers in 1997-98 was 2.9, 5.7 and 4.8 yuan per kg elementary N, P and K, respectively. The price of biocides varies greatly with different types. In this study, an average value of 40 yuan per kg active ingredient is used, based on the biocides commonly used for crop protection in China.

For machinery use, the price is estimated based on the information in northern China. Costs per hour use of machinery are estimated at 75 and 68 yuan for plowing and sowing, 50 yuan for weeding and fertilization, 15 yuan for transport of crop products or manure, 70 yuan for crop cutting and shredding of crop residues, and 6 yuan for threshing/winnowing. The cost for terracing is 150 yuan h^{-1}. Labor is supplied by family members, and oxen and donkey are owned by households. In the current version of the LP model, a price of 15, 20 and 10 yuan per 8-hour working day is used for labor, oxen and donkeys, respectively.

Table A3.12 Amount of seeds used per hectare, and prices (1997-98) of seeds and crop products

Item	Unit	Corn	Millet	Wheat	Soybean	Potato	Flax	Alfalfa
Seed amount	kg ha^{-1}	37	7	90	35	1200	60	15
Seed price	yuan kg^{-1}	5.6	6.5	4.0	5.5	3.0	3.6	30.0
Product price	yuan kg^{-1}	1.24	1.28	1.40	2.40	0.6	1.68	0.20

Appendix 4 Input-Output Coefficients of Selected Production Activities

A4.1 Input-output coefficients of selected cropping activities (a 3-year rotation of Corn-Soybean-Corn)

Table A4.1 Outputs, N and soil losses, and inputs of N, P and K

GCRN and RCRN: yield of corn and its harvested residue per ha in dry matter; GSOY and RSOY: yield of soybean and its harvested residues per ha in dry matter. N- and S-LOS: nitrogen and soil loss per ha. BIO: biocide inputs (active ingredient) per ha. IRRI: irrigation water per ha. Costs (COST) include only small equipment, seed and machinery use.

Activities*	GCRN	GSOY	RCRN	RSOY	N-LOS	S-LOS	BIO	IRRI	COST	N	P	K
	kg	kg	kg	kg	kg	t	kg	t	yuan	kg	kg	kg
5,nC,i,H,dT,FL	6965	926	5937	1356	38	0.7	1.9	2896	55	183	92	146
5,mC,i,H,dT,FL	6986	966	744	1179	33	0.2	1.9	2775	52	147	74	60
5,nC,r,H,dT,FL	4113	627	4353	950	24	0.7	1.7	0	54	136	56	97
5,mC,r,H,dT,FL	4291	660	557	831	17	0.2	1.7	0	51	98	44	36
5,RF,r,H,dT,FL	4552	687	4559	1032	24	0.1	1.7	0	65	143	60	102
5,FM,r,H,dT,FL	4612	696	573	870	18	0.0	1.7	0	62	105	47	38
5,nC,r,H,dT,GL	3576	617	3820	934	24	5.8	1.6	0	66	117	51	88
5,mC,r,H,dT,GL	3723	646	490	810	17	2.1	1.6	0	62	81	40	34
5,RF,r,H,dT,GL	3968	673	4052	1010	24	1.0	1.6	0	80	125	55	94
5,FM,r,H,dT,GL	4011	678	509	847	16	0.3	1.6	0	75	87	42	35
5,nC,r,H,bT,GL	4474	658	4356	983	23	0.2	1.6	0	57	140	59	98
5,mC,r,H,bT,GL	4476	660	2723	164	20	0.2	1.6	0	54	118	52	67
5,nC,r,H,sT,GL	3893	642	4048	968	23	1.0	1.7	0	64	123	54	93
5,mC,r,H,sT,GL	4005	664	1086	660	18	0.5	1.7	0	61	92	44	43
5,RF,r,H,sT,GL	4191	685	4224	1026	24	0.3	1.7	0	75	130	57	97
5,FM,r,H,sT,GL	4224	689	1100	688	17	0.2	1.7	0	71	96	46	44
5,nC,r,H,dT,ML	3460	532	3821	814	21	17.3	1.6	0	73	118	48	84
5,mC,r,H,dT,ML	3615	562	489	714	16	7.3	1.6	0	69	85	38	31
5,RF,r,H,dT,ML	3889	591	4053	892	29	4.4	1.6	0	88	133	55	95
5,FM,r,H,dT,ML	3919	589	508	742	20	1.7	1.6	0	84	94	42	34
5,nC,r,H,bT,ML	4379	644	4263	962	23	0.4	1.6	0	57	137	57	96
5,mC,r,H,bT,ML	4381	646	2665	161	20	0.4	1.6	0	54	116	51	66
5,nC,r,H,sT,ML	3850	584	4090	886	21	2.9	1.7	0	70	122	52	89
5,mC,r,H,sT,ML	3967	607	1120	585	17	1.4	1.7	0	66	94	42	41
5,RF,r,H,sT,ML	4174	629	4265	946	28	1.0	1.7	0	81	137	57	98
5,FM,r,H,sT,ML	4197	627	1135	606	20	0.6	1.7	0	77	102	45	44
5,nC,r,H,dT,SL	3104	475	3451	728	24	40.4	1.5	0	80	112	45	79
5,mC,r,H,dT,SL	3239	495	449	631	14	17.1	1.5	0	77	75	33	28
5,RF,r,H,dT,SL	3392	507	3670	770	18	13.5	1.5	0	97	109	46	80
5,FM,r,H,dT,SL	3508	532	465	672	19	5.2	1.5	0	93	85	38	31
5,nC,r,H,bT,SL	4093	602	3985	899	21	0.6	1.5	0	57	128	54	90
5,mC,r,H,bT,SL	4095	604	2491	150	18	0.6	1.5	0	54	108	47	62
5,nC,r,H,sT,SL	3719	560	3919	849	24	5.6	1.6	0	74	118	48	84
5,mC,r,H,sT,SL	3814	574	1265	495	16	2.7	1.6	0	71	87	38	37
5,RF,r,H,sT,SL	3919	582	4070	878	19	2.3	1.6	0	86	119	49	84
5,FM,r,H,sT,SL	4000	600	1276	524	20	1.3	1.6	0	82	96	41	40
5,mC,r,H,dT,VL	2720	420	385	538	18	38.4	1.4	0	85	69	31	26

Continued

Activities	GCRN	GSOY	RCRN	RSOY	N-LOS	S-LOS	BIO	IRRI	COST	N	P	K
5,RF,r,H,dT,VL	2766	426	3123	653	20	33.1	1.4	0	105	97	40	70
5,FM,r,H,dT,VL	2851	440	399	560	12	14.4	1.4	0	102	65	29	25
5,nC,r,H,bT,VL	3808	560	3707	837	20	1.0	1.4	0	57	119	50	84
5,mC,r,H,bT,VL	3809	562	2318	140	17	1.0	1.4	0	54	101	44	57
5,nC,r,H,sT,VL	3506	525	3713	798	31	11.5	1.6	0	80	113	45	80
5,mC,r,H,sT,VL	3576	540	1268	444	20	5.4	1.6	0	77	83	35	35
5,RF,r,H,sT,VL	3608	544	3819	825	22	4.8	1.6	0	92	113	43	76
5,FM,r,H,sT,VL	3669	555	1279	460	15	2.6	1.6	0	88	82	34	34
5,nC,r,H,dT,TL	4093	602	3985	899	21	1.5	1.5	0	61	128	54	90
5,mC,r,H,dT,TL	4095	604	2491	150	18	1.5	1.5	0	57	108	47	62
5,nC,n,H,dT,FL	2643	480	2841	724	11	0.7	0.7	0	57	58	38	64
5,mC,n,H,dT,FL	2807	519	368	649	8	0.3	0.7	0	52	40	30	24
5,RF,n,H,dT,FL	3156	577	3132	862	11	0.0	0.7	0	70	66	43	71
5,FM,n,H,dT,FL	3252	592	402	736	8	0.0	0.7	0	65	45	34	28
5,nC,n,H,dT,GL	2515	437	2738	662	12	6.2	0.7	0	58	58	36	62
5,mC,n,H,dT,GL	2630	478	353	602	9	2.6	0.7	0	56	40	29	24
5,RF,n,H,dT,GL	2968	525	3047	787	12	1.2	0.7	0	72	65	41	69
5,FM,n,H,dT,GL	3077	547	394	683	8	0.3	0.7	0	69	44	32	26
5,nC,n,H,bT,GL	2962	520	2886	774	11	0.2	0.7	0	49	62	40	66
5,mC,n,H,bT,GL	3002	528	1828	654	9	0.2	0.7	0	48	53	36	49
5,nC,n,H,sT,GL	2690	468	2839	706	12	1.1	0.7	0	57	59	38	65
5,mC,n,H,sT,GL	2788	502	747	629	9	0.5	0.7	0	54	44	31	31
5,RF,n,H,sT,GL	3034	536	3074	801	12	0.3	0.7	0	67	66	42	70
5,FM,n,H,sT,GL	3128	554	778	691	9	0.2	0.7	0	64	48	34	33
5,nC,n,H,dT,ML	2432	412	2723	502	12	18.7	0.7	0	65	57	35	60
5,mC,n,H,dT,ML	2589	464	353	587	9	8.1	0.7	0	62	40	28	23
5,RF,n,H,dT,ML	2833	502	2979	603	12	5.5	0.7	0	80	63	40	67
5,FM,n,H,dT,ML	2937	524	382	657	10	1.1	0.7	0	77	44	32	27
5,nC,n,H,bT,ML	2899	509	2824	757	11	0.4	0.7	0	49	61	39	64
5,mC,n,H,bT,ML	2938	517	1789	641	9	0.4	0.7	0	48	52	36	47
5,nC,n,H,sT,ML	2656	455	2855	593	11	3.1	0.7	0	62	57	37	64
5,mC,n,H,sT,ML	2785	496	771	625	9	1.5	0.7	0	59	43	31	31
5,RF,n,H,sT,ML	2959	523	3048	670	12	1.2	0.7	0	73	64	41	69
5,FM,n,H,sT,ML	3048	542	793	677	10	0.5	0.7	0	70	47	34	33
5,nC,n,H,dT,SL	2219	370	2487	565	18	43.8	0.7	0	73	60	36	63
5,mC,n,H,dT,SL	2369	412	332	523	9	19.3	0.7	0	70	39	26	22
5,RF,n,H,dT,SL	2642	446	2889	674	12	15.9	0.7	0	89	62	37	65
5,FM,n,H,dT,SL	2634	482	353	606	11	4.0	0.7	0	86	42	30	25
5,nC,n,H,bT,SL	2710	476	2640	708	10	0.6	0.6	0	49	57	37	60
5,mC,n,H,bT,SL	2747	483	1673	599	9	0.6	0.6	0	48	49	33	44
5,nC,n,H,sT,SL	2576	439	2735	663	15	6.0	0.7	0	66	57	39	66
5,mC,n,H,sT,SL	2694	470	871	592	9	3.0	0.7	0	64	43	31	32
5,RF,n,H,sT,SL	2869	491	3014	738	11	2.6	0.7	0	78	61	40	68
5,FM,n,H,sT,SL	2878	519	885	649	10	1.1	0.7	0	75	46	34	34
5,mC,n,H,dT,VL	2026	363	290	464	12	41.1	0.6	0	79	38	25	21
5,RF,n,H,dT,VL	2206	390	2508	594	16	39.5	0.6	0	98	58	35	62
5,FM,n,H,dT,VL	2384	411	331	522	8	10.1	0.6	0	96	39	26	21
5,nC,n,H,bT,VL	2521	443	2456	659	9	1.0	0.6	0	49	53	34	56
5,mC,n,H,bT,VL	2555	449	1556	557	8	1.0	0.6	0	48	45	31	41
5,nC,n,H,sT,VL	2435	419	2601	635	4	11.7	0.7	0	72	23	41	72
5,mC,n,H,sT,VL	2542	452	874	570	11	5.2	0.7	0	69	42	31	33
5,RF,n,H,sT,VL	2656	468	2844	707	14	5.0	0.7	0	84	58	40	68
5,FM,n,H,sT,VL	2798	486	903	612	9	1.7	0.7	0	81	45	32	33
5,nC,n,H,dT,TL	2710	476	2640	708	10	1.5	0.6	0	56	57	37	60
5,mC,n,H,dT,TL	2747	483	1673	599	9	1.5	0.6	0	51	49	33	44

Continued

Activities	GCRN	GSOY	RCRN	RSOY	N-LOS	S-LOS	BIO	IRRI	COST	N	P	K
5,nC,i,M,dT,FL	7334	935	6252	1369	39	1.2	3.3	2767	1095	195	95	152
5,mC,i,M,dT,FL	7353	1021	783	1246	32	0.5	3.3	2737	1148	154	76	62
5,nC,r,M,dT,FL	4113	627	4353	950	24	0.7	3.1	0	975	136	56	97
5,mC,r,M,dT,FL	4291	660	557	831	17	0.2	3.1	0	1014	98	44	36
5,RF,r,M,dT,FL	4552	687	4559	1032	24	0.1	3.1	0	1173	143	60	102
5,FM,r,M,dT,FL	4612	696	573	870	18	0.0	3.1	0	1207	105	47	38
5,nC,r,M,dT,GL	3576	617	3820	934	24	5.8	3.0	0	1138	117	51	88
5,mC,r,M,dT,GL	3723	646	490	810	17	2.1	3.0	0	1180	81	40	34
5,RF,r,M,dT,GL	3968	673	4052	1010	24	1.0	3.0	0	1328	125	55	94
5,FM,r,M,dT,GL	4011	678	509	847	16	0.3	3.0	0	1378	87	42	35
5,nC,r,M,bT,GL	4474	658	4356	983	23	0.2	2.9	0	978	140	59	98
5,mC,r,M,bT,GL	4476	660	2723	164	20	0.2	2.9	0	1168	118	52	67
5,nC,r,M,sT,GL	3893	642	4048	968	23	0.9	3.0	0	1011	123	54	93
5,mC,r,M,sT,GL	4005	664	1086	660	18	0.4	3.0	0	1093	92	44	43
5,RF,r,M,sT,GL	4191	685	4224	1026	24	0.2	3.0	0	1156	130	57	97
5,FM,r,M,sT,GL	4224	689	1100	688	17	0.1	3.0	0	1244	96	46	44
5,nC,r,M,dT,ML	3460	532	3821	814	21	17.3	2.9	0	1367	118	48	84
5,mC,r,M,dT,ML	3615	562	489	714	16	7.3	2.9	0	1417	85	38	31
5,RF,r,M,dT,ML	3889	591	4053	892	29	4.4	2.9	0	1594	133	55	95
5,FM,r,M,dT,ML	3919	589	508	742	20	1.7	2.9	0	1637	94	42	34
5,nC,r,M,bT,ML	4379	644	4263	962	23	0.4	2.8	0	978	137	57	96
5,mC,r,M,bT,ML	4381	646	2665	161	20	0.4	2.8	0	1168	116	51	66
5,nC,r,M,sT,ML	3850	584	4090	886	21	2.7	3.0	0	1094	122	52	89
5,mC,r,M,sT,ML	3967	607	1120	585	17	1.2	3.0	0	1185	94	42	41
5,RF,r,M,sT,ML	4174	629	4265	946	28	0.8	3.0	0	1265	137	57	98
5,FM,r,M,sT,ML	4197	627	1135	606	20	0.4	3.0	0	1352	102	45	44

* Note:
5 = a three-year crop rotation of corn-soybean-corn
nC = Contoured tillage and crop residues removed
mC = Contoured tillage and crop residue mulching
RF = Furrow-ridging and crop residues removed
FM = Furrow-ridging and crop residue mulching
i = Attainable irrigated yield level, r = Attainable rainfed yield level
n = (attainable) N-limited yield level
M = Semi-mechanization level, H = Hand labor/animal traction
bT = Bench terracing, sT = Spaced terracing, and dT = Non-terracing (hillside ditches)
FL = Flood plain, TL = Existing terraces, GL= Gently sloping land (< 9%)
ML = Moderately sloping land (10-18%),
SL = Steeply sloping land (19-27%), and VL = Very steeply sloping land (28-47%).

Table A4.2. Inputs of labor, oxen and donkeys

L2, 4, 5, and LbT are labor inputs (man-days per ha per year) in labor period 2, 4 and 5, and per year. Ox2, 4, 5, and OxT is oxen inputs (days of oxen unit per ha) in labor period 2, 4 and 5. Dk4,5, and DkT are donkey inputs (days of donkey unit per ha per year) in labor period 4-5. No labor, oxen and donkeys are required for this crop rotation in other labor demand periods.

Activities	L2	L4	L5	LaT	Ox2	Ox4	Ox5	OxT	Dk4	Dk5	DkT
5,nC,i,H,dT,FL	10.6	25.2	62.8	98.9	10.3	1.4	7.2	18.9	2.6	0.8	3.4
5,mC,i,H,dT,FL	10.6	24.1	67.0	102.0	10.3	1.0	7.3	18.6	1.8	0.8	2.6
5,nC,r,H,dT,FL	10.8	15.4	39.5	65.7	10.8	0.9	6.9	18.6	1.7	0.5	2.2
5,mC,r,H,dT,FL	10.8	15.1	43.7	69.6	10.8	0.6	6.9	18.3	1.1	0.6	1.7

Continued

Activities	L2	L4	L5	LaT	Ox2	Ox4	Ox5	OxT	Dk4	Dk5	DkT
5,RF,r,H,dT,FL	18.2	17.0	43.0	78.2	18.2	1.0	7.0	26.2	1.9	0.6	2.5
5,FM,r,H,dT,FL	13.5	16.2	46.4	76.1	18.2	0.7	7.0	25.9	1.2	0.6	1.8
5,nC,r,H,dT,GL	12.5	26.9	39.3	78.7	12.5	1.1	9.2	22.8	12.9	0.5	13.4
5,mC,r,H,dT,GL	12.5	22.7	43.4	78.6	12.5	0.8	9.3	22.6	8.6	0.6	9.2
5,RF,r,H,dT,GL	21.1	31.6	33.3	86.0	21.1	1.2	9.2	31.5	14.0	0.5	14.5
5,FM,r,H,dT,GL	15.7	24.3	45.9	85.9	21.1	0.8	9.3	31.2	9.2	0.6	9.8
5,nC,r,H,bT,GL	11.8	31.6	55.8	99.2	10.2	1.3	6.6	18.1	15.2	0.6	15.8
5,mC,r,H,bT,GL	11.0	27.6	49.7	88.3	10.2	1.1	6.6	17.9	11.9	0.6	12.5
5,nC,r,H,sT,GL	12.6	28.7	41.6	82.9	12.2	0.4	7.3	19.9	13.8	0.6	14.4
5,mC,r,H,sT,GL	12.4	24.5	43.1	80.0	12.2	0.3	7.3	19.8	9.6	0.6	10.2
5,RF,r,H,sT,GL	19.1	32.3	37.0	88.4	18.7	0.4	7.2	26.3	14.7	0.5	15.2
5,FM,r,H,sT,GL	14.8	25.7	45.0	85.5	18.7	0.3	7.4	26.4	10.1	0.6	10.7
5,nC,r,H,dT,ML	14.0	27.4	41.5	82.9	14.0	1.1	11.2	26.3	12.4	0.5	12.9
5,mC,r,H,dT,ML	14.0	23.4	45.9	83.3	14.0	0.7	11.3	26.0	8.2	0.5	8.7
5,RF,r,H,dT,ML	23.6	30.4	45.0	99.0	23.6	1.2	11.3	36.1	13.6	0.5	14.1
5,FM,r,H,dT,ML	17.5	25.1	48.4	91.0	23.6	0.8	11.3	35.7	8.7	0.5	9.2
5,nC,r,H,bT,ML	11.5	30.9	58.9	101.3	10.2	1.3	6.6	18.1	15.2	0.6	15.8
5,mC,r,H,bT,ML	10.8	27.0	52.9	90.7	10.2	1.1	6.6	17.9	11.9	0.6	12.5
5,nC,r,H,sT,ML	13.8	29.4	42.2	85.4	13.5	0.4	7.5	21.4	13.7	0.5	14.2
5,mC,r,H,sT,ML	13.6	25.3	43.9	82.8	13.5	0.3	7.5	21.3	9.5	0.5	10.0
5,RF,r,H,sT,ML	21.1	31.7	44.9	97.7	20.7	0.4	7.6	28.7	14.6	0.5	15.1
5,FM,r,H,sT,ML	16.3	26.6	45.8	88.7	20.7	0.3	7.6	28.6	10.0	0.5	10.5
5,nC,r,H,dT,SL	15.3	26.7	46.5	88.5	15.3	1.0	15.4	31.7	11.2	0.4	11.6
5,mC,r,H,dT,SL	15.3	23.0	50.8	89.1	15.3	0.6	15.4	31.3	7.3	0.4	7.7
5,RF,r,H,dT,SL	25.8	28.8	48.8	103.4	25.8	1.1	15.5	42.4	12.0	0.4	12.4
5,FM,r,H,dT,SL	19.2	24.9	53.2	97.3	25.8	0.7	15.5	42.0	7.9	0.5	8.4
5,nC,r,H,bT,SL	10.8	28.9	64.2	103.9	10.2	1.3	6.6	18.1	15.2	0.6	15.8
5,mC,r,H,bT,SL	10.1	25.2	58.6	93.9	10.2	1.1	6.6	17.9	11.9	0.6	12.5
5,nC,r,H,sT,SL	14.7	29.6	43.8	88.1	14.5	0.5	6.7	21.7	13.6	0.5	14.1
5,mC,r,H,sT,SL	14.5	25.6	44.7	84.8	14.5	0.4	6.7	21.6	9.6	0.5	10.1
5,RF,r,H,sT,SL	22.0	31.1	45.4	98.5	21.8	0.5	6.8	29.1	14.2	0.5	14.7
5,FM,r,H,sT,SL	17.2	26.9	46.3	90.4	21.8	0.4	6.8	29.0	10.0	0.5	10.5
5,mC,r,H,dT,VL	15.7	21.2	63.5	100.4	15.7	0.5	23.9	40.1	6.2	0.4	6.6
5,RF,r,H,dT,VL	26.5	25.7	60.7	112.9	26.5	0.9	23.9	51.3	10.0	0.4	10.4
5,FM,r,H,dT,VL	19.7	22.2	64.7	106.6	26.5	0.6	23.9	51.0	6.4	0.4	6.8
5,nC,r,H,bT,VL	10.0	26.9	74.4	111.3	10.2	1.3	6.6	18.1	15.2	0.6	15.8
5,mC,r,H,bT,VL	9.4	23.4	69.2	102.0	10.2	1.1	6.6	17.9	11.9	0.6	12.5
5,nC,r,H,sT,VL	15.5	28.9	44.7	89.1	15.6	0.6	5.0	21.2	13.3	0.5	13.8
5,mC,r,H,sT,VL	15.3	25.2	45.3	85.8	15.6	0.5	5.0	21.1	9.5	0.5	10.0
5,RF,r,H,sT,VL	23.2	29.9	45.5	98.6	23.3	0.6	5.0	28.9	13.7	0.5	14.2
5,FM,r,H,sT,VL	18.1	25.9	46.2	90.2	23.3	0.5	5.1	28.9	9.7	0.5	10.2
5,nC,r,H,dT,TL	10.1	28.5	63.8	102.4	9.3	1.2	6.0	16.5	13.9	0.5	14.4
5,mC,r,H,dT,TL	10.1	25.2	70.1	105.4	9.3	1.0	6.0	16.3	10.9	0.5	11.4
5,nC,n,H,dT,FL	10.8	13.5	25.2	49.5	10.8	1.7	3.9	16.4	3.3	0.4	3.7
5,mC,n,H,dT,FL	10.8	12.5	28.6	51.9	10.8	1.2	4.0	16.0	2.2	0.4	2.6
5,RF,n,H,dT,FL	18.2	16.0	29.5	63.7	18.2	2.0	4.1	24.3	3.8	0.5	4.3
5,FM,n,H,dT,FL	16.7	14.4	32.5	63.6	18.2	1.4	4.2	23.8	2.5	0.5	3.0
5,nC,n,H,dT,GL	12.5	19.1	27.4	59.0	12.5	0.8	5.8	19.1	9.3	0.4	9.7
5,mC,n,H,dT,GL	12.5	16.3	30.6	59.4	12.5	0.6	5.9	19.0	6.2	0.4	6.6
5,RF,n,H,dT,GL	21.1	23.9	24.3	69.3	21.1	1.0	5.8	27.9	10.7	0.4	11.1
5,FM,n,H,dT,GL	19.3	18.9	34.6	72.8	21.1	0.6	6.0	27.7	7.2	0.5	7.7
5,nC,n,H,bT,GL	11.8	21.7	41.0	74.5	10.2	10.4	3.8	24.4	10.5	0.4	10.9
5,mC,n,H,bT,GL	11.0	19.9	38.1	69.0	10.2	10.4	3.8	24.4	8.9	0.5	9.4
5,nC,n,H,sT,GL	12.6	20.2	28.6	61.4	12.2	2.7	3.9	18.8	9.8	0.4	10.2
5,mC,n,H,sT,GL	12.4	17.6	30.3	60.3	12.2	2.7	4.0	18.9	7.1	0.4	7.5

Continued

Activities	L2	L4	L5	LaT	Ox2	Ox4	Ox5	OxT	Dk4	Dk5	DkT
5,RF,n,H,sT,GL	19.1	23.9	26.3	69.3	18.7	2.7	4.0	25.4	10.9	0.4	11.3
5,FM,n,H,sT,GL	17.6	19.6	33.3	70.5	18.7	2.7	4.1	25.5	7.8	0.5	8.3
5,nC,n,H,dT,ML	14.0	19.6	29.8	63.4	14.0	0.8	7.5	22.3	8.9	0.4	9.3
5,mC,n,H,dT,ML	14.0	17.3	33.7	65.0	14.0	0.5	7.6	22.1	6.1	0.4	6.5
5,RF,n,H,dT,ML	23.6	22.7	33.3	79.6	23.6	0.9	7.7	32.2	10.1	0.4	10.5
5,FM,n,H,dT,ML	21.7	19.6	36.8	78.1	23.6	0.6	7.8	32.0	6.9	0.5	7.4
5,nC,n,H,bT,ML	11.5	21.3	44.4	77.2	10.2	10.4	3.8	24.4	10.5	0.4	10.9
5,mC,n,H,bT,ML	10.8	19.5	41.6	71.9	10.2	10.4	3.8	24.4	8.9	0.5	9.4
5,nC,n,H,sT,ML	13.8	20.8	29.3	63.9	13.5	2.9	3.9	20.3	9.6	0.4	10.0
5,mC,n,H,sT,ML	13.6	18.6	31.4	63.6	13.5	2.9	4.0	20.4	7.1	0.4	7.5
5,RF,n,H,sT,ML	21.1	23.1	31.9	76.1	20.7	2.9	4.0	27.6	10.6	0.5	11.1
5,FM,n,H,sT,ML	19.4	20.3	33.8	73.5	20.7	2.9	4.1	27.7	7.7	0.5	8.2
5,nC,n,H,dT,SL	15.3	19.5	35.6	70.4	15.3	0.7	11.4	27.4	8.2	0.3	8.5
5,mC,n,H,dT,SL	15.3	17.4	39.5	72.2	15.3	0.5	11.5	27.3	5.6	0.4	6.0
5,RF,n,H,dT,SL	25.8	23.1	39.1	88.0	25.8	0.9	11.6	38.3	9.7	0.4	10.1
5,FM,n,H,dT,SL	23.7	19.5	42.1	85.3	25.8	0.6	11.6	38.0	6.2	0.4	6.6
5,nC,n,H,bT,SL	10.8	19.9	50.6	81.3	10.2	10.4	3.8	24.4	10.5	0.4	10.9
5,mC,n,H,bT,SL	10.1	18.2	48.0	76.3	10.2	10.4	3.8	24.4	8.9	0.5	9.4
5,nC,n,H,sT,SL	14.7	21.1	31.1	66.9	14.5	4.0	2.9	21.4	9.7	0.4	10.1
5,mC,n,H,sT,SL	14.5	19.0	32.8	66.3	14.5	4.0	3.0	21.5	7.3	0.4	7.7
5,RF,n,H,sT,SL	22.0	23.6	33.6	79.2	21.8	4.0	3.0	28.8	10.7	0.4	11.1
5,FM,n,H,sT,SL	20.3	20.5	34.6	75.4	21.8	4.0	3.1	28.9	7.7	0.5	8.2
5,mC,n,H,dT,VL	15.7	16.4	53.6	85.7	15.7	0.4	19.9	36.0	4.8	0.3	5.1
5,RF,n,H,dT,VL	26.5	21.1	52.5	100.1	26.5	0.7	20.0	47.2	8.3	0.3	8.6
5,FM,n,H,dT,VL	24.3	19.1	56.8	100.2	26.5	0.5	20.0	47.0	5.6	0.4	6.0
5,nC,n,H,bT,VL	10.0	18.5	61.8	90.3	10.2	10.4	3.8	24.4	10.5	0.4	10.9
5,mC,n,H,bT,VL	9.4	16.9	59.4	85.7	10.2	10.4	3.8	24.4	8.9	0.5	9.4
5,nC,n,H,sT,VL	15.5	20.8	32.4	68.7	15.6	4.5	0.9	21.0	9.6	0.4	10.0
5,mC,n,H,sT,VL	15.3	19.0	34.0	68.3	15.6	4.5	1.0	21.1	7.3	0.4	7.7
5,RF,n,H,sT,VL	23.2	23.0	34.3	80.5	23.3	4.5	1.0	28.8	10.4	0.4	10.8
5,FM,n,H,sT,VL	21.4	20.9	36.3	78.6	23.3	4.5	1.1	28.9	7.8	0.4	8.2
5,nC,n,H,dT,TL	10.1	19.6	50.4	80.1	10.1	0.8	3.7	14.6	9.6	0.4	10.0
5,mC,n,H,dT,TL	10.1	18.2	55.9	84.2	9.3	9.5	3.5	22.3	8.2	0.4	8.6
5,nC,i,M,dT,FL	1.2	7.9	8.5	17.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,mC,i,M,dT,FL	1.2	7.0	9.0	17.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,nC,r,M,dT,FL	1.1	6.9	5.1	13.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,mC,r,M,dT,FL	1.1	4.3	5.5	10.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,RF,r,M,dT,FL	5.8	5.3	5.5	16.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,FM,r,M,dT,FL	1.4	4.6	5.8	11.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,nC,r,M,dT,GL	1.1	4.8	7.6	13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,mC,r,M,dT,GL	1.1	4.3	8.0	13.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,RF,r,M,dT,GL	6.0	5.2	6.4	17.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,FM,r,M,dT,GL	1.4	4.6	8.3	14.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,nC,r,M,bT,GL	1.1	5.6	18.4	25.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,mC,r,M,bT,GL	1.1	5.0	17.7	23.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,nC,r,M,sT,GL	1.1	5.1	7.7	13.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,mC,r,M,sT,GL	1.1	4.6	7.8	13.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,RF,r,M,sT,GL	4.9	5.4	6.7	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,FM,r,M,sT,GL	1.4	4.8	8.0	14.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,nC,r,M,dT,ML	1.3	5.0	10.3	16.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,mC,r,M,dT,ML	1.3	4.5	10.7	16.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,RF,r,M,dT,ML	6.7	5.5	10.7	22.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,FM,r,M,dT,ML	1.6	4.8	11.0	17.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,nC,r,M,bT,ML	1.1	5.4	22.3	28.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,mC,r,M,bT,ML	1.0	4.9	21.6	27.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Continued

Activities	L2	L4	L5	LaT	Ox2	Ox4	Ox5	OxT	Dk4	Dk5	DkT
5,nC,r,M,sT,ML	1.3	5.3	8.3	14.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,mC,r,M,sT,ML	1.3	4.8	8.4	14.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,RF,r,M,sT,ML	5.4	5.7	8.6	19.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5,FM,r,M,sT,ML	1.5	5.0	8.6	15.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

A4.2 Input-output coefficients of fruit and grass production activities

Table A4.3 Input-output coefficients (per hectare per year) of fruit activities

Land unit	yld t	N-loss kg	S-loss t	Wat t	bio kg	cost yuan	N kg	P kg	K kg	lab1	lab2	lab3	lab4	lab5	labT
FL	38	80	0	2400	14	129	266	74	232	45.3	70.8	21.3	63.8	138.8	340.0
GL	16	51	1.2	0	7	188	166	53	145	24.0	37.5	11.3	33.8	73.5	180.1
ML	16	51	1.4	0	7	244	166	53	145	26.4	41.3	12.4	37.1	80.9	198.1
SL	16	51	1.7	0	7	251	166	53	145	29.0	45.4	13.6	40.8	88.9	217.7
VL	16	51	2.1	0	7	298	166	53	145	31.9	49.9	15.0	44.9	97.8	239.5
TL	16	51	2.1	0	7	136	166	53	145	23.2	36.3	10.9	32.6	71.1	174.1

Notes: It needs 19 (FLP) and 8.8 (GSL-TRL) days of donkey units for transport of apple.
yld: apple yield in fresh weight, Wat: irrigation water, and bio: biocide use in active ingredient.
N- and S-loss is N and soil losses.
Lab1-5: Labor requirements in labor demand periods of 1-5 in man-days per hectare
LabT: total labor input in man-days per ha.

Table A4.4 Input-output coefficients (per hectare) of sown grass activities

Land Unit	Yield (DM) kg	N-loss kg	soil loss t	cost yuan	N kg	P kg	K kg	labor man-day	oxen day
Sown grass with use of fertilizer N									
GL	12590	59.0	0.3	76	373	94	269	2.5	2.5
ML	12232	60.1	1.1	77	366	93	268	2.9	2.9
SL	12073	64.8	2.7	77	356	90	260	3.6	3.6
VL	11599	72.8	7.7	77	357	91	261	4.2	4.2
Sown grass without use of fertilizer N									
GL	5085	1.3	1.1	76		32	92	0.9	0.9
ML	4871	4.1	4.2	76		30	88	1.1	1.1
SL	4557	8.9	11.5	76		29	82	1.2	1.2
VL	4153	19.3	32.7	76		26	75	1.4	1.4

Table A4.5 Input-output coefficients (per hectare) of firewood (planted shrubs) activities

Land unit	Yield (kg DM)	Soil loss (t)	cost (yuan)	labor (man-days)	donkey (days)
SL	2000	0.5	7.5	16.3	5.0
VL	1600	1.2	6.0	13.7	4.0

Appendix 5 A General Description of Animal Models and Technical Coefficients of Livestock Activities

The livestock activities are quantified on the basis of a stable herd structure that is determined by fecundity and mortality rates, sex ratio and culling age of the animals. For each activity, the inputs and outputs, and other production parameters are assumed to be identical each year. Feed requirements are expressed in terms of digestible energy (DE) and digestible crude protein (DCP). A simple model that is based on modeling methods, as described by Van Duivenbooden *et al.* (1991) and Hengsdijk *et al.* (1996), has been developed to determine the herd structure, and to derive the input and output coefficients. The modeling approaches and calculation procedures for the animal production activities of goats, sheep, cattle and donkeys are described in this appendix.

A5.1 Goats/sheep

The parameter values, formulae and calculation procedures are presented in Tables A5.1, A5.2 and A5.3 for cashmere goats, fine-wool sheep and small-tail sheep, respectively. In these tables, the first column gives the number of the row and the second the parameter. The third column is the parameter value of female (or total) animals as given or calculated by the formula listed in the last column. The fourth column is the parameter values of the male animals as given or calculated with the same equation as for the females.

A5.1.1 Herd structure

The herd structure is modeled on an annual basis, by assuming that the following factors are identical in each year:

- Fecundity rate, the number of animals born to a reproductive animal per year
- Mortality rate, the fraction of annual deaths as total animals. Two mortality rates, i.e., below and above 1 year of age are given in this study.
- Sex ratio, the ratio of reproductive female to breeding male animals. A value of 30 is used.
- Culling age, the age of animals at offtake. For the three activities, the breeding goats/sheep (female and male) are all culled at 5 years of age. For small-tail sheep, all born lambs except those for replacement are culled at 0.75 years. For cashmere goats and fine-wool sheep, two culling ages are defined: 0.75 years and 1.5 years. Of the born animals not used for replacement, 40% is culled in the first late autumn (0.75 years), and the remainder in next early autumn (1.5 years), assuming that the animals are born in spring.

Based on these assumptions, the herd structure can be modeled starting from the number of reproductive animals culled at 5 years of age, which is set to 30 (F15) in Tables A5.1, A5.2 and A5.3. The value does not affect the final results, as the herd composition changes proportionally. To arrive at the 30 animals, 31.6 females (F14, equals 30/(1-0.05)) should attain 4 years of age, taking into account the mortality rate of 0.05 (F3). The number of animals at other ages follows from the same procedure, with the equations as presented in the last column (rows 8-12). The same calculation procedures are applied for the males.

The number of animals annually born is the product of reproductive population (total breeding animals between 1 and 5 years of age excluding deaths) and the fecundity rate. Half of the annually born animals are female (F5) and half are male (M5). The number of non-reproductive animals including the females and males not used for replacement is determined by equations in the last column from rows 18 to 20. Culled animals include the obsolete and non-breeding goats that are not needed for maintenance of the population. Annually culled heads, and the equations applied are shown in rows 15 and 22-24. Total animal number is the sum of the breeding and non-breeding animals given in row 48 in Table A5.1, row 42 in Table A5.2 and row 40 in A5.3. The fraction of annually culled heads is presented in rows 54, 48 and 46 in the tables of A5.1, A5.2 and A5.3, respectively.

Liveweight and wool/cashmere of the animals at different ages are estimated according to Li (1996), Yu (1995), Mo & Zhao (1997). From these data, total liveweight of the breeding, non-breeding and culled animals is calculated, e.g., as presented in rows 49-51 in Table A5.1 for goats. Further, the average weight of the total and culled animals is determined, computed as the ratio of total liveweight to total number of animals, and total culled liveweight to total culled heads, respectively. The culling rate, expressed as ratio of total culled liveweight to total animal liveweight is calculated for the three animal types and presented in rows 55, 49 and 47 in Tables A5.1, A5.2 and A5.3, respectively. Wool/cashmere production is the sum of that produced by goats/sheep in each age group.

A5.1.2 Feed requirement and production

To derive the input-output coefficients for the LP model, the production data should be converted into a standard unit. In this study, an animal unit (AU) is used, that is defined as 500 kg total liveweight of total goats/sheep in the herd. Based on this unit, the input and output coefficients for the goats/sheep activities can be determined. The procedures to calculate the outputs and feed intake of an animal unit are given in rows 57-73 for goats in Table A5.1, rows 51-66 for fine-wool sheep in Table A5.2 and rows 49-64 for small-tail sheep in Table A5.3. The following description takes the goats as an example (Table A5.1).

First, the number of goats per animal unit is determined in row 59; then the number, liveweight and carcass weight of goats at offtake, and the production of wool and cashmere are computed in rows 60-65. DE requirement for maintenance is calculated from daily requirements, average metabolic liveweight of the goats, goat number and feeding days (365 days), as presented in row 66.

DE required for growth is calculated on the basis of utilization efficiency of metabolic energy (UEM) for the net body-weight gain, defined as the ratio of energy retention to metabolic energy intake. In this study, an average value of 0.41 for UEM according to Bondi (1982) is used. The factor 0.82 in the equation in row 69 is used to convert metabolic energy to digestible energy. Net weight gain for the animal unit equals total culling liveweight. Energy stored in the animal products is calculated on the basis of the content of protein and fat in the carcass. Constants 23.85 and 38.49 are heat of combustion values (MJ kg^{-1}) of animal protein and fat, respectively.

The requirement for digestible crude protein (DCP) is presented in row 71, assuming DCP proportional to intake of DE. The ratio of DE to DCP, i.e., 140 (MJ kg^{-1}) in row 1 is used to determine the required DCP. In the last rows 72-73, N retention in animal products and in urine is determined.

Table A5.1 Production parameters, calculation procedures of herd structure, and production of meat, wool or cashmere and urine N, and feed intake of the cashmere goats activity

No	Characteristics	F	M	Formula
1	Feed quality DE:DCP (MJ kg^{-1})	140	140	
2	Mortality rate <1 year of age	0.15	0.15	
3	Mortality rate >1 year of age	0.05	0.05	
4	Fecundity rate	1.3		
5	Kids born	84.1	84.1	=F4*F16*(1-F3)/2
6	Fraction of kids culled at 0.75 year	0.4	0.4	
7	*Number of reproductive goats that attain the age*			
8	At 0 year (birth)	43.1	1.4	=F9/(1-F2*0.75)
9	At 0.75 year	38.2	1.3	=F10/(1-F2*0.25)
10	At 1 year	36.8	1.3	=F11/(1-F3*0.5)
11	At 1.5 years	35.9	1.2	=F12/(1-F3/2)
12	At 2 years	35.0	1.2	=F13/(1-F3)
13	At 3 years	33.2	1.1	=F14/(1-F3)
14	At 4 years	31.6	1.1	=F15/(1-F3)
15	At 5 years (culled)	30.0	1.0	
16	Total breeding animals	136.2	4.6	=SUM(F12:F14)+F11*0.5+F10*0.5
17	*Number of non-breeding goats that can reach the age*			
18	At 0 year (birth)	41.0	82.7	=F5-F8
19	At 0.75 years	23.7	47.8	=F18*(1-F2*0.25)*(1-F6)
20	At 1.5 years	23.1	46.6	=F19*(1-F3/2)
21	*Number of annually culled goats*			
22	At 0.75 year	14.6	29.4	=(F5-F8)*(1-F2*0.75)*F6
23	At 1.5 year	23.1	46.6	=F20
24	Total heads	67.6	76.9	=SUM(F22:F23)+F15
25	*Weight of goats (kg)*			
26	At birth female	1.8	2.0	
27	At 0.75 year	30.0	32.5	
28	At yearling	32.0	37.5	
29	At 1.5 year	36.0	42.5	
30	At 2 years	39.2	47.5	
31	At 3 years	40.0	50.0	
32	At maturity	40.0	50.0	
33	*Annual wool production per goat (kg)*			
34	At 1 year	0.15	0.25	
35	At 2 year	0.25	0.40	
36	At 3 year	0.30	0.50	
37	At 4-5 year	0.30	0.50	
38	*Annual cashmere production per goats (kg)*			
39	At 1 year	0.15	0.20	
40	At 2 year	0.25	0.35	
41	At 3 year	0.30	0.40	
42	At 4-5 year	0.30	0.40	
43	Total wool production	39.0	13.8	=(F34+F35)/2*((F11+F10)*0.5+(F12+F11)*0.5)/2+(F35+F36)/2*(F13+ F12)/2+(F36+F37)/2*(F14+F13)/2+F37*(F15+F14)/2+F34*(F19+F20)/2
44	Total cashmere produce	39.0	11.0	=(F39+F40)/2*((F11+F10)*0.5+(F12+F11)*0.5)/2+(F40+F41)/2*(F13 +F12)/2+(F41+F42)/2*(F14+F13)/2+F42*(F15+F14)/2+F39*(F19+F20)/2
45	*Annual number of living goats in the herd*			
46	Total number of breeding goats	173.1	5.8	=0.5*((F8+F9)*0.75+(F9+F10)*0.25+(F11+F10)*0.5+(F12+F11)*0.5 +(F13+F12)+(F14+F13)+(F15+F14))
47	Number of non-breeding goats	46.7	94.3	=F18*(1-F2/2*0.75)*0.75+F19*(1+F2/2*0.25)*0.25+F20*(1+F3/2*0.5)*0.5
48	Total number of goats	219.8	100.1	=SUM(F46:F47)
49	Total liveweight of breeding goats	5938.9	241.5	=(F26+F27)/2*(F8+F9)/2*0.75+(F27+F28)/2*(F9+F10)/2*0.25+(F28+F29)/2* (F11+F10)/2*0.5+(F29+F30)/2*(F12+F11)/2*0.5+(F30+F31)/2*(F13+F12)/2+ (F31+F32)/2*(F14+F13)/2+F32*(F15+F14)/2
50	Total non-breeding liveweight	1045.4	2378.9	=(F26+F27)/2*F18*(1-F2/2*0.75)*0.75+(F27+F28)/2*F19 *(1+F2/2*0.25)*0.25+(F28+F29)/2*F20*(1+F3/2*0.5)*0.5
51	Total culled liveweight	2467.4	2983.8	=F22*F27+F23*F29+F32*F15

Continued

No	Characteristics	F	M	Formula
52	Mean weight of the goats	30.0		=(F49+M49+F50+M50)/(F48+M48)
53	Mean weight of culled goats	37.7		=(F51+M51)/(F24+M24)
54	Ratio culled to total heads	0.45		=(F24+M24)/(F48+M48)
55	Ratio culled to total liveweight	0.57		=(F51+M51)/(F49+M49+F50+M50)
56	*Annual production and feed requirements per animal unit (500 kg liveweight)*			
57	Liveweight of the animal unit	500.0		
58	Daily DE requirement for maintenance (MJ $W^{-0.75}$)	0.586		
59	Numbers of goats per animal unit	16.7		=F57/F52
60	Numbers of goats at offtake	7.5		=F59*F54
61	Meat in liveweight (kg)	283.8		=F57*F55
62	Dressing rate	0.45		
63	Carcass production (kg)	127.7		=F61*F62
64	Wool (kg)	2.7		=F57/(F49+M49+F50+M50)*(F43+M43)
65	Cashmere (kg)	2.6		=F57/(F49+M49+F50+M50)*(F44+M45)
66	DE requirement for maintenance (MJ)	52518.7		=F58*F52^0.75*365*F59
67	*Protein content of meat*	*0.21*		
68	*Fat content of meat*	*0.04*		
69	DE required for growth (MJ)	2874.9		=F61*F62*(23.85*F67+39.33*F68)/(0.41*0.82)*1.15
70	Annual DE requirement (MJ)	55393.6		=F66+F69
71	Annual DCP intake (kg)	395.7		=F70/F1
72	N exported by the product (kg)	5.1		=F67*F61*F62/6.25+(F64+F65)*0.16
73	Total urine N (kg)	58.2		=F71/6.25-F72

Table A5.2 Production parameters, calculation procedures of herd structure, production of meat, wool and urine N, and feed intake of the fine-wool sheep activity

No	Characteristics	F	M	Formula
1	Feed quality DE:DCP (MJ kg^{-1})	130	130	
2	Mortality rate <1 year	0.15	0.15	
3	Mortality rate >1 year	0.05	0.05	
4	Fecundity rate	1.3		
5	Number of annually born lambs	84.1	84.1	=F4*F16*(1-F3)/2
6	Fraction of lambs culled at 0.75 year	0.4	0.4	
7	*Number of breeding sheep that attain the age*			
8	At 0 year (birth)	43.1	1.4	=F9/(1-F2*0.75)
9	At 0.75 year	38.2	1.3	=F10/(1-F2*0.25)
10	At 1 years	36.8	1.3	=F11/(1-F3*0.5)
11	At 1.5 years	35.9	1.2	=F12/(1-F3/2)
12	At 2 years	35.0	1.2	=F13/(1-F3)
13	At 3 years	33.2	1.1	=F14/(1-F3)
14	At 4 years	31.6	1.1	=F15/(1-F3)
15	At 5 years	30.0	1.0	
16	Total breeding animals	136.2	4.6	=SUM(F12:F14)+F11*0.5+F10*0.5
17	*Number of non-breeding sheep that attain the age*			
18	At 0 year (birth)	41.0	82.7	=F5-F8
19	At 0.75 years	23.7	47.8	=F18*(1-F2*0.25)*(1-F6)
20	At 1.5 years	23.1	46.6	=F19*(1-F3/2)
21	*Number of annually culled sheep*			
22	At 0.75 year	14.6	29.4	=(F5-F8)*(1-F2*0.75)*F6
23	At 1.5 year	23.1	46.6	=F20
24	Total	67.6	76.9	=SUM(F22:F23)+F15
25	*Weight of sheep (kg)*			
26	At birth	3.5	3.7	
27	At 0.75 year	33	41	
28	At yearling	38	54	

Continued

No	Characteristics	F	M	Formula
29	At 1.5 year	43	68	
30	At 2 years	48	77	
31	At 3 years	50	86	
32	At maturity	50	90	
33	*Annual wool production per sheep (kg)*			
34	At 1 year	1.3	2.3	
35	At 2 year	2.5	4.5	
36	At 3 year	2.8	5.0	
37	At maturity	2.8	5.0	
38	Total wool production	366.0	128.6	=(F34+F35)/2*((F11+F10)*0.5+(F12+F11)*0.5)/2+(F35+F36)/2*(F13 +F12)/2+(F36+F37)/2*(F14+F13)/2+F37*(F15+F14)/2+F34*(F19+F20)/2
39	*Annual number and liveweight (kg) of sheep in the herd*			
40	Total number of feeding sheep	173.1	5.8	=0.5*((F8+F9)*0.75+(F9+F10)*0.25+(F11+F10)*0.5+(F12+F11)*0.5 +(F13+F12)+(F14+F13)+(F15+F14))
41	Number of non-breeding sheep	46.7	94.3	=F18*(1-F2/2*0.75)*0.75+F19*(1+F2/2*0.25)*0.25 +F20*(1+F3/2*0.5)*0.5
42	Total sheep heads	219.8	100.1	=SUM(F40:F41)
43	Total breeding liveweight	7224.8	398.1	=(F26+F27)/2*(F8+F9)/2*0.75+(F27+F28)/2*(F9+F10)/2*0.25+(F28+F29)/2*(F11+F10)/2*0.5+(F29+F30)/2*(F12+F11)/2*0.5+(F30+F31)/2*(F13+ F12)/2+(F31+F32)/2*(F14+F13)/2+F32*(F15+F14)/2
44	Total non-breeding liveweight	1200.6	3301.2	=(F26+F27)/2*F18*(1-0.5*F2*0.75)*0.75+(F27+F28)/2*F19 *(1+F2/2*0.25)*0.25+(F28+F29)/2*F20*(1+F3/2*0.5)*0.5
45	Total culled liveweight	2953.8	4423.1	=F22*F27+F23*F29+F32*F15
46	Mean weight of the sheep	37.9		=(F43+M43+F44+M44)/(F42+M42)
47	Mean culled weight	51.0		=(F45+M45)/(F24+M24)
48	Ratio culled to total heads	0.45		=(F24+M24)/(F42+M42)
49	Ratio culled to total sheep weight	0.61		=(F45+M45)/(F43+M43+F44+M44)
50	*Annual production and feed requirement per animal unit (500 kg liveweight)*			
51	Liveweight of the animal unit	500.0		
52	Daily DE requirement for maintenance (MJ $W^{-0.75}$)	0.586		
53	Number of sheep per animal unit	13.2		=F51/F46
54	Number of sheep for offtake	6.0		=F53*F48
55	Meat in liveweight (kg)	304.2		=F51*F49
56	Dressing rate	0.50		
57	Carcass production (kg)	152.1		=F55*F56
58	Wool (kg)	20.4		=F51/(F43+M43+F44+M44)*(F38+M38)
59	DE requirement for maintenance (MJ)	43084.4		=F52*F46^0.75*365*F53
60	*Protein content of meat*	*0.15*		
61	*Fat content of meat*	*0.26*		
62	DE required for growth (MJ)	7181.7		=F55*F56*(23.85*F60+39.33*F61)/(0.41*0.82)*1.15
63	Annual DE requirement (MJ)	50266.1		=F59+F62
64	Annual DCP intake (kg)	386.7		=F63/F1
65	N removed in products (kg)	6.9		=F60*F55*F56/6.25+F58*0.16
66	Total urine N (kg)	55.0		=F64/6.25-F65

Table A5.3 Production parameters, calculation procedures of herd structure, production of meat, wool and urine N, and feed intake of the small-tail sheep activity

No	Characteristics	F	M	Formula
1	Feed quality DE: DCP (MJ kg^{-1})	125	125	
2	Mortality rate <1 year	0.15	0.15	
3	Mortality rate >1 year	0.05	0.05	
4	Fecundity rate	2.5		
5	Number of annually born lambs	161.7	161.7	=F4*F16*(1-F3)/2
6	Fraction of lambs culled at 0.75 year	1.0	1.0	
7	*Number of breeding sheep that attain the age*			
8	At 0 year (birth)	43.1	1.4	=F9/(1-F2*0.75)
9	At 0.75 year	38.2	1.3	=F10/(1-F2*0.25)
10	At 1 years	36.8	1.3	=F11/(1-F3*0.5)
11	At 1.5 years	35.9	1.2	=F12/(1-F3/2)
12	At 2 years	35.0	1.2	=F13/(1-F3)
13	At 3 years	33.2	1.1	=F14/(1-F3)
14	At 4 years	31.6	1.1	=F15/(1-F3)
15	At 5 years (culled)	30.0	1.0	
16	Total breeding sheep	136.2	4.6	=SUM(F12:F14)+F11*0.5+F10*0.5
17	*Number of non-breeding sheep that attain the age*			
18	At 0 year (birth)	118.6	160.3	=F5-F8
19	At 0.75 years	0.0	0.0	=F18*(1-F2*0.25)*(1-F6)
20	*Number of annually culled sheep*			
21	At 0.75 year	105.3	142.3	=(F5-F8)*(1-F2*0.75)*F6
22	Total number of culled sheep	135.3	143.3	=F21+F15
23	*Weight of sheep*			
24	At birth	3.5	3.7	
25	At 0.75 year	38	44	
26	At yearling	44	56	
27	At 1.5 year	50	68	
28	At 2 years	55	76	
29	At 3 years	55	80	
30	At maturity	55	80	
31	*Annual wool produce per sheep (kg)*			
32	At 1 year	0.7	1.2	
33	At 2 year	1.4	2.5	
34	At 3 year	1.5	2.8	
35	At maturity	1.5	2.8	
36	Total wool production	179.8	11.2	=(F32+F33)/2*((F10+F11)*0.5+(F11+F12)*0.5)/2+(F33+F34)/2 *(F12+F13)/2+(F34+F35)/2*(F13+F14)/2+F35*(F15+F14)/2
37	*Annual number and liveweight (kg) of sheep in the herd*			
38	Total number of feeding sheep	173.1	5.8	=0.5*((F8+F9)*0.75+(F9+F10)*0.25+(F11+F10)*0.5+(F12+F11)*0.5 +(F13+F12)+(F14+F13)+(F15+F14))
39	Number of non-breeding sheep	83.9	113.5	=F18*(1-F2*0.75/2)*0.75
40	Total sheep heads	257.0	119.3	=SUM(F38:F39)
41	Total breeding liveweight	8144.3	379.5	=(F24+F25)/2*(F8+F9)/2*0.75+(F25+F26)/2*(F9+F10)/2*0.25+(F26+F27) /2*(F11+F10)/2*0.5+(F27+F28)/2*(F12+F11)/2*0.5+(F28+F29)/2*(F13+F 12)/2+(F29+F30)/2*(F14+F13)/2+F30*(F15+F14)/2
42	Total non-breeding liveweight	1739.8	2706.6	=(F24+F25)/2*F39
43	Total culled liveweight	5644.5	6340.8	=F21*F25+F30*F15
44	Mean weight of the sheep	34.5		=(F41+M41+F42+M42)/(F40+M40)
45	Mean culled liveweight	43.0		=(F43+M43)/(F22+M22)
46	Ratio culled to total heads	0.74		=(F22+M22)/(F40+M40)
47	Ratio culled to total sheep liveweight	0.92		=(F43+M43)/(F41+M41+F42+M42)
48	*Annual production and feed requirement per animal unit (500 kg liveweight)*			
49	Liveweight of the animal unit	500.0		
50	Daily DE requirement (MJ $W^{-0.75}$)	0.586		
51	Number of sheep per animal unit	14.5		=F49/F44
52	Number of sheep for offtake	10.7		=F51*F46

Continued

No	Characteristics	F	M	Formula
53	Meat in liveweight (kg)	462.0		=F49*F47
54	Dressing rate	0.50		
55	Carcass production (kg)	231.0		=F53*F54
56	Wool (kg)	7.4		=F49/(F41+M41+F42+M42)*(F36+M36)
57	DE requirement for maintenance (MJ)	44119.9		=F50*F44^0.75*365*F51
58	*Protein content of meat*	*0.16*		
59	*Fat content of meat*	*0.26*		
60	DE required for growth (MJ)	11095.8		=F53*F54*(5.7*4.184*F58+9.4*4.184*F59)/(0.41*0.82)*1.15
61	Annual DE requirement (MJ)	55215.7		=F57+F60
62	Annual DCP intake (kg)	441.7		=F61/F1
63	N removed in products (kg)	7.1		=F58*F53*F54/6.25+F56*0.16
64	Total urine N (kg)	63.6		=F62/6.25F63

A5.2 Cattle and donkeys

A5.2.1 Cattle

The cattle activity is defined for producing draught animals, with the assumption that the young cattle at 3 years of age are off-taken except for those kept for replacement. The herd structure is modeled similarly to that for goats/sheep. The reproductive period is set to 10 years, starting from 3 years of age. After use of 10 years, the cattle are culled at 13 years of age, and meat can be consumed.

Modeling of the herd structure starts by setting the number of reproductive cattle. In Table A5.4, 10 breeding female cattle are supposed to be culled at 13 years of age. From this 10 cattle, the number of female cattle in age groups 12-13 year, 11-12 year, …., and 0-1 year can be derived with Eqn A5.1. In that equation, t equals 1, 2,…., 12. For annually born cattle, Eqn A5.2 is applied.

$$RCF_t = \frac{RCF_{t+1}}{1-MR_t} \qquad \text{A5.1}$$

in which RCF_t or RCF_{t+1} is number of reproductive cows in age group t or $(t+1)$, and MR_t is average mortality rate of the cattle in age group t.

$$CB = \sum_{3}^{13} RCF_t \cdot (1 - MR_t) \cdot FR_t \qquad \text{A5.2}$$

in which CB is total number of calves born annually, and FR is fecundity rate that is number of calves born annually per reproductive cow.

The calves are partly kept for replacement, and the remainder goes to a category of draught animals. Half the calves born are males. The number of non-breeding and male cattle in each age group can be determined by Eqn A5.3:

$$NCF_1 = (0.5 \cdot CB - RCF_1) \cdot (1 - MR_1) \qquad \text{A5.3a}$$

$$NCM_1 = 0.5 \cdot CB \cdot (1 - MR_1) \qquad \text{A5.3b}$$

$$NCF_t = NCF_t \cdot (1 - MR_t) \qquad t = 2, 3 \qquad \text{A5.3c}$$

$$NCM_t = NCM_t \cdot (1 - MR_t) \qquad t = 2, 3 \qquad \text{A5.3d}$$

in which RCF_1 is the number of calves kept for replacement, NCF_1 and NCF_t are non-breeding female cattle in age group 1 and t, and NCM_1 and NCM_t are male cattle in age group 1 and t, respectively.

Total number of animals (OX) at off-take is the sum of non-breeding female and male cattle at 3 years of age, calculated with Eqn A5.4.

$$OX = NCF_3 + NCM_3 \qquad \text{A5.4}$$

Feed requirements (DE) for maintenance are proportional to the metabolic weight ($W^{0.75}$). For cattle in each age group, the DE requirements are calculated with Eqn A5.5.

$$DEF_t = 365 \cdot DE_d \cdot \frac{\left(WF_t^{\,0.75} + WF_{t+1}^{\,0.75}\right)}{2} \cdot TCF_t \qquad \text{A5.5a}$$

$$DEM_t = 365 \cdot DE_d \cdot \frac{\left(WM_t^{\,0.75} + WM_{t+1}^{\,0.75}\right)}{2} \cdot TCM_t \quad t \le 3 \qquad \text{A5.5b}$$

$$TCF_t = RCF_t \cdot (1 - 0.5 \cdot MR_t) + NCF_t \cdot (1 + 0.5 \cdot MR_t) \qquad \text{A5.5c}$$

$$TCM_t = NCM_t \cdot (1 + 0.5 \cdot MR_t) \quad t \le 3 \qquad \text{A5.5d}$$

in which DEF_t or DEM_t is DE requirement of female cattle or male cattle in age group t, and DE_d is daily requirement of DE for maintenance. The daily maintenance requirement for young cattle below 3 years of age is 0.61 MJ $W^{-0.75}$ according to NAC (1993). For cattle above 3 years of age, additional energy is needed for pregnancy and lactation of reproductive cattle. In this study, a value of 15% higher, i.e., 0.70 MJ $W^{-0.75}$ d^{-1} is used. WF_t and WM_t represent liveweight of female and male cattle at t years of age. TCF_t and TCM_t are total number of living female and male cattle in age group t; For NCF_t in Eqn A5.5c, $t \le 3$.

Cattle liveweight at different ages before maturity is estimated with Eqn A5.6 according to Hengsdijk *et al.* (1996):

$$W_t = W_p - (W_p - W_b) \cdot e^{-r \cdot t} \qquad \text{A5.6}$$

in which W_t is weight (kg) at age t (years), W_p is mature weight (kg) and W_b is birth weight, and r is relative growth rate per year. With this equation, the weight of female and male cattle, i.e., WF_t and WM_t at ages before maturity can be determined. The relative growth rate r is computed by the same equation, assuming that mature weight is reached for females at 5 years and for males at 6 years of age.

DE requirement for body-weight gain of cattle in each age group is calculated with Eqn A5.7:

$$GDF_t = 365 \cdot \frac{EWF_t \cdot TCF_t}{0.82 \cdot K_f}; \quad GDM_t = 365 \cdot \frac{EWM_t \cdot TCM_t}{0.82 \cdot K_f} \qquad \text{A5.7}$$

in which GDF_t and GDM_t is DE requirements (MJ) of female and male cattle in age group t. K_f is utilization efficiency of metabolic energy (ME). K_f is dependent on feed quality, i.e., ratio of DE or ME to total energy (GE) in the feed, the value of which can be determined by $K_f = 0.523 \cdot DE/GE + 0.00589$, where GE is total energy of the feed (Li *et al.* 1997). In this study, a value of 0.32 for K_f is used, assuming that the fraction digestible energy in the feed is 0.6. EWF_t and EWM_t are the net energy retention for body-weight gain for female and male cattle, calculated with

Eqn A5.8 (van Es 1978, cited by Li *et al.* 1997).

$$EW = \frac{IW_d \cdot (2.092 + 0.0251 \cdot W)}{1 - 0.3 \cdot IW_d} \qquad \text{A5.8}$$

in which EW is energy retention in body-weight gain (MJ), IW_d is weight increase (kg) per day and W is liveweight (kg). Eqn A5.8 is transformed into Eqn A5.9 to obtain net energy requirement for each age group:

$$EWF_t = \frac{IWF_t \cdot [2.092 + 0.0126 \cdot (WF_t + WF_{t+1})]}{1 - 0.3 \cdot IWF_d} \qquad \text{A5.9a}$$

$$EWM_t = \frac{IWM_t \cdot [2.092 + 0.0126 \cdot (WM_t + WM_{t+1})]}{1 - 0.3 \cdot IWF_d} \qquad \text{A5.9b}$$

$$IWF_t = \frac{WF_{t+1} - WF_t}{365}; \quad IWM_t = \frac{WM_{t+1} - WM_t}{365} \qquad \text{A5.9c}$$

in which EWF_t and EWM_t (MJ) is energy contained in the body-weight gain of female and male cattle in age group t, and IWF_t and IWM_t are daily weight increase (kg) of female and male cattle in age group t, which is calculated as the average of the annual weight gain.

The next step calculates the feed requirements and the associated outputs such as meat and manure, by producing one draught animal with the liveweight equal to the male cattle at off-take (3 years of age). With the following calculations, these coefficients are determined for one draught cattle produced. First the DE requirements (*TDE*) for maintenance and growth are calculated with an equation:

$$TDE = \frac{WM_3}{OW} \cdot \sum_{1}^{13} (DEF_t + DEM_t + GDF_t + GDM_t) \qquad \text{A5.10a}$$

$$OW = WF_3 \cdot NCF_3 + WM_3 \cdot NCM_3 \qquad \text{A5.10b}$$

$$DCP = TDE/R \qquad \text{A5.10c}$$

in which WM_3 and WF_3 is liveweight of the male and female cattle at off-take (3 years of age), OW is total liveweight of the draught animals at off-take, DCP is requirement of digestible crude protein in kg per year, and R is the ratio of DE to DCP in the feed in MJ DE kg^{-1} DCP.

Next the meat production (*MP*, kg per year) is calculated with Eqn A5.11. The subscript 14 represents the weight and number of the female cattle at 13 years of age.

$$MP = \frac{WM_3}{OW} \cdot WF_{14} \cdot RCF_{14} \qquad \text{A5.11}$$

The N exported by animal products is calculated with Eqn 4.7 in Subsection 4.6.3 of Chapter 4. The protein fraction in the carcass is estimated at 0.20 according to data of Yu *et al.* (1995).

Table A5.4 Parameters, outputs and feed requirements of the cattle activity (*RCF* is number of calves kept for replacement; *NCF* and *NCM* are number of non-breeding female and male cattle; *WF* and *WM* are liveweight of female and male cattle; *WDF* and *WDM* are total liveweight (kg) of female and male cattle at off-take; *DEF* and *DEM* are DE required for maintenance of female and male cattle; *GDF* and *GDM* are DE required for growth of female and male cattle)

Basic data

Feed quality: Ratio DE (MJ) to DCP (kg)	*R*	165.0
Mortality rate < 1 year	*MR*	0.08
Mortality rate > 1 year	*MR*	0.03
Fecundity rate	*FR*	0.8
Total breeding cows		118.7
Calves born	*CB*	92.1
Daily DE requirement for maintenance <3 yr in MJ $W^{-0.75}$	DE_d	0.607
Daily DE requirement for maintenance >3 yr in MJ $W^{-0.75}$	DE_d	0.698

Herd structure, weight and feed requirements

Age	Herd (head)			Weigh (kg)				DE requirement (MJ)			
group	*RCF*	*NCF*	*NCM*	*WF*	*WM*	*WDF*	*WDM*	*DEF*	*DEM*	*GDF*	*GDM*
0-1	15.7	28.0	42.4	17	19			314825	381835	163066	275548
1-2	14.4	25.7	41.1	215	284			542325	704829	52318	115660
2-3	14.0	24.9	39.9	264	**365**	6581	14536	576361	766392	13377	36781
3-4	13.6			276	389			231571		1534	
4-5	13.2			280	397			225845			
5-6	12.8			280	400			219069			
6-7	12.4			280	400			212497			
7-8	12.0			280	400			206122			
8-9	11.6			280	400			199939			
9-10	11.3			280	400			193940			
10-11	11.0			280	400			188122			
11-12	10.6			280	400			182478			
12-13	10.3			280	400			177004			
13 (culled)	10.0			280	400						
Total		290.4	461.8			6581	14536	3470099	1853056	230295	427989

DE and DCP requirement for producing one draught animal

Weight of a draught ox (kg)	WM_3	**365**
Dressing rate (kg kg^{-1})	*DR*	0.5
Meat production (liveweight, kg)	*MP*	48.4
Meat production (carcass, kg)		24.2
Annual DE requirement (MJ)	*TDE*	103286.7
Protein content of meat (fraction)	C_p	0.20
Fat content of meat (fraction)	C_f	0.06
Annual DCP intake (kg)	*DCP*	626.0
N removed in animal products (kg)	*Na*	1.55
Total urine N (kg)	*Un*	98.6

A5.2.2 Donkeys

The reproductive period of donkeys is 12 years starting from 3 years of age. The adult weight is 220 kg for the male and 180 kg for the female. Parameters of the donkey activity are derived from a stable herd structure. The feed requirements and meat production for producing one transport donkey with the liveweight equal to male donkey at 3 years of age are calculated with the same procedure and equations for cattle. The data used for the calculation and the results are given in Table A5.5.

Table A5.5 Production parameters, outputs and feed requirements of the donkey activity (*RCF* is the number of foals kept for replacement; *NCF* and *NCM* are the number of non-breeding female and male donkeys; *WF* and *WM* are liveweight of female and male donkeys; *WDF* and *WDM* are total liveweight (kg) of female and male donkeys at off-take; *DEF* and *DEM* are DE required for maintenance of female and male donkeys; *GDF* and *GDM* are DE required for growth of female and male donkeys)

Basic data

Feed quality: Ratio DE (MJ) to DCP (kg)	*R*	165
Mortality rate < 1 year	*MR*	0.08
Mortality rate > 1 year	*MR*	0.03
Fecundity rate	*FR*	0.75
Total breeding donkeys		147.1
Foals born	*CB*	107.0
Daily DE requirement <3 yr. in MJ $W^{-0.75}$ d^{-1}	DE_d	0.628
Daily DE requirement >3 yr. in MJ $W^{-0.75}$ d^{-1}	DE_d	0.690

Herd structure, weight and feed requirements

Age	Herd (head)			Weigh (kg)				DE requirement (MJ)			
group	*RCF*	*NCF*	*NCM*	*WF*	*WM*	*WDF*	*WDM*	*DEF*	*DEM*	*GDF*	*GDM*
0-1	16.6	49.2	12.0	12.0	13.5			83638	291202	84674	100846
1-2	15.3	47.7	135	133	149			148104	526797	29758	47219
2-3	14.9	46.3	185	167	**196**	5054	9055	159024	580180	8581	17259
3-4	14.4			176	212			174470		1054	
4-5	14.0			180	217			170518			
5-6	13.6			180	220			165402			
6-7	13.2			180	220			160440			
7-8	12.8			280	220			155627			
8-9	12.4			180	220			150958			
9-10	12.0			180	220			146430			
10-11	11.6			180	220			142037			
11-12	11.3			180	220			137776			
12-13	11.0			180	220			133642			
13-14	10.6			180	220			129633			
14-15	10.3			180	220			125744			
15 (culled)	10.0			180	220						
Total		46.3	185			5054	9055	2183444	1398179	124068	165324

DE and DCP requirement for producing one transport donkey

Weight of the transport donkey (kg)	WM_3	**196**
Dressing rate (kg kg^{-1})	*DR*	0.5
Meat production (liveweight, kg)	*MP*	24.9
Meat production (carcass, kg)		12.5
Annual DE requirement (MJ)	*TDE*	53643.6
Protein content of meat (fraction)	C_p	0.22
Fat content of meat (fraction)	C_f	0.05
Annual DCP intake (kg)	*DCP*	325.1
N removed in animal products (kg)	*Na*	0.88
Total urine N (kg)	*Nu*	51.1

A5.2.3 Draught oxen and transport donkeys

Draught oxen and transport donkeys are treated as an individual animal, which can be produced from the cattle or donkey activities or bought from market. The active period is set to 10 years for oxen and 12 years for donkeys. Draught oxen are expressed as an ox-unit with a liveweight equal to that of the adult male cattle, i.e., 400 kg. Transport donkeys are expressed as a donkey-unit with the liveweight equal to the adult weight of male donkeys, i.e., 220 kg. The feed requirement is simply calculated as:

$$DE = 365 \cdot de \cdot W^{0.75}; \qquad DCP = \frac{DE}{R} \qquad \text{A5.12}$$

in which *DE* is annual requirement of digestiable energy in MJ and *DCP* is annual requirement of digestibale crude protein in kg yr^{-1}. *W* is liveweight of animals, i.e., 400 kg for oxen and 220 kg for donkeys are used. *de* is daily requirement of digestiable energy in MJ, and a value of 0.698 MJ d^{-1} is used. *R* is feeding quality expressed as ratio of DE to DCP in MJ kg^{-1}, and a value of 200 is used.

The draught animals are slaughtered at the same liveweight after use of 10 and 12 years, of which half is carcass. With this assumption, the available meat per year can be obtained by dividing the total meat with 10 for oxen and 12 for donkeys. The protein content in meat is 20% for oxen and 22% for donkeys. The estimated coefficients are presented in Table A5.6.

A5.3 Input-output coefficients of the livestock activities

Summary data of the animal activities calculated with the approach presented in this Appendix and the descriptions in Chapter 4 are given in Table A5.6. The urine N in the table refers to total amount, assuming that a diet is exactly the same as the defined. This urine N is only used for the calculation of indoor feeding. The detailed procedure for the estimation of manure N, labor requirement and net return is described in Chapter 5. The market price of animal products based on 1987-98 is 13.4, 13.6 and 10.3 yuan kg^{-1} for mutton, beef and pork. There is no price available for lamb and goat meat. In this study, meat price is set to 12.4, 13.4 and 14.5 yuan kg^{-1}, for meat from goats, fine-wool sheep (mutton and lamb) and small-tail sheep (mainly for lamb) taking into account the meat quality. Wool price varies with qualities, and 7.2, 17.0 and 13.6 yuan kg^{-1} (marketable wool) are used for wool from goats, fine-wool sheep (better wool quality) and small-tail sheep (low wool quality), respectively, estimated based on prices of raw wool in 1997-98. For cashmere, the price is set to 180 yuan kg^{-1} (marketable part). For meat from cattle and draught oxen, the price is set to half the beef price, because of poor quality. For donkey meat, a price of 5.7 yuan kg^{-1} is used. For draught animals of oxen and donkeys, the price is 2150 and 1050 yuan per draught animal unit, estimated based on current prices.

Table A5.6 Input-output coefficients of animal activities on annual basis and per animal unit. DE is annual intake of digestible energy and DCP is annual intake of digestible crude protein. Meat is carcass. Exported N is the N exported by animal products.

Animal	DE	DCP	Meat	Wool (cashmere)	Urine N	Exported N	Cost
	MJ	kg	kg	kg	kg N	kg N	yuan
Cashmere goat	55393.6	395.7	127.7	2.7 (2.6)	58.2	5.1	200.4
Fine wool sheep,	50266.1	386.7	152.1	20.4	55.0	6.9	287.1
Small tail sheep	55215.7	441.7	231.0	2.5	63.6	7.1	340.8
Cattle	103286.7	626.0	24.2	0.0	98.6	1.5	108.2
Donkeys	53643.6	325.1	12.5	0.0	51.1	0.9	93.0
Pigs	7287.2	87.3	126.0	0.0	14.0	0.0	238.0
Draught oxen	34660.6	173.3	20.0	0.0	26.4	1.3	45.0
Transport donkeys	22899.8	114.5	8.5	0.0	17.7	0.8	40.0

Curriculum Vitae

LU Changhe was born on 13 July 1962 in Laiwu, Shandong Province of China. In July 1983, after four years of study in the former Department of Geography, Shandong Normal University, he graduated and obtained his B.Sc. Degree. In the same year, he started his graduate study in the former Department of Geography (now Department of Urban and Environment Sciences), Peking University. In December 1985, he graduated and obtained his M.Sc. Degree with a thesis entitled 'Survey and mapping of soil losses in the Boqinghe-Yanhe River, southern Shanxi Province'.

In December 1985, Mr. Lu was employed at the former Institute of Geography (now the Institute of Geographical Sciences and Natural Resources), Chinese Academy of Sciences. Up to September 1992, he was mainly involved in land resource surveying and land use planning in Tibet, except for the period from October 1988 to November 1989, during which he completed a postgraduate course on soil surveying at ITC, the Netherlands, for which he obtained a diploma. From October 1993 to March 1994, he studied at the Department of Theoretical Production Ecology, Wageningen University, and wrote a Ph.D. research proposal entitled 'Explorative land use study in the Loess Plateau, northern China', which resulted in this thesis.

From April 1994 to June 1998, his research mainly involved in sustainable land use and regional development. He participated in several research projects concerning sustainable land use and integrated control of environmental degradation in the fragile regions of China, in the Yellow River, in the Qadam Basin, and in the HKH (Hindu Kush-Himalayas) region of China. He completed data collection for his Ph.D. project by conducting fieldwork in the study area of Ansai and literature reviews in the Institute of Geography, Chinese Academy of Sciences.

Since July 1998, Mr. Lu has worked at the Department of Theoretical Production Ecology, Wageningen University and Research Centre, where he completed his thesis.