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The Research Institute for Agrobiology and Soil Fertility (AB-DLO) is part of the Agricultural Research Department (DLO) of the Dutch Ministry of Agriculture, Nature Management and Fisheries (LNV).

DLO's remit is to generate new knowledge and develop the expertise needed by that Ministry to develop and implement policy for promoting primary agriculture and agribusiness, planning and managing rural areas, and protecting wildlife and the environment.

AB-DLO carries out both fundamental strategic and application-oriented research. It is positioned between the fundamental basic research carried out by universities and the practically-oriented research done by research stations.

AB-DLO's research is targeted at:
- promoting the sustainability and quality of crop production;
- the sustainable use of land, water and energy;
- the development of agricultural systems within the framework of multifunctional land use.

This research contributes to the solution of problems concerning the efficient management of substance and energy flows in agro-production chains, the ecologisation of primary production, the regional and global provision of food, and the multifunctional use of rural areas.

The research is divided among three themes:
- Quality: the quality of crop production and crop products.
- Environment: minimisation of the environmental effects of agricultural activities in soil, air and water.
- Sustainable agriculture: development of farming systems within frameworks of multifunctional land use.

AB-DLO's core fields of expertise are plant physiology, soil biology, soil chemistry and soil physics, nutrient management, crop and weed ecology, grassland science and agrosystems research.

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1. Introduction

The Knowledge Center Wageningen has a reputation for its agricultural research, which goes far beyond the borders of the Netherlands. Several research activities presently focus on agriculture in China and are often executed in collaboration with Chinese Research Institutes or Chinese Universities. In 1997, a consortium of several Chinese Institutes and the Research Institute for Agrobiology and Soil Fertility in Wageningen (AB-DLO), formulated a Project on Food Security in China. To exchange ideas with ongoing research activities in Wageningen that focus on China and to discuss the new project proposal, AB-DLO organized a "Wageningen-China" workshop. Several research groups from Wageningen were invited to present their research activities with regard to China. This workshop resulted in these proceedings.

In an introductory chapter, Jikun Huang gives a broad overview of recent developments in agriculture, agricultural policy and food security in China. His main conclusion is that China is capable to solve its food problems in the near future, but that it will be necessary to carry out more analytical research, including agricultural policy studies, seminars and dialogues. Huang underlines that these studies will not only be of significant interest for China, but also for the rest of the world, as China will become more integrated into the world food market an eventually in the World Trade Organization.

Groot, Penning de Vries and Huang give the outline of a research approach to analyze the impact of political decisions on food security. In their approach they not only consider the supply side of food security (the biophysical potential), but also give attention to the socio-economic attainability of food security under different policy and trade scenarios. Future international food and technology trade is considered important as it will have impacts on the future food security situation of China; the contribution of van Meijl and van Tongeren analyzes the role of trade and technology spillovers on food production in China.

Food security is closely related to changes in land use, and the contribution of Verburg and Veldkamp gives a tentative analysis of the driving factors for land use change. A major threat to agriculture and food security is formed by soil degradation. Although the estimates of land lost through various forms of degradation vary considerably, the average land loss should be in the order of 300,000 - 400,000 ha per year. An assessment of soil degradation and conservation activities in China is given by Oldeman and van Lynden; over 45% of the total land area in China has been affected by human-induced soil degradation. Appropriate management of both soil and water resources will be necessary to minimize soil degradation in the future. An example of a regional water management study is given by Menenti.

Proper soil management is closely related to landowner-ship. The landowner-ship system is presently changing, but a major constraint in this process is that the value of arable land is either not known or difficult to estimate. In their contribution to the proceedings, Huang *et al.* present a tentative method for value-accounting of arable land.

We highly encourage all readers to contact the authors of the different contributions in case they would like to obtain additional information on the contents of the chapters.

Wageningen, October 1997 The editors

2. Agricultural development, policy and food security in China

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2.1. Introduction

In recent years food security was defined as "a condition in which all people at all times have both the physical and economic access to the basic food they need" (FAO, 1996). Thus, three conditions need to be met: *i.* adequate food availability or supply; *ii.* stability of this supply, and *iii.* access to food at household level, particularly by the poor. The International Conference on Nutrition in 1992 added a nutrition dimension to food security and defined it as "all people at all times have access to safe and nutritious food to maintain a healthy and active life".

This broad definition of world-wide food security is very useful in evaluating and monitoring the performance of food security at the national level and guiding national food policy. China's long pursuit to produce enough food for its growing population is highly recognized by international communities. Having over one fifth of the world population with only one fifteenth of the world's arable land, China has been able to achieve a high level in food self-sufficiency. From the founding of the People's Republic in 1949 to the end of the 1950s China was a net exporter of food, including grain. Although imports exceeded exports since the 1960s, the share of grain net imports to total domestic consumption was marginal and reached about 3% by the early reform period (1978-84) and declined to about 1% only in 1985-90. Except for a record level of nearly 20 million tons of net grain import in 1995, China in fact was net grain exporter with annual net exports of more than 5 million tons in 1992-94. While there might be a slightly growing trend in China's grain imports in the coming decades, China has developed its position as a net exporter of food (food here includes both grain and non-grain foods) in value terms during the reform period as China also exports significant amount of foodstuffs with a high added value (*i.e.* livestock products and other processed foods). Starting from almost balance trade (not in quantity but in value term) in 1980, net export in food was 2.3 billion US dollars in 1985 and reached a peak level of 3.8 billion US dollars in 1995 (Lu, 1996).

In spite of these developments there is growing concern about future food security in China:

- While there has been a general increase in food production in China over the last several decades, the year-to-year fluctuations of food supply and prices have been significant during the transition period of the economy. Market stabilization and food price inflation have been among the major concerns of government policy since the late 1980s. The

Chinese government considers maintaining a comparatively high level of food self-sufficiency, stability of food supply and consumer's prices a matter of national security and stability: "Only when the Chinese people are free from worries about food availability and stability of supply they can concentrate on and support the current reform, thus ensuring a sustained, rapid and healthy development of the economy" (The State Council, 1996). To this end, a series of measures was adopted recently in order to stabilize domestic food supply through both administrative and economic interventions on factor market, rural infrastructure development, food distribution and marketing system, national and local food reserve schemes, price regulation, international trade, *etc.*

- Although the national economy maintained a strong growth, the distribution of growth is unequal across regions. Farmer's income in the central and eastern parts of China continued to experience faster growth, while western and south-west regions followed a slower growth pattern. The income gap among regions and between the rural and urban areas has not narrowed (MOA, 1996). Moreover, income distribution within regions has also been worsening (MOA, 1996). While the strong economic growth has brought about a significant increase in the people's living standard, tremendous reduction in absolute poverty, and increasing access to food at household level in China (World Bank, 1992; MOA, 1996), a large part of the population still lives in poverty (70 million or 6% in 1995 according to the government as opposed to 30% from a recent estimate by the World Bank). Recently, both central and local governments have raised their financial commitment to poverty alleviation in the targeted poverty areas. This strategic policy encourages the leaders and farmers in poor areas to effectively develop the local economy with the assistance of the government and in line with market demands. This program has been referred to as moving from "blood transfusion" to "blood making" policy.

- Thirdly, and more importantly, availability of food will be a major component of China's food security in the coming decades. Although world-wide the rates of food production growth exceeded population growth in recent decades, and real international food and feed grain prices have declined for several decades, these situations differ from country to country.

China's agricultural performance over the past two decades has been much more impressive than that of other countries in South and Southeast Asia. Despite this fact, China is still facing great challenges of feeding its growing population, using its declining and limited resources of land, water and other resources for food production. The importance of availability of food supply in China is due not only to the fact that a large proportion of the world's population, consumption, and stocks occur in China, but also to rapid industrialization which has led to a competition in resource uses between agriculture and non-agriculture, and to strong income growth and rapid urbanization, which will lead to significant increase in demand for agricultural products and shifts in consumption patterns.

Because grain (both food and feed grain) is a major component of the food economy in China, the focus of food security issues has mainly been related to grain economy. Historically, the provision of adequate cereal grain supplies at low stable prices for urban residents has been an overriding concern and recurring food shortages, particularly the famine of the early 1960s, exacerbated the concern for assured and secure grain supplies. This concern, aggravated by Brown's prediction of China's massive imports of grain in the coming decades (Brown, 1995), got world-wide attention recently.

The sheer size of China's economy, its rapid growth, its gradual progress toward a market-oriented economy, its urbanization, the shifting of comparative advantage from agricultural to other sectors, dietary diversification, and diminishing agricultural land, water and labor resources to support its growing population, will make it a crucial player in the future development of world markets for inputs and outputs of food and agricultural products, agribusiness and industry. Small adjustments in the country's food supply and demand, any changes in demand for agricultural inputs as well as the modes or approaches selected by Chinese government in dealing with its food security will have large implications for world agricultural trade, including its trade with other Asian countries as well as the trade between the Asian countries and the rest of the world. This makes China's long-term food security an issue of both national and international significance.

The purpose of this paper is to review the present food security in China, the performance of the agricultural sector, the role of food policies in improving food security in China, and to identify key issues related to food security which will need further interventions.

2.2. Food security and the performance of the food and agricultural sector in China

2.2.1. Food security: an overview

China, with more than 1.2 billion people in 1995, is the world's most populous country, and is highly acclaimed for its ability to feed its over one fifth of the world population with only about 7% of the world's arable land. Despite the limited land resources and a population that doubled in the last 40 years, the country has not only been largely self-sufficient in food staple production since the 1950s, but also significantly improved per capita food availability. The Chinese experience demonstrates the importance of technological development, institutional changes, incentive structure improvement, rural development and other conducive policies in improving the food security situation in a country with limited natural resources.

Availability of food

China has experienced a substantial increase in per capita food consumption. Average per capita food availability increased from less than 1700 kcal in 1960 to over 2700 kcal per day in 1993 (Table 2.1). This increase in food availability was almost achieved exclusively through increases in domestic production. Protein intake and fat consumption per capita per day increased from 42 to 70 g, and 17 to 58 g, respectively. These values exceed food availability in countries with a per capita GNP comparable to China's.

In addition to absolute levels, the origin of the nutrition is an important indicator of the economic well-being of the population. The average diet of the people in low-income countries constitutes a high percentage of nutrients from crop sources, while a typical developed country population has a mixed diet with a relatively high percentage of nutrients from animal sources. The change in the nutrition composition of diet has been consistent with the increasing income of the Chinese population. Traditional diets have typically been based on cereals, vegetables, and small quantities of meat and fish. With rapid increase in per capita income, urbanization, and market expansion, the consumption of more expensive non-cereal food items, particularly the average consumption of livestock products and fish have increased over time (Huang & Bouis, 1996).

Table 2.1. China's average per capita daily food availability*, 1996-93.

				Crop Products			Animal Products		
Year	Energy (kcal)	Protein (g)	Fat (g)	Energy (%)	Protein (%)	Fat (%)	Energy (%)	Protein (%)	Fat (%)
1960	1676	42	17	97	93	76	3	7	24
1970	2087	53	23	96	93	67	4	7	33
1980	2470	64	32	94	90	60	6	10	40
1990	2547	70	54	89	81	53	11	19	47
1993	2757	70	58	86	na	na	14	na	na

Sources: data for 1993 are estimated by the Ministry of Agriculture, the others are from Wang *et al.*, 1993.

* Food availability is based on food balance sheets which may underestimate grain for feed use. As a consequence these figures may be larger than those presented in the following tables which are based on a food intake survey.

Aggregate household food security and household food security by income group

According to FAO's WFS (1996), the household food security situation in China from the beginning of the 1970s, as measured by the aggregate household food security index (AHFSI) and the level of food inadequacy, closely followed the average food availability at the national level. The status of AHFSI increased from a low level of 70% in 1969-71 to a relatively high level of nearly 80% in 1990-92, while the food gap (food inadequacy) declined from 14 to 3% over the same period. Household nutrient intake and nutrient sources by income group can be derived from the food and nutrition survey conducted by the Chinese Academy of Preventive Medicine (CAPM) and the State Statistical Bureau (SSB) in 1990, and food consumption and expenditure survey by SSB for the years of 1985-92. These studies present several interesting indicators of food security at household level, particularly of the poor.

First, there are substantial variations in nutrient intake among income groups. Energy intake by the poorest (bottom 10%) was only about 82% of the sample average. A similar pattern is also evident for protein and fat intakes. Second, the nutrient intakes are strongly linked with income. To meet the recommended daily energy intake level of 2200 kcal, the income of the poorest 10% should be doubled. Third, the average diet of the poor constitutes a high percentage of nutrients from cereal grain, while the rich diet has a relatively high percentage of nutrients from animal and other sources.

Data limitation prevents us to examine the progress of household food security over time for different income groups in detail. However, Table 2.2 gives indicators which could have impact on household food security over time for the rural population in general and the poor in particular. Improvement in the household food security is explained by two major factors: the strong income growth and the reduction of poverty in rural areas. Income is an important measure of food access and human health, particularly of children. Annual per capita rural real income raised by nearly 4 times during the last reform period (1978-95). In addition to the growth in agricultural sector, the growth in rural non-agricultural income has been the other major source of rural income growth. Ratio of agricultural (crop, forest, livestock, fishery) to non-agricultural income declined from 5.6 in 1978 to 1.7 only in 1995 (Table 2.2).

Table 2.2. Income, equity, food budget share and poverty in rural China, 1978-95.

	Real per capita income index		Agri/non-agri	Frequency of	Food budget share (%)	
	Rural	Poorest 20%	income ratio	poverty (%)	Rural	Poorest 20%
1978	72	na	5.6	32.6	68	na
1980	100	100	3.4	27.2	62	66
1985	189	165	3.0	12.0	58	63
1990	218	177	2.9	10.1	59	63
1995	272	193	1.7	7.6	59	na

Sources: Computed, based on rural food and consumption survey data, SSB and Statistical Yearbook of China, 1996.

Poverty is one of the causes for malnutrition and therefore the improvement in the food security situation is also illustrated by a significant reduction of poverty in China. The World Bank early estimates show the number of absolute poor to have declined from roughly 260 million in 1978 to 96 million in 1985, or from about one-third to 12% of the total rural population (World Bank, 1992). By 1995, the figure further decreased to 65 million, which is only about 7.6% of total rural population (MOA, 1996).

Which approaches improved food security in China?

The China experience demonstrates the importance of technology development, the incentive systems, institutional reforms, rural economic development and other conducive policies in increasing the availability of food. Technology has been the engine of China's agricultural economic growth (Stone, 1988; Huang & Rozelle, 1996). China's technological base grew rapidly during both the pre-reform and reform periods. For example, shortening the growing cycle of cereal varieties and introduction of photosensitive varieties allowing more intensive cultivation of the land, dramatically raised the multiple cropping index and increased annual grain production in the 1960s and 1970s. Hybrid rice, a breakthrough pioneered by Chinese rice scientists in the 1970s, increased yields significantly in many parts of the country, and rapidly spread to nearly one-half of China's rice area by 1990. Other grains experienced similar technological transformations (Stone, 1988).

Institutional arrangements and government food policies also played an important role in China's food production and food availability. Prior to the economic reform (before 1979), this was achieved by a centrally planned economy at the expense of economic efficiency. China had adopted an industry-biased development strategy since the early 1950s. To implement this strategy, the first concern was accumulation of capital for industrialization. This was done by keeping wages and food prices for industrial workers low, by prohibiting free market operations and through compulsory state agricultural procurement. There was a food rationing scheme on the market and distribution side, and a planned economy on the production side. Sown area and production had to follow the state production plan, as well as agricultural input levels and resource allocation. Much of China's irrigation and rural infrastructure was constructed by mobilized local labor.

The industry-oriented development strategy had several implications for food security at the national and household levels. Urban food supplies, and to a lesser extent supplies to food-deficient regions, were guaranteed by a food rationing system, providing a minimal amount of energy and protein depending on age, sex, occupation and allocation. In rural food surplus areas food consumption was determined by the local production and the state food procurements which were fixed for three to five years based on the previous production levels. Rural consumption, therefore, was strongly linked with the local production level. The low economic growth as a result of economic inefficiency prevented farmer's income growth and reduction of rural poverty. In 1978 one third of the total population was still under the poverty line.

After 1979, China began to adopt institutional and economic reforms to shift from a socialist to a more open, market-oriented economy. Since then remarkable progress has been achieved in the performance of agriculture and food production, as various reform measures gradually liberalized the institutional and market structure of production and consumption. The growth rate of gross domestic product (GDP) during this reform period is roughly twice of that of the immediate pre-reform period of 1970 to 1978. GDP has expanded at an average annual rate of more than 9% over the last 15 years. The growth rates of food and agricultural production nearly tripled and per capita consumption became four times higher (Table 2.3).

Table 2.3. The annual growth rates (%) of China's economy, 1970-95.

	Pre-reform	Reform period	
	1970-78	1978-84	1984-95
Gross domestic products[a]	4.9	8.5	9.7
Agriculture	2.7	7.1	4.0
Industry	6.8	8.2	12.8
Service	na	11.6	9.7
Foreign trade	20.5	14.3	15.2
Import	21.7	12.7	13.4
Export	19.4	15.9	17.2
Population	1.8	1.4	1.4
GDP per capita	3.1	7.1	8.3
Consumption per capita	1.6	8.0	6.8
Rural	0.6	9.2	4.9
Urban	3.7	5.2	7.6

a: Figure for GDP in 1970-78 is the growth rate of national income in real terms.
Source: SSB, Statistical Yearbook of China, various issues; A Statistical Survey of China, 1996.

Given the limited natural resources, particularly arable land, China realized from the very beginning of the reform that agricultural growth is necessary, but that other conditions are also required for a booming rural economy and to raise farmer's income. Efficient gains from the institutional reform resulted in increasing surplus of rural labor. A number of approaches have been followed to deal with agricultural labor surplus, including migration from rural to urban areas and job creation in the rural areas (both within the agricultural sector and in the non-agricultural sector), and a combination of these two approaches. The recent history of many developing countries has shown the importance of expanding industry in rural areas to create jobs for increasing agricultural labor surplus. China has succeeded quite well in this respect.

In China, the rural Township and Village Enterprises (TVEs) expanded at a remarkable rate after the rural reform starting in 1979 and now play a substantial role in China's economy and farmer's income. By 1994, rural TVEs accounted for about three-quarters of rural gross output values. TVEs dominate many industrial sectors such as textiles, farm machinery and equipment, other simple machinery, construction materials, food processing, and a variety of consumer goods. The development of TVEs in rural China not only generates jobs for increasing labor surplus in rural areas, but also raises farmer's income, promotes rural urbanization and market development, and stimulates structural changes in the rural economy.

The significant poverty reduction in China is closely related to rural economic growth. Broad participation in strong rural economic growth brought about a tremendous reduction in absolute poverty in China during the period 1978-85. The country has also succeeded in creating 200 million jobs to absorb rural labor surplus through the rural TVEs development, rural-urban migration, and other economic activities over the past decade.

Stability of food supply and access of food to the poor are other dimensions of national food security. In this regard, the government has developed its own strong disaster relief program and large-scale food-for-work schemes. The national capacity to confront emergencies was demonstrated during the unprecedented flood in 1991. The way the government handled the situation was highly commendable. It was proven that China's own capacity to natural disasters has been quite adequate (WFP, 1994). The major constraints in stabilization of food supply in China have been the poor market infrastructure and the internal transport system.

Unresolved food security issues

Although nutrition improvement took place in the past, malnutrition remains, particularly in the inland and for the poor. Children are among the most vulnerable and affected groups. According to a recent survey conducted by the Chinese Academy of Prevention Sciences, there has been a significant improvement in the nutrition security. On the average, about 15% of all children under five are underweight, about 30% stunted and 3% wasted, though these levels are considered as relatively low compared to the average for developing countries. About 25% of the population is considered to be at risk of vitamin A deficit. Iron deficiency anemia is present especially in rural areas. Data availability on drinking water, public health programs and farmers' education, limited us to conduct analysis on the impact of these factors on the health status of individuals. Recently the State Council (1996) states that in accordance with the "China Dietary Pattern Reform and Development Program in the 1990s" a healthy diet characterized by a moderate caloric intake, a high protein and a low fat content, will be gradually promoted among both urban and rural residents.
The income gap between regions and between cities and rural areas has gradually increased. The ratio of per capita income of urban residents and farmers increased from 1.72:1 in 1985 to 2.04:1 in 1990 and 2.60:1 in 1995. This raises questions on the impact of several biased urban policies such as the state grain and cotton procurements on farmer's income and food security in rural areas. Within rural areas, the income gap between the poor and the rich has expanded

since the late 1970s. The real income growth of the poor is lower than that of the whole population (Table 2.2).

China has been successful in developing new technology, changing institutional structures, mobilizing labor and other resources to support agricultural growth. However, new technology is uncertain and subject to investment policy and ongoing institutional research reform. The current technology extension system is deteriorating and efficient gains from further institutional change are limited. Current food domestic prices are close or even higher than world market prices and protection of domestic food production could be very costly and difficult if China wants to meet the requirement for entry of the World Trade Organization (WTO). Resources are shifting away from agriculture to non-agricultural sectors and expansion of resource frontiers is problematic due to the limited resource availability.

2.2.2. The changing role of agriculture in the economy

Over the past decades, the growth of agricultural production was essential in improving food security in China, and agriculture made important contributions to the development of the national economy in terms of gross added value, employment, capital accumulation, welfare of urban consumers, and foreign exchange earning. Growth in the food and agricultural economy provided the foundation of the successive transformations of China's reform economy. However, the importance of agriculture in the national economy has declined over time. Agriculture contributed more than 30% to GDP and 50% to export earnings before 1980, but each fell to only about 20% by the early 1990s (Table 2.4). It provided 81% of the labor employment in 1970 but only 52% in 1995.

The decline in agriculture's importance is even more marked in international trade. The share of primary (mainly agricultural) products in total exports was 50% in 1980 (Table 2.5). By 1995, that share was only 14%. It should be emphasized that the agricultural import share also declined significantly. The share of food export as the percentage of total export fell from 16% in 1988 to about 7% in 1995, the share of food imports fell from 15% to 5% in the same period. The declining importance of agriculture is a historical phenomenon common to all developing economies.

The dominance of cropping, contributing 80% of the gross value of agricultural output in 1978, declined significantly to less than 60% in 1995. During the same period the share of livestock output value doubled from 15% to 30%. The contribution of aquatic products to agricultural output value rose at an even more rapid rate during the reform period (Table 2.5).

However, it is interesting to note that the decline in agricultural comparative advantage in the economy has not been fully reflected in self-sufficiency of agricultural products in China. Rice self-sufficiency levels declined somewhat from 104% in the early 1960s to about 100% by the early 1990s (Table 2.6). For other major grain commodities over the last four decades, there is no clear indication of a long-term declining trend in the self-sufficiency levels. On the other hand, meat, aquatic products, vegetables and fruits have experienced enormous export expansion over the last two decades (Lu, 1996).

Table 2.4. Changes in the structure of China's economy, 1970-95.

	1970[a]	1980	1985	1990	1993	1994	1995
Share in GDP							
Agriculture	40	30	28	27	20	20	20
Industry	46	49	43	42	47	48	49
Services	13	21	29	31	33	32	31
Share in employment							
Agriculture	81	69	62	60	56	54	52
Industry	10	18	21	21	22	23	23
Services	9	13	17	19	21	23	25
Share in export							
Primary products	na	50	51	26	18	16	14
-Foods	na	17	14	11	9	8	7
Share in import							
Primary products	na	35	13	19	14	14	18
-Foods	na	15	4	6	2	3	5
Share of rural population	83	81	76	74	72	71	71

a: GDP data in 1970 is not available, national income was used in 1970.
Sources: SSB, Statistical Yearbook of China, various issues; MOFERT, 1980-1996, Almanac of China's Foreign Economic Relations and Trade, various issues.

Table 2.5. Sectoral shares (%) of agricultural and rural economy in China, 1978-95.

	1978	1980	1985	1990	1993	1994	1995
Share in rural output value	100	100	100	100	100	100	100
Agriculture	69	69	57	45	27	26	25
Industry	20	20	28	37	50	50	51
Construction	6	6	8	6	7	7	7
Transportation	2	2	3	4	4	5	5
Commerce and others	3	4	4	9	11	12	12
Share in agri. output value	100	100	100	100	100	100	100
Crop	80	76	69	65	60	58	58
Forestry	3	4	5	4	4	4	4
Livestock	15	18	22	26	27	30	30
Fishery	2	2	4	5	8	8	8
Real agri. output value							
(billion yuan in 1985's price)	226	285	362	608	730	966	1129
Crop	170	208	251	404	489	659	788
Forestry	8	13	19	32	40	44	49
Livestock	43	59	80	141	167	223	249
Fishery	4	6	13	22	33	39	43

Sources: SSB, Statistical Yearbook of China, various issues; Rural Statistical Yearbook of China, various issues.

Table 2.6. Self-sufficiency in grain in China.

Year	Rice	Wheat	Coarse grain
1961-64	104	80	97
1965-69	103	86	101
1970-74	105	93	104
1975-79	104	96	103
1980-84	101	86	100
1985-89	100	87	96
1990-95	100	91	96

Sources: Computed by author based on SSB, Statistical Yearbook of China, various issues, and Ministry of Foreign Economic Relations and Trade [MOFERT], Almanac of China's Foreign Economic Relations and Trade various issues.

2.2.3. Growth of food and agricultural production

The growth of agricultural production in China since the 1950s has been one of the main accomplishments of the country's development and national food security policies. Except during the famine years of the late 1950s and early 1960s, the country experienced rates of production growth that outpaced the rise in population growth. Even between 1970 and 1978, when a large part of the economy was reeling from the effects of the Cultural Revolution, grain production grew at 2.8% per annum (Table 2.7). Productivity of oil crops grew at 2.1% per year and output of fruits and meat grew even faster (3-7%).

Decollectivization, price increases, and the relaxation of trade restrictions on most agricultural products accompanied the takeoff of China's food economy in 1978-84. Grain production increased by 4.7% per year; the output of fruits rose by 7.2% (Table 2.7). The most spectacular growth occurred in oil crops, livestock and aquatic products which expanded in real value terms by 14.9, 9.0 and 8.8% annually, respectively.

However, as the efficiency gains from the shift to the household responsibility system were essentially reaped by the mid-1980's, the growth rate of food and agriculture decelerated (Table 2.7). This declining trend was most pronounced among grain and oil crops, where prices and marketing continued to be highly regulated. In contrast, for other crops, livestock, poultry and fishery products, where price and market liberalization was more advanced, and demand for these commodities was rising, growth rates generally exhibited increasing or steady rates throughout the reform period.

By 1995 grain production reached a level of 467 million metric tons (rice in paddy form), an increase of 162 Mt or 53% more than in 1978. Within cereal grains, rice production increased by 35%, and the productions of wheat, maize and soybean all nearly doubled during the reform period of 1978-95.

Table 2.7. Growth rate (%) of agricultural economy by sector and selected agricultural commodity, 1970-95.

	Pre-reform 1970-78	Reform period 1978-84	Reform period 1984-95
Agricultural output value	2.3	7.5	5.6
Crop	2.0	7.1	3.8
Forestry	6.2	8.8	3.9
Livestock	3.3	9.0	9.1
Fishery	5.0	7.9	13.7
Grain production	2.8	4.7	1.7
Rive	2.5	4.5	0.6
Wheat	7.0	7.9	1.9
Maize	7.0	3.7	4.7
Soybean	-1.9	5.1	2.9
Cash crops			
Oil crops	2.1	14.9	4.4
Cotton	-0.4	7.2	-0.3
Rape seed	4.3	17.3	5.4
Peanut	-0.2	10.8	5.2
Fruits	6.6	7.2	12.7
Red meats	4.4	9.1	8.8
Pork	4.2	9.2	7.9

Note: Growth rates are computed using regression method. Growth rates of individual and groups of commodities are based on production data; sectoral growth rates refer to value added in real terms.

Source: SSB, Statistical Yearbook of China, various issues; A Statistical Survey of China, 1996. MOA, Agricultural Yearbook of China, various issues.

Past studies have already demonstrated that there are a number of factors which simultaneously contributed to agricultural production growth during the reform period. The studies on measuring the contribution of the implementation of the household responsibility system concluded that most of the rise in productivity in the early reform years was a result of institutional innovations (McMillan *et al.*, 1989; Fan, 1991; Lin, 1992). Particularly the rural household responsibility system which restored the primacy of the individual household in place of the collective production team system as the basic unit of production and management in rural China was important.

More recently, Huang and Rozelle (1996) and Huang *et al.* (1996a) showed that since the household responsibility system reform was completed in 1984, technological change has been the primary engine of agricultural growth. Improvements in technology have by far contributed the largest share of grain production growth even during the early reform period. The results of these studies show that besides decollectization, other reforms also have high potential to affect agricultural growth. Price policy showed to have a sharp influence on the growth of both grain and cash crops during the post-reform period. Favorable output to input price ratios contributed to the rapid growth in the early 1980s. However, these new market forces are a two-edged sword. A deteriorating price ratio caused by slowly increasing output prices opposed to sharply rising input prices was an important factor of the slowdown of agricultural production in late 1980s and early 1990s. Rising wages and the higher opportunity cost of land have also held back the growth of grain output throughout the period, and that of cash crops since 1985.

Trends in environmental degradation, including erosion, salinization, and loss of cultivated land show that there may be considerable stress being put on the agricultural land base; erosion and salinization have increased since the 1970s. Recent studies showed that these factors affected output of grain, rice, and other agricultural products (Huang & Rozelle, 1995; Huang *et al.*, 1996b).

2.3. Agricultural development policies and food security

2.3.1. Government targets for agriculture by 2000 and 2010

Food self-sufficiency has been and will continue to be the central goal of China's agricultural policy. The Ninth Five-year Plan for 1996-2000 (Table 2.8) and National Long Term Economic Plan envisage continued growth in agricultural production and farmer income at 4% annually, nearly maintaining food self-sufficiency levels and eliminating absolute poverty. The plans strive to achieve the following key targets by 2000 and 2010:

- Increasing grain sown area and yield to raise grain production to 490-500 Mt (rice is measured by paddy grain) with an annual increase of 10 Mt by 2000; developing sustainable growth in grain production through increases in public investment in agriculture and science and technology with a target of 560 Mt grain production by the year of 2010.
- Increasing meat production and aquatic products by 10 million tons each by 2000;
- Increasing agricultural output value (in 1990 prices) by 4% per year to reach 1,210 billion yuan by 2000, and maintaining a similar rate of growth throughout the first decade of 21st century;
- Increasing poverty alleviation funds and eliminating poverty among the remaining 70 million absolutely poor by the year of 2000.

The strategy to achieve the above targets and goals includes measures to deepen rural economic and institutional reforms; improve incentives for farmers and local government to invest in agriculture, particularly in land; stimulating sustainable agricultural development through focusing on increasing the rate of regeneration of renewable resources and regulating the exploitation of non-renewable resources; providing incentives through input and output prices to increase the multiple cropping index; taking new measures to strengthen the application of scientific methods to the sector; undertaking structural adjustment in the rural economy; optimizing agricultural production linkages; strengthening anti-poverty programs; and further opening China's agriculture sector to foreign investment and improving the efficiency of foreign capital in agriculture.

Table 2.8. Government targets for agricultural development in 1996 and 2000.

Commodity	Metric million tons (Mt)	
	1996	2000
Grain[a]	465	490-500
Cotton	4.5	4.5
Oil crop	22.5	25
Meats	52	58
Sugar crop	85	110
Aquatic product	25.5	32

a: Grain is measured in unprocessed form, *i.e.* rice in paddy form.

Source: Li Peng, 1996.

2.3.2. Public financial and investment policies

China adopted the industrial-biased development strategy since the early 1950s. To implement this economic development strategy, the first concern was the accumulation of capital for industrialization. The solution taken by China for the primitive accumulation was through agriculture, which accounted for nearly 60% of national income and employed more than 80% of the country's labor force in the early 1950s. On the other hand, China also recognized the importance of agriculture and the rural sector in the development of the whole economy. Table 2.9 shows that the state financial expenditure on agriculture in real terms increased prior to the rural economic reform, initiated in 1979. However, it declined in the early 1980s, and did not recover to the levels of the late 1970s until the early 1990s. The decline in government expenditure in agriculture in the 1980s addressed a great deal of attention to the sustainability of agricultural production growth and domestic food supply in the future. The investment policy was reviewed and investment was increased in the early 1990s (Table 2.9). Both the Ninth Five-year Plan (1996-2000) and China's Long Term Plan to 2010 envisage the government increasing investment in agriculture, including rural infrastructure investment, and loans and credits for agricultural production with grain as a central crop. Irrigation and water control are listed as the first priorities of the government investments to be considered within "base industries".

Table 2.9. Government investment (billion yuan in 1985 price) in agriculture, 1965-1995.

Year	Financial expenditure			Index of government expenditure bias	Water control investment	Agric. research expenditure
	Total	Agriculture	%			
1965	60.3	7.1	12	26	1.3	357
1970	85.9	6.5	8	19	2.3	401
1975	108.3	13.1	12	32	3.4	539
1978	142.2	19.3	14	41	4.5	700
1980	143.4	17.8	12	34	3.2	791
1985	184.4	15.4	8	23	2.0	1104
1990	212.9	19.0	9	26	3.0	1043
1992	249.5	21.4	9	20	5.5	1323
1994	238.7	25.7	11	42	6.9	1458
1995	244.4	25.8	11	42	6.5	1474

Note: Values are in real 1985 prices. Government investment (expenditure) bias is constructed by comparing the relative size of its public expenditure in the economy with its contribution to the national income. Here we estimated the government investment (expenditure) bias using an approximation by *roughly* dividing the ratio of government expenditure in agriculture to total government expenditure by the ratio of net income of agriculture to total national income. If this index value equals 1, IB = 1 (or 100%), the investment policy is neutral, encouraging neither agricultural nor non-agricultural productions. If IB < 1, there is an anti-agriculture bias in the government expenditure (investment) policy. Otherwise, IB > 1 implies a pro-agricultural production bias.

Source: SSB, Statistical Yearbook of China, various issues; and SSTC.

2.3.3. Research and technology development policies

Developed from almost nothing in the 1950s, China's research system grew very rapidly after the 1960s. It has been successful at producing a steady flow of new varieties and other technologies since the 1950s. Farmers used semi-dwarf varieties developed in China several years before the release of Green Revolution technology elsewhere. China was the first country to develop and extend varieties of hybrid rice. Chinese-bred corn, wheat, and sweet potato varieties were comparable to the best varieties in the world in the pre-reform era (Stone, 1988).

Since the 1980s, China has gradually implemented a series of science and technology policies. Reform has attempted to increase research productivity by shifting funding from institutional support to competitive grants, supporting mainly scientific research focusing on problems that will be useful for economic development, and encouraging applied research institutes to earn their money by selling the technology they produce (Rozelle *et al.*, 1996a). While competitive grants programs have probably increased the effectiveness of China's agricultural research system, the reliance on commercial revenues to subsidize research and to compensate for falling budgetary commitment has weakened the system. Empirical evidence demonstrates the declining effectiveness of China's agricultural research capabilities (Rozelle *et al.*, 1996a) in the early 1990s.

As a consequence of the recent awareness of a weakening research system and the importance of science and technology in raising agricultural productivity, the Chinese government set up several programs to stimulate agricultural technology development and farmers' adoption of new technologies through an increasing public investment in agricultural research and extension. Both the Ninth Five-year Plan and the Long Term Plan for 2010 foresee that China will rely largely on introducing new technologies to raise agricultural production, particularly new varieties of grain, oil crops, and livestock.

2.3.4. Land tenure policy

China initiated its rural economic reform in 1979. While the Government maintained the ownership of collective land, the agricultural land within each production team (composed of approximately 20 households) was distributed among the households based on family composition or on a combination of composition and labor. Adjustments to the contracted land were made periodically in accordance with changes in the household's composition. The importance of this reform (so-called household responsibility system reform) on the growth of agricultural production in the early reform period has been shown in a wide range of publications. The implications of equity distribution of land to farmers for food security and poverty are also obvious. In the late 1970s, average farm size was 0.57 ha cultivated land per household and the size of the farm has declined over time. It was only 0.41 ha in 1995. Farmers normally keep 70-80% of grain production for own consumption and the remaining 20-30% are sold to the state or in the market.

The other recent significant change in institutional arrangements in agricultural land is the renewal of the land contract system. The new land contract introduced in 1994/95 extended the term by 30 years (or 50 years) from the expiration of the original contract. While the regime of collective land ownership remains unchanged, land-use rights can be sold. This change of policy was designed to overcome the problem of farmers being increasingly unwilling to invest in agricultural production, especially grain production, because of unclear land titles and the small scale of their holdings. It also has implications for land consolidation and the commercialization of agricultural production. A recent land tenure survey conducted by the author in 8 provinces in China indicates that there would be a potential gain in agricultural production resulting from efficient use of land and other inputs and farmer's willingness to invest in agricultural land if a well defined land use right tenure system were developed. What extent this impact will have on agricultural production needs further investigation. However, the current "renewal of land contract system" should not have a significant impact on agricultural production as the legal and institutional framework has not been developed.

2.3.5. Food price and marketing policies

Price and market reforms have been key components of China's development thrust as it gradually shifts from a socialist to a market-oriented economy. Although the process has been characterized by cycles of deregulation and reinstatement of controls, there has been a decisive trend towards liberalization. Moreover, nominal protection rates, while in general high, have declined rather than increased with rapid economic development, as predicted by the political economy of agricultural protection (Huang & David, 1995). China's case is unique because of its socialist history. The state not only balances the interests of producers and consumers, the state itself often considers its own interest as a direct consumer of agricultural products in its own commercial enterprise, and prior to the reform period, also as a producer of agricultural products. However, the grain marketing was partially re-centralized (re-imposing the state grain quota procurement) after 1994 as a result of high food price inflation in 1993 and continued in 1994-95. This partial re-centralization of the grain procurement system reflects the importance of the other two central goals of government food policy: stabilization of food prices and the political economy of the urban consumer.

Other important developments in the agricultural marketing system are the "two-line operation system" in grain and the provincial governor's "Rice Bag" responsibility system. The former is designed to separate the policy operation of the state grain procurement from market operations. The system was tested in 1994 and the government decided in July 1995 to implement the reform all over the country in 1996. This reform is an outcome of the "inability" of the State grain bureaus to stabilize the grain markets. Their full commitment to profit maximization while still retaining some monopsony and monopoly power in the grain market led to contradictory incentives from their separate State mandated market trading activities. The "two-line operation system" in grain marketing may increase market efficiency and contribute to the stabilization of food price and market, but the degree of gain will largely depend on the actual implementation of the policy.

The provincial governor's "Rice Bag" responsibility system seeks to set up a regional food security and grain balancing mechanism where provincial governors and governments are held responsible for balancing grain supply and demand and stabilizing local food market and prices in their respective regions. This policy has contributed to increase output, a higher degree of stabilization in grain production, and a significant reduction in agricultural price fluctuations in the short-run. However, such a policy is not without cost. It has very likely impeded the grain market integration process, had an adverse impact on the efficiency of resource allocation, diversification of agricultural production and farmer's income. The impacts of this policy on grain marketing, resource allocation, agricultural outputs, farmer's income and food security should be carefully analyzed.

2.3.6. Input price and marketing policies

Most agricultural input prices and markets have been liberalized since the 1980s, but the process of price and market reform for fertilizer has not been completed after one-and-a-half decades. With the persisting increase of agricultural input prices (especially of fertilizer) the Chinese government issued a series of new measures to control input prices in order to balance its supply and demand.

A market retrenchment policy on fertilizer was attempted in 1994, but it was much weaker than the grain quota procurement policy. The state readjusted the factory price of chemical fertilizer. The new fertilizer factory-gate target band was applied to control price inflation before reaching the wholesale level. Further efforts were also made to control fertilizer marketing by trading more through the state main channel. In 1994 the State Council called a national conference on reform of the distribution of agricultural inputs. The targets of this policy were to strengthen macro control and market management, reduce marketing costs, and stabilize fertilizer prices.

Measures adopted by the government in 1995 and early 1996 included:

a) Implementing a responsibility system at provincial level for fertilizer pricing and marketing. The provincial government would be responsible for meeting excess demand of agricultural inputs and maintaining the stability of input prices;
b) Efforts to continuously control fertilizer distribution. The maximum amount of fertilizer that the government allowed to be sold directly through the non-government channels by the factories was limited to 10% of total production;
c) Trade control. Fertilizer imports were continuously licensed and managed by appointed trade agents. The price of imported fertilizer would be determined in agreement with local authorities.

China depends heavily on the international market for fertilizer, importing about one fourth of its requirements. Domestic potassium production is extremely limited, about 90-98% is imported. Trade policy has strong impacts on domestic fertilizer price and availability.

Prior to 1985, government policy to promote domestic production of inputs subsequently raised the domestic prices paid by farmers above the world price more than 100% in the early 1970s (Huang & David, 1995). That rate of penalty declined over time, mainly because the depreciation of the yuan raised the border price in domestic currency when domestic fertilizer prices raised significantly in the 1980s. It was not until the early 1990's that farmers received a price subsidy close to 30%. But as all price controls at the retail level were lifted in 1993, the Nominal Protection Rate (NPR) for fertilizer rose again to more than 20% after 1993. Such input price policy has not compensated for the low output procurement price policy on many major food commodities.

Finally, although tariffs on fertilizer were relatively low at a level of 18% in 1992 (World Bank, 1994), quantitative trade interventions through import controls or licensing are commonly applied to agricultural inputs, such as fertilizers, or protecting domestic producers.

2.3.7. Grain reserve policy

In order to ensure food security for China's 1.2 billion people under the current economic environment, a new grain reserve system has been established in 1990 as a major government intervention on stabilization of food supply and domestic market prices. The precise grain reserve remains confidential but the estimates from various sources indicate that the State might maintain a "special" reserve of about 40 million tons of grain procured by the State Grain Bureau from domestic production and imports. As a part of disaster prevention measures, the government encourages the establishment of village-level food "help-each-other" reserves. Villagers contribute a portion of their harvest to these reserves. The government also operates a large-scale food-for-work program as one of the main instruments for helping the poor and, at the same time, for constructing a basic infrastructure for development. Meantime, a state grain market risk fund system was also established in 1994 by various levels of the governments to stabilize their local grain market.

2.3.8. Foreign exchange and agricultural trade policy

Significant changes in the nature and extent of government trade interventions occurred during the reform process. China's Open Door policy has contributed greatly to rapid growth and also led to increasing reliance on trade (domestic and international) to meet consumers' needs. But the historical overvaluation of the domestic currency due to the trade protection system has undervalued agricultural incentives. This distortion in price incentive depressed agricultural production, but the degree and extent of distortions have been declining over time as a result of foreign exchange reform. China's exchange rate policy during the reform period has clearly been successful in affecting substantial depreciation in real exchange rate (Huang & David, 1995). Whereas real exchange rates remained constant, and even appreciated over three decades prior to the reform period, they rapidly depreciated during the reform period except for a couple of years after 1985 when high domestic price inflation occurred. Within 15 years, the real exchange rate depreciated by more than 400%. The success of the exchange rate adjustments stemmed mainly from the productivity effects of the economic reforms and technological innovations in agriculture, foreign trade, and industry which contributed to the relatively low inflation. China was second only to Indonesia in pursuing aggressive adjustments in the exchange rate in the region over the past two decades. The favorable trends in the real exchange sharply increased export competitiveness and thus significantly contributed to the phenomenal export growth record (*i.e.* non-grain food products) and consequently the spectacular performance of the country in the 1980s.

Trade has also been liberalized. Prior to the reform period, the allocation of imports and exports including foreign exchange were strictly based on administrative planning and undertaken by 12 foreign trade corporations (FTC). The process of trade policy reform has involved the introduction of greater competition in international trading and the gradual development of instruments for indirect control. In 1984 the foreign trade system was decentralized considerably. Provincial branches of national FTCs were allowed to become independent and each province allowed to create its own FTCs. By 1986 there were more than 1200 FTCs. By the early 1990s the number was more than 3000. Foreign trade in what are considered strategic products such as food grains, textiles and fiber, and chemical fertilizer, however, continue to be restricted to specialized national trading corporations to have stronger controls on the level of exports and imports of these products.

2.3.9. Anti-poverty policy

Central and local governments have both sustained their strong commitment to poverty alleviation efforts. Dozens of line ministries and agencies play a role in poverty alleviation in China, including Ministries of Civil Affairs, Finance, Agriculture, Labor, Domestic Trade, Water Resources, Public Health, and the State Education Commission, the State Science and Technology Commission, the Agricultural Bank of China, and the People's Bank of China. To improve the organization of this increasing complex poverty reduction structure and in order to institutionalize the anti-poverty program, the State Council in 1986 authorized the establishment of a task force and executive agency structure to be replicated at all administrative levels. At the central level is an inter-ministerial task force, called the Leading Group for the Economic Development of Poor Area (LGEDPA). The anti-poverty executive agency, the Poor Area Development Office, reports directly to the State Council via the

LGEDPA. This institutional set-up strengthens the leadership of the national anti-poverty program, and facilitates policy implementation.

After the mid-1980s, while continuing pre-existing rural social and relief services, China began to adopt a new poverty alleviation strategy to emphasize economic development programs in the poor areas. This strategic policy encourages the leaders and farmers in poor areas to effectively develop the local economy with the assistance of the government and in line with market demands. This program has been referred to as moving from "blood transfusion" to "blood making" policy.

Infrastructure improvement has been emphasized through the Food-for-Work program administered by the State Planning Commission which assists with building roads and river transport, drinking water systems, irrigation works and other capital injections in poor areas. These projects help to create conditions for the local economic growth, and increase the short-term job opportunities and income of the poor.

More recently, the Government declared its objective to eliminate absolute rural poverty by 2000, substantially reduce relative poverty, and make available adequate nutritionally balanced food in all parts of the country. To this end, new poverty alleviation initiatives have been introduced. The measures included the extension and strengthening of assistance to the poorest of the poor residing in the worst physical environments; the integration of production, education, health, family planning and transport program into comprehensive local intervention packages; and initiation of a new strategy or plan for assisting the poor in 1994. A total of 592 counties will be assisted under the plan.

2.3.10. Rural enterprise development policy

In China, the TVEs expanded at a remarkable rate after rural reform started in 1979 and now play a substantial role in China's rural economy. The gross output value of TVEs in real terms increased at an annual rate of 23.5% during 1978-95, increased from 63.2 billion yuan in 1978 to 2479.1 billion yuan in 1995. By 1995, rural TVEs accounted for about three-quarters of rural gross output and for about 40% of the country's export earnings (SSB, 1996). Currently, TVEs dominate many industrial sectors such as textiles, farm machinery and equipment, other simple machinery, construction materials, food processing, and a variety of consumer goods. The development of TVEs in rural China not only generates employment for increasing labor surplus in rural areas, but also raise farmer's income, promotes rural urbanization and market development, and stimulates structural changes in the rural economy.

Tables 2.10 and 2.11 show the trends of TVE development in the 1978-95 period in terms of numbers of enterprises and employment, respectively. As the number of TVEs increased in rural areas, their development maintained momentum by absorbing surplus of rural labor. The sector employed 128.6 million rural laborers in 1995, 4.5 times more than in 1978, with an increase of more than 6 million annually. Among TVEs, employment growth in rural industry accounted for about 60% of the total increase in TVE employment. However, the growth of employment in other sectors, including construction, transportation and commerce and food service experienced an even higher rate than that in industry (Table 2.11). As a consequence, the development of TVEs in rural China is becoming one of major sources of rural income growth.

Table 2.10. Number (thousands) of TVEs in China, 1978-1995.

Year	Total	Agriculture	Industry	Construction	Transportation	Commerce & food service
1978	1524	495	794	47	65	124
1980	1425	378	758	51	89	148
1985	12225	224	4930	83	106	6881
1990	18504	224	7220	904	3814	6342
1995	22027	278	7182	1067	4952	8548

Source: Statistical Yearbook of China, 1996.

Table 2.11. Employment (millions) in TVEs in China, 1978-94.

Year	Total	Agriculture	Industry	Construction	Transportation	Commerce & food service
1978	28.3	6.1	17.3	2.4	1.0	1.4
1980	30.0	4.6	19.4	3.3	1.1	1.5
1985	69.8	2.5	41.4	7.9	1.1	16.9
1990	92.6	2.4	55.7	13.5	7.1	14.0
1995	128.6	3.1	75.6	19.3	9.5	21.0

Source: Statistical Yearbook of China, 1996.

Policy has played an important role in setting up and encouraging the development of TVEs in China. In the early 1950s, rural industry was mainly staffed by farmers holding part-time jobs in commercialized handicraft industries. Many of these workshops operated on a small scale, either because their technology or the organization did not allow economies of scale. During the commune era (1958-78), these workshops and individual handicraft workers were organized into larger groups as commune, brigade and team enterprises. A variety of activities were profitably undertaken in this environment and were mainly arranged through local government, including the production of building materials and farm inputs, subcontracting urban industrial activities, and simple processing of agricultural outputs.

The economic reform since 1979 has largely altered the operation of the commune-run enterprise system. The state-owned enterprises' (SOE) monopoly and monopsony powers eroded during this era and opportunities in the urban economy were becoming more accessible to TVEs.

TVEs emphasize the development of labor-intensive industry and have significant flexibility to respond to changing market conditions. A main feature of TVEs' development has been their attempt to accommodate the country's increasing demand for a greater variety of consumer goods using increasing surplus labor in rural areas. TVEs development is also closely linked with that of urban industry in terms of products, technologies, staffing and facilities, especially in the early stages of the development: subcontracting production from large urban industries, directly or indirectly hiring retired urban technicians in the TVEs, and purchasing of written off urban equipment. In 1978-84, transferring urban industry assets and written off equipment to rural areas accounted for 35-45% of new assets in the TVE.

2.4. Prospects for China's food economy

2.4.1. Existing projections

One of the most closely watched debates by researchers of China's agricultural economy, particularly of the food economy, addressed the question: Will China be able to produce most of what it needs to feed itself in the 21st century? The preponderance of evidence produced by those who have seriously addressed this debate favors the viewpoint that China essentially should be able to feed itself even though imports of grain will most likely rise over the next several decades. For example, Yang and Tyers (1989) have forecast that China will import around 50 Mt of grain per year in the late 1990s. Huang *et al.* (1996b) and Rozelle *et al.* (1996b) predict that China will need up to 40 Mt annually to meet domestic needs in the first two decades of the next century. While China will need to import substantially more grain than in the past, most international food trade and production specialists believe such a rise in demand can be met by current suppliers without long-term price increase and threatening world food security.

On the other hand, Garnaut and Ma (1992) forecast that China will face up to a 90 Mt shortage in grain production by the year 2000. Brown (1995) argues that China's production will fall between 216 and 378 Mt short of meeting demand. According to Brown's analysis, the imports flowing into China to meet this shortfall, financed by the foreign exchange earnings of its booming export sector, will drain world supplies, force prices up, and deny less able nations grain stocks needed to feed their populations.

The range of net import predictions is perplexing. The consequences of China emerging as either a major importer or significant exporter could be enormous for world grain markets and prices. China is a country experiencing rapid development and transformation. The dynamic nature of the economy and continuing reform requires that the projection should be frequently updated to better reflect changes in policy.

The goal of this section is to report our projection results which incorporate the most recent government policies based on a projection framework developed by Huang *et al.* (1996b). In this model in addition to price response of both demand and supply, a series of important structural factors and policy variables are accounted for explicitly, including urbanization and market development on the demand side, and technology, agricultural investment, environmental trends, and competition for labor and land uses on the supply side.

Recent policy trends as discussed in previous sections and other factors that will influence future supply of and demand for food are considered in the projection. These trends provide input for the growth assumptions for key parameters employed in the simulation procedure. It should be kept in mind that there are also some other important factors which have not been included in the projection, such as availability of water for agricultural use and possible decline in return to agricultural research. The other strong assumptions in the model include that increasing demand for livestock and aquatic products are met by domestic supply, and domestic food prices in the long term will follow the "world prices". Therefore the "world price" already accounts for the impact of China's grain economy on world prices.

After presenting the results of our baseline projections, alternative scenarios are examined under different rates of growth in income, population, and investment in research and irrigation, and implications for policy and food security are derived from the alternative scenarios.

2.4.2. Food requirement: results of baseline projection

According to the analysis, per capita food grain consumption (all figures in this section are measured in trade grain, not unprocessed grain) in China hits its zenith in the late 1980s and early 1990s. From a baseline high of 225 kg, food grain consumption per capita falls over the forecast period (Table 2.12). The average rural resident will consume greater amounts through the year 2000, before reducing food grain demand in the first decade of the next century. This decline in the rural areas occurs at a time when income elasticities, although lower than the late 1990s, are still positive. As markets develop, rural consumers have more choice, and will move away from food grains. Urban food grain consumption per capita declines over the entire projection period.

In contrast, per capita demand for red meat is forecast to rise sharply throughout the projection period (Table 2.13). China's consumers will more than double their consumption by 2020, from 17 to 43 kg per capita. Rural demand will grow more slowly than overall demand, but urbanization trends will shift more people into the higher-consuming urban areas (in 1991 an urban resident consumed about 60% more red meat than his/her rural counterpart). While starting from a lower level, per capita demand for poultry and fish rise proportionally more.

Table 2.12. Projected annual per capita food grain consumption under alternative income growth scenarios in China, 1996-2020.

	Per capita food grain consumption (kg)			
Alternative scenario	1996	2000	2010	2020
Base Line				
National	224	223	214	203
Rural	244	246	243	239
Urban	178	177	174	168
Low income growth				
National	222	220	211	202
Rural	242	243	240	237
Urban	176	175	172	167
High income growth				
National	225	225	215	203
Rural	246	249	246	240
Urban	177	177	173	165

Source: Author's estimates

Table 2.13. Projected annual per capita consumption of meat and fish under alternative income growth scenarios in China, 1991-2020.

Alternative scenario	Per capita meat consumption (kg)			
	1991	2000	2010	2020
Baseline				
Red meat	17	23	32	43
Rural	15	20	26	33
Urban	24	30	40	52
Poultry	2	3	5	8
Rural	1	2	3	4
Urban	4	6	8	12
Fish	6	10	17	28
Rural	4	6	9	14
Urban	12	18	28	43
Low income Growth				
Red meat	17	22	27	34
Rural	15	18	22	27
Urban	24	28	34	42
Poultry	2	3	4	6
Rural	1	2	2	3
Urban	4	5	7	9
Fish	6	9	14	20
Rural	4	6	8	10
Urban	12	16	22	30
High income Growth				
Red meat	17	25	36	53
Rural	15	21	30	41
Urban	24	32	46	65
Poultry	2	4	6	10
Rural	1	2	3	5
Urban	4	6	10	16
Fish	6	11	21	40
Rural	4	7	12	19
Urban	12	20	35	61

Source: Author's estimates.

The projected rise in demand for meat, poultry, fish, and other animal products will put pressure on aggregate feed grain demand (Table 2.14). In the baseline scenario, demand for feed grain will increase to 109 Mt by the year 2000. Although China does not publish aggregate feed grain statistics, our calculations show an increase of 30% during the 1990s (up from 76 Mt in 1991). By the year 2020, the projected grain needed for feed will reach 232 Mt. At this rate of growth, feed grain as a proportion of total grain utilization will move from 20% in 1991 to 38% in 2020. This process of moving from an agricultural economy which procures grain primarily for food to one which is becoming increasingly animal feed-oriented is typical of rapidly developing economies elsewhere in the world (Yotopolous, 1985), and also has been predicted to occur in China by others (Carter & Zhong, 1991).

Table 2.14. Demand for feed grain under alternative population and income growth scenarios in China, 1996-2020.

Alternative scenario	Demand for feed grain (million metric tons)			
	1996	2000	2010	2020
Baseline	92	109	158	232
Low population growth	92	108	153	218
High population growth	93	110	163	242
Low income growth	90	103	139	189
High income growth	95	116	181	286

Source: Author's estimates.

The projected per capita demands for food and feed grain imply that aggregate grain demand in China will reach 450 Mt by the year 2000 (Table 2.15), an increase of 17% over the level of the early 1990s (386 Mt). Although per capita food demand is falling in the later projection period, total grain demand continues to increase through 2020 mainly because of population growth and the increasing importance of meat, poultry, and fish in the average diet. By the end of the forecast period, aggregate grain demand will reach 590 Mt, about 50% higher than the initial baseline demand (Table 2.15).

Table 2.15. Projections of grain demand (Dem.), production (Prod.), and net imports (Imp.; million metric tons) under various scenarios with respect to population, income, and technology, 2000-2020.

Alternative scenario	2000			2010			2020		
	Dem.	Prod.	Imp.	Dem.	Prod.	Imp.	Dem.	Prod.	Imp.
Baseline	450	426	24	513	486	27	594	570	25
Low population growth	444	426	19	496	486	11	562	570	-8
High population growth	445	426	29	528	486	42	622	570	52
Low income growth	440	426	15	490	486	4	550	570	-20
High income growth	460	426	34	537	486	51	648	570	78
Low investment rate	450	418	32	512	462	50	593	517	76
High investment rate	454	429	22	514	507	7	596	606	-10
High income & high investment	460	429	31	538	507	31	650	606	43
Low income & low investment	440	418	22	489	462	27	548	517	31
High income, high investment & low population growth	454	429	25	520	507	13	613	606	7
Low income, low investment & high population growth	445	418	26	503	462	40	573	517	56

Source: Author's estimates.

2.4.3. Availability of grain supply: results of baseline projection

Baseline projections of the supply of grain show that China's producing sector gradually falls behind the increases in demand. Aggregate grain supply is predicted to reach 426 Mt (in trade weight) by the year 2020. This projection implies a rise in grain output of only about 10.6% over the early 1995s, a figure somewhat below the more optimistic government target given in the Ninth Five-year plan which had hoped to meet a target of 440-450 Mt by 2000 (or 490-500 Mt in non-trade weight/unprocessed grain figures).

Production is expected to rise somewhat faster in the second and third decades of the forecast period. Mostly as a result of the resumption of investment in agricultural research during the forecast period, aggregate grain production is expected to reach 486 Mt in 2010, an increase of 14% during the preceding 10 years; production will reach 570 Mt by 2020, an even higher percentage increase for the decade (17% over the 2010 level).

Under the projected baseline scenario, the gap between the forecast annual growth rate of production and demand implies a rising deficit. Imports surge in the late 1990s to 24 Mt (Table 2.15). After peaking in 2010 at 27 Mt, grain imports remain at 25-26 Mt level through 2020.

2.4.4. Alternative scenarios

To test the sensitivity of the results to changes in the underlying forces behind the supply and demand balances, a number of alternative scenarios are run. In these scenarios the baseline growth rates of the key variables, including income, population, and investment in technology were altered. The results, shown in Table 2.15, indicate that low population growth rates would reduce grain demand by 6, 17 and 32 Mt in 2000, 2010 and 2020, respectively, as compared to the baseline, with total grain imports falling to zero by 2015. With a high population growth, annual imports increase to about 30 and 50 Mt in 2000 and 2020, respectively. Low income growth causes a decline in projected total grain demand from 594 to 550 Mt, resulting in small exports of grain after 2015. With rapid income growth, projected imports would rise significantly.

Perhaps the most important result shown in Table 2.15 is the very large impact of investment in agricultural research on production and trade balances. This is hardly surprising given the large contribution that agricultural research has made to agricultural productivity in recent years. Increases in the rate of growth in investment in agricultural research and irrigation from a baseline level of 3.5% to an alternative of 4.5% per year, are projected to shift China from an import to an export position by 2020. If, instead, the growth in annual investment in the agricultural research system and irrigation fell only moderately (from 3.5% per year as forecast under the baseline projections to 2.5%, by 2020), total production would only be 517 Mt. Without a change in the assumption regarding the level of food demand, imports under such a scenario would reach a level of 76 Mt. This level of grain imports can be expected only if there will be a continued decline in the growth of agricultural investment, and if the government does not respond with countervailing policy measures as rising import levels. Such a scenario is only realistic if the government is unwilling or unable to undertake policies to stimulate food production growth. However, agricultural research and irrigation investments have already recovered in recent years. As grain prices have risen in response to short-term tightening of grain supplies, government policy makers have responded with promises of greater investments in agriculture. While most of the investments have been targeted at irrigation, improvements in the operations of research institutes have also been announced.

In addition to domestic investments, the government could also look to the international market for technological products. China is planning to initiate a technological transfer program to introduce 1000 kinds of advanced agricultural technologies from abroad. Such moves could reduce the expected decline in the growth rates of grain production, and also decrease the expected level of imports even if growth in public investments slows down.

High income growth may result in a high investment in agricultural technology and infrastructure. Simulation results of this combined scenario indicate that the grain import could be reduced by 35 Mt (from 78 to 43 Mt) by 2020 if the high income growth scenario were accompanied by a high investment assumption. The import level would fall further to only 7 Mt by 2020 if the high income and high investment scenario were combined with a likely low population growth assumption (Table 2.15). On the other hand, a scenario with low growth in income and investment and high growth in population could raise China's grain import from a baseline of 25 to 56 Mt by 2020.

Simulations also show that production, demand, and import are relatively insensitive to small changes in price trends. For every 0.5% increase in the annual projected grain price trend, imports fall by 2-3 Mt. Similar magnitudes are observed with changes in the price of fertilizer; by increasing the projected growth of fertilizer prices by 1%, imports increase by 4 Mt. Hence, if the rise of fertilizer prices are higher than those of grain output prices, the change in China's output to input price ratio means that more imports will be required to meet the nation's projected deficit.

Finally, assuming a linear response of production to erosion and salinity as the level of environmental deterioration increases, slight increases in their trends (*e.g.* an increase in growth rate of 0.2% per year from 0.2 to 0.4) have little impact on output (a decline of only about 7 Mt in 2020). Extrapolating from these results, substantial impacts would not be found until the erosion and salinity rates accelerate to 1% per year. Even at this level projected grain imports in 2020 only rise to 60 Mt.

2.4.5. Summary and implications

In the past, food self-sufficiency was the central goal of China's agricultural policy, and it will continue to be in the future. When we consider the likely agricultural policies and trends of economic development, our projections show that under the most plausible expected growth rates of the important factors, China's imports will steadily rise throughout the next decade. By 2000, imports are expected to reach 24 Mt. Increasing imports arise mainly from the growing demand for meat and feed grains. However, after the year 2000 grain imports are expected to stabilize.

There is a considerable range in the projections when the baseline assumptions are varied in both the short- and long-run. Different rates of agricultural investments and income growth create the largest differences in expected imports. From the point of view of China's own domestic needs and relative to the size of current world market trade, there are several factors that may keep China from becoming too large a player in the world market:

(*i*) World grain prices would certainly rise in reaction to large Chinese imports, a tendency which would dampen the Chinese grain demand and would stimulate domestic supply.

(*ii*) There may be major foreign exchange constraints to import large volumes of grain. Either government policy makers will not allocate foreign exchange for additional grain imports, or changing exchange rates will discourage imports.

(*iii*) Limitations on the capacity of China's ports and that of other parts of the nation's transportation and marketing infrastructure may constrain imports.

(*iv*) There are political factors that will make China's leaders react to increasing grain shortages and food security. China's leaders have been and will be concerned with a near self-sufficient domestic agricultural production capacity. National security, pride, and ideology will necessarily put a premium on maintaining a rough balance between domestic demand and supply.

2.5. Issues and challenges

On the basis of the projection results presented in the last section, it seems likely that in the coming decades China will become a more important player on the world grain market as an importer. Net annual grain import of 25 to 30 Mt is a likely level of China's annual grain imports in the coming decades and is also a figure likely to be acceptable to the Chinese government as this represents about 4-5% of domestic grain demand only. Thus, China could face the challenge of feeding its growing population (an annual increase of nearly 14 million in 1990s) and pursuing its high level of food security in the coming decades. However, there is a growing concern about the efficient use of the country's limited agricultural resources, the difficulties to overcome the technical constraints on food production, and the complicated task to fomulate conducive food and agricultural policies to increase domestic agricultural production and to achieve a higher level of national food security.

2.5.1. Resources constraints

Declining agricultural land

China is an extremely land-scarce country. Total cultivated land was about 95 million ha in the early 1990s, less than 0.1 ha per capita (declining from 0.13 in 1970 to 0.08 in 1995). Although these official data could be underestimated by about 30% (Crook, 1994), this does not imply that China's grain yields are low and that China could easily reduce its future grain deficit and become a grain exporter. Potential yield gain is very limited for that "un-reported land". Based on our most recent household survey conducted in Zhejiang, Jiangsu, Fujian and Yunan provinces in late 1996 and early 1997, un-reported lands mostly fall under the categories of marginal, fragile and newly reclaimed land, and mainly belong to "private plots" planted to vegetables and other minor crops for household consumption. This implies that there might be an underestimation of food consumption (*i.e.* vegetables) of rural households if the consumption data are based on the national production and food balance sheet.

On the other hand, local officials in our recent survey stated that there has also been an increasing tendency to over-report cultivated land since the 1980s. First, there is an incentive for local officials to under-report the extent of shifting agricultural land to non-agricultural use (for rural industry, infrastructure, housing and others) as the degree of protection of agricultural land is an indicator of local government performance. Second, there is also an incentive for the higher authorities to let the lower authorities over-report the cultivated land as this will ensure fulfillment of the state grain quota procurement.

Finally, it should be noted that land use efficiency in China has been high and the potential for land reclamation and expansion of the land base is modest. This situation is further galvanized by the increasing competition for land use from non-agricultural sectors and environmental degradation. Moreover, declining irrigation water supplies might endanger the future use of large agricultural land tracts.

Water shortage for agricultural use

China is one of the most water-short countries in the world and the water shortage, particularly in the North Plain of China and in Northwest China, has been become severe. The rising demand for urban and industrial water supplies poses a serious threat to irrigated agriculture as the marginal benefits of water are generally believed to be higher in non-agricultural uses and without specific allocation mechanisms much of the water would be used for these purposes.

Through large government projects the irrigated area strongly increased before 1980. However, investments in irrigation decreased from 1980 onwards as the costs of irrigation increased rapidly. Moreover, many irrigation systems perform poorly and many irrigation schemes have degraded through waterlogging, salinization, and mining of aquifers.

Shifting labor to non-agricultural sectors

Increased employment opportunities in the non-cropping and off-farm sectors in rural non-agricultural sectors such as industry and services have led to large shifts in labor use patterns. After putting ever-increasing amounts of labor into grain production in the 1950s through 1970s, labor use on all crops fell substantially from 1975 to 1994 (Table 2.16), and presently the labor requirement of rice and wheat is over 50% less than in the pre-reform era. The majority of the remaining laborers in agriculture is either aged or unskilled.

Table 2.16. Labor inputs (days/ha) in agricultural production in China, 1975-94.

Year	Rice	Wheat	Maize	Soybean	Cotton	Rape seed
1975	638	402	375	221	919	453
1980	506	384	360	213	818	442
1985	347	222	270	190	680	317
1990	309	210	259	180	664	288
1994	279	180	220	165	650	254

Sources: SPB (1988-95), SSB, Statistical Yearbook of China, various issues.

2.5.2. Technical constraints

Research and technology

While research and technology played a critical role in the growth of food production in the past, recently falling budgetary commitments to research has weakened the system. A recent national seed program focuses on maintaining a stable increase in agricultural production. However, a number of issues need to be solved before the program can be successful. These include barriers to entry and free market prices, phasing out of subsidies, and development of intellectual property rights. China's grain yields are among the highest in the world. A common believe is that arable land has been underreported by more than 30%. As we discussed above, this might not be true for grain yield, so the over-estimation in grain yield might be much lower than the figure indicates. More research efforts in the future will be required to achieve a similar productivity gain as in the past.

Fertilizer

Chemical fertilizer use in China is among the highest in the developing countries. Marginal gains from additional fertilizer use may be modest. More important issues of fertilizer use in China will be the unbalanced use of N, P and K, with a generally low K-content (Huang *et al.*, 1994) and the inefficiency of the state monopoly on the fertilizer market and distribution system. China depends heavily on the international market for fertilizer, importing about 25% of its requirements; domestic production is limited and 95% of the potassium used is imported. Further reforms in fertilizer pricing, market/distribution, and trade are needed to improve the system.

Infrastructure

China's limited grain handling and internal transport capacity will continuously have its impacts on the stability of supply in the future. Moving from a plan economy to a market-oriented economy with a poor infrastructure, market stabilization has become a major issue for food policy. Railways, being the primary mode of freight transport, are efficient but have insufficient capacity to meet transport needs. Major production and consumption areas are quite distant. Shipment of grain (*i.e.* maize) from Northeast China to Southern China is more expensive than the transportation costs of grain from abroad. The volume of grain stored in deficit areas could be smaller under improved transport conditions. Any short-term fluctuation of food production in a particular area often causes a fluctuation in local prices.

2.5.3. Food and agricultural policies

China's government has frequently made statements that it is capable to solve its food problem, recognizing that government policies are important for an effective supply of food, stabilization of food market and access of food to the poor. However, there are still many constraints and challenges for the government to improve food production and food security in future.

Land tenure system

China should continue to reform its land contract system. Recent modifications of land tenure rights may not have much impact on agricultural production and land investment in the short run, since a proper institutional and legal framework needs to be established before the market can work efficiently. Currently, this legal framework related to land ownership as well as agricultural input and product markets is not well adapted to a rapidly expanding and increasing market economy.

Water management

Current water management is commonly believed to be one of the main causes for the increasing water shortage problem, which is largely ignored by reformers. As a result of poor management, unclear water property rights and inadequate maintenance, irrigation systems in China are showing signs of structural deterioration and declining productivity. There is no standard method for calculation, assessment and restrictions of water management charges. The conflicts for water use have expanded beyond agriculture, occurring not only among farmers within the same irrigation district, but also between the government departments over the right to manage water, in particular, to collect water fees and give out water withdrawal permits.

Investment policies

Reform has accelerated the growth of agriculture since the late 1970s, but new institutional arrangements have not provided incentives for both the public and private sector to invest in the agricultural infrastructure, research and extension. The investment in agricultural research declined in the late 1980s, thereby weakening the basis for future cereal productivity. During the rural reform, the government realized the need to improve the educational level and technological capabilities of millions of farmers. Given the importance of technology in the growth of agricultural production, strengthening research, education and extension should be given high priority. Several programs have been initiated, but these programs are facing the constraint of increasing shortage of funding.

Food price and marketing

After nearly two decades of reform, farmers are still required to deliver specified quantities of grain to the Grain Bureau at lower prices (more than 50% lower than the market prices in 1994-96). In addition to the 50 million tons of quota procurement, State marketing agencies are charged with capturing 80% of the marketed grain surpluses to ensure that government can exercise a substantial control over the open market as well. Despite procurement of 50 million tons of grain at below-market prices, less than one-third of these grains are sold at concessional prices to urban consumers. The balances are sold or stored for later sale at "free market" prices creating windfall gains for the Grain Bureaus which are competing with non-state traders.

The Provincial Governor's Grain Responsibility policy made provincial governors responsible for the balance between supply and demand at provincial level. This responsibility was transmitted to lower levels of decision and appears to have fragmented the national market into provincial and sub-provincial markets. Governors of surplus provinces hesitate to release grains for inter-provincial trade until provincial needs are fully satisfied and prices within the province are relatively low. This practice might hinder food security in deficit provinces, exacerbate spatial grain price differences, contribute to volatile temporal grain prices, and create inefficiency of resource allocations. The negative impact of this governor's responsibility system on the grain market integration process and on the efficiency of resource allocation should not be ignored in evaluating these policies.

Input price and marketing

While food price inflation was under control and prices were stable in 1996, agricultural input prices kept rising at a rate higher than the overall price inflation. Increase in agricultural input prices was mainly driven by that of chemical fertilizer. This was taken by the reformer as an indicator of failure of the fertilizer liberalization policy, which led to the market retrenchment policy on fertilizer in 1994.

However, there was little evidence to indicate that these fertilizer price policies had the desired effect. Prices of fertilizer continued to increase at an uncontrolled rate. The actual retail price of urea reached as high as 1600 yuan per ton in most of the country in 1994 and more than 2200 yuan per ton in late 1995, compared to the 1400 yuan per ton "ceiling price" set by the government. The national retail prices of agricultural material inputs rose by 22% in 1994 and 28% in 1995. In the first half of 1996, they rose by an additional 12.1%. Several questions are raised: What are the roles that both public and private sectors could play in stabilizing the fertilizer market and price? Is the recent fertilizer price inflation related to the private sector's participation in the market or related to the state monopoly on the market and to its trade policies? Or is the fertilizer price inflation due to manipulation by private traders and to supply deficits due to domestic production and trade policies?

Trade

External trade policy also underwent a cycle of liberalization and retrenchment. In 1992 the import/export responsibility was partially delegated to the provincial authorities for all international grain transactions. But quantity licensing and control policy was re-emphasized for major food commodities (grain). The implication of this policy for the national food security should be evaluated. Other important issues include trade-off of importing feed grain and livestock, the trade management system reform, and cooperation between production, domestic and international trade. As consumption of livestock products increases, it becomes more important for Chinese officials to know whether importing livestock products may be more efficient than growing/importing feed stuffs and producing livestock domestically. There have also been conflicts between domestic and international trade, production and marketing arrangements and input and output policies, because of the lack of coordination between the Ministry of Agriculture (agricultural production), the Ministry of Commerce (domestic agricultural trade and marketing), the Ministry of Foreign Economic Relations and Trade (agricultural export/import), and the National Production Materials Authority.

Poverty and equity

Great achievement in the poverty alleviation has been made since the late 1970s. But further reduction of poverty has been proven to be difficult due to wide dispersion of the poor population in remote upland areas and the increasing income gap between the poor areas and the developed coastal areas. The fast reductions of poverty through agricultural growth were largely exhausted by end 1984. The Ministry of Agriculture estimated that the population in absolute poverty dropped by less than 30 million after 1985 and remained 65 million in rural areas in 1995, accounting for 7% of the rural population. Most of these residual poor have remained trapped in the more remote upland areas where agricultural productivity gains have proven far more problematic. More attention also needs to be focused on the problems of the poor people outside the poor regions. The challenges are not only to eliminate absolute poverty, but also relative poverty.

2.6. Concluding remarks

China is the world's most populous country, and is highly acclaimed for its ability to feed its >20% of the world population with only about 7% of the world's arable land. Despite this extremely limited natural resource and the doubling of the population in the last four decades, per capita daily availability of food, household food security and nutrition all have improved significantly. The increase in per capita availability of food occurred almost exclusively through increasing domestic production. The growth of agricultural production since the 1950s and particularly after the 1970s, has been one of the main accomplishments of the country's development and national food security policies. China's experience demonstrates the importance of technology changes, institutional reforms, the incentive system, rural development, and sector specific policies in ensuring adequacy of food supply through increases in domestic production. China's research system has successfully produced a steady flow of new varieties and other technologies since the 1950s. China's robust growth of the stock of research capital contributed significantly to these dramatic changes. Since the early 1950s, China has invested heavily in irrigation, raising the irrigated area from 18% to nearly 50% of the cultivated area. Favorable output to input price ratios contributed to the rapid growth in the early 1980s.

China's experience shows that strong rural economic growth is a key factor for significant reduction of absolute poverty. Country-wide participation in the rural economic growth brought about a tremendous reduction in absolute poverty during the period 1978-85. The country has also succeeded in creating jobs in both farming and non-farming, particularly in rural industry, to absorb the rural labor surplus since the early 1980s. Diversification of production and development of rural enterprises (TVEs) stimulated the growth of farmers' income and improved farmers' living standards. But further reduction of poverty has been proven to be difficult due to wide dispersion of the poor population in the remote upland areas and the increasing income gap between the poor and developed coastal areas. Most of these residual poor have remained trapped in the more remote upland areas where agricultural productivity gains have proven to be far more problematic. Although nutrition improvement took place over the last two decades, malnutrition remains. While the economy has been successful in keeping a high growth rate, this growth also persisted its uneven pattern across regions and among income groups.

The grain reserve system, a strong disaster relief program and a large food-for-work programme contributed substantially to the stability of food supply and access of food to the poor. The major constraints in stabilization of food supply in China are the poor market infrastructure and internal transport system.

China's experience also demonstrates the important relations between economic growth, political and social stability, and food security, in a large country where the economy is undergoing a fundamental adjustment and is growing rapidly. Maintaining the relatively high level of food self-sufficiency is desirable for ensuring not only domestic but also global food security. In the past, food self-sufficiency has been the central goal of China's agricultural policy, and it will continue to be in the future. The Ninth Five-year Plan for 1996-2000 and the National Long Term Economic Plan aim at continuing growth in agricultural production and farmers' income, maintaining a high level of food self-sufficiency and eliminating absolute poverty. The strategy for achieving the above targets includes several aspects:

- measures to provide more incentive structures and mechanisms for both public and private sectors;
- to increase productivity enhancing investments in agriculture (investment in land, irrigation, research, extension, *etc.*);
- to increase trade through price and marketing reforms;
- to raise farmers' income through promotion of rural industrial development and non-farming employment;
- to strengthen anti-poverty programs by raising poverty alleviation funds and emphasizing economic development programs and infrastructure development;
- to enhance the state grain reserve system as a major government intervention on stabilization of food supply and market prices, *etc.*

Projection results presented in this paper, based on the most recent government policies and economic trends discussed above, show that China will neither empty the world grain markets, nor become a major grain exporter. It does seem likely, however, that China will become a more important player in the world grain market as an importer in the coming decades. But China is not a major threat to the world economy. Increased grain imports will benefit grain-exporting countries, especially those dealing with wheat and maize. The likely level of China's annual grain imports in the coming decades is in the order of 25-50 Mt. The increase in net grain import is due mainly to the accelerating demand for meat and feed grains and from the slowing supply as a result of reduced agricultural investments since the 1980s. China's grain economy is becoming increasingly animal feed-oriented. After the year 2000, however, imports are expected to stabilize as the domestic supply growth rate will have stabilized with the recovery of investment in agricultural research and irrigation. In the worst case scenarios China will need 70-80 million tons of grain.

There is growing concern about the efficient use of the country's limited agricultural resources, the difficulties to overcome the technical constraints on food production, and the complicated task to formulate more conducive food and agricultural policies that will increase domestic agricultural production and national food security in the coming decades. On the other hand, there is still room for improvement in the institutional arrangements, the incentive system, the price and marketing policies, to promote food and agricultural production and food security at the household level. The legal framework related to land ownership as well as input and product markets is not well adapted to a rapidly expanding, increasingly market-based economy.

A better incentive system is needed to encourage both public and private investments in the agricultural infrastructure, research, extension, and farmers' education. Given the importance of technology in the growth of agricultural production, strengthening research, education and extension should be given high priority.

After nearly two decades of reform, farmers are still required to deliver specified quantities of grain to the Grain Bureau at low prices. The impact of the grain procurement system and the provincial Governor's grain balance responsibility system on grain production, marketing and resource allocation and welfare of producer and consumer should be carefully evaluated. Also, there has been little evidence that the state monopoly fertilizer market policy had the desired effect as the prices of fertilizer continued to increase.

The major issue in stabilization of food supply in China will not be the food relief system and grain reserve program, but China's constraint on limited grain handling and internal transport capacity. The poor market infrastructure is one of predominant factors shaping China economy.

To summarize, China is capable to solve its food problems in general and China's government will have an important role to play in improving national and global food security. In this regard, full knowledge about the present policies and their impacts on food production, stability of supply, trade, and household food security are essential in designing more conducive policy measures and to develop an institutional framework to improve the level of food security. In this regard it will be necessary to carry out more analytical investigations, including agricultural policy studies, seminars and dialogues, focusing on the issues discussed above. These studies will not only be of significant interest for China, but also for the rest of the world, as China will become integrated into the world market and eventually in the WTO. Therefore, with regard to China, more international cooperation and strengthening of research is needed. In this regard, the international organizations could play an important role in initiating future programs.

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3. A research approach to analyze food security scenarios for China

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Abstract

This contribution identifies the research that needs to be done to provide decision-makers the right tools to assess the impact of policy decisions on national and provincial food security in China. Food security in China may have a decisive impact on world food security in the near future. In China, cereal grain requirements in 2030 will exceed the current ones by 60% and livestock demand will increase more than 2.5 times, while there is limited scope for expansion of arable land and agricultural production levels are already relatively high. The growing demand for energy in China calls for increased biofuel production, and meeting these needs and those for other non-food crops will put further pressure on the use of natural resources for food production. Planning for a food-secure future is rapidly being moved to the top of the policy agenda in China that until recently was dominated by the need for rapid industrial expansion. It will be necessary to use land and water resources at maximum efficiency to meet the fast rise in the demand for food, feed, non-food crops, and bio-energy in China, and so minimize importation of these products. This, on the one hand, illustrates the importance of food security at the national level. On the other hand, food security and access to food are partly poverty issues. As poverty is largely determined at the household or village level, a multi-scale approach will be applied, starting the food security analysis with data derived from research at the household or village level, and aggregating these data up to higher scales (County, Province and National level). Such a bottom-up approach is very appropriate in China: the hierarchy in the decision-making system (National, Province, District, County, town and village) can be reflected in the different scales used in the ecoregional approach. The impact of decision-making on food security and poverty-related issues will be made transparent at various decision levels. Simultaneously, possibilities for interprovincial and international trade will be made explicit. The final objective of the research is to explore the potential impact of alternative policies at various decision levels on food security.

3.1. Introduction

The world's population is expected to grow to over 8.5 billion people by the year 2030. Estimates of the associated increase in food requirements vary from three- to six-fold, depending on the changes in diet that are expected to occur as a result of income development. China's food outlook is one of the most debated issues in the world food economy. Recent economic reforms have brought about accelerating income growth. As a result, demand for food, particularly meat and feed grain has continued to grow. According to the projections by Huang *et al.* (1997) and Rosegrant *et al.* (1995), demand for cereal grain will increase by 40 to 50% and demand for livestock is expected to be more than double by 2020 (Huang *et al.*, 1997; Rosegrant *et al.*, 1995). Among cereal grains, demand for maize, widely used as feed, will increase more than the projected increase in supply.

China was a net grain importer in most years of the past decade, annual imports ranging from 5 to 10 million tons. Net import of grain hit an historical high of nearly 20 million tons in 1995 (SSB, 1996). Although grain production recovered and reached a record level in 1996, this will not significantly decline China's net grain import. China is expected to raise its total net import of grain in the coming decades, and livestock demand will increase by more than 2.5 times, while cereal grain demand increases by 60% by 2030 (as compared to the base year 1995; Huang *et al.*, 1997). Moreover, the growing demand for energy in China calls for increased biofuel production, and meeting these needs will compete with food production for nature resources.

On the supply side, China has been successful in developing new technologies, changing institutional structures, mobilizing labor and other resources to support agricultural growth in the past several decades. However, there are growing concerns on uses of the country's limited agricultural resources, the difficulties to overcome the technical constraints to raise food production, and the complicated issue to formulate more conducive food and agricultural policies to increase domestic agricultural production at levels which sustain national food security in the coming decades.

China is a land-scarce and water-short country. This situation would be further galvanized by increasing competition for land and water use from non-agricultural sectors, continuing loss through environmental degradation and poor land and water management. Recent reports that China is losing about 500,000 hectares of irrigated land every year, mainly due to salinization, call for thorough analysis of the use of irrigation water and drainage effluent (Heilig, 1996; Smil, 1993). At the same time, it is necessary to consider the predicted emergence of new high-yield grain varieties such as super high-yield rice varieties, able to produce up to 15 tons per hectare per year (Hossain & Fisher, 1995; Khush, 1995). Moreover, resources are shifting away from agriculture to non-agricultural sectors and expansion of resource frontiers is problematic due to limited availability and costly development.

Food security in China will have a decisive impact on world food security. Some predict that China will be a major importer of food (Brown, 1995; Brown & Kane, 1995); others say this will not be the case (Huang *et al.*, 1997; Rosegrant *et al.*, 1995; Alexandratos, 1995). The Chinese Government has decided to restrict the conversion of agricultural land into industrial areas, and has taken other policy measures to increase food security (Huang, 1996). Planning for a food-secure China is rapidly being moved to the top of the policy agenda that until recently was dominated by the need for rapid industrial expansion. The detailed analysis of the actual agricultural and food security situation in China in Chapter 2 shows that Chinese leaders, policy makers, and planners need reliable and comprehensive food-security scenarios.

FAO defines food security as "a condition in which all people at all times have both the physical and economic access to the basic food they need". Thus, three conditions need to be met: *i.* adequate food availability or supply; *ii.* stability of this supply, and *iii.* access to food at household level, particularly by the poor. To meet the first condition it will be necessary to use land and water resources at maximum efficiency to satisfy the rising demand for food, feed, non-food crops, and bio-energy, and so to avoid or minimize massive importation of these products. Stability of food supply does not only depend on the production capacity of the agricultural sector, but is also determined by socio-economic factors. Therefore, a comprehensive approach to food security models, combining both biophysical and socio-economic factors, is necessary. The factors that determine food production and stability of food supply include: resources, incentive system, price and marketing mechanisms, institutional arrangements, rural infrastructure, investment strategies and other agricultural policies, education, research and extension. Food demand is mainly a result of population growth, urbanization, economic growth, consumption pattern changes, etc.

A prerequisite for food security is access to food at household level, particularly by the poor. This illustrates that food security is partly a poverty issue. Great achievements in the poverty alleviation have been made since the late 1970s, but as the distribution of the national economy is unequal across regions, further elimination of poverty remains important. Farmer's income in the central and eastern parts of China continued to experience faster growth, while western and south-west regions followed a slower growth pattern. The income gap among regions and between the rural and urban areas has not narrowed while income distribution within regions has worsened (MOA, 1996). The strong economic growth has brought about a significant increase in the people's living standard, tremendous reduction in absolute poverty, and increasing access to food at household level in China (World Bank, 1992; MOA, 1996), but a large part of the population still lives in poverty. Poverty is one of the causes for malnutrition and therefore the improvement in the food security situation is also illustrated by a significant reduction of poverty in China. The World Bank early estimates show the number of absolute poor to have declined from roughly 260 million in 1978 to 96 million in 1985, or from about one-third to 12% of the total rural population (World Bank, 1992). By 1995, the figure further decreased to 65 million, which is only about 7.6% of the total rural population (MOA, 1996).

To date, ecoregional approaches to food production have been based mainly on the definition of ecoregions according to biophysical factors. Food security models, however, require a more comprehensive approach. The proposed research combines biophysical and socio-economic factors in a comprehensive and innovative methodology, which will provide decision-makers the right tools to assess the impact of policy decisions on national and provincial food security.

3.2. Research approach

The proposed research is ecoregional in the sense that it determines both demand and supply in relation the spatial distribution of biophysical and natural resources as well as socio-economic and political features. Data on biophysical and natural resources, and socio-economic and political data are different in nature. Biophysical and natural resource data are geographically explicit while socio-economic and political data are delimited by administrative boundaries. A multi-scale approach is introduced which includes the ecoregional aspect at different levels of integration. The analysis of the structure of food demand in relation to socio-economic and political factors will follow a bottom-up approach. The data will first be analyzed on household or village level, subsequently these data will be aggregated to translate the results into administrative zones (County, District), and will finally be aggregated at the Province and National level. Aggregated demand data will be compared with the agricultural production potential for a given region to assess the effect of alternative development policies at various decision levels on food security. This last step requires a downscaling approach, in order to translate the effects of political decisions at a high level of aggregation to the lower levels.

This multi-scale approach (ecoregional and provincial, biophysical and socio-economic) will allow to investigate food security not only in terms of demand and agricultural production capacity, but also in terms of interprovincial and international trade, labor availability and changing economic situation.

3.3. Expected results

3.3.1. A comprehensive database on both biophysical and socio-economic information

A comprehensive digital database for detailed analyses of China's food situation will be established in order to conduct reliable parameter estimates of both biophysical and economic models.

On the supply side the following data will be collected:

- Availability of land for biomass production. An evaluation of land use at various levels will be done based on existing data sources in China, using GIS. Environmental variables (erosion, salinity, natural disasters, soil fertility, *etc.*) and the extent of and of loss of land to urban developments will be quantified in the second step.
- Agricultural data: time series data for all major agricultural commodities at county and province level. A database with experimental results of agricultural production under limiting and non-limiting conditions derived from field experiments from Chinese research networks will be set up to validate crop production simulations for different agro-ecological zones.
- Climatic data.
- Availability of water for irrigation of crops. Availability of water in space and time for agricultural use at the regional level and water use efficiency of different cropping systems will be quantified for modeling potential production and yield gap determination.

On the demand side, the data to be collected are:

- Food consumption data: household level food consumption by commodity and by region (both time series (1990-1995) and cross section (by region and by rural versus urban)). Data on food prices, income (household expenditure survey data), urbanization, market development and other structural change variables will also be collected for the food demand study.
- Demographic data: Historic population development at provincial and lower levels, and population prospects (including age structure changes, urbanization prospects) will be considered.
- Energy data: Data on rural energy consumption are available. For the bio-energy analysis, other data on rural energy supply and the availability of rural energy from food production will be collected.
- Data on animal grain and fodder consumption.

3.3.2. Actual productivity and biophysical potential

The methodology developed at AB-DLO to compare different scenarios of agricultural development and their consequences for sustainable food production and the environment will be improved (Groot *et al.*, 1997; Penning de Vries *et al.*, 1995). Agricultural production is calculated on a grid basis, each grid cell being characterized by its suitability for arable farming or grassland, soil and climatic conditions and the availability of irrigation water. Inputs are derived from digital databases containing soil, climatic, agronomic and demographic data. The biophysical potential for agricultural production is calculated with a simple crop growth module, a soil water balance and a soil nitrogen balance. Production data are aggregated to agricultural production regions and finally administrative regions. Secondary production potential (animal husbandry) will be derived from aggregated data of calculated pasture productivity potentials, feed and fodder availability; the level at which aggregation will take place needs further investigation.

Several methodological aspects will be improved. In the earlier approach, potential production levels were calculated on the basis of all suitable soils, regardless its present use; these yields can be considered as the upper biophysical limit to food production. Calculation of attainable yields for the actual cropped area (and the associated yield gaps) was not possible as accurate measurements of the spatial pattern of land use and land cover were lacking. High resolution (1 km x 1 km) georeferenced data on land-use and land-cover based on remote sensing techniques recently became available (IGBP-DIS Land Cover data set), allowing calculation of a detailed yield-gap distribution for China for the agricultural suitable land that is currently in use. This yield-gap distribution will indicate whether the availability of natural resources allows a further intensification of agriculture without additional land reclamation, or if land reclamation is required to increase productivity.

Irrigation water availability is a major yield-determining factor in China, but a theoretical basis to allocate irrigation water to the individual grid cells is actually lacking. These methodological aspects are presently subject of research, and the evolving methodologies will be incorporated in the Project.

3.3.3. The structure of demand for agricultural products

Based on household food consumption and expenditure data, the structure of food demand will be modeled. This comprises both the impacts of income and price on food consumption and the impacts of structural changes in the economy on the food consumption pattern. The demand system model will be based on a detailed description of the demand structure, derived from time series and cross-sectional data on China's food consumption. Because consumption patterns are inherently different between rural and urban consumers (Huang & Bouis, 1996), and among regions, rural and urban demand by region will be modeled separately.

Once the demand for meat (pork, beef, mutton, chicken, eggs and milk), fish and other animal products is known, the implied feed demand (and hence the overall demand for grain) will be calculated by applying a set of feed conversion ratios. Efforts will also put on creation of a consistent database for feed demand and livestock production and consumption. Currently, estimates of livestock production are more than double the consumption (with only a very small amount of export of livestock product), making any projection implausible if the data on livestock production and consumption are not reconciled.

A review will be made of the per capita bio-energy demand and the efficiencies of the use of crop residues and the different crops that are grown to produce energy (*e.g.* annuals, tree plantations). The shortage of fuel energy in most rural areas causes land degradation and competes with the food production. The aggregated bio-energy demand (both household and industry) and the supply of bio-energy from crop residues and fuel crops will be estimated for different areas based on the efficiencies of use of these biofuels. The land required for biofuel production and the environmental impacts of biofuel use will be evaluated.

3.3.4. Biophysical constraints to increase domestic agricultural production

Once the structure of food demand has been analyzed and socio-economic scenarios have been defined, the total future domestic market demand and its distribution over different administrative regions can be derived. For these regions, attainable yields will be calculated and comparison with actual production levels will provide the yield gaps that indicate if possibilities to increase productivity do exist. Data on current efficiencies of inputs to produce food crops, non-food crops, feed, and bio-energy will be selected from a database from an all-China network and a differential analysis of the different key factors that determine productivity will identify which factors may significantly contribute to increasing domestic agricultural production as well as which resources may prevent China from being able to increase production as domestic demand rises in the future.

Degradation of resources (land degradation, urbanization losses of land, limiting water resources, climate change) which may prevent China from further increasing its production will be considered. The impacts of different inputs (fertilizers and pesticides) on the environment will be quantified for different cropping conditions to assess to which extent input use is environmentally acceptable.

Scenarios for future development of agricultural production systems will be generated based on existing projections of the key factors that determine production (climate, soil degradation, land loss through urbanization, water availability).

3.3.5. Socio-economic constraints to increase domestic agricultural production

Effects of technology, public investment, agricultural price and marketing policies, infrastructure development, comparative advantage of agriculture, environmental stress and other supply-related factors on agricultural and food supply will be examined. An innovative dynamic supply response system model will be used to estimate agricultural supplies. The model is derived from the dynamic dual value function. The dynamic duality model will be used because it recognizes important production factors, such as labor and land, while response to changes in prices and other exogenous factors, only adjusts to their equilibrium levels after several years (because of transaction costs, fixed investments, informational barriers, risk, or other such factors). These models have been successfully applied to China's crop sectors in recent studies by one of the principal investigators of the proposed study (Huang *et al.*, 1995). The model will be desegregated by agricultural production regions. A set of agricultural output supply elasticities for each commodity with respect to technology, public investment, opportunity costs of land and labor, input and output price, institutional changes, environmental stress (erosion, salinity, and natural disasters), *etc.* for both short-run and long-run will be estimated using the above model.

The demand and supply parameters estimated in this study will be used in a projection model, a framework similar to the one created by Huang, Rozelle and Rosegrant for the IFPRI 2020 Vision program. An updated model which covers more commodities (also including non-grain crops, livestock products and horticulture) will be developed in the proposed project. In this projection model, in addition to price response of both demand and supply, a series of important structural factors and policy variables will be accounted for explicitly, including urbanization and market development on the demand side, technology, agricultural investment, environmental trends, comparative advantage of agriculture, major agricultural production constraints such as availability of water and land for agricultural use, and barriers of international technological transfer on the supply side, and major pricing and marketing trade policies on the international trade.

The models developed above for China will be tied to the IMPACT model (*i.e.*, a model developed by IFPRI/IRRI's Rice Economy Project) to assess the impact of global economy changes on China's food security and China's impact on the world food economy.

3.3.6. A projection model for agricultural production, consumption and trade

The modeling of changes in the demand structure in relation to socio-economic and political factors will follow a bottom-up approach, based on a data analysis at household or village level, which are consequently aggregated to translate the results into administrative zones (County, District). The highest levels of aggregation will be the Province and National level. The effect of alternative development policies at various decision levels on food security will be assessed. This last step requires a downscaling approach in order to translate the effects of political decisions at a high level of aggregation to the lower levels. This multi-scale approach (ecoregional/spatially explicit and administrative, biophysical and socio-economic) will allow to investigate food security not only in terms of demand and agricultural production capacity, but also in terms of trade, labor availability and changing economic situations at different levels of integration (national food security, provincial or county level food security, international trade, interprovincial trade, impact of urbanization on demand structure, *etc.*).

3.4. The impact of alternative policies on food security

Both, available documents and influential decision-makers will be consulted on China's long-term economic - particularly food - policies and government development plans to the early 21st century. Identifications and assessment of these policies and development plans then will be made. A similar approach on reviewing international trade environments will also be made by the project. Socio-economic scenarios will be developed with the following procedure: a) the driving forces behind the process of economic development and agricultural growth will be identified; b) key problems and challenges which China might face in the coming decades will be examined; c) any long-term trends that could affect the development process will be discussed, and relationships between these long-term trends and China's agricultural and food supply, demand and trade will be explored. An analysis will be made of the comparative advantage of various crop and non-crop economic activities which will be important determinants of the allocation of land, water and human resources in the near future.

After the specification of the socio-economic scenarios, the development trend of the agricultural and food sector in each scenario will be set out. This will be done by the models described in section 3.6. For each of the scenarios an assessment will be made of the potential impact on food security. This will not only be done for the national level, but the impact of political decisions on food security at provincial and lower levels of decision will also be made visible.

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4. Trade, technology spillovers and food production in China

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Abstract

This paper studies endogenous technology spillovers between China and other countries. Technology spillovers increase agricultural productivity without previous R&D activities in the technology-receiving country. We utilize a global multi-region applied general equilibrium model to analyze Chinese opportunities to benefit from foreign technology improvements in grain production. It is shown that possible negative welfare effects of unilateral trade liberalization of China against North American imports of agricultural inputs may be more than compensated by productivity gains if technology spillovers are included. This holds especially in case of agricultural inputs which improve productivity of scarce arable land in China. It is also shown that knowledge spillovers from Europe carry a higher potential for China than spillovers from North America.

4.1. Introduction

Several observers have recently pointed towards possible adverse effects of rapid Chinese growth on world food markets. Specifically the Worldwatch Institute's scenarios have drawn international attention by suggesting massive grain imports by China in the next century (Brown, 1995). Others have a more optimistic view (FAO, IFPRI), but point to the importance of continued agricultural productivity growth to counterbalance an increased per capita food consumption and a growing Chinese population (Anderson *et al.*, 1996; Alexandratos, 1995; Bach *et al.*, 1996; Mitchell *et al.*, 1995). This paper explores some possibilities for China to realize productivity growth by learning from agricultural innovations which are developed in other countries.

China's food production is characterized by a shortage of arable land and capital with an abundance of labor (Anderson, 1991). This characterization of endowments points towards the possibility that China's comparative advantage may not lie in grain crops but in less land-extensive agricultural products (Lu, 1996). Nevertheless, increasing grain output ranks high on the agenda of policy makers and international observers. The relative shortage of land for grain production with little prospects for expansion of arable land implies that productivity increases are necessary to at least partially match the growing demand for grain. The origins of this growth in demand lie both in increased volumes for final consumption and in increased use as feed input in livestock production. The latter being induced by changing consumption patterns which accompany rapid income growth in recent years.

In this paper we focus on the international transmission channels which mediate productivity growth between China and other countries. Our framework of analysis are endogenous technology spillovers in a multi-region applied general equilibrium setting. Technology spillovers are said to exist if one market party receives productivity benefits from technologies developed by others, while there is no monetary compensation for the technology transfer. We introduce an international transmission mechanism of knowledge in an applied multi-region general equilibrium model to study the impact of knowledge spillovers on grain production and to investigate Chinese government policies that may influence the transmission mechanism.

Knowledge flows may be classified into embodied and disembodied spillovers. Embodied knowledge spillovers represent knowledge that comes together with commodity purchases, or in other words knowledge that is embodied in goods. On the other hand, disembodied spillovers are unlinked to commodity flows. Examples are scientific conferences, international journals, patent information, *etc.* There is empirical evidence that both types of spillovers are important for the productivity growth of sectors (see Mohnen, 1994 or van Meijl, 1995 for a review).[1] In this paper we limit ourselves to embodied knowledge spillovers as the main transmission mechanism of knowledge.

Technology spillovers receive much attention; the so-called "new" trade and "new" growth theory.[2] This literature identifies international trade and foreign direct investments as prime carriers of technology spillovers; see Coe *et al.* (1995) who identified four channels in particular. First, international trade enables a country to employ a larger variety of intermediate products and capital equipment, which enhances the productivity of its own resources. Second, international trade provides channels of communication that stimulate cross-border learning of production methods, product design, organizational methods, and market conditions. Third, international contacts enable a country to copy foreign technologies and adjust them to domestic use. Imitation is widespread and it has played a major role in the growth of high-performing economies such as Japan and the Newly Industrialized Countries (NIC's). Finally, international trade can raise a country's productivity in the development of new technologies or the imitation of foreign technologies, thereby indirectly affecting the productivity level of its entire economy.

In this paper it is assumed that knowledge is embodied in agricultural inputs which are imported into China. We hypothesize that the usability of foreign knowledge in China is dependent on the local absorption capacity (*e.g.* knowledge infrastructure and human capital) and on structural differences (factor endowments, climate) between China and the country which originally develops a new technique. Second, our focus on technical change in agriculture implies that a large part of the knowledge is embodied in inputs which cause factor-biased technical change in the receiving sectors. This latter feature is especially important in the Chinese context of scarce arable land. Third, we provide an empirical

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1 *Despite the fact that there are many empirical papers that measure the existence of inter-industry spillovers, only Sterlacchini (1989) and van Meijl (1997) estimate the influence of both embodied and disembodied spillovers on productivity growth. Both authors find a statistically significant influence for both kinds of spillovers on the productivity growth of sectors.*

2 *Seminal contributions to this field are Romer (1986), Lucas (1988) and Grossman & Helpman (1991). For a summary see Lucas (1993) and contributions to the Symposium New Growth Theory in the Journal of Economic Perspectives, Vol 8, 1994.*

implementation of endogenous technology spillovers in the GTAP multi-region applied general equilibrium modeling framework (Hertel, 1997) to investigate potential Chinese productivity gains in grain production.

4.2. Technical change and endogenous spillovers

A distinguishing feature of agricultural innovations is their embodiment in physical inputs (Timmer, 1988). The two main kinds of inputs that carry technology are hybrid seeds, fertilizers and insecticides on the one hand and agricultural machinery on the other hand. However, the implications of technological progress embodied in these inputs for the various production factors are different. These inputs embody "factor-biased technical change".

Factor-biased technical change was introduced by Hicks (1932) to describe techniques that facilitate the substitution of other inputs for a specific production factor. He called techniques that facilitated the substitution of other inputs for labor "labor-saving" and ones designed to facilitate the substitution of other inputs for land "land saving". According to for example Heady (1949) and Hayami & Ruttan (1985, p. 75) *biological-chemical* innovations, such as hybrid seeds, fertilizers, and pesticides all tend to be yield-increasing and thus substitute for land. In Hicks' terminology they are land-saving. *Mechanical* technology can also have a yield effect when it permits more timely cultivation and an extension of multiple cropping, cultivation of soils, or the use of water pumps on dry land, but most mechanical technology is designed to make agricultural work less physically burdensome and to save the amount of labor to produce a unit of output: *i.e.*, they substitute machines for labor and are therefore labor-saving. Both prototypical patterns of agricultural innovations are incorporated into the present modeling exercise.

While domestic farmers and agricultural research institutions are engaged in improving farming techniques, foreign innovations are an additional source of potential productivity growth. The question is how domestic farmers can learn about new foreign techniques, and subsequently if and how they are able to adopt these techniques to local circumstances.

Our basic spillover formulation endogenously relates technological change in a foreign region or country to technological change in China. Technological change manifests itself through productivity growth which is factor-biased. Depending on the type of innovation, we consider land-saving and labor-saving effects in Chinese grain production. We hypothesize that knowledge about improved technologies is embodied in commodities. Our main assumption is that China can only benefit from technological change which is occurring elsewhere if it acquires the commodities in question from the region where the technological change occurs initially. In other words, the destination region learns from the source region by using the goods which are technologically progressing. International trade is therefore a prime vehicle of knowledge spillovers.

The *size of trade linkages* between China and the innovating region plays an important role in technology transfer. If we think of technology as being embodied in commodities, so that a certain amount of knowledge is embodied in each unit of the commodity being used, then the size of the knowledge flow is directly related to the volume of imports. Therefore the size of the trade linkages represents the *amount of knowledge* received by a country.[3]

Next to the amount of knowledge received by trade flows, our spillover concept takes into account the *effectiveness* of this amount of knowledge in the receiving region, *i.e.*, China. The effectiveness of the received knowledge is dependent on two main factors. First, *the absorption capacity* is important because the destination region must be able to absorb the knowledge which is developed in the source region. The ability to absorb knowledge is dependent on, for example, the level of human capital, the research capacity, the knowledge infrastructure, own innovation capacity, *etc.* If a country has a low absorption capacity it will only be able to partially understand and use the foreign technology. Second, the *structural similarity* of countries in terms of current agricultural production characteristics is important for the effectiveness of a certain amount of knowledge because knowledge is partly country-specific.

To fix ideas we let r denote the region of origin of the productivity growth, and let s denote the destination region. In this paper we take China to be the destination region and we will focus on North America and Western Europe as source regions. We will use E_{rs} to index the amount of knowledge which is embodied in trade linkages between the two regions, and we let a_r and a_s denote productivity growth rates in respectively the regions of origin and destination. Our spillover hypothesis is summarized as:

$$\frac{a_s}{a_r} = E_{rs}^{1-\delta_{rs}} \quad 0 \leq \delta_{rs} \leq 1 \quad 0 \leq E_{rs} \leq 1 \qquad \text{(Eq. 4.1)}$$

s = {China}
r = {North America, Europe}

Generally speaking, the index E_{rs} is taken to be a function of the domestic use in region s which is satisfied by imports from region r. We elaborate on the specification of this index below. The initial productivity growth in region r, a_r is viewed as the result of an R&D process which is not modeled explicitly here, and which is taken to be exogenous.

The particular functional form of the spillover equation implies that: (i) region s (China) cannot benefit from productivity growth in region r if there are no trade linkages between the two regions, (ii) the maximum rate of productivity growth that can be achieved in region s equals the exogenous productivity growth in region r, (iii) the marginal returns of increasing trade linkages (in terms of productivity growth) to region s are positive, but diminishing. This feature reflects the notion that relatively large marginal gains can be achieved by moving from a state of very low interactions to a situation which allows knowledge to move more freely between regions, whereas the marginal gains are lower if two regions are already closely knitted.

Marginal returns are governed by the parameter δ_{rs}. In our model the efficiency (δ_{rs}) of the received amount of embodied knowledge is dependent on the absorption capacity of the receiving country and the structural similarity of the receiving country with the innovating

3 *This approach is similar to factor content theory in international trade (see, for example Deardorff & Staiger, 1988).*

country. In particular, we take δ_{rs} to be a function of an absorption capacity index H_{rs} and an index of structural similarity D_{rs} : $\delta_{rs} = \delta(H_{rs}, D_{rs})$.

4.2.1. The absorption capacity index: H_{rs}

The first important determinant of the productivity of the received amount of knowledge is the absorption capacity of a country. This determines whether a country *is able* to understand and absorb the newly produced knowledge. The level of human capital and indigenous research capacity are critical factors in the innovation and diffusion process (*e.g.* Lucas, 1988). A country should have a sufficient level of education among the population (*e.g.* farmers and people in input-providing industries) so that they are able to adapt new technologies. Sufficient absorption capacity is a necessary condition for adoption of foreign technology.

The absorption capacity has been quantified by using information on schooling years from the well-known Barro & Lee (1993) data set. The idea is that it takes sufficient trained and educated persons to absorb knowledge produced in other countries. The most preferred proxy of a country's absorption capacity for foreign agricultural technologies would employ information on schooling levels in agricultural sectors in conjunction with information on local knowledge infrastructure. The number of engineers, agricultural extension workers, level of schooling of farmers and similar indicators of the local level of schooling all can be expected to have a significant impact on the absorption capacity of new technologies. Such indicators have not been at our disposal at a global scale, and consequently we opted for a more aggregate measure of absorption capacity. From the 129 countries in the Barro & Lee data set we calculated population weighted average years of schooling for each region distinguished in our model. Table 4.A.3 in the Appendix displays the results. On the whole, Asian countries have fewer years of schooling on average, which hampers their ability to benefit from technologies developed in for example North America.

From the data in Table 4.A.3 we construct an absorption capacity index (H_{rs}) which relates to differences in the human capital between pairs of regions, and reflects the destination region's ability to use the new technology. Letting h_s and h_r stand for an index of human capital in the two regions, our absorption capacity index (H_{rs}) becomes:

$$H_{rs} = \min \left[1, \frac{h_s}{h_r} \right] \qquad \text{(Eq. 4.2)}$$

This particular form of the H-measure incorporates the notion that there are no human capital obstacles to absorbing a foreign technology if the destination region has a larger amount of human capital than the source region, while absorption is more difficult if the level of human capital in the destination region lags behind in the source region.

4.2.2. The structural similarity index: D_{rs}

The second determinant of the effectiveness of the received amount of knowledge is the structural similarity of countries. The hypothesis is that a part of the newly created knowledge is country-specific and is only useful for the specific structure of the innovating country. The knowledge is of less value for countries that have a different structure. Therefore, the more similar the structure of the countries the higher the expected usefulness of the received knowledge. See for example Schultz (1964) and Hayami & Ruttan (1985) who notice that for agricultural techniques the international diffusion process is even more difficult than for manufacturing industries because "Agricultural technology is highly *location specific* and techniques developed in advanced countries are not, in most cases, directly transferable to less developed countries with different climates and different resource endowments" (Hayami & Ruttan, 1985, p. 59).

Focusing on grain crops, the major distinguishing factors between regions are land and labor intensities. This approach follows closely Hayami & Ruttan (1985). Additional indicators which might be employed in future applications include regional climate and soil quality indicators. Appendix Table 4.A.4 shows the data used in this paper. Observe that China displays the lowest land/labor ratio among our regions. This again reiterates the point that Chinese endowments for grain production are characterized as land-scarce and labor-abundant region. From the data in Table 4.A.4 we calculate an index of structural similarity using the equation:

$$D_{rs} = \exp[\, -|(l_r - l_s) / d_{max}|\,] \qquad \text{(Eq. 4.3)}$$

Where l_s and l_r denote land/labor ratios in the source region (r) and destination region (s) respectively, and d_{max} is the largest absolute difference in land/labor ratios found between all pairs of regions, *i.e.*, the difference between Australia and China (d_{max} = 122.9). This formulation scales the differences in land/labor ratios on the unit interval. Furthermore, the exp[.] function takes the value one if the two countries are identical in terms of their land/labor ratios, and declines exponentially towards zero if land/labor ratios are vastly different.

4.2.3. The interaction between structural characteristics and local absorption capacity

Structural differences between countries limit the usefulness of agricultural knowledge in countries with a different structure. A local absorption capacity can increase the usefulness of this knowledge by breeding plant and animal varieties locally to adapt them to local ecological conditions and modifying imported machinery designs in order to meet climatic and soil requirements and factor endowments of the economy. Hayami and Ruttan (1985) hypothesize that the most serious constraints on the international transfer of agricultural technology are limited experiment station capacity in the case of biological technology and limited industrial capacity in the case of mechanical technology. The inelastic supply of scientific and technical manpower represents a critical limiting factor in both cases. In other words: Being smart is not sufficient to benefit from foreign technologies. The foreign technology has to fit to structural characteristics as well. Likewise, a perfect match in terms of structural characteristics is not sufficient: it also takes a sufficient absorption capacity to benefit from foreign technologies.

In order to incorporate the notion that both absorption capacity and structural similarity need to be present, we combine the measures H_{rs} and D_{rs} multiplicatively to yield the efficiency or productivity parameter δ_{rs}:

$$\delta_{rs} = H_{rs} \cdot D_{rs} \qquad \text{(Eq. 4.4)}$$

4.3. Implementing spillovers and factor biases

Our analysis uses the GTAP model, a multi-regional computable general equilibrium (CGE) model primarily designed for analysis of trade policy issues. See Hertel (1997) for a comprehensive description. The model and its associated database have a global coverage of trade and production, taking 1992 as the base year. (For a description of the regional and commodity aggregations used the reader is referred to the Appendix.) Each single region in GTAP is modeled along the lines of the ORANI family of single-region CGE models (Dixon *et al.*, 1982), and consequently employs behavioral assumptions which are common in CGE modeling. In GTAP, single regions are linked through bilateral trade flows and through capital flows.

The incorporation of bilateral trade flows allows for a straightforward specification of the spillover embodiment index. Letting X_{jrs} represent the bilateral trade flows of input j (chemicals, *crp*, or machinery, *trm*) that are exported from the source country r to the destination country s, (China), Y_{is} production of sector i in country s, and Y_{jir}^{d} are domestic inputs of sector j delivered to sector i in country of origin r. The coefficient $a_{crp,\,gro,\,s}$ denotes the factor-specific productivity growth rate of chemical inputs in grain (*gro*) production in China, and the coefficient $a_{crp,\,gro,\,r}$ denotes the corresponding productivity growth rate in the country of origin of the innovation.[4] The fully specified spillover equation for chemical augmenting technical change in the Chinese grain sector becomes:

4 *The a-parameters relate directly to the GTAP production function. The GTAP production structure may be formalized as follows, skipping region indices:*

$$\frac{Y}{A_0} = \min[A_{i1} Q_{i1}, \ldots, A_{in} Q_{in};\; Q_v]$$

where Y denotes output, Q_{ij} denote intermediate inputs, and the primary input composite Q_v is given by the CES-composite:

$$Q_v = [\Sigma (A_e Q_e)^{-\rho}]^{-\frac{1}{\rho}} \quad e = \{land,\ labour,\ capital\}$$

The parameter A_o is a Hicks-neutral technical change term, and $A_{i1} \ldots A_{in}$ and A_e denote input-output coefficients and input share parameters, ρ ($-1 < \rho < \infty$) is a substitution parameter. Technical change is modeled by varying the A-parameters. Adopting the GTAP notation, lower-case variables denote the proportionate change of the corresponding upper-case levels variable. E.g. $a_{crp,\,gro} = dA_{crp,\,gro} / A_{crp,\,gro}$.

$$\frac{a_{crp,gro,s}}{a_{crp,gro,r}} = \left(\frac{X_{crp,r,s} / Y_{gro,s}}{Y^{d}_{crp,gro,r} / Y_{gro,r}}\right)^{1-H_{rs} \cdot D_{rs}} \qquad \text{(Eq. 4.1')}$$

s = {China}
r = {North America, Europe}

The spillover equation for machinery augmenting technical change in the grain sector is identical except that subscript *crp* is replaced with subscript *trm*.

The bracketed term on the right hand side of Equation 4.1' measures the relative amount of embodied knowledge per unit of output that the grain sector in China receives from the innovating foreign input-producing sector relative to the amount of knowledge per unit of output that the domestic grain sector receives in the country of origin. The denominator is the 'domestic' input-output coefficient of inputs from the innovating sector in production of grains in the country of origin. The numerator is an input-output coefficient of foreign-sourced inputs from the innovating sector in production of grains in China.

As has been explained above, technical progress in agriculture often occurs in the form of new technology packages which become available to farmers. Such 'packages' combine improved productivity of intermediate inputs with productivity improvements of primary factors. This feature is incorporated by linking directly productivity growth in intermediate goods to productivity growth of primary factors land and labor. On the one hand, chemical innovations lead to land saving technical change:

$$a_{land,gro,s} = \beta_{land} \cdot a_{crp,gro,s} \qquad \text{(Eq. 4.5)}$$

where $a_{land,gro,s}$ is land saving technical change in the Chinese grain (*gro*) sector, β_{land} is the land-bias coefficient and $a_{crp,gro,s}$ is the chemical augmenting technical change in the grain sector in China.

On the other hand we have innovations in machinery leading to labor-saving technical change:

$$a_{labour,gro,s} = \beta_{labor} \cdot a_{trm,gro,s} \qquad \text{(Eq. 4.6)}$$

where $a_{labor,gro,s}$ is the labor-saving technical change in the grain (*gro*) sector in China, β_{labor} is the labor-bias coefficient and $a_{trm,gro,s}$ is the machinery augmenting technical change in the Chinese grain sector. The introduction of the β-parameters offers some flexibility in modeling primary factor biases, and can eventually be inferred from econometric studies.

4.4. Illustrative simulations

4.4.1. Spillovers from Europe and North America

In this section we present results of simulations which assume an initial 10% productivity shock in the sectors Chemicals (*crp*) or Transport Equipment & Machinery (*trm*) in the source countries North America (NAM) or Western Europe (EUR). The innovation receiving sector is the Chinese Grain sector, and the primary factor bias coefficients were set to unity (β_{labor} or $\beta_{land} = 1$).

It is illustrative to look at some numerical values for the spillover coefficient, *i.e.* the right-hand side of Equation 4.1', for different sectors and countries of origin. Table 4.1 shows the post-simulation values of spillover coefficients for innovations in the Chemical and Transport sector in Europe and Northern America. The first column shows that an innovation in the Chemical sector in Europe leads to an spillover coefficient of 0.25 for Australia. This means that the 10% increase in the productivity of chemicals in grains in Europe leads to a 2.5% increase in the productivity of chemicals in grains in Australia. For China, the same innovation leads to a 4.9% increase in productivity of chemicals in grain production. The spillover coefficient is higher in China despite the fact that the amount of embodied knowledge is higher in Australia than in China. This is caused by the structural similarity effect: the structure of grain production in Australia is much more different from Europe than the structure of China.

Table 4.1. Value of spillover coefficient.

	Innovation in chemicals (crp)		Innovation in machinery (trm)	
	Europe EUR	North America NAM	Europe EUR	North America NAM
AUS	0.25	0.35	0.50	0.62
NAM	0.35	-	0.43	-
ARG	0.74	0.05	0.58	0.01
EUR	-	0.08	-	0.07
JAN	0.78	0.06	0.65	0.02
RAS	0.29	0.05	0.21	0.04
SAM	0.50	0.15	0.25	0.06
CHN	**0.49**	**0.12**	**0.40**	**0.06**
ROW	0.71	0.04	0.68	0.06

Source: GTAP simulations, author's calculations

Note: See the Appendix for regional aggregation. Initial productivity shock equals 10% in country and sector of origin.

We get an indication of the source country effect for a specific country when we compare columns one and two. It is apparent that the value of the spillover coefficients for a country of destination are very different across different countries of origin (*i.e.* EUR and NAM). For example, the spillover coefficient for China is equal to 0.12 when the innovation occurs in North America and equals to 0.49 in the case of Europe. Furthermore, it is striking that almost all spillover coefficients are higher when Europe is the source country (the notable exception is AUS which is structurally most similar to NAM). The reason is that Europe exports a larger part of its chemical products, has a lower level of human capital and its structural characteristics are average while North America has a rather extreme position in terms of its land/labor ratio.

The spillover coefficients when the innovation originates in the Transport Equipment & Machinery sector are given in columns three (innovation in EUR) and four (innovation in NAM). A comparison of columns one and three or columns two and four indicates that the source sector is also an important determinant of the spillover coefficients. The difference in spillover coefficients is only caused by the amount of embodied knowledge in trade flows, because the productivity of this amount of knowledge is identical across sectors of origin (same D- and H-indices).

The effects on Chinese grain output in the four constellations is summarized in Table 4.2, which also shows simulated effects on other food products. This table reveals some noteworthy features. First of all, we may note that the percentage output growth in China which follows a 10% productivity increase in the agricultural input (Chemicals or Machinery & Transport equipment) in the country of origin (Europe or North America) appears to be rather small. Taking an innovation in Chemicals in Europe as an example, the first-round effect of the simulated innovation is a 4.9% increase in productivity of Chemicals in grain production in China (10% x 0.49). If output would stay at the same level, and disregarding the land-saving effect of chemicals, this would imply a cost reduction of 1.5% since the input-output coefficient of chemicals in grain equals 0.3. However, due to resource shifts into other sectors, the cost reduction is not fully translated into higher grain output, which only grows at a modest 0.43%. Observe that other agricultural sectors benefit from the technological improvement in the grain sector. Livestock and processed food are even able to realize a higher growth rate than the grain sector itself: 0.57% and 0.65%, respectively. The productivity improvement in grains leads to a release of land, labor and capital which is reallocated to other food-producing sectors where the factor returns are higher.[5] Those food sectors which make intensive use of arable land have a comparative advantage over grain crops.

Most striking are perhaps the results in the second column of Table 4.2. If the innovation occurs in North America, all effects are smaller than the corresponding results for an innovation originating in Europe. Chinese grain production is structurally more similar to the European than to the North American situation according to our measure of structural similarity. This implies that it is easier for Chinese farmers to adopt a European technology than a North American technology. As can be seen in Table 4.2, the output effect on China may even be negative. The reason for this result is that North America is itself a big player in world grain markets, hence the productivity improvement benefits North American farmers, who are able to expand their supply to world markets leading to a drop in world grain prices. Lower world prices for grain put Chinese -and other- grain producers in a less advantageous position, since their terms of trade deteriorate and it becomes cheaper to import grains from North America. Subsequently, we observe a release of resources out of the domestic grain sector into other food-producing activities, most notably livestock and processed food.

5 *In fact labor is assumed to be fully mobile across sectors, while land can only move to a limited extent between alternative agricultural uses.*

Table 4.2. Chinese output growth with spillovers (percentage change from 1992 base).

Innovating sector	Commodity	Region of origin of innovation	
		Europe EUR	North America NAM
	grain	**0.43**	**-0.02**
	non-grain crops	0.33	0.1
Chemicals	livestock	0.57	0.15
	forestry & fisheries	0.16	0.07
	processed food	0.65	0.18
	other processed agric.	0.4	0.14
	grain	**0.4**	**-0.07**
	non-grain crops	0.39	0.08
Machinery &	livestock	0.6	0.1
Transport equipment	forestry & fisheries	0.36	0.08
	processed food	0.68	0.12
	other processed agric.	0.48	0.11

Source: GTAP simulations, author's calculations.

Note: An initial productivity shock of 10% is assumed in all cases. The innovation-receiving sector is Grain. Effects on other agri-food sectors are indirect effects.

4.4.2. Gains from domestic research in China

While international technology spillovers allow China to acquire foreign technologies at no cost, domestic research activities have to be financed domestically. Simulated gains from domestic research in chemicals and fertilizer inputs into Chinese grain production are presented in Table 4.3. Again we assume an initial 10% chemicals augmenting technical change in grain production, but this time the innovation occurs in China. We allow for complete protection of the newly developed technology by simulating the case of no international spillovers, which means that the productivity gain is limited to Chinese farmers. This case is contrasted with the case of full international spillovers according to Equation 4.1', which allows other countries to adopt the Chinese technology.

If no spillovers are present, China realizes a 1.3% output growth in grain production, while the growth rate drops slightly to 1.1% if the knowledge leaks to other countries. Welfare for China does not show a marked difference between the two scenarios, US$ 1951 mln and 1913 mln respectively, indicating that the losses to the innovator from knowledge spillovers are rather limited.[6] However, technology spillovers from China allow other regions to improve on their grain production. Most notably, Japan and the NICs (JAN), Rest of Asia (RAS), and the Rest of World (ROW) benefit from the Chinese innovation. These regions are similarly land scarce and have little human capital restrictions to adoption of the Chinese technology.

6 *We use the Equivalent Variation (EV) as a measure of welfare changes. The equivalent variation measures a change in income which is equivalent to a change in utility which occurs as a consequence of price changes, taking the original prices as the base. The EV is thus a measure of willingness to pay -at original prices- to achieve the same utility change as that which arises as a result of some exogenous shock or policy measure.*

Table 4.3. Domestic research: chemicals augmenting technical change in Grains (relative to 1992 base).

	Without spillovers		With spillovers	
	% output growth	Equivalent variation 1992 US$ mln	% output growth	Equivalent variation 1992 US$ mln
AUS	-0.76	-22	-2.43	-78
NAM	-0.43	-13	-1.65	-20
ARG	-0.14	-5	0.2	-4
EUR	-0.14	69	-0.29	877
JAN	-0.31	196	2.72	1092
RAS	-0.11	85	0.12	519
SAM	-0.06	3	0.1	298
CHN	**1.31**	**1951**	**1.11**	**1913**
ROW	-0.07	19	1.01	1220

Source: GTAP simulations, author's calculations.

Note: See the Appendix for regional aggregation. Initial productivity shock equals 10% China.

In terms of output growth, the losers are the traditional grain exporters Australia (AUS), North America (NAM) and Europe (EUR), which witness a drop in export supplies. This effect is magnified if technology spillovers exist, so that traditional importing regions expand their own supplies. Observe that the drop in output in Europe coincides with a positive welfare gain. In the base situation the European grain sector absorbs too many resources as a consequence of domestic protection. The drop in output frees resources from the European grain sector which subsequently find employment in manufacturing industries where their returns to society are higher. Hence, the macro-economic welfare effect of shrinking European grain production is simulated to be positive.

4.5. Trade policy experiments

The previous analysis showed that Chinese gains from North American innovations are rather limited. In this section we explore some trade policy options to foster Chinese benefits from foreign innovations. Inclusion of embodied spillovers adds an additional dimension to trade liberalization issues. Not only does tariff protection isolate a region form foreign goods, it also isolates a region from foreign knowledge, and hence from possible welfare gains through productivity increases. Although China is recently taking steps to become more interwoven with the network of international trade, it is still hesitant to fully subscribe to WTO trade liberalization agreements. This section illustrates that even a unilateral liberalization of US imports to China may be beneficial to China if embodied technology spillovers are taken into account.

China's relatively isolated position in the global trade system hampers its ability to benefit from foreign technologies. In the embodied spillover framework, one possible option to increase the benefits from foreign technologies is a reduction of import barriers towards innovating countries. A series of simulation experiments has been designed to investigate the welfare effects of such a policy.

Throughout the experiments we assume North America (NAM) to be the region of origin of innovations. The innovation may occur either in Chemicals (CRP) or in Transport equipment and machinery (TRM). In NAM, the innovation in Chemicals leads to an initial 10% increase in productivity of Chemicals in the production of grain, and simultaneously to a land-augmenting effect of the same size in NAM ($\beta_{land} = 1$). Similarly, the innovation in Transport equipment and machinery leads to an initial 10% increase in productivity of TRM in production of grain, but has a labor-augmenting effect of the same size ($\beta_{labor} = 1$).

Unilateral trade liberalization by China involves a complete abolition of import barriers against North America in either CRP or TRM. The initial powers of import tariffs are 1.16 and 1.27 respectively (source: GTAP database version 3, author's calculations).

In Table 4.4 the row labeled **TL** shows the welfare and output results of a run with only trade liberalization and neither technical change nor spillovers, whereas the row **TC** shows results if there is only technical change but no trade liberalization and no spillovers.

Table 4.4. Policy experiments China: welfare and output effects (relative to 1992 base).

				China		North America	
	Trade liberalization (a) **TL**	Technical change (b) **TC**	Spillovers (c) **SP**	Equivalent variation 1992 US$ mln	Grain output % change	Equivalent variation 1992 US$ mln	Grain output % change
	Innovative good Chemicals (crp)						
TL	+	-	-	-306.4	0.01	487.1	-0.05
TC	-	+	-	1.0	-0.17	729.0	1.75
TLTC	+	+	-	-305.2	-0.16	1216.1	1.69
TCSP	-	+	+	261.1	-0.02	728.9	1.48
TLTCSP	+	+	+	7.5	0.03	1214.8	1.42
	Innovative good Transport equipment and Machinery (trm)						
TL	+	-	-	-4562.9	-0.02	4590.8	-0.41
TC	-	+	-	4.6	-0.15	868.4	1.54
TLTC	+	+	-	-4558.3	-0.17	5455.7	1.12
TCSP	-	+	+	178.1	-0.07	879.7	1.29
TLTCSP	+	+	+	-4267.3	-0.02	5473.8	0.85

Source: model simulations.

Note: (a) '+' = import tariff = 0,'-' = no policy change; (b) '+' = 10% productivity increase in use of good in grain production in NAM, '-' = no change; (c) '+' = ON, '-' = OFF.

From run **TL** we see that unilateral trade liberalization in CRP has negative welfare effects for China, while North America gains. This is a standard result and arises as a consequence of domestic tax distortions on chemicals in China. Trade liberalization reduces the share of CRP in domestic production, since imports from North America reach the domestic market at a lower price. In the presence of domestic taxes there are too little resources employed in this sector, and hence the marginal welfare contribution of these sectors could be higher if domestic distortions were removed. Contraction of the CRP further withdraws resources from this sector and Chinese welfare is reduced by 134.7 $US mln according this allocative efficiency effect. A further reduction by 171.6 $US mln results from adverse terms of trade effects for China, which experiences declining world prices of some of its export products. For North America, we find the reverse picture, leading to a total welfare gain of 467.1 $US mln, of which 107.8 $US mln is attributable to allocative gains and 379.3 $US mln to terms of trade effects.

Run **TC** shows results for the case when there is no change in Chinese policy, with no spillovers, but technical change in North America. This is very much welfare-enhancing for North America itself because of the higher productivity of Chemicals in grain crop production. However, since we assume no spillovers in this simulation, the knowledge is kept inside North America and other countries cannot benefit from improved technologies. The negligible Chinese welfare gain of 1.0 $US mln is the joint result of a small positive allocative effect and a small negative term of trade effect.

Combining trade liberalization and technical change in run **TLTC** yields results which are approximately the sums of the previous runs. Without spillovers, but with technical change in North America, trade liberalization is still not preferable for China.

Focusing on the effects of spillovers alone, we see that run **TCSP** generates favorable results for China, while North America still experiences a positive welfare gain of about the same size as in the case without spillovers.

Finally, run **TLTCSP** refers to the situation when China liberalizes, there is technical change and spillovers are present. Looking at the combined effects, we observe that China is now able to experience a positive welfare gain, and so does North America. Hence, unilateral trade liberalization may be less disastrous to the liberalizing country when technical change and embodied spillovers are taken into account. The positive net gain to China is explained by large positive productivity effects in the use of Chemical in grain production, which more than compensates the negative allocative effects and terms of trade effects. Due to embodied spillovers, Chinese producers are able to increase their productivity in grain production.

Turning to the case when the innovation is the sector Transport equipment and machinery (TRM) in North America, we observe a similar pattern of welfare effects. However, the spillover effect is now insufficient to compensate for the losses occurring as a consequence of unilateral reduction in import barriers by China. This is fully explained by the factor bias inherent in our formulation. China receives relatively high benefits from a land-augmenting technical change coupled to a productivity increase in the use of chemical in grain production, while the benefits of a labor augmenting technical change coupled to a productivity increase in the use of agricultural machinery is less beneficial. The factor bias favors the activity which depends heavily on the relatively scarce production factor. In the Chinese case this is agricultural land.

Looking at output effects in columns six and eight in Table 4.4, we observe that the achieved productivity growth in China is rather limited. This is largely due to the low value of the spillover coefficient between North America and China, see Table 4.1. Existing trade linkages between the two regions are relatively small, and in addition the regions are structurally dissimilar. Technical change in chemical inputs in grain production in North America has a negative impact on grain output in China. This is explained by the huge share of North America in world grain markets, leading to decreasing international grain prices following the innovation which subsequently leads to increased imports to China. Observe again that technology spillovers lead to a sign reversal in case of innovations in chemicals. Through

technology spillovers, China can achieve a productivity gain which more than compensates for the losses if North America keeps the technology within its own region.
In case of an innovation in transport equipment and machinery in North America, the output effects on China are negative in all cases. The cheaper transport equipment which enters China after abolition of import barriers is used in sectors outside grain production, primarily Other Manufacturing and Mining, because the marginal returns are higher in those sectors. We thus see a resource shift away from grain production and into industrial activities.

Summarizing this subsection, we may observe that the inclusion of embodied spillovers may lead to some qualifications in trade policy analysis. Specifically, negative welfare effects of unilateral trade liberalization in specific sectors may be compensated by large productivity gains which are achieved by getting access to foreign technologies. The positive effects will be highest for those technologies which lead to productivity gains in the relatively scarce production factor. Comparing the case of innovations in Chemicals to innovations in Transport equipment and machinery, we may again see the importance of targeted policies. China's potential for gains from international technologies lies in the land-intensifying technologies, such as chemical inputs.

4.6. Conclusions

Endogenous embodied technology spillovers bear some important implications for trade policy. If knowledge is embodied in traded commodities, protective measures preclude countries not only from cheaper imports but also from foreign technologies. The potential gains from trade liberalization under embodied technology spillovers are illustrated by taking Chinese barriers against North American imports as a case study. It is shown that negative welfare effects of unilateral trade liberalization may be more than compensated by the productivity advantages which are achieved. This holds especially in the case of chemical innovations which improve land productivity in China. Furthermore, the innovating country does not experience negative welfare consequences from the increased leakage of its technologies.

While welfare effects from technology spillovers are generally positive, Chinese gains in terms of output growth are rather limited if innovations occur in North America. The two regions display structural dissimilarities which limit the usefulness of American technologies in the Chinese context. In addition, productivity improvements within North America further strengthen this region's competitive position in world grain markets and lead to falling grain prices which makes expansion of Chinese grain production relatively unattractive.

Higher gains can be achieved from innovations which originate in Europe, because structural differences in agricultural production are less severe. Lowering import barriers for innovative inputs may foster productivity growth in China. However, such a policy should be carefully targeted towards those inputs which are most scarce in the Chinese context and which originate from regions which display similar agricultural production characteristics.

The simulation studies within the GTAP modeling framework also point towards a shifting pattern of specialization within agriculture. Land-intensive crops and livestock absorb labor and land resources which are released if grain productivity increases. We hasten to add that this aspect requires more in-depth research and conclusions in this respect should be considered as preliminary.

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Appendix: Data

4.A.1. The GTAP database

The GTAP model is supported by a unique database which comprises input-output tables for each region, bilateral trade data derived from United Nations Trade Statistics, and support- and protection data from various sources. For the applications reported in this study, we use the current version 3 of the database, which takes 1992 as the base year and employs pre-Uruguay round protection information. This data set is fully documented in McDougall (1997). The complete database provides detail on a total of 30 countries, or regional groupings, and 32 sectors of activity. Our focus on technology spillovers in agriculture prompted an aggregation into 9 regions and 12 sectors.

The regional aggregation displayed in Table 4.A.1 attempts to maximize within-region homogeneity with respect to grain crops production patterns. This is achieved by utilizing the structural similarity index (Equation 4.2) as a clustering criterion.

Table 4.A.1. Regional aggregation used.

Identifier		Original version 3 regions included
1 AUS	Australia	Australia, New Zealand
2 NAM	North America	Canada, United States of America
3 ARG	Argentina	Argentina
4 EUR	Europe	European Union 12, Austria Finland and Sweden (EU3), EFTA
5 JAN	Japan and NICs	Japan, Republic of Korea, Singapore, Hong Kong, Taiwan
6 RAS	Rest of Asia	Indonesia, Malaysia, Philippines, Thailand, India, Rest of South Asia
7 SAM	South America	Mexico, Central America and Caribbean, Brazil, Chile, Rest of South America, Middle East and North Africa
8 CHN	China	China
9 ROW	Rest of World	Central European Associates, Former Soviet Union, Sub Saharan Africa, Rest of World

The sectoral aggregation shown in Table 4.A.2 zooms in on primary agricultural production and agricultural processing industries. Note that the aggregation distinguishes the two important groups of agricultural inputs chemical (*crp*), such as fertilizers, and transport equipment and machineries (*trm*).

Table 4.A.2. Sectoral aggregation.

Identifier			Original version 3 sectors included
1	gro	grain crops	paddy rice, wheat, grains
2	ngc	non grain crops	non grain crops
3	lst	livestock	wool, other livestock
4	fof	forestry & fisheries	forestry, fisheries
5	min	mining & extraction	coal, oil, gas, other minerals
6	pcf	processed food	processed rice, meat products, milk products, other food products
7	opa	other processed agriculture	beverages and tobacco, lumber, pulp paper
8	tex	textiles	textiles, wearing apparels, leather, *etc.*
9	crp	chemicals	chemicals, rubbers and plastics
10	trm	transport equipment and machinery	transport industries, machinery and equipment
11	omf	other manufacturing	petroleum and coal, non-metallic minerals, primary ferrous metals, non-ferrous metals, fabricated metal products, other manufacturing
12	svc	services	electricity water and gas, construction, trade and transport, other services (private), other services (govt), ownership of dwellings

We used an automated aggregation procedure which not only aggregates basic flows, but also takes care of calibrating parameters of production and consumption functions. On the production side, the key parameters to be aggregated are substitution elasticities in CES-nests of primary inputs land, labor and capital, and Armington substitution elasticities. On the consumption side, the substitution - and expansion parameters of (non-homothetic) CDE expenditure functions are fitted to the aggregated data. See McDougall (1997) for a description of parameter estimates.

4.A.2. Human capital data

Human capital data have been downloaded from World Bank's Internet site. The Barro & Lee and other data sets are found at the following URL:
http://www.worldbank.org/html/prdmg/grthweb/dataset.htm

Table 4.A.3. Average years of schooling in the 9 model regions.

AUS	NAM	ARG	EUR	JAN	RAS	SAM	CHN	ROW
10.5	11.6	8.13	8.2	9.3	4.2	4.7	5.9	6.6

Source: Barro & Lee database, author's calculations

The table displays population-weighted average years of schooling. The highest average years of schooling are observed in North America (NAM), followed by Australia & New Zealand (AUS). The figure for Western Europe (EUR) seems to be on the low side, but is explained by the limited years of schooling in Mediterranean countries.

4.A.3. Land/labor ratios

The data have been downloaded from the FAO Database Collection at:
http://app.fao.org/lim500/agri_db.pl

The total number of persons employed in agricultural production from FAOSTAT adjusted with GTAP (version 3) labor shares to obtain an estimate of persons employed in grain production only. Wheat acreage is directly available from FAOSTAT.

Table 4.A.4. Land/labor ratios (hectares per person).

AUS	NAM	ARG	EUR	JAN	RAS	SAM	CHN	ROW
123.6	87.1	17.1	9.18	1.4	1.3	2.0	0.7	1.1

Source: FAOSTAT, author's calculations

5. Modeling the spatial pattern of land use change in China

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Abstract

Due to its growing population and changing economy, China is facing large changes in land use. This will have major consequences for food security and environmental issues like soil degradation and greenhouse gas emissions. China's large variation in biogeophysical and socio-economic conditions causes large regional differences in land use change patterns. To assess these patterns of land use change, a spatial explicit approach is needed. It is proposed to use the CLUE modeling framework, a GIS-based land use change model. The model is based upon empirical relations between land use and its biogeophysical and socio-economic determinants. To test the feasibility of this approach a preliminary data analysis was done. In spite of regional differences it is possible to explain the larger part of the variability in land cover and yield by multiple regression models including both biogeophysical and socio-economic factors. A multi-scale approach is used to reveal that the factors determining land use are dependent on the scale of analysis.

5.1. Introduction

China has a total land area of about 9.6 million km^2 of which less than 15% is cultivated while about 20% is covered by forests and woodlands. Of the remaining 65% approximately 30% is covered by grasslands. Only part of these grasslands can be used for grazing while the quality is often poor (People's University Press, 1991). Most of the remaining land in China is covered by glaciers, permanent snow, deserts and other marginal lands and is therefore not habitable or suitable for agricultural production. In spite of the population of about 1.2 billion, the land area covered by infrastructure, residential area and industrial sites is only a few percent of the total land area.

There are large inconsistencies in estimates of the total cultivated area (Wu Chuan-jun, 1990; People's University Press, 1991; Crook, 1993) but it is clear that the total surface of cultivated land is steadily decreasing. This trend can be attributed to the conversion of cultivated land to non-farm uses such as the construction of factories, housing, and roads. These changes, in combination with a growing population and increasing welfare levels, are often regarded as a serious threat to future food security in China (Brown, 1995).

Apart from its implications for food security, land use change can also have important consequences for environmental sustainability (Fresco & Kroonenberg, 1992; Wang Xiaoke *et al.*, 1994). In China land degradation is considerable: large areas are prone to severe soil erosion and an increasing area of cultivated land is facing saline conditions (Wu Chuan-jun, 1990). In some areas grass production has been reduced by 30 to 50% in the last twenty years due to land degradation (People's University Press, 1991).

These trends in land use and possible consequences of land use changes make it important to gain insight in the causes and possible consequences of these trends. Based on an analysis of land use changes in the recent past, pathways of possible future developments can be explored. This region-specific approach is a valuable addition to models that simulate land use dynamics at the global scale such as the AGE model (Fischer *et al.*, 1988) and the IMAGE2 model (Alcamo *et al.*, 1994).

This paper introduces the main concepts of our spatial and scale specific approach and outlines the structure of the modeling framework used. A preliminary analysis of the available data and proposed methodologies is presented to test the feasibility of this approach.

5.2. Modeling land use change in a spatial explicit way

Only few models have attempted to assess the spatial patterns of the process of land use change (Hall *et al.*, 1995). Broad scale, highly aggregated analysis of land use change at the national level can provide us with information on the extent of land use change. However, it does not provide us with the spatial information needed to calculate the consequences of land use changes. The high level of aggregation of data obscures the variability of situations and relationships, which can cause the underestimation of the effects of land use change for certain regions and certain groups of the population. When world food production is evaluated at a global scale only, production does not appear to be a limiting factor for food demand. However, at the same time about 20% of the world population is undernourished (FAO, 1996) due to, among other factors, unequal spatial distribution of production and consumption.

Spatial explicit information on land use change is needed when the environmental consequences of land use changes are assessed. The amount of carbon-dioxide released upon deforestation can make significant differences depending on the biomass level of primary forest (Brown *et al.*, 1994). So, not only the amount of deforestation, but also the location and associated biomass level are required for reliable assessments of the carbon-dioxide release. Also for the calculation of changes in nutrient balances and subsequent assessments of sustainability of agro-ecosystems (de Koning *et al.*, 1997; Smaling & Fresco, 1993) spatial explicit land use change data are required.

5.3. Socio-economic and biogeophysical driving factors of land use change

Socio-economic activities that use or change land attributes are considered as the proximate sources of land use/cover change. Most recent land cover modification and conversion is clearly driven by human use, rather than natural changes (Skole & Tucker, 1993). Land use and land use changes are constrained by biogeophysical factors such as soil characteristics, climate, topography and vegetation (Turner *et al.*, 1993).

Relating the socio-economic driving forces of land use to changes in land cover is difficult because of the complexity of the interactions between socio-economic and biogeophysical factors, and the different ways that these interactions unfold in particular areas of the world. Many studies at detailed scales have been undertaken which offer detailed insights into specific cases that unfortunately cannot be generalized. Literature is rich in insights and 'stories', but weak in quantitative assessments that analyze the influence of socio-economic and biogeophysical driving factors on land use change at coarser scales. Causal relations between actors and land use change, as identified at detailed scales (de Groot & Kamminga, 1995), can often not be used at coarser scales. At coarse scales we need to use factors that represent or proxy the driving factors at the more detailed scales. For the process of deforestation typical examples like road density, population density and average incomes can be used. Detailed studies are essential to identify which factors can be used as proxies to avoid the problem of unknown causality (does deforestation cause roads or do roads cause deforestation?).

Statistical methods allow us to analyze the influence of socio-economic and biogeophysical driving factors, and offer the possibility to quantify their relative importance.

5.4. Structure of the CLUE modeling framework

The CLUE Modeling Framework is a dynamic, multi-scale land-use change model developed at Wageningen Agricultural University. It has been developed for Costa Rica by Veldkamp and Fresco (1996). The CLUE model consists of four main modules: a population module, a demand module, an allocation module and a yield module (Fig. 5.1). Changes in demand, yield, population and land cover are calculated on a yearly basis. The time horizon for scenario simulations is limited due to the empirical nature of the model that is based on past and actual relations between land use and its drivers and constraining factors. Simulations of reliable pathways of land use change development are probably impossible for time spans longer than about 20 years (Veldkamp & Fresco, 1997).

The following paragraphs present some aspects of the four modules of the model. Methodologies and data requirements for implementation of the model for China are illustrated by an exploration of the available data.

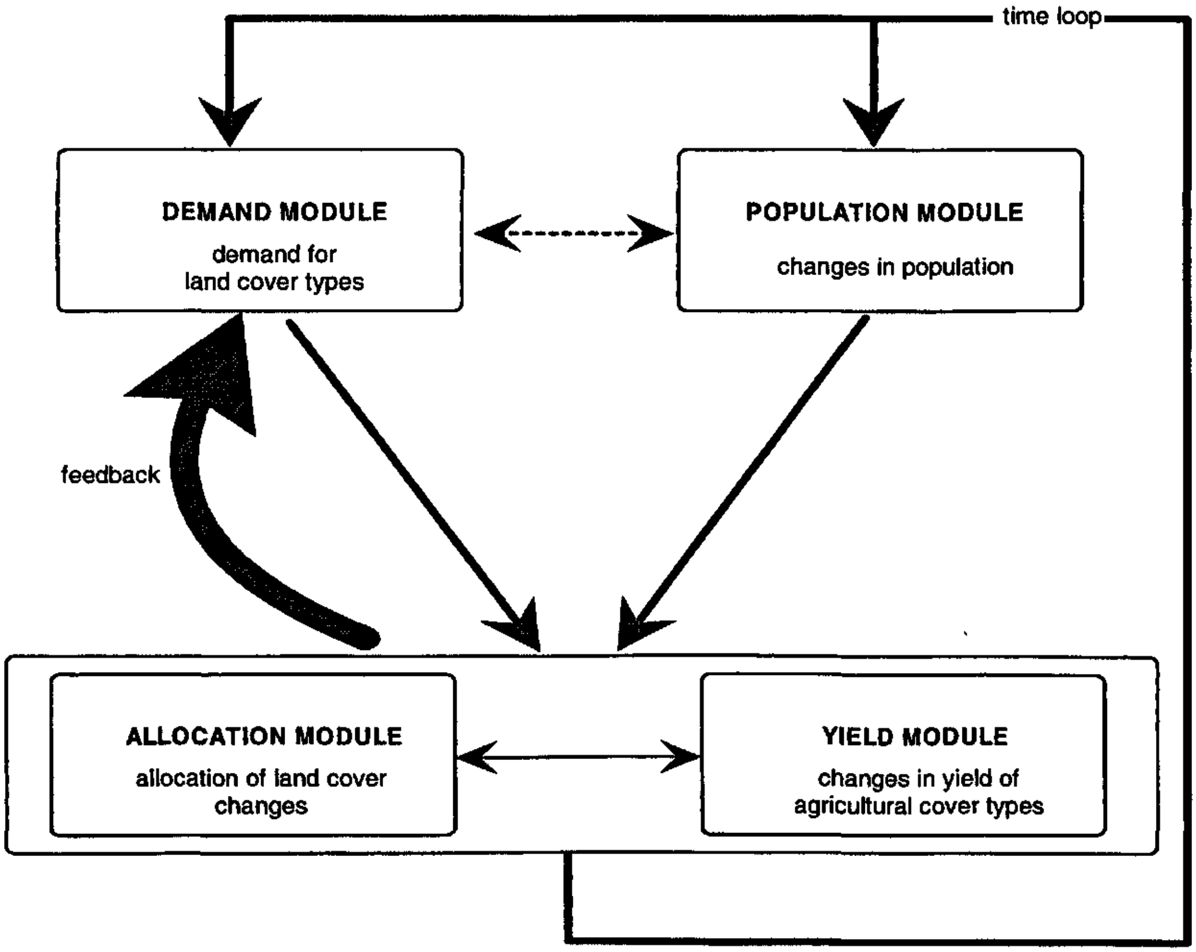

Figure 5.1. Structure of the CLUE modeling framework (v3.0).

5.5. Demand for agricultural production

The population module calculates changes in population based upon different projections (Lutz *et al.*, 1994; Johnson, 1995; UN, 1995). Historic demographic analysis and scenarios are used to calculate the spatial distribution of the population. Migration flows, governmental policies and cultural differences are important driving factors of the spatial distribution of population. The demand module calculates at the national scale the demand (production/area) for the different land cover types in a certain year, taking into account the relevant developments of population, consumption patterns and governmental policies.

Changes in demand are inevitable because China's population of around 1.2 billion persons is expected to rise to more than 1.6 billion by the year 2050 (UN, 1995). These additional 400 million people will need a large quantity of extra food. Apart from the influence of population growth itself on consumption, urbanization will have a large influence on diet and behavior of consumers. Urban dwellers consume less grain and demand more meat, milk products, and fish than their rural counterparts, even after accounting for differences in income and prices. China's urban population has grown from 19.4% in 1980 to 27.6% in 1992 (Huang *et al.*, 1995). Rapid economic growth and associated rises in income for parts of the population will further enhance dietary changes. Finally it is possible that Western influence on Chinese food preferences is more rapid and profound than expected (Heilig, 1996). Especially shifts in consumption from vegetable products to animal products will require additional agricultural production, as input energy conversion of animal production is less efficient. Huang *et al.* (1995) expect that the rise in demand for meat and other animal products will raise the proportion of feed grain in total utilization of grain from 20% in 1991 to nearly 40% in 2020. Figures 5.2 and 5.3 show that food consumption patterns are already changing: total calorie intake increases with an increasing share of animal products while the relative consumption of cereals is already decreasing.

Several studies (Brown, 1995; ERS, 1995; Huang *et al.*, 1997) already assessed the mentioned trends and implications for demand of agricultural products. These projections can be used as the basis to calculate the demand for arable land.

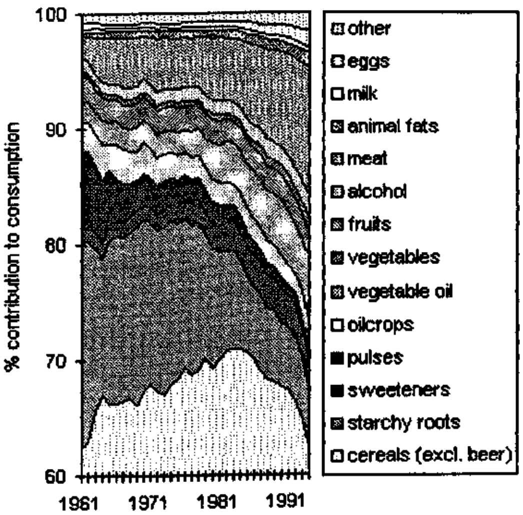

Figure 5.2. Development of diet composition in China between 1961 and 1994 as percentage of total calorie consumption. Source: FAOSTAT electronic database.

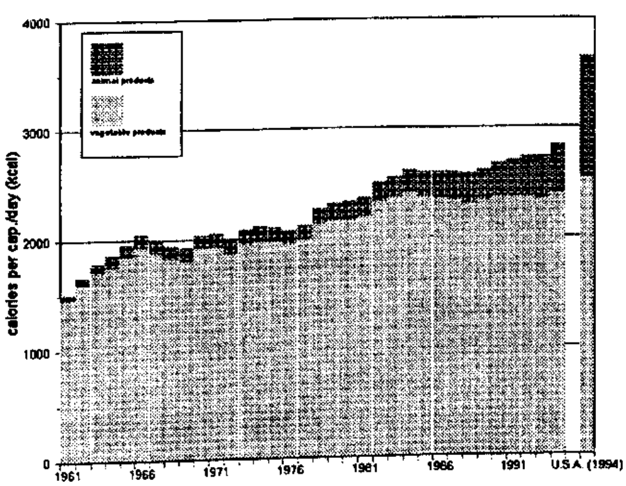

Figure 5.3. Development of food consumption in China and 1994 food consumption of the U.S.A. Source: FAOSTAT electronic database.

5.6. Spatial structure of land cover

The allocation module allocates the land use changes calculated in the demand module. Therefore one has to understand the spatial structure of land use (change), *i.e.* one has to know 'what is happening where and why'. Here we seek to extract the crucial relationships between land use and biogeophysical and socio-economic factors based on data included in a GIS system. The relations between these factors and land use are dependent on the scale of observation (Veldkamp & Fresco, 1996). Hall *et al.* (1995) found that, at detailed scales, land use in tropical rain forest areas is strongly correlated with topography. However, at a coarser scale land use was strongly correlated with precipitation and cloud cover. Most often coarse scales are useful to reveal the general trends and relations between land cover and its determining factors. Factors that influence land cover over a considerable distance (like cities) can only be observed at these coarse scales. However, the high level of aggregation at these coarse scales can obscure the variability of units and processes and is therefore considered inaccurate for detailed scale and local assessments. A multi-scale approach which identifies and quantifies the determinants of land cover at multiple scales gives the most complete description of the structure of land use.

To analyze the spatial structure of land use a GIS system was developed which contains data on land use and biogeophysical and socio-economic conditions. Data concerning land use and socio-economic conditions are organized by administrative units (about 2350 counties; Fig. 5.4) while the biogeophysical conditions are derived from maps at various scales. The different factors used and their sources are listed in the Appendix. A correlation analysis (at county level) between the different land use types gives a first impression of the land use structure (Table 5.1). Arable land is negatively correlated with forests and grasslands but positive with housing and infrastructure indicating the competition between agriculture and urban development. Forests and grasslands are negatively correlated with all other land use types due to their location in more remote areas unfavorable for agriculture. Regional differences in the results of such a correlation analysis are large. In the northern region (Beijing, Tianjin, Hebei, Shanxi, Henan and Shandong provinces) the correlations between arable land and grassland are clearly negative (-0.58) whereas the same correlation is much lower in the south (Fujian, Jiangxi, Hunan, Guangxi and Guangdong provinces): -0.12. This difference can be explained by the large difference in land use pattern between the two regions. The northern region consists of large plain areas which are covered by arable land; grassland areas are found in some specific parts of the region. In the south the landscape is hilly where we find agriculture in the valleys and grasslands and forests more uphill. This explains that the correlation between grassland and arable land is only slightly negative in this region. The results of such a correlation analysis are of course dependent on the aggregation level (scale) of analysis.

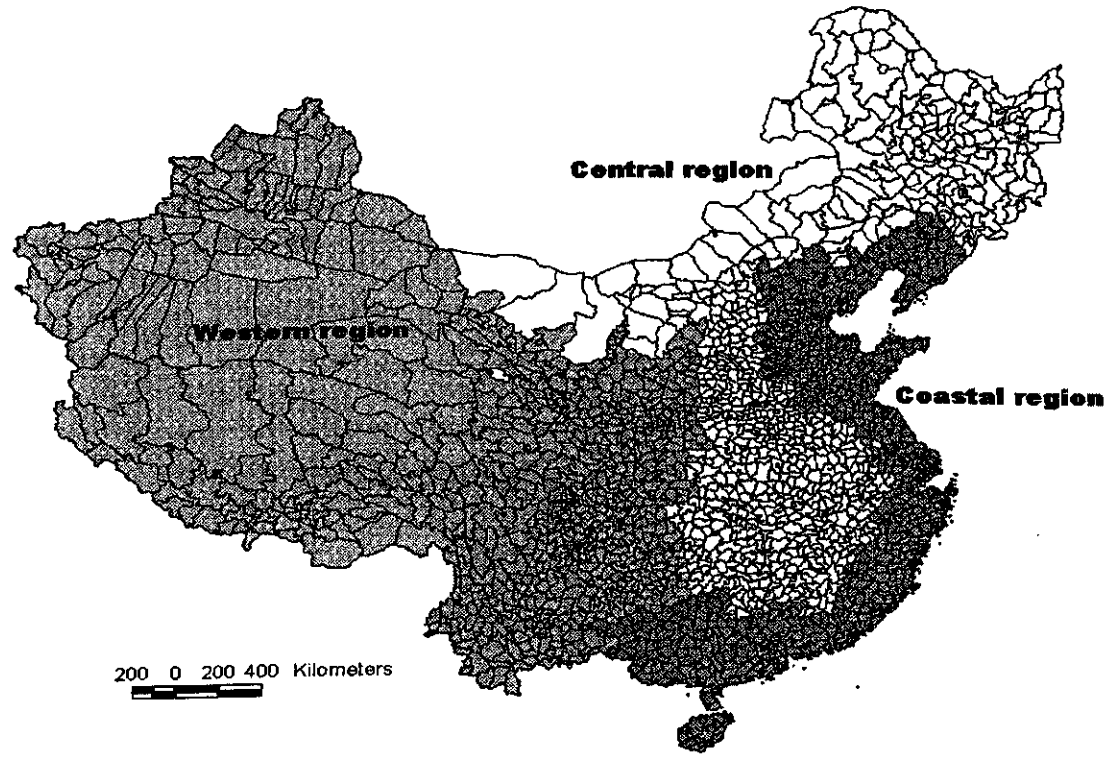

Figure 5.4. Administrative units at county level in China.
Source: China Dimensions WWW database/CIESIN.

Table 5.1. Correlation coefficients between land use types (n = 2350).

	Arable	Horticulture	Forest	Grassland	Housing	Infrastructure	Unused
Arable	.	+0.17*	-0.55*	-0.51*	+0.41*	+0.46*	-0.28*
Horticulture	+0.17*	.	-0.01	-0.24*	+0.14*	+0.10*	-0.15*
Forest	-0.55*	-0.01	.	-0.23*	-0.34*	-0.23*	-0.25*
Grassland	-0.51*	-0.24*	-0.23*	.	-0.34*	-0.34*	+0.02
Housing	+0.41*	+0.14*	-0.34*	-0.34*	.	+0.31*	-0.18*
Infrastructure	+0.46*	+0.10*	-0.23*	-0.34*	+0.31*	.	-0.17*
Unused	-0.28*	-0.15*	-0.25*	+0.02	-0.18*	-0.17*	.

* significance at 0.1%

More insight in the structure of land use can be obtained by relating land use to the biogeophysical and socio-economic conditions. A stepwise regression procedure was used to identify the factors that contribute significantly (at 0.05 level) to the explanation of land use. Table 5.2 presents the identified factors and associated standardized regression coefficients that explain the spatial distribution of cultivated land. The factors are related to population, soil, geomorphology and climate, respectively. A strong relation between the rural population density and the coverage with cultivated land is found. In the coastal region this relation is modified by the negative coefficient of the urbanization index. Highly urbanized counties have less cultivated land than their rural counterparts. Highly urbanized areas are mainly found in the coastal region which explains that the parameter is not identified in the other regions.

Table 5.2. Standardized coefficients (stb) of multiple regression equations explaining the coverage with cultivated land[1].

whole country ($r^2 = 0.75$)		coastal region ($r^2 = 0.85$)		central region ($r^2 = 0.73$)		western region ($r^2 = 0.79$)	
parameter	stb	parameter	stb	parameter	stb	parameter	stb
rural population (%)	0.18	*rural population density*	0.08	*rural population (%)*	0.24	*rural population density*	0.91
rural population density	0.34	*urbanization-index*	-0.19	*rural population density*	0.39	*rural labor force*	-0.10
nutritional density	-0.13	shallow soils	-0.19	*nutritional density*	-0.11	*population density*	-0.18
poorly drained soils	0.18	moderately fertile soils	0.18	NS soil (not suitable)	-0.26	rich fertility soils	0.17
moderately fertile soils	0.11	rich fertility soils	0.31	rich fertility soils	0.15	mean altitude	-0.18
rich fertility soils	0.24	variation in elevation	-0.26	coarse textured soils	-0.10	variation in altitude	-0.11
variation in elevation	-0.17	level land	0.29	variation in elevation	-0.19	steep land	0.13
level land	0.17			*average temperature*	0.19		
average temperature	0.19			*yearly precipitation*	-0.40		
months with precipitation > 50 mm	-0.15						

[1] all coefficients significant at 0.05

Table 5.3. Multiple regression models (parameters and standardized regression coefficients (stb)) explaining the area devoted to cultivated land at different aggregation levels[1].

32·32 km resolution ($r^2 = 0.69$)		64·64 km resolution ($r^2 = 0.72$)		128·128 km resolution ($r^2 = 0.66$)		256·256 km resolution ($r^2 = 0.84$)	
parameter	stb	parameter	stb	parameter	stb	parameter	stb
population density	0.08	-	-	-	-	-	-
rural population density	0.73	rural population density	0.82	rural population density	0.82	rural population density	0.89
poor fertility soils	-0.19	poor fertility soils	-0.19	-	-	poor fertility soils	-0.20
-	-	-	-	average temperature	-0.24	-	-

[1] all coefficients significant at 0.05

Soil and topographic parameters are important to explain the area of cultivated land in all three regions. Cultivated areas are found preferably on soils of good fertility, low altitude, and on level land. The parameter's variation in elevation and level land originate from respectively a 1x1 km Digital Elevation Model (DEM) and a coarse-scale geomorphologic map. Although a low variation in elevation and level land coincide, both parameters turn out to add value to the explanation of the land use. A strange situation is found in the western region: while cultivated land has a negative relation with the variation in altitude, a positive relation with steep slopes is found. This result is probably a consequence of the relatively large county size in the western region; small areas of cultivated land reported in the statistics are equally divided over the county area, which is of course not the case in the real situation.

Climatic variability is only important in the central region or when the country is analyzed as a whole. This can be explained by the relatively smaller variations in climate in the other regions. The central region stretches from the northern end of the country to the tropical south (Fig 5.4), thus including an enormous climatic variation, which, of course, has effects on land use.

The area devoted to residential and industrial sites is obviously correlated to the population density. Other parameters contributing significantly to the explanation of the spatial distribution of residential and industrial sites are altitude and soil type. It is found that the low-lying, fertile, poorly drained soils are correlated with the area devoted to housing and industrial complexes[7]. With increasing areas devoted to housing and industrial complexes this presents a threat to the most productive lands for agriculture.

The influence of the scale of analysis on the relations found was studied by repeating the analysis for data at different aggregation levels. In order to allow a systematic analysis the data were gridded with cell sizes of 32·32 km (approx. the average size of a county in the coastal and central region), 64·64, 128·128 and 256·256 km, respectively. In the preliminary analysis presented here a stepwise regression was used to identify to which extent the population density, the rural population density, the coverage of poor fertility soils and the average temperature contributed to the explanation of the spatial distribution of cultivated land. The stepwise regression procedure revealed that not all 4 parameters made a significant contribution to the explanation of land use at all aggregation levels (Table 5.3). Temperature did only contribute at the resolution of 128 km, while at this resolution soil fertility did not have any significance for the explanation of land use. The total population density can only be found significant at the most detailed aggregation level: large areas of cultivated land are located in the neighborhood of cities. At the more aggregated levels the population density is more smoothed and the direct influence of the neighborhoods of cities cannot be found anymore.

5.7. Actual yield distribution

Whereas the area of arable land has remained stable or has decreased a few percent during recent years and population growth has continued, China has been able to keep up with food production (Prosterman *et al.*, 1996). This is mainly due to slight increases in multiple cropping

7 *Standardized beta coefficients for population density, poorly drained soils, poor fertility soils and mean altitude are 0.44, 0.25, -0.14 and -0.18, respectively; all significant at 0.05; total model adj. R-sqr = 0.47.*

index and major increases in yield. Figures 5.5 and 5.6 show these developments for the different regions of China. Yields are low in the southern region while in that area the multiple crop index is very high; the opposite situation holds for the northern regions. From the graphs it is clear that yields and multiple crop index and their development in time are highly dependent on the regional conditions.
Because of the growing demand for food and limited possibilities for extension of the cultivated area, intensification of agriculture will continue to be a major concern in China. The yield module will be developed to analyze the development and spatial distribution of yields.

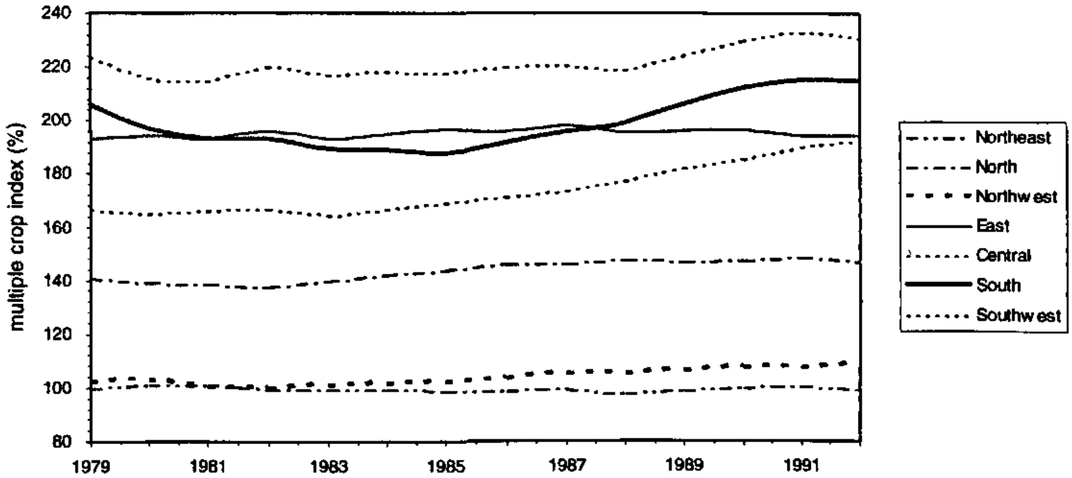

Figure 5.5. Development of the multiple crop index from 1970 to 1993 in different regions of China. The multiple crop index is calculated by dividing the harvested area by the cultivated area. Source: USDA-ERS electronic database.

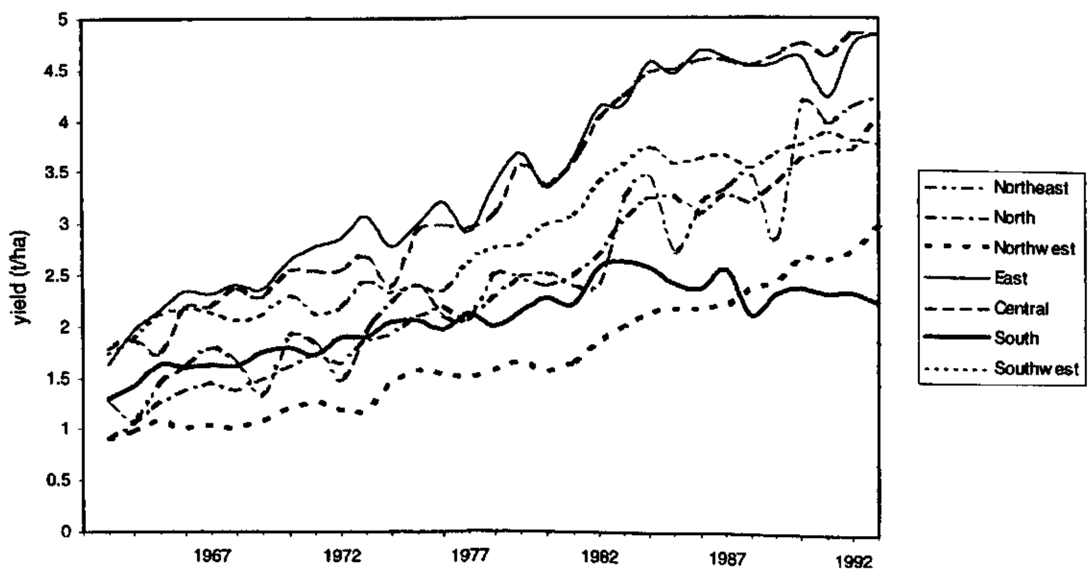

Figure 5.6. Development of grain yield from 1961 to 1993 in different regions of China. Source: USDA-ERS electronic database.

Although potential yields are largely constrained by climate, soil conditions and water availability (Penning de Vries *et al.*, 1995), the actually achieved yields are mainly determined by management and socio-economic conditions. The yield module calculates the actual yields based upon an integrated analysis of the determinants of the actual yields and scenarios of developments in management.

Table 5.4 presents the results of a correlation analysis at county level between actual grain yield in 1990 and a number of socio-economic and biogeophysical factors. This analysis reveals that the actual yield is strongly correlated to the rural population density and irrigation and fertilizer management. High yields are obtained in low-lying flat areas with high temperatures. The fertility of the soils itself has a negative correlation with grain yield: the more fertile soils in a county, the lower the yields. This indicates the overruling influence of (fertilizer) management on yields. From the correlation analysis one might also conclude that a better education (lower illiteracy) might lead to higher yields. Although extension workers might favor such a conclusion we must be very careful with interpretations from a statistical analysis. In this case a causal relation between illiteracy and grain yield is not probable because most illiterate people in China are found in remote areas (*e.g.* the Qinghai-Tibetan Plateau area), where natural conditions are unfavorable for crop production and access to inputs like fertilizer is low. This is revealed by the correlations between illiteracy and altitude (0.71) and illiteracy and fertilizer input (-0.37). This example indicates that interpretations should be made very carefully. Results from case studies should be used to help us interpreting the correlations obtained and selecting parameters which really 'explain' the land use structure.

Table 5.4. Correlation analysis of yield of grain crops (n = 2323); all parameters are expressed relative to the total population, total cultivated area or the total land area of the counties, respectively.

Parameter	Coefficient*	Parameter	Coefficient*
population density	0.27	coarse textured soils	-0.06
rural population density	0.37	medium textured soils	-0.05
rural labor force per cultivated area	0.15	fine textured soils	0.12
mechanization	0.07	**mean elevation**	-0.41
tractor plowed area	0.27	variation in elevation	-0.24
irrigated area	0.60	**level land**	0.39
fertilizer per area	0.60	sloping land	-0.28
illiterate population	-0.40	steep land	-0.20
poorly drained soils	0.33	**temperature in warmest month**	0.37
shallow soils	-0.28	average temperature	0.33
S1 soil (suitable for irrigated paddy)	0.34	yearly precipitation	0.20
S2 soil (moderately suitable)	0.23	months with precipitation > 50 mm	0.28
NS soil (not suitable)	-0.36		
poor fertility soils	0.04		
moderately fertile soils	0.18		
rich fertility soils	-0.21		

* Pearson correlation coefficients all significant at 5% level

Based upon the correlations found, a stepwise regression procedure is used to derive a multiple regression equation that explains the differences in yield throughout the country. Table 5.5 gives the standardized (beta) coefficients for multiple regression equations based on biogeophysical, socio-economic and a complete set of parameters, respectively. It is obvious that actual yield levels are poorly explained by solely biogeophysical conditions. Socio-economic conditions, particularly management, are essential to explain the actual yields. Combination of both parameter sets yields the best fit.

Table 5.5. Standardized (beta) coefficients (stb) for multiple regression equation explaining grain yield[1].

Environmental conditions (r^2 = 0.26)		Socio-economic conditions (r^2 = 0.49)		Environmental and socio-economic conditions (r^2 = 0.51)	
parameter	stb	parameter	stb	parameter	stb
level land	0.43	fertilizer per area	0.40	fertilizer per area	0.39
rich fertility soils	-	irrigated area	0.39	irrigated area	0.36
months with precipitation		population density	0.06	months with precipitation > 50 mm	0.14
> 50 mm	0.19			temperature in warmest month	0.06

[1] all coefficients significant at 0.05

5.8. Conclusions

The framework for modeling land use change in China as presented in this paper seems to be appropriate for the Chinese situation. Expected changes in both land cover and land management/productivity can only be described in an integrated way, dealing with both biogeophysical and socio-economic conditions. This is clearly illustrated by the spatial distribution of land use types as well as the distribution of grain yields: any model which only takes into account either biogeophysical or socio-economic conditions is incomplete and consequently has a poor explaining capacity. A preliminary analysis of the effect of the aggregation level on the relations found indicated that it is essential and valuable to identify and quantify the determinants of land use at different aggregation levels. Implementation in a dynamic land use change model seems promising and will be useful to explore the spatial patterns of land use change under different scenarios of population growth and food demand. In combination with studies based on quantitative land evaluation methods and multi-criteria models such as interactive linear-programming models (de Wit *et al.*, 1988; WRR, 1992) and studies exploring the yield potentials for larger regions (Penning de Vries *et al.*, 1995) this will lead to a more complete description of land use and land use changes at the regional level.

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Appendix

Parameters in GIS database: description and source.

Parameter	Description	Source
arable	cultivated lands, including paddy and dry-land	IIASA-LUC pers. comment
horticulture	horticultural lands, including orchards, tea plantations, *etc.*	"
forest	forestry lands, including timber forests, natural forests, shrubs, *etc.*	"
grassland	grasslands, including natural grasslands and artificial grasslands	"
housing	land for settlement and mining	"
infrastructure	land for transportation, including railways, highways, harbors, *etc.*	"
unused	other lands including glaciers, permanent snow, deserts	"
population density	population density - 1990 census	G. William Skinner *et al.* China
rural population density	rural population density - 1990 census	County-Level Data on Population
rural population (%)	percentage rural population of total population - 1990 census	(Census) and Agriculture, Keyed to
urbanization-index	fraction residents of urban wards of total population - 1990 census	1:1M GIS Map,
rural labor force per cultivated area	rural labor force per cultivated area - 1990 census	Published and Disseminated by
illiterate population	percentage illiterate people of total population 15+ - 1990 census	CIESIN
nutritional density	population divided by cultivated area - 1990 census	"
mechanization	watts used per area of cultivated land - 1990 census	"
tractor plowed area	tractor plowed area divided by total cultivated area - 1990 census	"
irrigated area	irrigated area as percentage of total cultivated area - 1990 census	"
fertilizer per area	fertilizer per sown area - 1990 census	"
poorly drained soils	% of area with very poorly, poorly and imperfectly drained soils	Digital Soil Map of the World
very shallow soils	% of area with very shallow and shallow soil depth	and Derived Soil Properties
S1 soil (suitable for irrigated paddy)	% of area with suitable soils for irrigated paddy	Version 3.5. FAO 1995
S2 soil (moderately suitable)	% of area with moderately suitable soils for irrigated paddy	"
NS soil (not suitable)	% of area with not suitable soils for irrigated paddy	"
coarse texture soils	% of area with coarse textured soils	"
medium textured soils	% of area with medium textured soils	"
fine textured soils	% of area with fine textured soils	"
poor fertility soils	% of area with soils with a low fertility index	IIASA-LUC pers. comment
moderately fertile soils	% of area with soils with a moderate fertility index	"
rich fertility soils	% of area with soils with a rich fertility index	"
mean elevation	mean elevation based on 1x1 km DEM	GTOPO30 US Geological survey;
variation in elevation	variation in elevation based on 1x1 km DEM	EROS data center
level land	level land (gradient < 8%; relief intensity < 100m/km)	adjusted SOTER database ISRIC
sloping land	sloping land (gradient 8-30%)	"
steep land	steep land (gradient >30%; relief intensity > 600m/2 km)	"
temperature in warmest month	average temperature in month with highest average temperature	Leemans and Cramer; IIASA
average temperature	mean monthly temperature (long time average)	database
yearly precipitation	total precipitation (long time average)	"
months with precipitation > 50 mm	number of months with more than 50 mm precipitation	"

6. Regional water resources management and land surface processes in northwestern China

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6.1. Introduction

In the arid northwestern regions of China, water availability in the inhabited areas depends on precipitation and melt in the upper reaches of rivers at high elevations. Gao and Du (1997) defined the arid zone of China as comprising Xinjiang, West Gansu, Qin Hai, North Ning Xia and Alashan Plateau (Inner Mongolia) and located north of latitude 32° N and west of longitude 114° E. In this region annual precipitation is less than 100 mm a^{-1}, except the Hexi Corridor, Yin Chuan plain and eastern Qin Hai. More than half of yearly precipitation falls in the mountains. These authors gave an overview of yearly runoff for all basins and sub-basins of the region, adding up to a total yearly runoff of 1.4 10^{11} m^3, of which 66% or 9.3 10^{10} m^3 applies to inner drainage basins. In these basins a large fraction of runoff (4.25 10^{10} m^3) recharges aquifers. After correcting groundwater recharge to shallow aquifers for the fraction due to river runoff and discounting outflow through the Yellow River, Gao and Du (1997) estimated total water resources at 1.1 10^{11} (m^3 a^{-1}), of which 0.3 10^{11} (m^3 a^{-1}) unused.
It is worth noting that groundwater storage in deep aquifers is considered not-renewable resource and that groundwater stored underneath the deserts is estimated at 10^{13} m^3 (or the same order of magnitude applying to the aquifers underneath the Sahara). Storage in depressions and lakes is estimated at 3 10^{10} m^3, but evaporation losses are neglected, while they represent a truly renewable resource. Considering that the area of lakes and depressions with shallow water table amounts to 1.7 10^4 km^2 and both lakes and depressions receive surface and groundwater, this component of the regional water balance should be given more attention.

A better understanding of the previous figures may be gained by looking at a representative watershed such as the Hei He basin. Rather long records (1945 to present) of observations are available for the central and upper reaches of this river in the Qilian Mountain. Analysis of observations and derived climatic variables (*e.g.* maximum and actual evaporation) indicates that a decrease in air temperature over the last 30 years led to decreasing runoff, thus reducing water available in summer (Yang, 1989). This author did also point out the difficulty of obtaining accurate estimates of total basin precipitation due to the small number of gauges in relation with the extension of the basin and, particularly, the distribution of area with elevation. When gauges are not adapted for the measurement of snowfall (*e.g.* heated gauges or snow-pillows), the rain gauges will measure a fraction only of actual total precipitation and correction factors have to be estimated. According to Yang (1989) measured precipitation represents 20% to 25% of actual total precipitation. The largest fraction of runoff is due to precipitation exceeding infiltration capacity and, therefore, occurs during short periods after each event. Estimates of fresh water resources were given by Yang (1989): on average 13.81 10^8 m^3 is glaciers storage and 15.2 10^8 m^3 a^{-1} is stream flow.

Climate variability, and specifically of precipitation, is rather large in this region and has received significant attention. Besides studies based on records of actual observations, proxy climate variables such as tree rings have been used (Kang, 1997). This author established the transfer function between temperature, precipitation and ring width using records of observations extending over a period of 23 to 35 years for different stations. The derived records of the temperature and precipitation indices extend through some 500 years and the analysis of the time series identified cold and warm periods, as well as dry and wet periods. As the previous description of hydrological processes indicates, such climate variability led to significant changes in river flow and, therefore, water supply.

6.2. Development of water resources and environmental conservation

Use of fresh water resources has two kinds of environmental impacts: directly through deterioration of water quality and indirectly through reduced water supply to natural oasis and other ecosystems. Gao and Du (1997) describe a few examples, such as the Min Qing basin and the Eji Na oasis in the Hei He basin where the oases have been seriously degraded by upstream water diversion and the many irrigated lands where excess irrigation led to rising water tables and secondary salinization.

The lower reaches of the Hei He provide us with an example of the impact of large-scale water diversion: the degradation of the Eij Na delta, described by Gong *et al.* (1997). These authors stress that the delta and the natural oasis have been inhabited since the Han Dinasty (206 BC) and threatened in several ways, including massive migration of its inhabitants. Climate is hyperarid with 50 mm a^{-1} precipitation and 4000 mm a^{-1} pan evaporation. Runoff amounts to 18.5 10^8 m^3 a^{-1} and renewable groundwater resources 7 10^8 m^3 a^{-1}, of which 80% seepage of surface water. During the Han Dinasty the Ju Yan Lake (the Hei He terminal lake) was 720 km^2 in extent, while its remnants (Ga Shun Nur and Suo Go Nur) dried out in 1992. At the same time the groundwater table dropped and groundwater salinity increased. Forest area is decreasing at a pace of 2600 ha a^{-1} and the carrying capacity of grasslands has been halved during the last 40 years. Climate variability during the last 40 years has been studied, but observed changes are far from accounting for observed impacts. The latter were compounded by a five-fold increase in livestock.

Similar conditions occur in other rivers in northwestern China as described by Xiao (1997) who emphasized how ancient oases and settlements disappeared with the development of new irrigation schemes. This author mentioned several historical references to the number of streams and lakes in the desert and to the original extension of the Nop Nor, the large lake at the end of the Tarim river. The most striking example of irrigation-induced degradation is the disappearance of the Zhu Ye Ze lake in the lower reaches of the Shi Yang He river, where civilization has been traced back to 3000 BC. In the same basin the current irrigated area can only be sustained with groundwater overdraft, resulting in a significant drawdown of the groundwater table. Xiao (1997) described similar degradation processes in the Zhungaer basin.

The area affected by secondary salinization is estimated at 114 km^2 or 30% of total irrigated land in northwest China. Gao and Du (1997) estimated that the combined impact of diverting water to newly irrigated lands and exploitation of groundwater led to the disappearance of forest area and to serious degradation ("sandy desertification") of some 3.9 10^4 km^2. The same authors stress that a better balance is urgently needed between the current emphasis on short-term development of industry and agriculture and the long-term protection of the environment, including water supply to forests and grassland. They suggest that usable water resources can be increased substantially by having a closer look at:

- collect and store water produced by short, high intensity rainfall events;
- improve regulation of natural runoff by means of new dams and of improved operation of existing infrastructure;
- increase groundwater use;
- improve water use efficiency in industry;
- reduce water allocation to agriculture, presently 1300 mm a^{-1};
- water use for pasture;
- re-use of drainage water in industry and agriculture;
- price water according to its value and quality.

As stressed by Gong *et al.* (1997), all of the above must address water management taking an entire watershed as a reference, since local interventions are doomed to failure because of the hydrologic characteristics of these arid zones. Xiao (1997) gave a clear description of the interrelation of irrigation development with degradation processes in the middle and lower reaches of the rivers in NW China. The main issue is to establish whether the substitution of the ancient oases with modern irrigation schemes did fulfill the objective of raising the basin-wide water use efficiency.

6.3. Land surface processes

A major element of uncertainty in all of the above is the amount of evaporation from the main units of arid landscapes. This applies not only to actual but also to maximum evaporation: irrigation modifies near surface air temperature and humidity, spatial heterogeneity has a significant impact on heat and vapor fluxes and these effects depend on the spatial arrangement of the landscape elements.

The elevation, aridity and continental climate add up to rather high maximum evaporation, as for example shown by Zeng and Xie (199?) who used the Penman combination equation. Moreover it is a well established notion that rather different values are obtained with different formulae for maximum evaporation.

The relation between maximum evaporation and environmental conditions is further complicated by the strong influence of the desert - oasis system described above on heat and mass transfer in the planetary boundary layer (PBL). Su and Hu (1988) compared the effect of a lake and of an oasis on PBL with the urban heat island effect. They showed that a stable stratification is found over the oasis, at the same time as an unstable stratification over the surrounding desert. This conclusion is quite relevant for the estimation of potential evaporation, since the heat and vapor transfer coefficients depend on atmospheric stratification. The structure of the vertical cross sections of air temperature and humidity clearly indicate that the near-surface values (*i.e.* the ones controlling transpiration) are significantly different from the surrounding desert: air temperature up to 4 C° lower and humidity up to 10 mg kg^{-1} higher. The impact of the oasis on PBL depends on stratification in the surrounding desert: when stratification is neutral or stable, the cold island effect is observable at higher elevations and larger distances.

The simulation studies of Su and Hu (1988) were done by taking a horizontally homogeneous oasis. This is an approximation only as for example shown by Wang *et al.* (1995) and did not take into account the effect of spatial heterogeneity on roughness lengths for momentum and heat transport. These effects can be rather large as shown by Menenti *et al.* (1997).

6.4. Land surface processes and water requirements

Bastiaanssen and Wang (1997) did show that the remarks given above have a significant impact on calculated crop water requirements. The latter were obtained with the Penman-Monteith combination equation, following recent FAO guidelines. Errors were evaluated by comparison with accurate measurements of evapotranspiration at a well watered wheat plot (large oasis surrounded by desert), where state-of-the-art micrometeorological instruments were used. The PM-equation gave values up to 80% higher than the values measured with an eddy-correlation system when considering total evapotranspiration over a period of 9 days. Errors were larger when considering individual days. The authors stressed error sources such as the impact of errors in the calculation of net radiation and in the estimation of canopy parameters such as the roughness lengths for heat and momentum transport. Furthermore, it should be noted that spatial variability and especially the large differences in meteorological variables between oasis and desert patches easily lead to errors when using observations at stations not representative of the sites for which they are needed. Bastiaanssen and Wang (1997) did also show that net radiation is an useful upper bound for potential evapotranspiration.

In another study Wang *et al.* (1995) demonstrated that spatial variability of heat fluxes, including net radiation, at heterogeneous land surfaces can be quantified using satellite observations. They concluded that the evaporative fraction is a reliable measure of water stress and that useful indicators of hydrological conditions can be obtained with satellite observations.

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7. Valuation of arable land in mainland China: comprehensive estimates for the agricultural sub-regions

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Abstract

Estimates of the value of agricultural land can be of great use for land transactions, assignment of land use rights, and agricultural taxation in China. In this paper, we present a methodology for the estimation of arable land values which takes into account future production potentials, socio-economic factors (including measures taken to prevent soil degradation), and the scarcity of land. The proposed method is applied to available data for the 30 agricultural sub-regions in mainland China.

7.1. Introduction

In mainland China, ownership of urban land belongs to the State while rural land is owned by the collectives. User rights of urban land can be sold through auctions, invited tenders, or negotiation. The price is usually based on the land price calculated by Land Administration Bureaux on the basis of current net benefits derived from the land. Since 1978-83, rural land use rights have been assigned to individual farm households within a collective for a period of (mostly) 15 years. In recent years, these land use rights are being extended with a period of 30 years. Although rural land use rights can be transferred, this usually only happens when farmers migrate to urban areas or find a (temporary) job in rural enterprises. No compensation is paid for land obtained in this way. It is distributed by the collective over the remaining farmers.

The assignment of land use rights by collectives to farm households belonging to the collective is done on the basis of equality, taking into account differences in land quality, distance to dwelling, infrastructure, and household composition. As a result, each household is assigned many different small plots of different quality. In 1990, the average land area cultivated by farm households in China amounted 8.0 mu (1 ha = 15 mu), divided over 7.8 plots on average (Qu *et al.*, 1995). Evidently, land productivity is likely to suffer from the high degree of fragmentation resulting from these land assignment procedures.

The problem of land fragmentation can be reduced substantially when the distribution of land over farm households would be based on equality of land value. In that case, a small plot of high-quality land will have a value equal to that of a large plot of low-quality land. Arable land will become more concentrated and circulating mechanisms can be formally established when land use rights are assigned on the basis of land value. Farmers will have an increased interest in sustainable land use, since soil degradation will decrease the value of their land. In addition, the taxation of agriculture (which uses the productivity of the land in 1951 as a basis) will be more efficient when it is based on the present value of the land. Evidently, the distribution of income over government (agricultural taxation), collectives (contribution payments by farmers) and farm households will be affected considerably.

In the absence of a market for rural land, the value of land has to be estimated from available information on relevant indicators. In this paper, we present a method that can be used for the valuation of arable land in mainland China, taking into account its agronomic, socio-economic as well as ecological dimensions. The proposed method is applied to the 30 agricultural sub-regions in mainland China. In section 7.2 we discuss the different dimensions that are included in the analysis and present data on indicators of these dimensions. In section 7.3 the methodology used for estimating land value from indicators of these dimensions is explained, and the results obtained for the 30 regions in mainland China are presented. Concluding remarks are presented in section 7.4.

7.2. Factors determining land value in China

The fundamental characteristic of agriculture is that natural productivity and economic productivity are interwoven. Any valuation of agricultural land should therefore be based on both natural and economic conditions. He and Zhang (1994), in their pioneering study on cultivated land valuation in China, base their land value estimates on the actual income derived from arable land in the 30 provinces. Land valuation, however, should be based on forecasts of future benefits derived from the land, not on past benefits. Future yields evidently depend on the production potential of the land as well as on socio-economic factors that determine the realization of this potential. Furthermore, the value of land partly depends on factors like urbanization and industrialization which increase the scarcity of land without necessarily increasing its yields. Estimates of the value of agricultural land in China should therefore preferably be based on the production potential of the land as well as on information on (future) socio-economic conditions and land scarcity.

Mainland China is characterized by a wide variety in land resources, climatic conditions, agricultural technologies used, social customs, and other socio-economic conditions. To estimate differences in land value between different regions in mainland China, we start from the regional subdivision used by the Chinese Academy of Agricultural Sciences (CAAS). According to this subdivision, the territory of China is divided into ten regions and 31 sub-regions (including Taiwan) with relatively homogeneous agricultural conditions (CAAS, 1984). A map showing the division of China into agricultural (sub)regions is provided in Figure 7.1. Evidently, such a classification into agricultural (sub)regions is better suited for our purpose than a subdivision into administrative regions (provinces) as is done in the study by He and Zhang, 1994. Because of a lack of suitable data, the Taiwan sub-region unfortunately could not be included in the analysis.

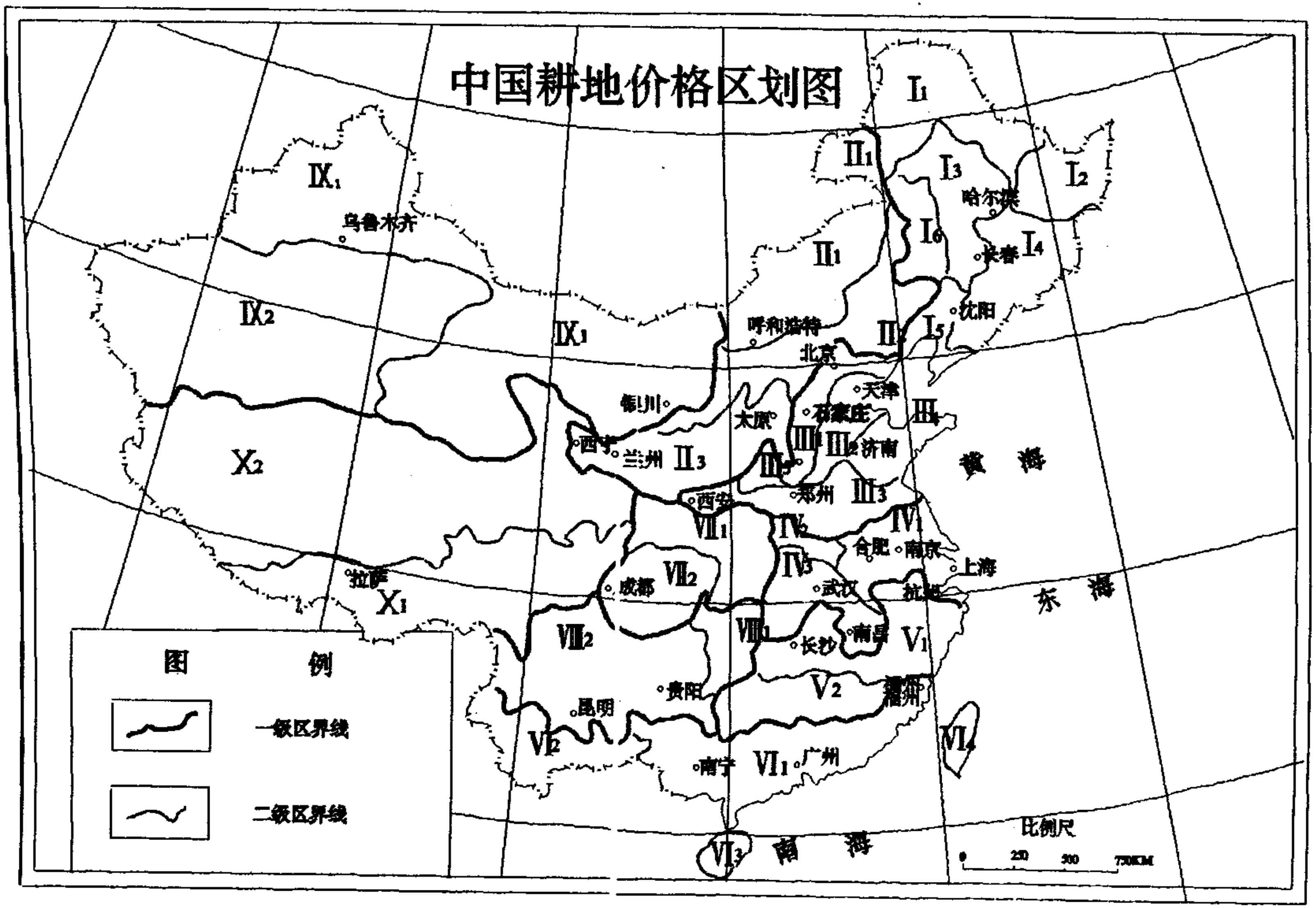

Figure 7.1. Agricultural (sub)regions in China.

A basic element of the proposed methodology is the estimation of the production potential of each agricultural sub-region. To this end, estimates of potential cereal yields per agricultural sub-region are multiplied by the so-called ideal multiple crop index per sub-region, indicating the average number of harvests obtained from the cropland. The resulting production potentials are shown in Table 7.1.

Socio-economic factors play a crucial role in transforming potential agricultural productivity into actual productivity. Large differences exist in the socio-economic environment of agriculture between the sub-regions that we distinguish. Of special importance are the use of inputs in agriculture and the extent to which farmland is protected against degradation. Inputs distinguished in the analysis include mechanical power, electricity, chemical fertilizer, and agricultural labor. Measures taken to protect farmland against degradation include soil conservation measures and measures to protect production against water-related risks and natural disasters. Finally, average income of farm households and social output per capita are included as indicators of potential levels of (conservation) investment and external input use. This gives the following list of socio-economic variables:

MPCL: mechanical power per area of cultivated land (kw ha^{-1});
PESY: percentage of cultivated land with stable yields in cases of drought or excessive rains (as a result of e.g. irrigation);
PRLF: percentage of land where soil erosion is resolved through soil conservation measures;
ECPA: electricity consumption per area of cultivated land (kwh ha^{-1});
ACFP: chemical fertilizer applied per area of cultivated land (kg ha^{-1});
ALPA: agricultural laborers per area of cultivated land (persons ha^{-1});
CAAC: percentage of cultivated land regularly struck by natural disasters (hurricanes, flood) with stable yields;
NIPF: net income per farm household (yuan);
TSOU: total social output value per capita (10000 yuan).

Table 7.2 gives the values of these nine variables for the 30 Provinces in mainland China. Estimates for the 30 agricultural sub-regions are obtained by weighing the value for each Province that is (partly) located in an agricultural sub-region by the share of that Province's cultivated land in the total cultivated land of the agricultural sub-region.

The scarcity of land depends on a number of factors. The population density and the amount of cultivated land per capita indicate the demographic pressure. The extent to which cultivated land is able to satisfy the demand exerted by the population is reflected in the production of cereals and vegetables per capita. The process of industrialization and urbanization increase the scarcity of cultivated land. The degree of urbanization and the share of the non-agricultural sector in GNP are used as indicators of this process. This gives the following lists of variables used as scarcity indicators:

CLPC: cultivated land per capita (ha)
PFPC: production of cereals per capita (kg)
VEPA: production of vegetables per capita (kg)
POPT: percentage of off-farm population in total regional population
PODE: population density (persons km^{-2})
POSO: percentage of off-farm sector output value in regional GNP

Table 7.1. Productive potentials of farmland in mainland China.

Agricultural (sub)regions	Potential cereal yield ($t\ ha^{-1}\ yr^{-1}$)
I Northeast Region	
I1 Greator and Lesser Xing'an Mountains	5.4
I2 Sanjiang Plain	6.0
I3 Songnen Plain	7.8
I4 Changbaishan Mountains	9.9
I5 Liaoning Plain Mountains	8.9
I6 West Heilongjiang and Jilin	6.7
II Plateau Region of North China	
II1 Northern Inner Mongolia	3.4
II2 Along the Great Wall	8.0
II3 Loess Plateau	9.2
III Region of Huanghai Sea and Huaihai Sea	
III1 Yan-Taihang Foot Plain	11.1
III2 Jiluyu Lowland Plain	9.2
III3 Huanghuaihai Plain	13.2
III4 Shandong Hills	13.0
III5 Fenwen Valley-West Henan Hills	8.6
IV Middle and Low reaches of the Yangtze River	
IV1 Changjiang Low Reaches Plain	19.4
IV2 Eyuwan Hills	11.2
IV3 Changjiang Middle-low Reaches Plain	15.6
V Hilly Region of South China	
V1 Jiangnan Hills	14.2
V2 South Nanling Hills	13.9
VI South China	
VI1 South Ming Yuqian	13.4
VI2 South Yunan	8.8
VI3 Hainan-Leizhou Peninsula	15.3
VI4 Taiwan area	
VII Basin Region of Sichuan Province and Shaanxi Province	
VII1 Quinling-Daba Mountains	11.1
VII2 Sichun Basin	13.8
VIII Plateau Region of Yunnan Province	
VIII1 West Human-East Guizhou	13.9
VIII2 West Guizhou-Middle North Yunnan	10.7
IX Greenbelt Region of Northwest China	
IX1 Mengninggan-Beijiang	7.6
IX2 South Xingjiang	13.8
X Plateau Region of Qinghai and Xizhang	
X1 South-West Tibet - West Sichun	7.3
X2 North Tibet - South Qinghai	4.6
Average	10.7

Source: Cao, 1993 (production potentials per subregion) and Wang, 1994 (ideal multiple crop index per subregion).

Table 7.2. Socio-economic conditions of cultivated land in mainland China in 1993.

Region	MPCL	PESY	PRLF	ECPA	ACFP	ALPA	CAAC	NIPF	TSOU
Beijing	11.00	62	59.31	4189	370	1.80	55.83	2255	1.42
Tianjing	10.96	53	54.24	5387	189	2.02	52.68	1398	1.52
Hebei	4.88	43	62.52	1302	296	2.82	54.61	743	0.41
Shanxi	3.30	17	52.67	1022	184	1.74	53.90	711	0.37
Inner Monggu	1.61	20	22.82	261	88.9	0.97	47.68	781	0.34
Liaoning	2.90	29	73.86	2149	277	1.74	64.34	1132	0.81
Jielin	1.54	15	64.09	503	220	1.41	48.33	901	0.47
Helongjiang	1.33	5	40.80	247	112	0.53	46.23	991	0.49
Shanghai	5.86	98	90.00	16567	663	2.09	80.00	2130	2.31
Jiangsu	4.63	62	69.36	3764	555	3.62	52.41	1204	0.88
Zhejiang	8.44	61	75.89	6947	515	7.46	43.37	1315	0.78
Anhui	3.60	46	57.46	64.9	413	4.51	63.05	650	0.29
Fujian	5.69	51	43.99	2395	756	6.63	43.13	1179	0.49
Jiangxi	2.71	61	41.38	950	403	4.54	59.44	801	0.29
Shandong	5.20	51	48.67	1577	525	3.84	48.36	952	0.46
Henan	3.82	44	53.10	889	419	4.22	47.98	678	0.27
Hubei	3.27	56	43.44	985	539	4.19	56.36	734	0.32
Hunan	4.20	66	37.40	917	452	6.62	54.55	686	0.30
Guangdong	5.88	67	80.20	5419	701	6.22	53.00	1477	0.83
Guangxi	3.60	45	54.69	729	404	6.03	49.33	822	0.25
Hainan	3.67	39	59.32	278	341	3.77	52.86	823	0.42
Sichuan	2.25	30	13.50	956	345	6.63	52.62	569	0.29
Guizhou	1.90	28	13.85	293	316	7.42	52.75	468	0.16
Yunnan	2.76	25	32.05	589	277	5.63	61.24	459	0.23
Xizang	2.42	35	25.00	148	166	3.88	35.19	900	0.24
Shaanxi	2.12	25	53.54	1044	269	3.05	54.70	613	0.30
Gansu	1.91	23	28.26	626	125	1.95	56.94	551	0.28
Qinghai	2.67	24	17.88	327	105	2.19	23.65	534	0.28
Ningxia	2.17	37	21.47	598	162	1.67	43.60	507	0.27
Xinjiang	1.95	57	32.76	442	162	0.89	71.70	749	0.44
Total	3.32	37	37.57	1282	331	3.50	52.63	838	0.48

Source: China Economy Yearbook, 1994.

Table 7.3 presents data on these six variables for the 30 Provinces in mainland China. The same procedure as described above is used for converting these data to estimates for the thirty agricultural sub-regions.

7.3. Methodology and results obtained

In order to estimate the value of land per agricultural sub-region from the data presented in Tables 7.1 to 7.3, the following procedure is used. First, the potential cereal yield per sub-region is normalized by dividing its value by the average for mainland China. The result is an index I^{p} of relative production potential per sub-region. Similarly, the variables in Tables 7.2

and 7.3 are normalized by dividing the data by the average value of each variable for mainland China.

Table 7.3. Scarcity conditions of cultivated land in mainland China in 1993.

Region	CLPC	PFPC	VEPA	POPT	PODE	POSO
Beijing	0.039	268.7	353.2	66.36	629	88.09
Tianjing	0.048	224.6	262.4	56.43	787	84.91
Hebei	0.104	377.2	261.0	15.70	336	63.67
Shanxi	0.172	335.0	83.8	23.04	189	74.80
Inner Monggu	0.231	504.3	154.2	31.68	18	52.51
Liaoning	0.087	425.8	209.3	43.58	273	73.73
Jielin	0.158	761.5	262.1	40.91	134	53.10
Helongjiang	0.252	675.6	195.9	43.56	78	66.67
Shanghai	0.025	162.2	124.8	69.01	2055	92.41
Jiangsu	0.066	469.3	194.8	23.48	664	65.82
Zhejiang	0.039	333.0	105.6	17.39	424	66.83
Anhui	0.074	437.8	101.0	16.42	422	41.35
Fujian	0.040	280.4	157.9	18.09	256	57.45
Jiangxi	0.061	393.3	134.1	19.71	231	46.59
Shandong	0.079	459.9	316.1	22.00	551	57.53
Henan	0.077	408.2	213.0	14.44	534	54.80
Hubei	0.061	416.0	180.3	23.79	300	56.33
Hunan	0.053	411.4	142.7	16.70	295	48.80
Guangdong	0.037	243.3	174.2	27.47	370	67.86
Guangxi	0.059	330.4	153.7	15.27	186	41.78
Hainan	0.064	270.0	161.3	22.21	201	43.26
Sichuan	0.057	377.2	189.5	15.80	193	49.70
Guizhou	0.055	260.9	103.9	12.65	189	45.68
Yunnan	0.075	285.4	126.3	12.99	97	50.98
Xizhang	0.097	286.2	54.1	13.73	1.9	31.35
Shaanxi	0.103	360.7	109.0	19.58	164	59.00
Gansu	0.150	327.1	90.6	16.93	51	59.60
Qinghai	0.130	265.7	28.2	28.01	6	66.85
Ningxia	0.163	418.0	137.2	24.36	95	63.92
Xinjiang	0.199	440.4	120.4	33.82	9	54.97
Total	0.082	392.6	178.7	22.42	121	61.20

Source: China Agriculture Yearbook; China Economy Yearbook; China Population Statistical Yearbook, 1994.

Next, composite indices of socio-economic conditions and land scarcity are derived by taking the geometric averages of the (normalized) variables in Tables 7.2 and 7.3, respectively[8]. *Unfortunately, no suitable information is available on the relative importance of each variable.*

8 *For the variables CLPC, PFPC, and VEPA, reciprocals of the normalized values are used in calculating the composite index, because the scarcity of land will be higher the lower the values of these three variables.*

As a result, each variable receives equal weight in calculating the composite indices of socio-economic conditions and land scarcity. As a third step, a synthetic index of the (relative) socio-economic and scarcity conditions in a sub-region is derived by taking the geometric average of the two composite indices. The resulting synthetic index I^S is transformed into an index I^R with values between 0.8 and 1.2 by using the following transformation:

$$I^R = 1.2 \quad \text{when} \quad I^S > 1.7$$
$$I^R = 0.39 * I^S + 0.53 \quad \text{when} \quad 0.7 < I^S = 1.7$$
$$I^R = 0.8 \quad \text{when} \quad I^S = 0.7$$ [9]

The resulting revised index I^R is multiplied by the aggregate potential yield index I^P. This gives the index I^V of relative land value per sub-region. As a final step, the index I^V of relative land value is multiplied by two different estimates of the average land value for mainland China. The first estimate used is the compensation paid by the Government for cultivated land (six times the average output over the last three years; Method 1). This gives an average value of 32,174 yuan per ha for mainland China in 1993. The compensation payments of the Government are generally considered an underestimation of true value of land. As an alternative, therefore, the net income from cultivated land is divided by the prevailing interest rate (Method 2). This gives an average value of 39,797 yuan per ha for mainland China in 1993.

Table 7.4 shows the resulting estimates of land value per agricultural sub-region in mainland China. The first column gives the results when the average value for China as a whole is based on the compensation payments paid by the Government, the second column the results when the alternative method is used.

The total value of cultivated land according to these two methods is 3,060 billion yuan and 3,780 billion yuan, respectively. In the Yangtze Low Reaches Plain (sub-region IV1), the value of cultivated land is highest. It equals 2.36 times the average value for mainland China. The value of cultivated land is lowest in Northern inner Mongolia (sub-region II1), where it equals about one fourth of the average value for mainland China.

7.4. Conclusion

Compared to the pioneering study on cultivated land valuation by He and Zhang, 1994, the method we propose in this study contains a number of aspects that are likely to improve the quality of the estimates of land value in agricultural areas in China:

- by including potential agricultural production, potential future benefits of the land are incorporated;
- factors causing land scarcity are included; they put an upward pressure on land value without necessarily increasing the income derived from the land;
- measures taken by farmers to protect the land against degradation (erosion, droughts, floods, and so on) are explicitly taken into account;

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9 The resulting sub-regional data on the index IR are divided by 0.92 to account for differences in statistical overestimation between data at the national and sub-regional levels.

Table 7.4. Estimated value of land for 30 agricultural sub-regions in mainland China.

Agricultural (sub)regions	Land value (yuan ha^{-1}) Method 1	Method 2
I Northeast Region		
I1 Greator and Lesser Xing'an Mountains	12,226	15,123
I2 Sanjiang Plain	15,765	19,501
I3 Songnen Plain	20,270	25,073
I4 Changbaishan Mountains	24,453	30,246
I5 Liaoning Plain Mountains	26,383	32,634
I6 West Heilongjiang and Jilin	16,409	20,297
II Plateau Region of North China		
II1 Northern Inner Mongolia	9,009	11,143
II2 Along the Great Wall	19,626	24,276
II3 Loess Plateau	20,913	25,868
III Region of Huanghai Sea and Huaihai Sea		
III1 Yan-Taihang Foot Plain	43,435	53,726
III2 Jiluyu Lowland Plain	24,130	29,848
III3 Huanghuaihai Plain	38,931	48,155
III4 Shandong Hills	40,218	49,747
III5 Fenwen Valley-West Henan Hills	21,235	26,266
IV Middle and Low Reaches of the Yangtze River		
IV1 Changjiang Low Reaches Plain	75,932	93,922
IV2 Eyuwan Hills	34,748	42,981
IV3 Changjiang Middle-low Reaches Plain	53,409	66,064
V Hilly Region of South China		
V1 Jiangnan Hills	53,409	66,064
V2 South Nanling Hills	36,679	45,369
VI South China		
VI1 South Ming Yuqian	48,262	59,696
VI2 South Yunan	40,218	49,747
VI3 Hainan-Leizhou Peninsula	24,453	30,246
VI4 Taiwan area		
VII Basin Region of Sichuan Province and Shaanxi Province		
VII1 Quinling-Daba Mountains	28,957	35,820
VII2 Sichun Basin	40,861	50,543
VIII Plateau Region of Yunnan Province		
VIII1 West Human-East Guizhou	27,992	34,624
VIII2 West Guizhou-Middle North Yunnan	26,383	32,634
IX Greenbelt Region of Northwest China		
IX1 Mengninggan-Beijiang	18,661	23,082
IX2 South Xingjiang	38,288	47,359
X Plateau Region of Qinghai and Xizhang		
X1 South-West Tibet - West Sichun	18,983	23,480
X2 North Tibet - South Qinghai	11,261	13,929
average	32,174	39,797

- the method is applied to regions with relatively homogeneous agro-ecological conditions instead of administrative regions (provinces) with a wide diversity in agro-ecological conditions.

Because the factors that determine the value of land are continuously changing, the value of arable land changes over time. A logical next step is the development of a model that can be used for estimating arable land value in mainland China.

We are aware that, although the proposed method is an improvement over previous methods, further refinement is still required. In particular, different weights should preferable be attached to each factor in the composite indices of socio-economic conditions and land scarcity.

Land value estimation in China should not remain at the macro or meso level. A similar method has been applied to urban land at the city level (Huang, 1996). At the moment, applications at the level of rural towns and villages are being carried out. The results of such analyses will be very useful for land transactions, the assignment of land to farmers, agricultural taxation, *etc.*

7.5. References

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8. Assessment of the status of human-induced soil degradation in China[10]

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8.1. Background

In October 1993, an Expert Consultation of the Asia Network on Problem Soils (Dent, 1994) recommended that the methodology of the Global Assessment of Human-Induced Soil Degradation[11] (Oldeman *et al.*, 1990) be adopted as a common methodology in a new and more detailed assessment of soil degradation in South and Southeast Asia[12] (van Lynden & Oldeman, 1997). The International Soil Reference and Information Centre (ISRIC) was requested to amend the GLASOD guidelines, based on suggestions for revision by Network member countries. A physiographic basemap at a 1:5M scale was prepared by FAO and ISRIC utilizing the internationally endorsed Global and National Soils and Terrain Digital Database[13] approach. Network nodal institutions would prepare national soil degradation maps and databases, utilizing the revised guidelines. In China, two institutions participated in the project: the Institute of Soil Science of the Academia Sinica in Nanjing (Prof. Dr Gong Zitong), dealing with the southern part of the country and the National Agro-Technical Extension Service Centre in Beijing (Mr. Sui Pengfei), providing information on the northern part.

ASSOD is more than just a revised and magnified GLASOD map for Asia. More emphasis was placed on trends of degradation (recent past rate) and on the impacts of degradation on productivity in relation to the level of management. Unlike GLASOD, moreover, the end

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10 based on the Assessment of the Status of human-induced SOil Degradation in South and Southeast Asia (ASSOD)
11 GLASOD
12 ASSOD
13 SCOTER

product of the project is not a single map, but a range of possible outputs generated by the database and GIS: various thematic maps, graphics, statistics, *etc.*

8.2. Methodology

8.2.1. Types of soil degradation

The type of soil degradation refers to the degradation process. *Only degradation as a result of human activities is considered!* Types of soil degradation are represented by a two- or three-letter code, the first capital letter giving the major degradation type, the second lowercase letter giving the subtype. A third *lowercase* letter is given in some cases for further specification. See Table 8.1.

8.2.2. Impact on productivity

As a rather simplified approximation for assessing the degradation impacts on productivity, five classes have been defined to indicate changes in productivity (ranging from 'negligible' to 'extreme', taking the level of management into consideration (see Table 8.2). The latter may include: introduction of fertilizers, biocides, improved varieties, mechanization, various soil conservation measures, and other important changes in the farming system.

The *impact* considers only the effect of the degradation process, not the intensity of the process itself. Consequently it is possible that for instance in an area with deep fertile soils, erosion is quite intense, but the impact is only light or even negligible. 'Negligible' is thus not necessarily synonymous with 'stable', which means no degradation!

8.2.3. Extent of soil degradation

The extent of degradation is defined as the area affected by a certain type of degradation expressed as a percentage of the entire polygon[14]. For each polygon on the map, one or more specific degradation types (and/or 'stable areas') are indicated.

Where two or more (sub)types of degradation belonging to the same main type (*e.g.* Wt and Wd) are indicated within the same map polygon, it has been a standard assumption for area calculations that (unless specifically stated otherwise) these overlap, whereas different main types (*e.g.* W and E) are normally considered to have no overlap. This is only a pragmatic assumption, by lack of detailed figures on overlap percentages, even though it may not always reflect reality. In all maps and area calculations that consider only main types, the subtype with the highest extent has been taken as reference. If this subtype has a light impact, it is possible that locally another subtype with higher impact occurs although it does not feature on the

14 A unique, physiographically delineated area on the map.

Table 8.1. Types of degradation.

Water erosion		
Wt	*Definition:*	loss of topsoil by sheet erosion/surface wash
Wd	*Definition:*	terrain deformation' by gully and/or rill erosion or mass movements
	Description:	an irregular displacement of soil material (by linear erosion or mass movements) causing clearly visible scars in the terrain
Wo	*Definition:*	off-site effects of water erosion in upstream areas
	Description:	three subtypes may be distinguished:
	- Wos:	sedimentation of reservoirs and waterways
	- Wof:	flooding
	- Wop:	pollution of water bodies with eroded sediments
Wind erosion		
Et	*Definition:*	loss of topsoil by wind action
	Description:	a decrease in depth of the topsoil layer (A horizon) due to more or less uniform removal of soil material by wind action
Ed	*Definition:*	terrain deformation'
	Description:	an irregular displacement of soil material by wind action, causing deflation hollows, hummocks and dunes
Eo	*Definition:*	off site effects of wind erosion
	Description:	covering of the terrain with wind borne sand particles from distant sources ('overblowing')
Chemical deterioration		
Cn	*Definition:*	fertility decline and reduced organic matter content
	Description:	a net decrease of available nutrients and organic matter in the soil
Cs	*Definition:*	salinization/alkalinization
	Description:	a net increase of the salt content of the (top)soil. Two subtypes may be distinguished:
	- Csi:	inland salinization
	- Css:	intrusion of seawater (which may occur under all climate conditions)
Cp	*Definition:*	pollution
	Description:	two types are distinguished:
	- Cpl :	local source pollution (waste dumps, spills, factory sites, etc.
	- Cpa:	diffuse or airborne pollution (atmospheric deposition of acidifying compounds and/or heavy metals are considered under this category).
Ct	*Definition:*	dystrification
	Description:	the lowering of soil pH through the process of mobilizing or increasing acidic compounds in the
Ce	*Definition:*	eutrophication
	Description:	An excess of certain soil nutrients, impairing plant growth
Physical deterioration		
Pa	*Definition:*	aridification
	Description:	decrease of soil moisture
Pc	*Definition:*	compaction
	Description:	deterioration of soil structure by trampling or the weight and/or frequent use of machinery
Pk	*Definition:*	sealing and crusting
	Description:	clogging of pores with fine soil material and development of a thin impervious layer at the soil surface obstructing the infiltration of rainwater
Ps	*Definition:*	lowering of the soil surface
	Description:	subsidence of organic soils, settling of soil
Pu	*Definition:*	urban/industrial land conversion
	Description:	soil (land) being taken out of production for non-bio-productive activities, but not the possible 'secondary' degrading effects of these activities.
Pw	*Definition:*	waterlogging
	Description:	effects of human induced hydromorphism
Land without human-induced degradation		
Sn	Stable under natural conditions; *i.e.* (near) absence of human influence on soil stability, and largely undisturbed vegetation. NB: some of these areas may nevertheless be vulnerable to even small changes in conditions which may disturb the natural equilibrium.	
Sh	Stable under human influence; this influence may be passive, *i.e.* no special measures had or have to be taken to maintain stability, or active: measures have been taken to prevent or reverse degradation.	
W	'Wasteland': land without appreciable vegetation and with (near) absence of human influence on soil stability, *e.g.* deserts, high mountain zones. Natural soil degradation processes may occur!	

Table 8.2. Impact of degradation: Management level and productivity changes

Level of production	Level of management		
increase/decrease	*A) High*	*B) Medium*	*C) Low*
1) Large increase	Negligible	Negligible	Negligible
2) Small increase	Light	Negligible	Negligible
3) No increase	Moderate	Light	Negligible
4) Small decrease	Strong	Moderate	Light
5) Large decrease	Extreme	Strong	Moderate
6) Unproductive	Extreme	Extreme	Strong to Extreme

map. Figures on the overall occurrence of the main degradation types thus reflect the maximum extent - but not per se the maximum impact - of *one or more* subtypes.

8.2.4. Rate of degradation

The recent past rate of degradation indicates the rapidity of degradation over the past 5 to 10 years, or in other words, the *trend* of degradation. A severely degraded area may be quite stable at present (*i.e.* low rate, hence no trend towards further degradation) whereas some areas that are now only slightly degraded, may show a high rate, hence a trend towards rapid further deterioration.

8.3. Results of the assessment: China

In the following some of the results of this assessment will be discussed with specific reference to China. Figs 8.1 and 8.2 show the relative distribution of the degradation main types and their dominant causes, respectively.

Water erosion

Water erosion in China, like in most of the South and Southeast Asia, is the dominant type of human-induced soil degradation (163 Mha, see Fig. 8.1), mostly in the form of sheet erosion (Wt: 81% of all water erosion), see Fig. 8.3. Although water erosion is a quite extensive phenomenon in China, its impact on productivity is generally modest: about 3/4 of the occurring water erosion has a negligible to light impact on productivity (Map 8.1, Fig. 8.1). Even off-site effects (Wo) were considered to be rather unimportant, but this appears to deserve some further study. There is, however, a trend towards further deterioration for about 86% of all occurring water erosion, while in almost 20% of the cases slight improvements were noted. Somewhat surprisingly, the major causative factor contributing to water erosion was indicated to be deforestation, almost twice as much as agriculture (Fig. 8.2). However, deforestation is often succeeded by agricultural activities and the two cannot always be separated very clearly.

Most water erosion (47%) occurs under high management level, with another 38% under medium and 15% under low management level (Fig. 8.4).

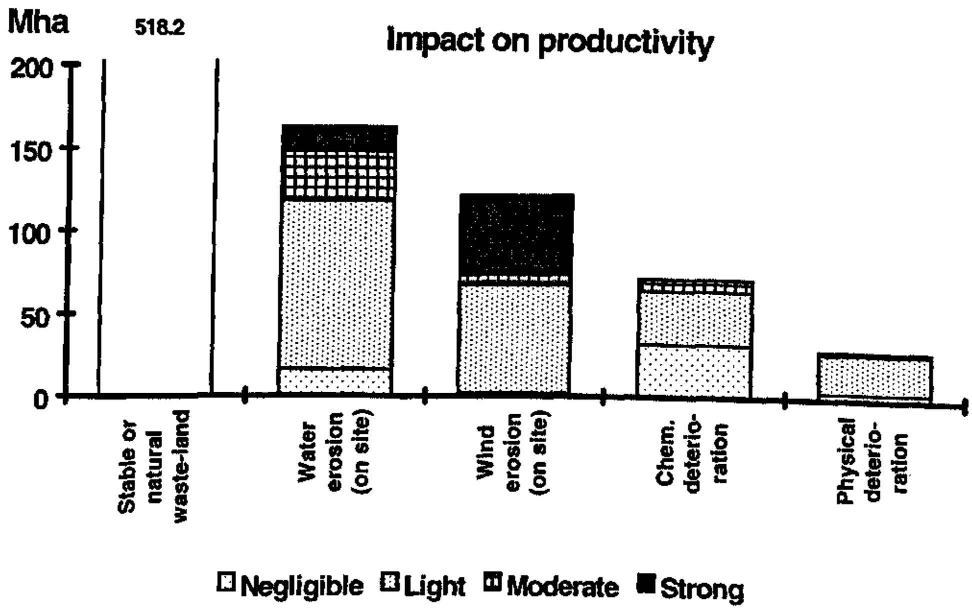


Figure 8.1. Main degradation types in China.

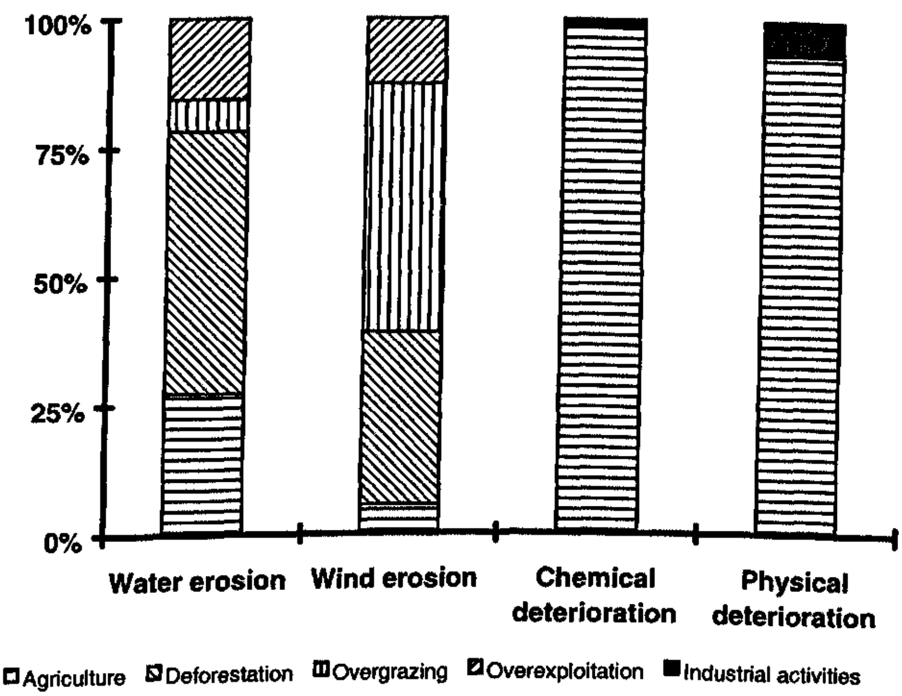


Figure 8.2. Dominant causes of main degradation types in China.

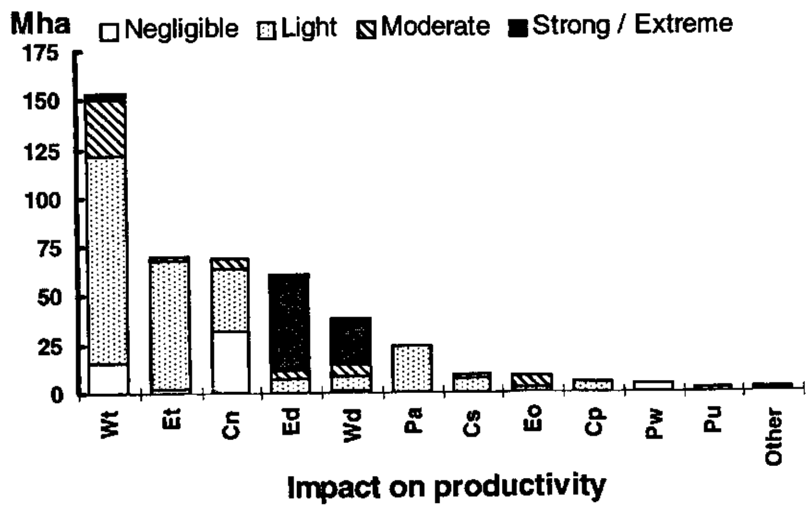


Figure 8.3. Subtypes of soil degradation in China.

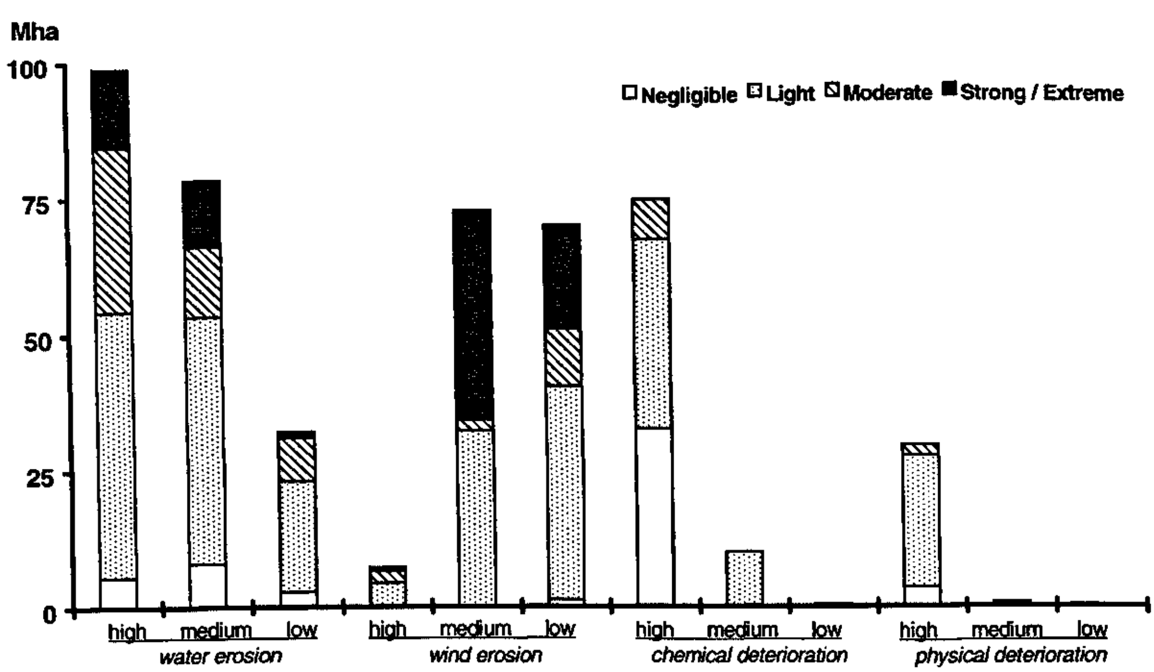
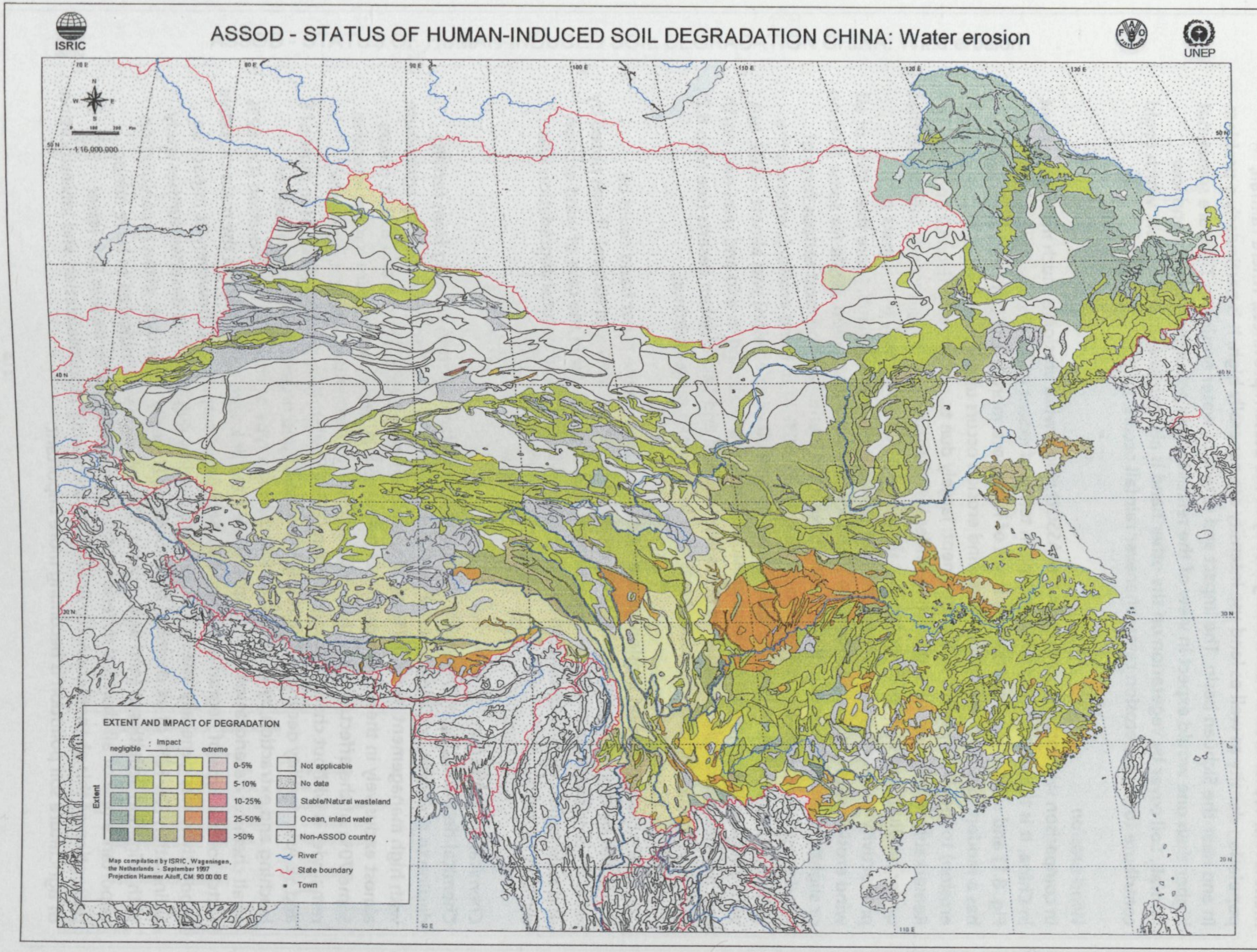


Figure 8.4. Impact of degradation for different management levels.



Map 8.1. Status of human-induced soil degradation China: water erosion.

There is no marked difference in the impact on productivity between the different management levels. Water erosion is occurring mainly in the eastern provinces, where rainfall, population density as well as land use intensity are generally high. It is particularly a problem in and near the Sichuan basin. The impact and extent of water erosion in Tibet are somewhat higher than one would expect in view of the relatively low population density and low rainfall. Soil cover by vegetation on the other hand is also minimal in this region, which could contribute to higher erosion rates whenever rainfall occurs.

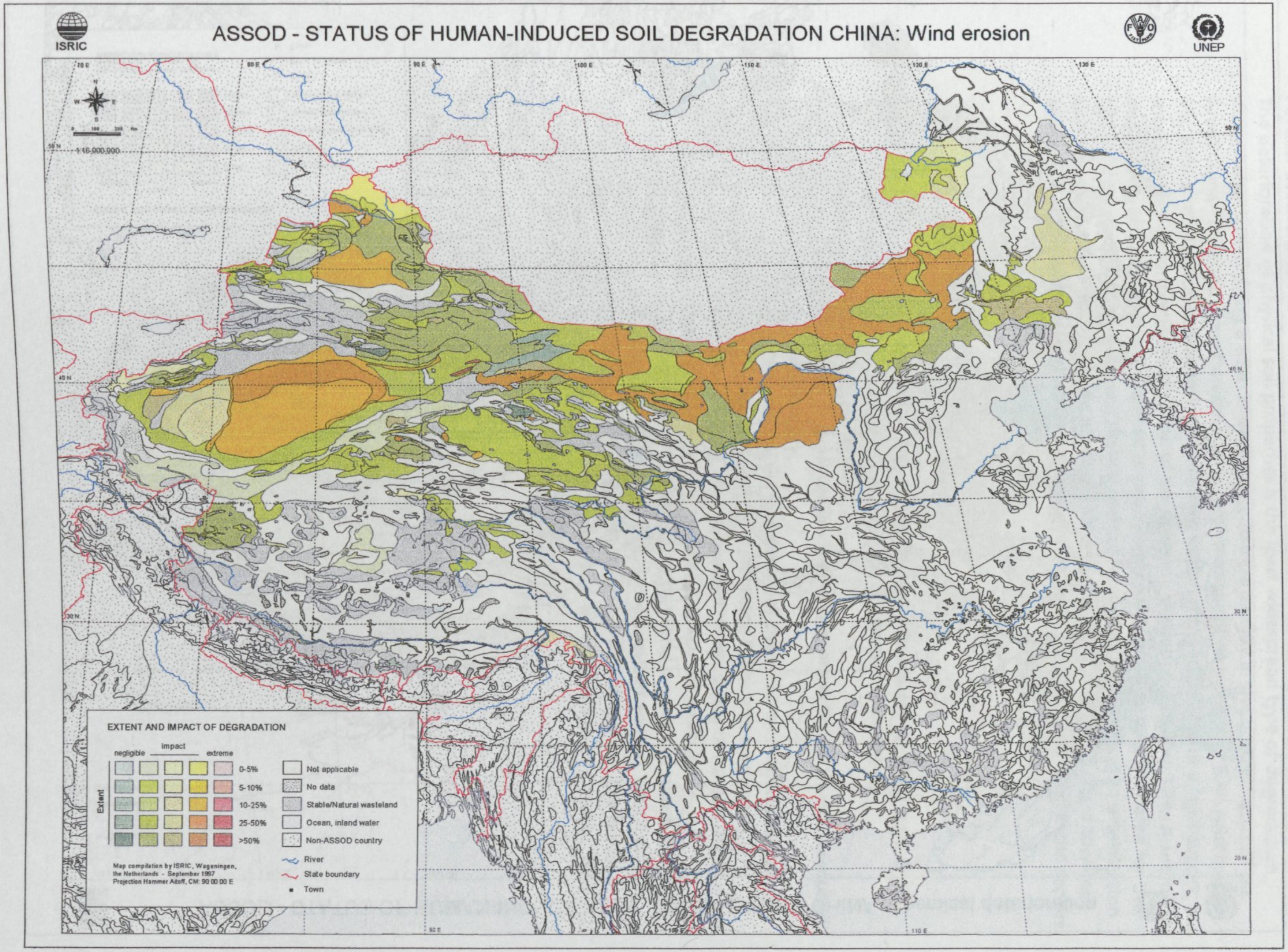
Wind erosion

In comparison with other countries in the ASSOD study, wind erosion is much more important in China. It is the second degradation type in terms of extent (122 Mha; see Map 8.2 and Fig. 8.1) and even more important in terms of its impact: more than 50% of all wind erosion has a moderate or strong impact. Most wind erosion occurs under medium (48,5% of all wind erosion) to low (47%) levels of management: largely due to overgrazing (Fig. 8.2 and 8.4). Remarkably, the impact of degradation under low management is significantly inferior to that under medium and high management. It should be noted, however, that impact on productivity on grazing land is more difficult to assess than on cropland. More than 85% of all wind erosion shows a slight to medium tendency towards aggravation, while for some 10% no or slightly positive changes in degradation have been identified. The most serious form of wind erosion was perceived to be 'loss of topsoil' (Et: 50% of all wind erosion), whereas the extent of 'terrain deformation' (Ed, deflation: 43% of all wind erosion) was almost equal, but with a higher impact (Fig. 8.3). Wind erosion is obviously occurring in arid and semi-arid north and northeastern regions, including areas like the Gobi and Takla Makan deserts (see Map 8.2), although human influence in those areas may be assumed rather minimal.

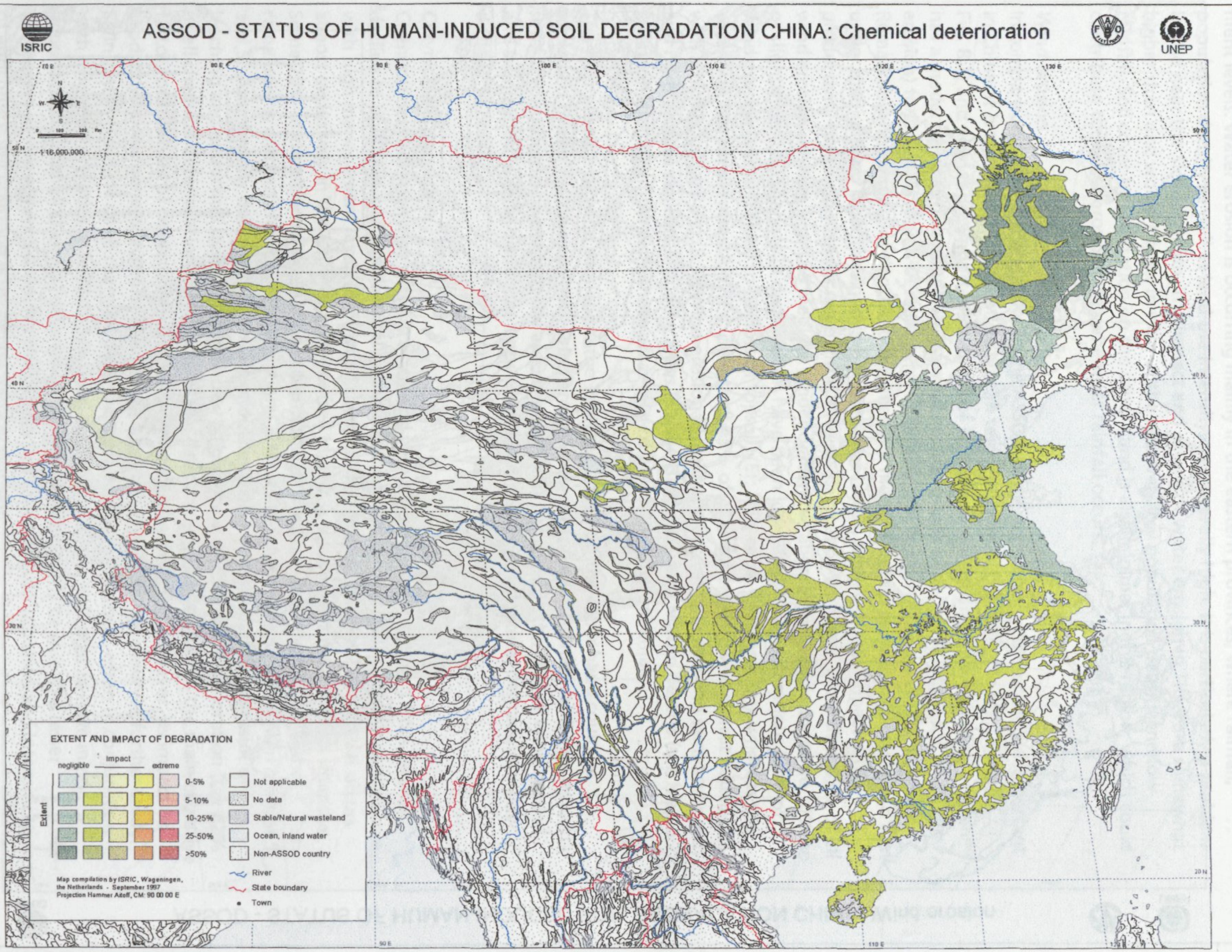
The near absence of wind erosion on the Tibetan plateau on the other hand could be explained by this factor, since most wind erosion here is probably also natural. It was noted by several contributors involved in the assessment that in particular in the case of wind erosion and salinization, a clear distinction between human-induced and natural degradation was difficult to make.

Chemical deterioration

Chemical deterioration may occur in many and very different forms, ranging from fertility decline to pollution. In China its total extent is just over 70 Mha, largely caused by agriculture with high management levels (87% of all chemical deterioration, Fig. 8.2 and 8.4). It occurs almost exclusively in the eastern provinces (see Map 8.3), where agriculture is most intensive. Some 70% of the affected areas show a trend towards further degradation, while the remainder is without change in degradation (25%) or slightly improving (5%). As in most of S and SE Asia, fertility decline through loss of nutrients and organic matter as a result of leaching and extraction by crops is the most common type of chemical deterioration (Cn: 82% of all chemical deterioration). This explains the clear link with agriculture as the main causative factor for this type of degradation (Fig. 8.2). Somewhat surprisingly, however, its impact on productivity was generally assessed as being rather low (Fig. 8.3). This deserves further study. Salinization (Cs: 12% of all chemical deterioration) is locally important, often in conjunction with irrigation activities in semi-arid regions. Soil pollution was indicated to have minor importance (6% of all chemical deterioration), but this may partly be due to a lesser perception of this phenomenon. No doubt with increasing industrialization and intensification of agriculture soil pollution is becoming more important.



Map 8.2. Status of human-induced soil degradation China: wind erosion.



Map 8.3. Status of human-induced soil degradation China: chemical deterioration.

Physical deterioration

The deterioration of physical soil properties is the least widespread type of degradation, nevertheless still covering a total area of about 30 Mha (mainly in the northern part of the Great China Plain) and almost entirely under high management levels (Fig. 8.4). Aridification (Pa, 80% of all physical deterioration) is the most important, generally with a light impact, but showing signs of further intensification of the problem. Water logging (Pw, 13%) is second in importance, but its impact was assessed as negligible. Moreover, the trend indicated for this type of degradation was nil or even slightly positive. Loss of productive land to urbanization and industrialization (Pu) occurs on another 2 Mha but with a rather strong trend towards worsening of the degradation, which is obviously related to the rapid growth in those sectors.

8.4. References

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