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Predicting China’s cultivated land resources and supporting capacity in the twenty-first century

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Key words: China, land use, cultivated land, supporting capacity, food security

SUMMARY

In recent years, China’s cultivated land has been shrinking, a change which has become one of the potential challenges to national sustainable development and global food security. In our research, we have predicted China’s cultivated land resources for the next 50 years, based on scrutiny of systematic data and analyses of the loss of cultivated land. We have also designed an indicator of cultivated land equivalent per capita (CLEPC) to assess the capacity of cultivated land to support our population. The results show that China’s cultivated land will decline to a minimum of 113.31 million ha between 2001–2010, while cultivated land per capita will decline from 0.101 ha to 0.083 ha. After 2010, the area of cultivated land will begin to increase slowly to 118.98 million ha in 2050. However, cultivated land per capita will still decline to 0.079 ha between 2010–2030; after 2030, it will start to increase and reach 0.085 ha in 2050. In contrast to the total area and per capita area of cultivated land, the CLEPC will remain at 0.101 ha between 2001–2010, and then increase to 0.156 ha in 2050. Overall, there will be increasing stress on China’s cultivated land during the next two or three decades. Although the supporting capacity of cultivated land may not decline obviously with improvement in agricultural technology and infrastructure, China has to make great efforts to reduce the loss of cultivated land and to improve its productivity to ensure food security in the near future.

INTRODUCTION

China maintains 22% of the global population (ca.1.3 billion) on only 7% of the global cultivated land. Changes of cultivated land in China have a significant effect on China’s sustainable development, as well as its global food security. In recent years, China’s demand for grain has increased due to a rapidly developing economy and associated population growth, while the area and quality of cultivated land have declined constantly as a

consequence of urbanization, industrialization, eco-environmental degradation and population growth. As a result, these issues of China’s cultivated land and food security have attracted the attention of many scholars (Brown 1995; Brown and Halwell 1998; Smil 1995; Heilig 1999; Chen 2001; Liu and Lu 2001; Wu and Li 2002). There are different views on China’s prospects in terms of cultivated land resources and food security. Brown, whose

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representative pessimistic view has aroused world-wide discussion, predicted that, by 2030, there would be a great gap between food demand and supply in China that would shake the global food market (Brown 1995; Brown and Halwell 1998). Smil (1999) and Heilig (1999) maintained the optimistic view that China's potential annual grain productivity would reach 650 million tons, which would generally meet increasing grain demand in the future. There have also been many relevant investigations in China (Liu and Lu 2001; Chen 2001; Wu and Li 2002). Chen (2001) indicated that China's predicted food demand could not be met by depending only on the grain productivity of cultivated land. However, if the productivity of other agricultural resources (e.g. grasslands, ponds, woodlands) was taken into account, the grain productivity would reach 830 million tons in 2030 and 940 million tons in 2050 and these would be sufficient for China's food demand.

One of the important reasons for the discrepancies between such research results is that they depend on different understandings of the status and development trend of China's cultivated land. Compared with the present situation and changes of cultivated land in China, the predictions are obviously inaccurate because of a lack of reliable and consistent data on land use before 1996 and anticipation of new trends of land-use change in recent years. For example, data reported by China's State Statistical Bureau (CSSB) before 1996 and cited by Brown, have been shown to be 30% less than the actual area of cultivated land. Chen greatly underestimated the cultivated land loss caused by the 'Grain for Green' project (a project for restoring cultivated land to forest and grassland), and did not take the impacts of agricultural structure adjustment into account, although this is one of the main reasons for China's cultivated land change.

Land-use change is a comprehensive process affected and driven by socioeconomic and natural factors. The period from 2001–2050 is a crucial phase for the Chinese government to implement the 'three-step development strategy' for national economic development, with the goal of reaching the standard of moderately developed countries. Meanwhile, China will reach and pass a population peak of 1.4–1.5 billion. Both growing demand for grain yield and more serious impacts on cultivated land resources are being caused by increases in the economy, living standard improvements and

population growth. Thus, the changes and sustainable utilization of cultivated land have become important issues in the study of China's sustainable development and food security. However, systemic research and prediction on issues of cultivated land are still lacking, although they are essential in the comprehensive analyses of driving factors, changing trends in China's land use, combined with the development of China's economy, society, population and policy. The objectives of this study are: (1) to review historic changes of China's cultivated land, especially changes since 1996, and to analyze the driving forces; (2) to predict the situation of China's cultivated land between 2001–2050, integrated with the goals of China's national economic development strategy and scenario on society, economy, population and policy in the future; and (3) to analyze and assess the supporting capability of China's cultivated land resources.

METHODS

Sources of data

Until recently, relevant research work has been hampered by difficulties caused by inconsistency and contradictions of land-use data from different sources. For example, the area of cultivated land was stated as 94.97 million ha by CSSB (1996), 125.23 million ha by the China State Land Administration Bureau (CSLAB 1996), 124.15 million ha by the Food and Agricultural Organization of the United Nations (FAO 1996), and 138.67 million ha by the Chinese Academy of Sciences (Shi 1991). In 1996, this confusion was resolved by the accomplishment of the 1996 land survey, the first nationwide land survey adopting standardized land classification and scientific investigation methods. Since 1996, CSSB also adopted this dataset and reported new data in 2001 (CSSB 1996–2003).

In this study, the detailed data from the 1996 land survey and data after 1996 from the annual land-use change survey conducted by CSLAB were used to analyze the current change trend of cultivated land and the sources of cultivated land loss, and these formed the basis of prediction. The data from 1949–1995 are from CSSB, and were used to analyze the historic trend of China's cultivated land.

In addition to the data sources derived from FAO, the classification of land-use patterns is also

different. In China, cultivated land is defined as land which includes: (1) land ploughed constantly for growing crops and under cultivation; (2) land newly cultivated in the current year; (3) farmland left without cultivation for less than 3 years and fallow in the current year; (4) rotation land; (5) rotation land of grass and crops; and (6) farmland with some fruit trees, mulberry and other trees, and cultivated seashore land, lake land, etc. Ditches, roads and ridges between cultivated fields that are less than 1 m wide in the south or less than 2 m wide in the north are included in cultivated land, while the land for mulberry fields, tea plantations, orchards, nurseries of young plants, forest land, reed land, natural and man-made grassland and other land are not included. The area of cultivated land is determined independently of the times of cropping per annum (CSSB 2001).

Analyses of status and change of cultivated land

Utilizing data gathered in the 1996 survey, we analyzed the present situation and spatial distribution characteristics of China's cultivated land and the relationships with population, economy and local natural conditions. Based on data from the annual land-use change survey, we especially analyzed changes in cultivated land and sources of cultivated land loss between 1986–2003. Furthermore, we discuss the driving forces of cultivated land change.

Prediction of China's cultivated land resources, 2001–2050

Prediction of China's population, economy and society in the twenty-first century

Predictions of relevant socioeconomic factors were achieved in our previous research (Table 1) (Zhao,

Research on theory frame and development models of China's sustainable development, 2003), and were used as the foundation and background for prediction of cultivated land change.

Prediction of total area and per capita area of cultivated land

The analyses show that cultivated land loss includes the 'Grain for Green' project, construction land expansion, agricultural structure adjustment and natural hazards, while cultivated land supply lies in reclamation, land consolidation and abandoned land re-cultivation. Thus, total area of cultivated land in year_{yr} can be calculated by the following formula:

Area_CL_{yr} = Area_CL_{yr0} + R_(yr0, yr) + LC_(yr0, yr) + ALR_(yr0, yr) - GFG_(yr0, yr) - C_(yr0, yr) - ASA_(yr0, yr) - NH_(yr0, yr) (1)

where Area_CL_{yr} is the total area of cultivated land in year_{yr}, Area_CL_{yr0} the total area of cultivated land in year_{yr0}, Subscript (yr0, yr) the period from year_{yr0} to year_{yr}, R the increased area from reclamation, LC the increased area from land consolidation, ALR the increased area from abandoned land re-cultivation, GFG the lost area for 'Grain for Green', C the lost area for construction, ASA the lost area for agricultural structure adjustment, and NH is the lost area of natural hazards. We analyzed the status and potential of each of these factors, and then predicted their trends using trend analysis and scenario analysis.

Cultivated land per capita is calculated using

Area_CL_PerCapita_{yr} = Area_CL_{yr} / Popu_{yr} (2)

where Area_CL_PerCapita_{yr} is the cultivated land per capita in year_{yr}, and Popu_{yr} is the population in year_{yr}.

Table 1 Prediction of China's population, economy and society during 2000–2050

Year		2000	2010	2020	2030	2040	2050
Population	Total (million)	1,282.05	1,369.88	1,440.87	1,460.57	1,449.23	1,400.23
	Urban population (million)	459.06	630.15	792.48	905.55	999.97	1,050.17
	Rural population (million)	808.37	739.74	648.39	555.02	449.26	350.06
Society	Urbanization level (%)	36.22	46.00	55.00	62.00	69.00	75.00
Economy	GDP(US\$ billion, 2000 price)	1,080.0	1,934.1	3,463.7	5,127.1	7,589.4	11,234.2
	GDP per capita (US\$, 2000 price)	842	1,412	2,404	3,510	5,237	8,024

Expansion of construction land mainly has five aspects: city and town, rural settlement, stand-alone industrial and mining site, transportation facility, and other. For calculating the total cultivated land loss caused by construction, we first calculated the increased area of city and town, rural settlements and transportation facilities; then estimated the total expansion of construction land area according to the relationship between the sum of increased area of those three aspects (city and town, rural settlements and transportation facilities) to total increased construction land area; third, we calculated the cultivated land loss for construction ($C_{(yr0, yr)}$) from the proportion of cultivated land occupied by construction to the total increase in area of construction land.

Increased area of city and town, rural settlement and transportation facility is calculated using:

$$\begin{aligned} Area_HC_{(yr0, yr)} &= (Popu_{yr} - Popu_{yr0}) \times \\ &Area_H_PC_{(yr0, yr)} + Popu_{yr} \times \\ &Area_C_PC_{yr} - Popu_{yr0} \times Area_C_PC_{yr0} \end{aligned} \quad (3)$$

where $\Delta Area_HC_{(yr0, yr)}$ is the increased area of city and town, rural settlements and transportation facilities during year $yr0 - year_{yr}$, $Popu_{yr}$ the population of year yr , $Popu_{yr0}$ the population of year $yr0$, $Area_H_PC_{(yr0, yr)}$ the construction land area per capita of city and town and rural settlement during year $yr0 - year_{yr}$ (predicted by weighted averaging construction land area per capita of city and town and rural settlement, weights are respective proportions of urban population and rural population to total population.), $Area_C_PC_{yr}$ the construction land per capita of transportation facilities in year yr , and $Area_C_PC_{yr0}$ is the construction land per capita of transportation facilities in year $yr0$.

The cultivated land loss for construction ($C_{(yr0, yr)}$) is calculated using:

$$C_{(yr0, yr)} = \frac{Area_HC_{(yr0, yr)}}{Prop_{(HC, CTotal, yr0 - yr)}} \times Prop_{(CL, CTotal, yr0 - yr)} \quad (4)$$

where $Prop_{(HC, CTotal, yr0 - yr)}$ is the proportion of the increased area of city and town, rural settlement and transportation facility to total increased area of construction land, and $Prop_{(CL, CTotal, yr0 - yr)}$ is the proportion of cultivated land occupied by construction to total increase in area of construction land.

Analyses of cultivated land equivalent per capita (CLEPC)

The supporting capacity of cultivated land to population and society relates not only to quantity of cultivated land but also to productivity per unit of cultivated land. In order to estimate the change in supporting capacity of cultivated land, we designed the indicator CLEPC. CLEPC refers to the relative area of cultivated land per capita at a future level of technology and agricultural production conditions, which equals the area of cultivated land with the same productivity at base time. The formula is:

$$\begin{aligned} Area_CL_Equi_PerCapita_{(yr, yr0)} &= \\ Area_CL_PerCapita_{yr} \times \frac{Yield_{yr}}{Yield_{yr0}} \times \frac{MCI_{yr}}{MCI_{yr0}} \end{aligned} \quad (5)$$

where $Area_CL_Equi_PerCapita_{(yr, yr0)}$ is CLEPC of year yr contrasted to year $yr0$, $Yield_{yr}$ grain productivity per ha of year yr , $Yield_{yr0}$ grain productivity per ha of year $yr0$, MCI_{yr} the multiple cropping index (MCI) of year yr , and MCI_{yr0} is the MCI of year $yr0$.

Adopting the factors of yield per ha of cultivated land and MCI, the changes in CLEPC can directly reflect the changes in grain productivity per capita in the future, caused not only by a change of cultivated land per capita, but also by agricultural technological advancement, and infrastructure improvement. Thus, we can use CLEPC to describe changes in the supporting capacity of cultivated land.

RESULTS

Land-use change trend for China's cultivated land

The 1996 land survey (Table 2) (Liu 2000; Lin and Hob 2003) shows that the total area of China's cultivated land is 130.039 million ha, and per capita is 0.106 ha, only 40% of the world average. China's cultivated land does not spatially match the water sources. Only 40% of China's cultivated land is irrigable; 79% of total cultivated land is medium or low-yield land. The average yield per ha is only 3200 kg (from the adjustment of statistical data according to the 1996 survey). China's high-intensity land use is dominated by agricultural land, which is 66.7% of China's total territory, including cultivated land, mulberry fields, tea plantations,

Table 2 China's land-use pattern, 1996, by region (unit: 1,000 ha)

	China		East China (1)		Central China (2)		West China (3)	
	Area	% Total	Area	% Total	Area	% Total	Area	% Total
Total area	950676.2	100.00	131890.1	100.00	281590.2	100.00	537196.0	100.00
Agricultural land	633736.5	66.66	93419.2	70.83	222432.3	78.99	317885.0	59.17
Cultivated land	130039.2	13.68	36955.9	28.02	56118.9	19.93	36964.5	6.88
Other agricultural land	503697.3	52.98	56463.3	42.81	166313.4	59.06	280920.5	52.29
"yuan di" (4)	10023.8	1.05	5514.5	4.18	2221.5	0.79	2287.8	0.43
Forest	227608.7	23.94	48868.5	37.05	91557.4	32.51	87182.8	16.23
Pasture	266064.8	27.99	2080.3	1.58	72534.5	25.76	191449.9	35.64
Settlement and industry/ mining site	24075.3	2.53	9164.8	6.95	9448.2	3.36	5462.3	1.02
Land used for transportation	5467.7	0.58	1837.1	1.39	2305.9	0.82	1324.7	0.25
Water area	42308.8	4.45	11775.5	8.93	13908.3	4.94	16625.1	3.09
Unused land	245087.9	25.78	15693.5	11.90	33495.5	11.90	195898.9	36.47

The data do not include Taiwan (36000 km²), Hong Kong (1098 km²) and Macao (23.8 km²); 1 Liaoning, Beijing, Tianjing, Hebei, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Hainan, and Guangxi; 2 Heilongjiang, Jilin, Nei Mongol, Shanxi, Henan, Anhui, Jiangxi, Hubei, and Hunan; 3 Sichuan (including Chongqing), Guizhou, Yunnan, Qinghai, Tibet, Shaanxi, Ningxia, Gansu, Xinjiang; 4 Including orchards, vineyards and plantation

orchards, nurseries of young plants, forest land, reed land, natural and man-made grassland and other land. Only 25.78% of the total territory is unused land, mainly consisting of uncovered stony regions (42%), sand (20%) and sparse grassland (20%). 79.9% of unused land is located on steep slopes with a thin layer of soil and in arid land in West China with threats of soil erosion, salination and desertification if reclaimed. The result of an ecological suitability evaluation indicated that only 6.61 million ha (0.7% of total territory) can be reclaimed (Chen 2001). It is almost impossible for China to expiate cultivated land loss by depending only on reclamation.

Land-use pattern and its change depend primarily on population density, level of economic development, urbanization, changes in diet and institutions (Heilig 1999; Verburg *et al.* 2000; Lin and Hob 2003). Historic change and spatial structure of land use in China have also proved crucial to land-use patterns. Comparing the 1996 survey with 1949 land-use data collected from CAS, Ministry of Agriculture, State Forestry Administration and CSSB (Lin and Hob 2003), we found that the obvious characteristics of land use change between 1949–1996 were a great expansion of construction land, *yuan di* and cultivated land with an equally great decline in pasture and unused land. The process of cultivated land expansion mainly occurred before the 1980s, while the first task of the Chinese government was to provide

adequate food and clothing; thus, with the policy of 'grain production as agriculture core' (*yi liang wei gang*), Chinese people reclaimed unused land, grassland and woodland on a large scale and finally increased cultivated land to 70.80 million ha. Although massive reclamation increased total grain yield, China had paid a great eco-environmental cost for it. Pasture declined by 125.85 million ha and the proportion dropped from 41.2% to 28.0% of the total land.

Since the 1980s, the main goal of the Chinese government has changed to developing the industrial economy. Industrialization, urbanization, population growth and adjustment of food consumption structure have become the main driving forces of land-use change. The characteristics of land-use change varied, with construction land and *yuan di* expanded dramatically, while cultivated land started to shrink. From 1949 to 1996, the area of *yuan di* has been increased nearly 8.5-fold, industrial and mining sites four-fold, and transportation land 1.7-fold. Construction land, *yuan di* and natural hazards have caused huge cultivated land loss (38.647 million ha). In the spatial structure of the land-use pattern, a high intensity of land use in East and South China is the consequence of the high population density (2.5 times that of Central China and eight times that of West China) and rapid economic development (80% higher than that of Central China and 130% than that of West China in terms of GDP per capita). This situation has

obviously led to a decline in cultivated land in these regions, mainly in Shandong, Liaoning, Jiangsu, Beijing, Tianjing, Shanghai and Fujian. In contrast, with inferior natural conditions, lower population density and economic development, West China is the main area for marginal land exploitation to make up for cultivated land loss in East China. These reclamations are mainly located in Heilongjiang, Inner Mongolia, Yunnan, Guizhou, Guangxi and Xinjiang (Wang *et al.* 2002; Tian *et al.* 2003; Liu *et al.* 2003). Measured by grain productivity, 1.56–1.59 ha of cultivated land in West China can only compensate for 1 ha of cultivated land loss in East China (Yang and Li 2000; Lin and Hob 2003).

Because of the increasing population, cultivated land per capita has decreased in most provinces since 1949, except for Tibet, Yunnan and Guizhou.

The largest decrease in cultivated land per capita has occurred in the Shandong peninsula, the North China plain, the southeastern coastal area and Qinghai, causes of which in the first three regions are growth of population and economic development, while in the last region it is soil erosion (Lin and Hob 2003).

Recent land-use change surveys indicate that cultivated land has declined at an alarming rate from 130.092 million ha to 123.392 million ha between 1996–2003 and, per capita, was only 0.095 ha in 2003 (Figure1) (CSLAB 2000~2003).

Where has the cultivated land gone? From Figure 2, we show that there are different sources at different stages. During the period 1986–1995, 6.79 million ha of cultivated land were lost due to agricultural structural adjustment, construction and natural hazards. 62% of the total losses were

Figure 1 Total cultivated land and per capita, 1996–2003

Figure 2 Sources of cultivated land loss, 1986–2003

taken for agricultural structural adjustment, annually 420.86×10^3 ha. A further breakdown of the category of agricultural restructuring revealed that 39% was converted into *yuan di*, 33% into forest and woodland, 20% into pasture, and 8% into fishponds. 21% of the total removed cultivated land went into construction projects, annually 142.68×10^3 ha. The remaining 17% was lost to natural hazards and environmental degradation, annually 115.42×10^3 ha. After 1996, at the launch of the 'Grain for Green' project, cultivated land restored to pasture became the single main source of cultivated land loss. The total amount of removed cultivated land during 1997–2003 was 9.071 million ha, and the net loss was 6.647 million ha (5.1% of total cultivated land), annually 950×10^3 ha, balanced out the increasing amount resulting from land exploitation, consolidation and reclamation. In total, 5.74 million ha of cultivated land were taken by the 'Grain for Green' project, which is 63.35% of the total cultivated land loss; 1.459 million ha (16.08% of the total loss, 43.8% of the total loss excluding the loss for 'Grain for Green') by agricultural restructuring, annually 0.208 million ha, whose scale is slightly reduced compared with that in 1986–1995; 1.326 million ha (14.62% of total loss, 39.8% of total loss excluding the loss for 'Grain for Green') by construction, annually 0.189 million ha, whose scale and percentage of total cultivated land loss are obviously higher than that during 1986–1995; 0.546 million ha (6.02% of total loss) to natural hazards, with slightly declining trend.

At present, the driving forces behind 'Grain for Green', construction land expansion, agricultural restructuring and natural hazards are mainly population, economy, society, eco-environment and policy of China (Zhang 2000; Li *et al.* 2001; Lin and Hob 2003). The 'Grain for Green' project is intended to compensate for ecological loss by the former massive reclamation, when China has met her basic food demand and improved her economic power, and its driving forces are national policy and stress on the ecological environment. After several years of experiments in some provinces, the pace of 'Grain for Green' has been rapid since 2000. In the future, the progress of 'Grain for Green' will depend mainly on national plans, investment and expected ecological benefits.

The driving forces behind construction land expansion are primarily population growth,

industrialization and urbanization. Nowadays, China is one of the countries with the fastest economic growth in the world and, in the next several decades, China will continue to make great efforts to develop the industrial economy. Additionally, China will reach and pass a population peak of 1.4–1.5 billion. Thus, population growth, industrialization and urbanization will continue to have significant effects on cultivated land change.

Agricultural restructuring is mainly driven by the reform of China's economic system towards a market system and the change of people's food structure. With further innovation in the rural management system and building-up a social market economic system, some cultivated land has been transferred to orchards, plantations, nurseries, ponds, pasture, etc. in pursuit of increased benefits. In addition, the Chinese people's food structure is becoming more prosperous. The demand for eggs, milk, vegetables, marine products and fruit is increasing while the amount of grain consumed directly is decreasing. These changes in diet also lead to constant agricultural structural adjustment. However, the people's diet will become more stable when the people's living standards reach and exceed a relatively rich level, and economic reform will be accomplished ultimately in the next decades. Thus, the effect of agricultural restructuring on cultivated land change will diminish.

Natural hazards are another important source of cultivated land loss. Increasing human disturbance of nature has made natural hazards more frequent and wide. In order to moderate the spread and intensity of natural hazards, China has made great efforts to implement many grand ecological projects (e.g. a natural forest preservation project, a desertification combating project, the 'Grain for Green' project). Although the process of improving the ecological situation is difficult, the cultivated land loss from natural hazards is expected to decrease gradually in the future.

The trend in cultivated land decrease has aroused Chinese government attention to cultivated land protection. Many actions have been taken to make up for cultivated land loss, including land reclamation, abandoned land recultivation and land consolidation. During 2000–2003, the total supplement to cultivated land was 1.07 million ha, 15% of the total cultivated land loss occurring simultaneously (Table 3) (CSLAB 2000–2003). In future, the Chinese government will place more

Table 3 Sources of cultivated land during 2000–2003

Year	Reclamation		Recultivation		Consolidation		Sum (10 ⁴ ha)
	Area (10 ⁴ ha)	% Total	Area (10 ⁴ ha)	% Total	Area (10 ⁴ ha)	% Total	
2000	18.40	63.2	6.60	22.7	4.20	14.4	29.10
2001	13.45	66.4	2.45	12.1	4.36	21.5	20.26
2002	17.33	66.5	3.51	13.5	5.25	20.1	26.08
2003	21.39	68.8	3.25	10.5	6.44	20.7	31.08

Table 4 Prediction of China's cultivated land, 2001–2050 (unit: million ha)

Year		2001–2010	2011–2020	2021–2030	2031–2040	2041–2050
Supplementary sources	Reclamation	2.026	1.877	1.137	0.557	0.267
	Consolidation	1.784	1.233	1.143	1.053	1.328
	Abandoned land recultivation	44.7	79.2	103.7	112.7	107.2
	‘Grain for Green’	–14.667	–	–	–	–
Sources of loss	Construction land	–2.023	–1.635	–0.948	–0.890	–0.741
	Agricultural structural adjustment	–1.839	–0.904	–	–	–
	Natural hazards	–0.648	–0.523	–0.460	–0.432	–0.423
Change of cultivated land		–14.920	0.840	1.909	1.415	1.503
Total cultivated land		113.313	114.153	116.062	117.477	118.980
Per capita (ha)		0.083	0.079	0.079	0.081	0.085

emphasis on abandoned land recultivation and land consolidation, and support controlled reclamation of scarce land.

China's cultivated land in the next 50 years

Based on analyses of sources and driving forces of cultivated land change and prediction of China's population, economy and society, we have predicted changes in China's cultivated land during 2001–2050 (Table 4). Table 4 shows that the first decade of the twenty-first century is the period with the most rapid rate of cultivated land loss. Cultivated land will decline dramatically from 128.233 million ha to 113.313 million ha, most of which will come from the ‘Grain for Green’ project. The cultivated land loss of 14.667 million ha from ‘Grain for Green’ is consistent with the national plan for the project, which will be continued until 2010 at its current pace of implementation. In addition, a large amount of cultivated land will be lost to construction, estimated as 2.02 million ha. In the same period, although the annual supplement of cultivated land from land consolidation and abandoned land recultivation will increase gradually, reclamation

will still be the main source for the supply of new cultivated land. Excluding the land for ‘Grain for Green’ the net loss of cultivated land will be 0.26 million ha. After 2010, there will be no cultivated land loss to this project as all the cultivated land threatened by serious soil erosion will be ultimately restored to forestry or grassland by 2010. Annual loss for construction will still be over 0.1 million ha, but will decrease gradually; because more efforts will be made in land consolidation and abandoned land recultivation and agricultural restructuring will taper off, the decreased trend of total cultivated land is converted. When China reaches its peak population in 2030–2040, the total area of cultivated land will be around 117.5 million ha. Subsequently, the driving forces will weaken gradually because the pressure of population will ease gradually and the intensiveness of economic development and land utilization will be greatly improved. It is then expected that the area of cultivated land will continuously increase again. In 2050, the total area of cultivated land will be 118.98 million ha, 9.25 million ha less than that in 2000. As to cultivated land per capita, during 2001–2010, it will decline by about 18%, from 0.101 to 0.083 ha. During 2020–2030, despite a small increase of total cultivated land, cultivated

land per capita will still decline and reach its lowest point of 0.079 ha because of the growing population. In 2030–2050, as the population decreases, cultivated land per capita will increase at a faster speed than the expanding rate of cultivated land and reach 0.085 ha in 2050.

CLEPC in the next 50 years

To calculate China's CLEPC in the next 50 years, we first predicted the average grain yield per hectare and MCI. When predicting the trend of change in grain yield per hectare, we adjusted the corresponding data during 1978–2002 from statistical bulletins to the actual area of cultivated land from the 1996 survey and treated these adjusted data by the method of moving averages, with a length of 5 years, ($Yield_{year} = \sum_{a=year-2}^{year+2} Yield_a / 5$, year 1980, 1981, . . . 2000) in order to reduce the fluctuations in grain yield caused by climate and natural hazards (Figure 3). Two important points are obvious when Figure 3 is studied. First, the average grain yield per hectare has been improved by about 56.6%, from 2044 kg/ha to 3210 kg/ha during 1980–2000, an annual growth rate of 2.27%. Second, the growth rate of the grain yield per hectare slows down gradually, the annual rate during 1981–1990 is 3.26% but only 1.48% during 1990–2000.

From the viewpoint of production factor input, the increase of the average grain yield per hectare mainly depends on advances in agricultural technology, construction of farmland infrastructure, fertilizer utilization, labour and machine

input, planting structure of different food crops, agricultural water supply, agricultural product price and policy. In the past 20 years, the increases of fertilizer utilization, irrigable land and machine input has contributed greatly to the increasing grain yield, while the contributions of agricultural technology advancement and labour input were relatively less. Labour input even had negative effects on the increase of grain yield per hectare as agricultural labour migrated to cities (Chen 2001).

In the future, the increase in China's grain yield per hectare will benefit from such factors as irrigated land expansion, agricultural machine input increase, agricultural technology advancement and cropping structure adjustment. At present, irrigated land, which is 40% of total cultivated land and whose grain yield is 80% of the total yield, has a major positive effect on grain yield per hectare. The decline in cultivated land and the increase in food demand in future will encourage China to enhance investment in farmland infrastructure to increase the area of irrigated land. We have predicted that, in 2050, there will be 65 million ha irrigated land, 10 million ha extra, which will significantly benefit the improvement in grain yield per hectare. Growth of agricultural machinery input allows peasants to select more efficient cropping patterns and breeds that need less labour input, and ultimately improves MCI. In addition, the shortage of agricultural labour resulting from the movement of rural population to cities in the accelerated process of industrialization and urbanization can only be compensated by an increase in agricultural

Figure 3 Moving average of grain yield per hectare, 1980–2000

machinery input. Thus, if the future agricultural energy need can be met, the agricultural machinery input will increase rapidly and greatly increase the grain yields per hectare over a long period in the future. Heavily and improperly utilized fertilizers have produced serious problems in China, such as a decrease in soil fertility and increased environmental pollution. In addition, the marginal contribution of fertilizers to grain yield growth has been decreasing (Chen 2001; Tong *et al.* 2003). The growth rate of fertilizer use has diminished in recent years, and will continue to decline in the future as the high product cost of grain yield will prevent fertilizer inputs from constantly increasing. The effect of fertilizer on increasing grain yield will diminish in the future.

The increase in the average grain yield per hectare also has a close relationship with cropping structure and the grain yield per hectare of different food crops. From 1980, the grain yield and planting area of maize and wheat have risen continuously, while that of paddy has decreased. The results of a study on the relationships between the average yield per hectare and the yields per hectare of each food crop show that the contribution of maize to the increase of the grain yield per hectare has been the greatest (36%), followed by paddy (32%), and the smallest was for wheat (17%) during 1980–2000. With the improvement in people's living standards and diet in the future, the proportion of grain for direct consumption will decline and that of grain for feed will increase (Verburburg and Veldcamp 2001).

The climatic effects of sunlight, temperature, water and soil on potential grain yields show that maximum yields can be 14,000 kg/ha in China (Wu and Li 2002). Although this potential grain yield is only theoretical and is perhaps impossible to achieve, it suggests that there is enough room for China to increase its average grain yield per hectare, while the present grain yield level is only 20–40% of the maximum potential yield (Dang *et al.* 2000; Chen

2001). Based on such analyses, we believe that China's grain yield per hectare will increase continuously in spite of a reduction in the growth of grain yield per hectare. We predict that the annual growth rate during 2000–2010 will be 2%, will be maintained at 1.0–1.5% during 2010–2030 because of the intensive pressure of food demand, and will be 0.6–0.8% during 2030–2050 through the impetus of technological advancement.

MCI is another important parameter in the calculation of CLEPC. In China, MCI has improved from 1.483 to 1.578 for 1985–1995. MCI can be heightened by advances in agricultural technology, increases of agricultural input, strong pressure of food demand, and a policy of encouraging grain yield increases in the future; but will be restricted by limited agricultural labour and a reduction of the quality of cultivated land. In addition, the historical experience of the world's developed countries has indicated that both cultivated land and MCI decline in the process of industrialization. So, we conclude that MCI in China will neither drop nor rise greatly.

Based on analyses and discussion, we have estimated CLEPC during 2000–2050 (Table 5). Table 5 indicates clearly that CLEPC will remain at the level of 2000 (0.101 ha) during 2000–2010, although the total and per capita areas of cultivated land will decline. This result highlights the fact that the conflict between grain supply and demand, which is stimulated by cultivated land decrease and population growth, can be solved by improvement of grain yield per hectare. After 2010, the trend towards decline of total cultivated land will generally stop, and the rate of decrease of cultivated land per capita will gradually slow down and then begin to rise after 2030. During 2010–2050, the increase of grain yield per hectare can counteract the yield decrease by cultivated land decline and meet the grain demand of the growing population. Thus, CLEPC will stably rise to 0.156ha in 2050, 55% larger than in 2000.

Table 5 Prediction of CLEPC during 2001–2050

Year	2000	2010	2020	2030	2040	2050
Grain yield per ha (kg/ha)	3245.8	3956.6	4591.8	5072.2	5492.9	5831.5
MCI	1.60	1.61	1.62	1.63	1.63	1.63
Cultivated land per capita (ha)	0.101	0.083	0.079	0.079	0.081	0.085
CLEPC (ha, 2000 as benchmark)	0.101	0.102	0.113	0.126	0.140	0.156

CONCLUSIONS AND DISCUSSION

4.1 Cultivated land resource

Our prediction shows that China's cultivated land resources will decrease continually in the first decade of the twenty-first century. Continuous decline of cultivated land will conflict more seriously with economic development and population growth. After 2010, the driving forces for China's cultivated land loss will be lighter and cultivated land resources will achieve a dynamic balance. Compared with results of other similar studies (Chen 2001; Liu and Lu 2001), the predicted result of cultivated land resources is smaller (except for Brown 1995). The main reason for this difference is that the cultivated land losses by the 'Grain for Green' project and agricultural structural adjustment were fully considered in this present research. These two forms of cultivated land loss were neglected or underestimated in most previous prediction studies. In addition, analyses of the driving effects of society, population and economy on cultivated land changes in most relevant studies are not systemic and detailed. Brown's study is based on the statistical data of the CSSB and his prediction of China's cultivated land was made by simple analogy with the declining trend of cultivated land in the processes of industrialization in Korea and Japan. Lack of consideration of China's idiographic situation is a major reason why his prediction departs from reality.

It is very difficult to predict change of cultivated land, especially long-term change. The reliability of predictions has a close relation with comprehensive and objective analyses of the present situation of cultivated land, population growth, social development, economic growth and structure, technological progress, and so on. Our prediction is on the following basic hypotheses:

1. The 'Grain for Green' project will be completed in 2010 and all the sloping cultivated land in regions with serious soil and water loss will generally have been converted into forest or pasture. In consequence, there will not be any cultivated land loss through this project after 2010.
2. China will strictly maintain its family planning policy in the next several decades.
3. The structure of the people's diet and social food demand will become stable after 2020 when China achieves the goal of creating an all-round well-off society. In addition, there will be no large-scale agricultural adjustment with the stabilization of China's market economic system after 2020.
4. The loss of cultivated land from natural hazards will decrease gradually due to the benefits of ecological projects and land-use pattern adjustment.

In order to make our predictions coincide with facts, we used uniform, continuous and conservative prediction methods. When estimating the increase of construction land, we set the standard of construction land per capita according to the present situation and the trend towards an increasing degree of land-use intensity. As to the predictions of land consolidation and reclamation, we took a more conservative estimate than current relevant planning. All these assumptions can help us to obtain better actual predicted results.

Sustainable utilization of cultivated land in China

Since the concept of sustainable utilization of land was proposed, there has not been a clear and uniform definition of the concept. We consider that sustainable utilization of cultivated land contains at least two primary principles: (1) the productivity of cultivated land must meet the people's need for food; and (2) cultivated land resources and productivity are sustainable. Analyzing our predictions of cultivated land in the next 50 years, we found sustainable utilization of cultivated land in China will face two great challenges:

1. Loss of cultivated land for construction. Most of this will be land around cities with high quality and productivity (Li 1999), and the loss is permanent and unrecoverable. Although there is also great cultivated land loss for the 'Grain for Green' project and for agricultural structural adjustment, these negative effects on agricultural productivity can be neglected because of benefits to the local ecological environment and the sustainability of land-use (Li *et al.* 2002).

2. Land degradation, nutrient deficiency in cultivated land and soil pollution. At present, the area of desertification in cultivated land is 2.53 million ha (2% of total cultivated land); the area of cultivated land with water and soil erosion is 45.33 million ha (35% of total cultivated land); but desertification and soil erosion are expanding continuously (Zhao *et al.* 2002). Nutrient imbalance and deficiency are produced by overuse of fertilizers and failure to use organic fertilizers; the percentage of organic matter content in cultivated land is only 1.5%, and 70–80% of cultivated land is nutrient deficient. The polluted cultivated land is 13.33 million ha (10% of total cultivated land), resulting from overuse of fertilizers and pesticides and the increasing emission of industrial waste water, solids and gases.

CLEPC and supporting capability of cultivated land

Our prediction shows that CLEPC will generally be maintained at the level of 2000 during 2001–2010 and then continuously increase after 2010. The population carrying capacity of resources is related closely not only to the quantity and quality of the resource supply, but also to the level of people's demand. The CLEPC advanced in this paper does not consider the change of grain demand per capita resulting from the living standard improvements. Therefore, this prediction of CLEPC during 2001–2010 can only indicate that grain yield per capita will not decrease in this period, and does not suggest that the supporting capacity of cultivated land will meet social demand. Furthermore, with the anticipation of economic development and living standard improvements, we can conclude that the pressure on grain supply will continue to increase.

In addition, the 'Grain for Green' project will benefit national average grain yield per unit area. The cultivated land, restored to forestry and

grassland, has much lower productivity, less than 100 kg/mu (1 ha is equal to 15 mu) (Feng *et al.* 2002; Zheng and Zhu 2002). Even if estimated on the basis of a relative high yield of 100 kg/mu, the decrease in grain yield of cultivated land loss (14.67 million ha) for the project is only 4.8% of total grain yield, while the area is 11% of total cultivated land. That means that removing the area for the 'Grain for Green' project will increase national average grain yield per unit area. Because of the difficulty of making accurate calculations, we did not consider this effect. Consequently, the actual cultivated land per capita equivalent in the prediction period may be more optimistic than we have estimated.

Suggestions on policy

In this study, we found that the supporting capacity of China's cultivated land and food security will face severe challenges, and the Chinese government should pay much more attention to agriculture and cultivated land in the process of developing the industrial economy. The following actions should be taken to promote sustainability of cultivated land and to ensure food security:

1. Maintain the family planning policy.
2. Strictly conserve cultivated land and improve grain yield by all possible methods.
3. Improve the quality of economic growth and land-use efficiency, decrease the loss of cultivated land to construction.
4. Develop water-saving and ecological agriculture.

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