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Cultivated land conversion and potential agricultural productivity in China

Xiangzheng Deng[a,*], Jikun Huang[a], Scott Rozelle[b], Emi Uchida[b]

[a]Center for Chinese Agricultural Policy, Chinese Academy of Sciences, No. Jia 11, Datun Road, Anwai, Beijing 100101, China
[b]Department of Agricultural and Resource Economics, University of California, Davis, USA

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Abstract

In China there is a growing debate on the role of cultivated land conversion on food security. This paper uses satellite images to examine the changes of the area of cultivated land and its potential agricultural productivity in China. We find that between 1986 and 2000 China recorded a net increase of cultivated land (+1.9%), which almost offset the decrease in average potential productivity, or *bioproductivity* (−2.2%). Therefore, we conclude that conversion of cultivated land has not hurt China's national food security. We also argue that more recent change in cultivated area likely has had little adverse effect on food security.

Keywords: Cultivated land; Land use changes; Potential agricultural productivity; China

Introduction

Land is a critical input that is needed to keep the development process moving, allowing for the shift of people from the rural to the urban sector (CCICED, 2004). It is possible, however, that as cultivated land is converted to built-up area, it will conflict with national food security goals. While little was heard about this conflict in the late 1990s through 2003, as grain prices rose through the early part of 2004, policy makers and scholars began to debate the role of cultivated land conversions in the rise of food prices (Ministry of Land and Resources, 2004a; Feng et al. 2004; CCICED, 2004). On the one hand, at China's pace of development local leaders and developers in many parts of coastal China and in suburban areas around inland cities are in the middle of a period in which they have already committed large amounts of capital to development zones, factories and housing projects; they obviously are going to need access to land so that their plans can be fulfilled. Tens of millions of jobs in construction in the short run and hundreds of millions of jobs in the longer run depend on completing these projects and continuing on with more in the future. On the other hand, others have labeled the conversion as an irreversible destruction of cultivated land that will hurt national food security (Feng et al., 2004).

Is the rate of cultivated area conversion in China normal relative to the experiences of other rapidly developing nations or is it occurring at such a rapid pace that it is threatening national food security? That is the question that is at the core of the food security versus growth debate. International experience shows that rapid economic growth is always accompanied with shift of land from agriculture to industry, infrastructure and residential use (Ramankutty et al., 2002). Countries in East Asia, North America and Europe have all lost cultivated land during their periods of economic development (Caradec et al., 1999; Hamamatsu, 2002; Ramamkutty et al., 2002).

Although economic growth started later than in many other nations, China has grown extremely fast in recent years (NSBC, 2004). Since 1978 China's economy doubled itself more than three times. By 2002 the economy was about 8.5 times greater than at the beginning of the economic reforms. Such rapid economic growth has significantly improved the livelihood of China's population. During the 25 year period, agriculture also increased

*Corresponding author. Tel.: +86 10 64889440; fax: +86 10 64856533.
E-mail address: dengxz.ccap@igsnrr.ac.cn (X. Deng).

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substantially, with agricultural GDP rising by around 5% per year. Since the population growth rate during the period was only 1.2%, food availability also improved (Huang et al., 1999). Hence, according to many indicators, rising income and food production have considerably improved China's food security and substantially reduced the rate and severity of poverty (World Bank, 2000). The rise of food output improved so dramatically that between 1983 and 2003, China was a net food exporter during every year. After the mid-1990s the nation also has been a net exporter of grain during every year except 2004 (Anderson et al., 2004).

Despite the achievements, concern over national food security remains as leaders worry that economic growth both increases the demand for land and can weaken incentives for agricultural production (CCICED, 2004). Since the late 1980s structural change allowing the emergence of cash crops, new export opportunities for labor-intensive fruits and vegetables and rising wages encouraged some of China's farmers to move out of grain production. At the same time urbanization and industrialization began to accelerate and cultivated land began to be converted to non-agricultural uses, such as for industrialization, the building of residences and the construction of infrastructure (Seto et al., 2000; Naughton, forthcoming). Such trends are expected to continue into the future as China maintains a high economic growth that can double the nation's economic output once again during the first decade of the 21st century.

Although food security concerns have always been part of the agricultural policy-making equation, at no time in the past decade have they surfaced as they did in 2004. Triggered by five successive years of falling grain sown area and production, food security once again has moved onto the agenda of national agricultural policy makers (CCICED, 2004). Food security concerns rose as the price of China's major grains began to rise in late 2003. Among other actions, in the early part of 2004 the State Council came out with strongly worded directives about the importance of slowing down the conversion of cultivated land to built-up area (Ministry of Land and Resources, 2004b). When the price rises continued, a directive came from the top leadership banning any further conversion, except for under certain extreme conditions (Central Committee of the Communist Party of China and China State Council, 2004). The issue of land conversion also immediately became a topic of intense debate. Interviews with local leaders and the reading of commentaries in local and national periodicals demonstrate that different sets of actors have had strong reactions favoring and opposing the strong measures against continuing with the conversion of cultivated land into built-up area. Some researchers believe the reversal of the policies is unnecessary and could slow down economic growth (CCICED, 2004). Another group of scholars claim the move is critical to maintaining national food security (Brown, 1995; Yang and Li, 2000; Verburg et al., 2000).

Surprisingly, although the issue is so important and has such far-reaching consequences, there is almost no empirical research studying the economic impact of land conversion in China. Several key questions are in need of being addressed. During the reform era, how much cultivated land has been shifted to non-agricultural use? Of the cultivated area that has been lost, how much has been due to urbanization and industrialization? While land is being converted out of cultivated area, how much land has been converted into cultivated area? What are the implications of cultivated land changes to the nation's food security?

Answers to the above questions are critical for China to be able to formulate appropriate policies that can ensure both food security and high economic growth in the coming decades. The overall goal of this study is to answer these questions by examining the changes in cultivated land base, the effect on productivity and its ultimate impact on food security. To meet the goal, changes in China's cultivated area over time and its conversion to built-up area and other uses due to urbanization, industrialization and rural settlement expansion are compared with the experiences of other countries in the world and are examined based on Landsat thematic mapper (TM)/enhanced thematic mapper (ETM) digital images covering China's entire territorial area during the past 15 years. After identifying areas that have changed from cultivated areas to built-up area, we then calculate the corresponding changes in the potential productivity of the agricultural land (henceforth, *bioproductivity*), using a methodology called Agro-Ecological Zones (AEZ).

Our study finds that, contrary to popular perception, there was not a large shift of land from agricultural to non-agricultural uses. In fact, although a large area of cultivated land was converted to built-up area, China's farmers and others converted even more land into land that could be used for cultivation. Hence, in a net sense China's cultivated land actually increased between 1986 and 2000. Because of differential qualities between land converted into and out of cultivated area, we do find that there was a fall in the bioproductivity of China's cultivated land. It is important to note, however, that the net decline in bioproductivity over the study period was so small that the rise in total cultivated area was almost large enough offset it. In the end there was only a very slight decrease (-0.3%) in total agricultural potential output, which is a measure that capture changes in both cultivated area and average bioproductivity. Based on this, it can be claimed that there was no adverse effect on food security from land conversion between 1986 and 2000. A final section also examines briefly the situation since 2000 and likewise concludes that land conversion has not had a major negative effect on food security.

Addressing such a broad topic obviously is not possible to do in a single paper. Consequently, we need to limit the paper's scope. In particular, while we address at length the nature of the change of land use and the impact that it has on agricultural productivity potential, we do not address the impact of other dimensions of urbanization. Urbanization frequently is accompanied by a number of other economic forces, such as increasing income, changing consumption patterns and rising wages. Although all of these may affect agricultural production and productivity, a complete analysis of them is not included here. The interested reader is directed to a number of other papers that have examined such issues in greater detail (for example, Huang and David, 1993; Huang and Bouis, 2001). We also abstract away from regional disparities in the paper. Although issues of access of food by people in different parts of China could be an issue, its discussion also is beyond the scope of the paper. Concerns about the difficulty of moving food around the country, however, should be allayed by reading Huang et al. (2004). In this paper, the improvements to China's markets are documented and it is shown that agricultural commodity markets are becoming increasingly competitive, integrated and efficient.

Cultivated land conversion in an international perspective

While many scholars and policy makers in China often discuss the loss of cultivated land as if it were happening due to the weak property rights and other characteristics that are unique to China, a review of the international literature shows that land conversion is not only occurring in China (Ramankutty et al., 2002). In fact, land conversions happen in all countries, especially those that are rapidly developing. For example, in Japan cropland has been declining during the last three decades (Hamamatsu, 2002). In the 1990s Japan lost at a rate of 1% per year—with losses both to development and to the abandonment of cultivated land due to low profitability. A similar trend can be found in South Korea since the 1970s. The US is losing its agricultural land at a rate of 0.1 to 0.3% per year to development and conservation set aside (National Resources Conservation Service, 2003). In most European countries, the utilized agricultural area declined between 1975 and 1995. The national figures show trends ranging from −12% (United Kingdom) to −1.5% (Luxembourg—Caradec et al., 1999).

While we (and others) have presented these trends in a way that make them often appear to be comparable, there should be a note of caution. Creating series of conversion losses are inherently difficult. They are even more difficult to compare. The difficulties in calculations and comparisons are mainly due to differences across nations and over time in definitions of cultivated land, orchards, the base (cropland or cropland + rangeland/pasture) and other factors. However, regardless of the exact definition, few would argue that most or all countries, as they develop, lose cultivated land.

In addition to the quantity of land being converted, a common concern in Japan, South Korea, Europe and the US is that the quality of land also is being compromised by development (Hamamatsu, 2002; National Resources Conservation, 2003). Policy makers and scholars often express their worry that some of the most productive agricultural land is being lost due to urbanization. In fact, this is intuitive because productive agricultural land is usually flat and often relatively rich land (which is also where urbanization is likely to occur). While of concern, it also is recognized that the productivity of such land when it is put into urban uses is even more productive and more highly valued (Verburg et al., 1999; CCICED, 2004). Hence, given China's development path in the past and expected growth in the future, it is rational that policy makers and scholars should both expect changes in the cultivated area as well as maintain concern about both the trends of quantity and quality of cultivated land conversion. The real question, then, is whether the pace of China's conversion is reasonable or not.

Methodology

In trying to assess the trends in the quantity and quality of China's cultivate land, some researchers have relied on secondary data collected by those in the nation's land administration (Crook, 1993; Ash and Edmonds, 1998; Fischer et al., 1998; Smil, 1995, 1999; Zhang et al., 2000; Seto et al., 2000). Unfortunately, there are many reasons to be concerned about the quality of the statistical system's land conversion data. Local officials, who benefit from land sales, have an incentive to misreport land conversions—on both the up and down sides. Existing data series frequently include inconceivable trends. For example, the amount of cultivated land shifts from 95 to 130 million hectares between 1995 and 1996 (NSBC 1996 to 2000, 2004). Such inconsistencies should not be surprising given the fact that during the past three decades a number of different agencies have had responsibility for managing China's land.[1]

Without access to quality data from traditional statistical databases, we rely on methods that use Landsat TM/ETM data to generate estimates of changes in land quantity and quality. Given characteristics of alternative data sources, even compared to the best estimates from enumeration-based series, we believe our approach has several features that make it a relatively effective way to study land conversion. In this section we introduce the methods that we use to track land conversion, first by describing how land use is detected in the different time periods for which we have data (which will give us measures of changes in land quantity) and second how the data are transferred into measures of potential

[1] In fact, even if such secondary data from statistical sources were accurate, we still could not rely on such a data set. The quality of the national, statistical data on land conversions really does not have anything to do with our choice of working with Landsat-based land use data. Even if the statistical system's data were high quality, one could only tell the quantity of land that was converted. There is no plot by plot measure of the quality of land conversions available from official statistical sources.

agricultural productivity (which will give us measures of land quality). In the following section we discuss the land use trends from the data.

Detection models of land use change (LUC), 1-km area percentage data models

The vector data model and raster data model are two of the most widely used models in spatial data analyses (Lin and Kao, 1998; Wicks et al., 2002). In a vector data model, each location or point is recorded as a single coordinate (x, y). A line is a series of ordered coordinates. Areas are recorded as a series of coordinates defining line segments that enclose an area. The term polygon in our analysis means a many-sided figure (Felleman, 1990; Chen et al., 1999). Vector data models represent each surface as a series of isolines. For example, elevation is represented as a series of contours. While the vector data model is useful for displaying information, its disadvantage is that it is not a convenient platform for analyzing land surfaces with more than two characteristics (Chen et al., 1999), such as slope and elevation along with some other aspect.

An alternative to the vector data model, the raster data model is more like a photograph than a map. In a raster data model, each location is represented as a cell. The matrix of cells, organized into rows and columns, is called a grid. Each row contains a group of cells with values representing some geographic phenomenon (Chen et al., 1999). Cell values are numbers, which represent nominal data such as land use types and measures of light intensity.

Although there are other choices, vector and raster data models each have a number of advantages (Felleman, 1990; Chen et al., 1999). By combining the best features of these two types of data models, Liu et al. (2002, 2003) further developed a 1-km area percentage data model (1-km APDM) to detect and represent land use changes on a 1×1 km grid scale. This model has been widely used in the past to analyze spatial and inter-temporal characteristics of land use change in China (Albersen et al., 2002; Liu et al., 2002, 2003; Deng et al., 2002, 2003).

Based on the prototype of the 1-km APDM, we develop a set of programs to generate 1-km area percentage data. The generated 1-km area percentage data are based on map-algebra concepts, a data manipulation language designed specifically for geographic cell-based systems (Albersen et al., 2002; Liu et al., 2002, 2003; Deng et al., 2002, 2003). The procedures to generate the 1-km area percentage data are conducted in five steps. The first step is to generate land use maps during the study periods at the scale of 1:100,000. This is done by man–computer interpretation in an ArcGIS 8.02 software environment. The second step is to generate a 1-km FISHNET vector map geo-referenced to a China boundary map at the scale of 1:10,000. The third step is to intersect the land-use change map with a 1-km FISHNET vector map. This is followed by aggregating the conversion areas for each land use category in each 1-km grid identified by 1-km FISHNET vector cell IDs in the TABLE module of Arc/Info 8.02. Finally, the area percentage vector data are transformed into grid raster data to identify the conversion direction and intensification. The design and experienced data handling procedures ensure that there is no loss in area and produces the basic data that are used for monitoring land use change (LUC), i.e., the encroachment of urban land onto cultivated land.

Agro-ecological Zones (AEZ) methodology

In addition to estimates of the quantity of the cultivated land conversions, there are several ways to estimate the changes in the quality of cultivated land. One way is to estimate changes in the potential productivity of cultivated land. As with any of the alternative methods for estimating potential productivity, a number of assumptions are needed about the crops or mix of crops that can be produced on each plot of land.[2] Other assumptions are needed to estimate the acceptable level of output, the social acceptance of land-cover conversions and the constraints related to land use that may be overcome by technology, management and investment. Such assumptions are well documented in the literature as being standard ways to estimate potential productivity (e.g., Keyzer, 1998).

The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA), has developed a commonly used method of calculating potential productivity, the AEZ methodology. The AEZ methodology can serve as an evaluative framework for biophysical limitations and production potential of major food and fiber crops under various levels of inputs and management scenarios at global and regional scales (Keyzer, 1998; Fischer et al., 2000, 2005; Heilig et al., 2000; Fischer and Sun, 2001; Albersen et al., 2002). In its simplest form, the AEZ framework contains three elements: selected agricultural production systems with defined input/output relationships; geo-referenced land resources data (including climate, soil and terrain data); and procedures for calculating potential yields, matching environmental requirements for crop (by land units and grid cells) with the corresponding environmental characteristics available in the land resources database.

The LUC group of IIASA has applied the AEZ methodology in China to assess the cultivated land potential throughout China. In IIASA's procedure the land-resources inventory of China comprises 375,000 grid cells measuring 5×5 km. As part of the agro-climatic characterization, Fischer and Sun (2001) and Fischer et al. (2000) employed a water-balance model in each grid cell, based on monthly historical data from 1958 to 1988 to

[2]Ultimately, what is desired is a measure of foregone yields from land converted out of cultivated land and increased yields from land converted into cultivated area. The problem with using data is that all of the land use data are in 1 km^2 units and yields are only available at the county level.

simulate when and for how long water is available to sustain crop growth. The model also uses soil moisture, together with other climatic characteristics (such as radiation levels and temperature profiles) in a simple crop growth model to calculate potential biomass production and yields. In the next step, LUC group combines the potential yield of each cell in a semi-quantitative manner with several reduction factors directly or indirectly related to agro/climatic factors (e.g., pests and diseases) and/or soil and terrain conditions. The reduction factors vary according to crop type, the specific environment of each grid cell and assumptions about the level of inputs and management. The final result consists of attainable crop yields under various production circumstances. To ensure that the results relate to sustainable production, LUC imposes fallow periods and excludes terrain slopes and soils that are highly susceptible to topsoil erosion (Fischer and Sun, 2001; Fischer et al., 2000, 2005). In this study we follow the results of cultivated land production from IIASA as baseline values to estimate the changes of potential agricultural productivity of cultivated land due to land use conversions.

Although the agricultural productivity analysis in our paper is executed at a low level of disaggregation, we aggregate to the provincial level. However, it should be stressed that our approach should minimize aggregation problems. To do so, we first calculate the agricultural productivity levels at the pixel level. This is done for the initial time period (for the year 1986). We then overlay the agricultural productivity information onto a map of the changes in cultivated area in each period, which is also done at the pixel level. After this, we then aggregated the changes in agricultural productivity measures to the provincial level. Although we aggregate our analysis up to the provincial level for convenience of presentation purposes, we do acknowledge that such aggregation can affect the precision with which land use changes are detected. At the boundary of each province, the decision to include/exclude a 1 km^2 cell could lead to slight aggregation errors (Evans and Kelley, 2004; Kok, 2004). More importantly, aggregating into administrative units inevitably smoothes out some variation in topography, and hence, potential agricultural productivity, within provinces.

Appropriateness of AEZ for Analysis in China

Although the use of AEZ-based methods is common, some researchers have criticized the approach (van Diepen, 1993; Laya et al., 1998). One of the main criticisms is that there is a distinct difference between potential and realized productivity (and potential output and actual output). Research has been done in Africa that shows that there are certain places with high potential productivity (measured with AEZ), which are, in fact, poor and unproductive (FAO, 1982).

We also acknowledge that in China there do, in fact, exist differences between total agricultural potential output that was estimated using the AEZ methodology and actual (or historic) output. Although there may be several reasons for this, one of the main reasons is due to the variability among regions in terms of their levels of production effort, technology and investment. In other words, while AEZ is measuring the "potential," statistical sources are measuring (and officials and scholars are interested in) the realization of that potential. Unfortunately, we can not use actual output because such statistics are not collected at the level of disaggregation in which the process of conversion is occurring (e.g., from cultivated land to built-up area; and from other uses to cultivated area).

So the ultimate question here is how well in the context of China's agriculture do AEZ-estimated total agricultural potential output match up to actual output? In fact, at least in the recent past, we find that there is a fairly high (albeit not perfect) correlation between estimated potential and actual output. To demonstrate this, we begin by collecting information on the two components of actual output: actual yields (Yields) and cropping intensity (as measured by the multiple cropping index—MCI). The lowest level of disaggregation at which these are available are at the county level. We collected yields and cropping intensity for the year 2000. We then seek to understand the relationship between our AEZ-estimated total agricultural potential output (TAPO) and actual output by regression analysis. To do so, we take two steps: First, we aggregate the variable TAPO to the county level using GIS-based aggregation methods. When we match them with our county level data base that includes county level measures of Yields and MCI we have in total more than 2000 observations (covering more than 90% of China's cultivated land area).[3] Second, we run the following regression:

$$\ln(\mathrm{TAPO}) = a_0 + a_1 \ln(\mathrm{Yields}) + a_2(\mathrm{MCI}) + e.$$

In running this regression, the goodness of fit measure, adjusted R^2, is 0.64. This means that about two thirds of the variation in the estimated total agricultural potential output is explained by the two components that make up actual output. Hence, we believe in some small way this legitimizes the use of the AEZ methodology for the case of China.

Data

One of the strengths of our study is the quality of data that we use to estimate cultivated land use change and potential agricultural productivity. Satellite remote sensing digital images for our purposes are the most suitable data for detecting and monitoring LUC at global and regional scales (Kok, 2004). There are a number of choices. Satellite sensors, such as Landsat TM, and the French SPOT system, have been used successfully for measuring

[3]Unfortunately, at least from our perspective, there is really no other approach that could be taken since actual yields and actual cropping intensity are not available at the 1×1 km square level.

Table 1
The classification system of land use categories in this study

Land use types	Explanations
Cultivated land	Original data include both paddy and non-irrigated uplands, which is aggregated into total cultivated land for this study.
Forestry area	Natural or planted forests with canopy covers greater than 30%; land covered by trees less than 2 m high, with a canopy cover greater than 40%; land covered by trees with canopy cover between 10% and 30%; and land used for tea-gardens, orchards and nurseries.
Grassland	Lands covered by herbaceous plants with coverage greater than 5% and land mixed rangeland with the coverage of shrub canopies less than 10%.
Water area	Land covered by natural water bodies or land with facilities for irrigation and water reservation, including rivers, canals, lakes, permanent glaciers, beaches and shorelines, and bottomland.
Built-up area	Land used for urban and rural settlements, industry and transportation.
Unused land (remaining area)	The rest of all other lands.

Table 2
Summary of the accuracy validation by each land use category in 1986, 1995 and 2000

Items	Cultivated land	Forestry area	Grassland	Built-up area	Other use types	Total
Sample patch number, 1986 (number)	5058	4104	1512	1714	912	13,300
Degree of accuracy, 1986 (%)	94.94	90.13	88.16	96.32	95.72	92.92
Sample patch number, 1995 (number)	20,211	7585	5457	1607	4366	39,226
Degree of accuracy, 1995 (%)	98.30	97.91	98.40	99.65	99.26	98.40
Sample patch number, 2000 (number)	22,710	7985	6656	2115	4798	44,264
Degree of accuracy, 2000 (%)	97.33	97.42	97.43	99.15	97.31	97.45

Note: Random sample approach was used to evaluate the degree of accuracy (%).

deforestation, biomass burning and other land cover changes, including the expansion and contraction of deserts (Skole and Tucker, 1993). Remote sensing techniques also have been used widely to monitor the conversion of agricultural land to infrastructure (Palmera and Lankhorst, 1998; Woodcock et al., 2001; Milesi et al., 2003; Ogud et al., 2003).

In our study we use a land use dataset developed by the Chinese Academy of Sciences. Based on Landsat TM scenes with a spatial resolution of 30×30 m, our study's data are from satellite remote sensing data provided by the US Landsat TM/ETM images (Vogelmann et al., 2001). The database includes time-series data for three time periods: (a) the late 1980s, including Landsat TM scenes from 1986 to 1989 (henceforth, referred to as 1986 data for simplification purposes); (b) the mid-1990s, including Landsat TM scenes from 1995 and 1996 (henceforth, 1995); and (c) the late 1990s, including Landsat TM scenes from 1999 and 2000 (henceforth, 2000). For each time period we used more than 500 TM scenes to cover the entire country. Specifically, we used 514 scenes in the late 1980s, 520 scenes in the middle 1990s and 512 scenes in the late 1990s.

The Landsat TM images also are geo-referenced and ortho-rectified. To do so, the data team used ground control points that were collected during fieldwork as well as high-resolution digital elevation models. Visual interpretation and digitization of TM images at the scale of 1:100,000 were made to generate thematic maps of land cover (Deng et al., 2002, 2003). A hierarchical classification system of 25 land-cover classes was applied to the data. In this study the 25 classes of land cover were grouped further into six aggregated classes of land cover—cultivated land, forestry area, grassland, water area, built-up area and unused land (Table 1).

The interpretation of TM images and land-cover classifications was validated against extensive field surveys (Liu et al., 2003). The interpretation team from CAS conducted ground truth checks for more than 75,000 km of transects across China. During the ground truthing more than 8000 photos were taken using cameras equipped with global position system (GPS). The average interpretative accuracy for land-cover classification is 92.9% for 1986, 98.4% for 1995 and 97.5% for 2000 (Table 2). By comparing land cover patterns between 1986 and 2000, we determined the changes in land cover for the entire country in 1986–2000. Additional details about the methodology, which we used to generate the databases of land cover from Landsat TM, have been documented in Liu (2002) and Deng (2003).

In order to obtain even more accurate estimates of land use, we also designed a matrix that will help us account for

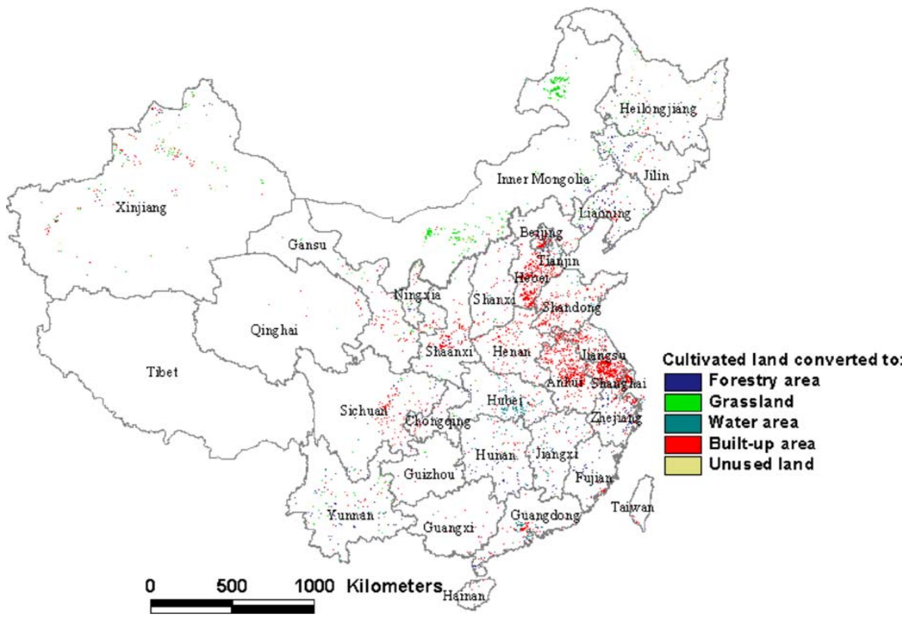

Fig. 1. Distribution of land converted from cultivated land to other uses, 1986–2000.

the areas in which there are ground objects that are linear in shape. To do so, we use information from aerial patches based on the CAS LUC dataset. The precision of measurement was up to the centimeter level. The width of linear objects, including small canyons, ditches and roads, were measured via the ZOOM IN functions in the ArcGIS 8.02 environment (the smallest of the magnifying function is 10 times). For irregular linear thin objects, we divided them into more regular ones and measured them one by one and then aggregated them into areas of the entire thin objects. When handling the data in this way, we guarantee the accuracy of the discounting of linear thin objects as well as the measurement for the aerial patches. In addition, for small objects, we measured their true areas rather than generalized areas (the traditional way which is less accurate) in order to guarantee the accuracy of aerial patches and ensure that they are relatively free from aggregation errors.[4]

Results

Using Landsat imagery and associated methods we estimate changes in China's cultivated land between 1986 and 2000. In the first part of the section we examine the changes in the areas of different land uses. In the second part we estimate changes in the average potential agricultural productivity of the land. From these two components we can come up with an estimate of the net impact of land conversions on food security during the late 1980s and 1990s.

Changes in cultivated land

Using the methods and data described above, our study shows that the total conversion of cultivated land to other uses was surprisingly low during the study period, 1986 to 2000. According to our results, the conversion of cultivated land to non-agricultural uses totaled 3.06 million hectares between 1986 and 2000. When compared to total cultivated area in 1986, the converted land accounted for 2.21% of total cultivated land. Conversion of this amount of land implies that the *annual* conversion of cultivated land to other uses was on average only 0.16% of total cultivated land during the study period, a rate that is much lower than that experienced in many other countries during the times in which their economies were taking off.

Using the output of the GIS mapping and spatial analysis, we are able to create a map showing the geographical distribution of cultivated land conversions into other land use categories (Fig. 1). Among land converted out of agriculture, a considerable amount of land was in the east coast of China. In examining the provinces that experienced the most conversions as a percentage of their location's total cultivated area, it should be noted that only in the case of Beijing, Shanghai and Zhejiang did the conversions exceed 5%. Interestingly, while the share of land that was converted in these localities is high, since the regions are among the smallest provinces and province-based municipalities in the country, the reduction of land in these three areas represents a loss of less than 0.2% of all of China's cultivated area in 1985. Given that there are few forests or grasslands in these

[4]Another indication that we are using high quality data is that other scholars that have used parts of the data have published their work in a wide variety of median. See, for example, Xiao et al. (2002, 2003), Frolking et al. (2002), Tian et al. (2003).

relatively urbanized areas, a large part of this area was converted to built-up areas (see areas in red). We also can see that smaller shares of cultivated land were converted to other land uses. For example, in the Loess Plateau and the Sichuan Basin areas of cultivated land were converted into built-up areas in the areas around Chengdu, Chongqing, Xian and other provincial capitals. In addition to the areas that turned into industrial, infrastructure and residential area, cultivated area also was converted to forestry area (areas in blue). Most of the area converted from cultivated area into forests was in the south and southwest. Finally, the figure shows that the cultivated land also changed into grasslands (mostly in the northeast) and other types of land use.

Although considerable cultivated land was converted at the national level to other uses between 1986 and 2000, during the same time period even more land was converted from other uses into cultivated area. According to our data, during our period of analysis, 5.7 million hectares of new cultivated land was created. As a share of cultivated land in 1986, the conversion of other land to cultivated land resulted in a gross expansion of 4.1%.

Mapping analysis also shows the distribution of the areas that were newly converted from other land uses into cultivated land (Fig. 2). Most of the area converted from grasslands, as expected, is mainly located in the northwestern part China and the eastern parts of Inner Mongolia. In northeast China, the map shows that there were large tracts of forests that were converted to cultivated land during the study period. Some areas in Sichuan also were converted from forests to cultivated area during the study period. Finally, in northeast China, especially in Heilongjiang, large tracts of unused wetland and unused barren land were converted to cultivated area. Interestingly, although not counted as conversion of cultivated area, our analysis also shows that there is considerable conversion of one type of cultivated land (e.g., upland) to other types of cultivated area (e.g., paddy).

Aggregating across China, our data can be used to estimate at the national level the net total changes in cultivated land (Fig. 3, left hand panel). When taking the net gain (5.7 million hectares) from the net loss (3.1 million hectares), we find that between 1986 and 2000, far from losing significant quantities of land, the cultivated land area of China actually increased by 2.7 million hectares. When compared to the base of cultivated area in 1986, China's farmers were cultivating 1.9% more land in 2000 than they were in 1986.

Fig. 3 also summarizes the sources and use of China's cultivated land during the study period. Of all of the land that was land converted out of cultivated area, the most—about 38%—was converted to built-up areas (see white bars). In absolute terms, this means that during the period between 1986 and 2000 about 1.2 million hectares were converted from cultivated area into built-up area. Hence,

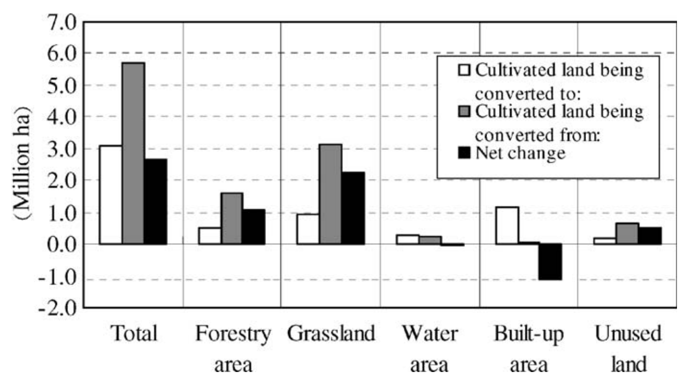

Fig. 3. Conversion of Cultivated Land in China, 1986–2000.

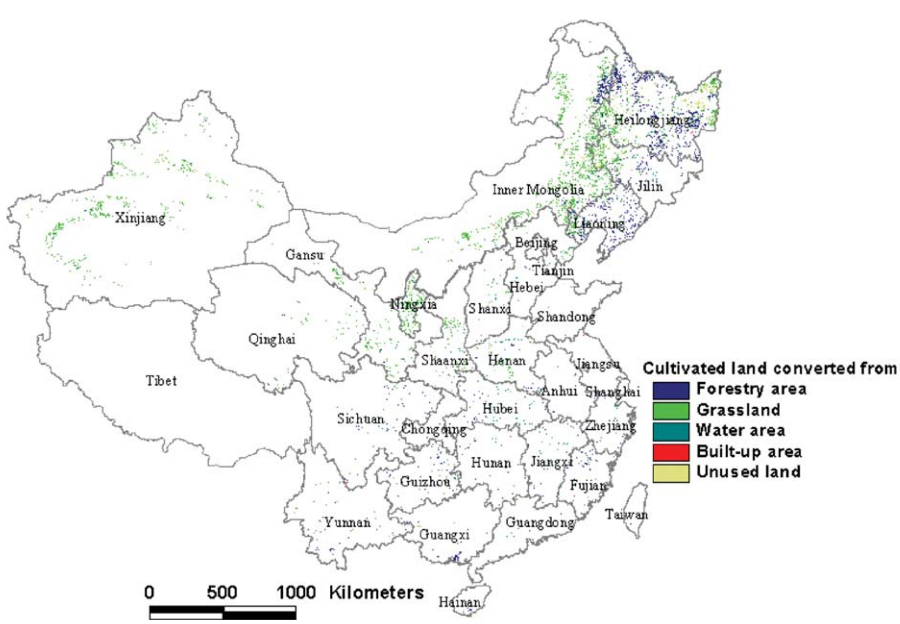

Fig. 2. Distribution of land converted to cultivated land from other uses, 1986–2000.

while China's total conversions out of cultivated area during the study period were already relatively small, the amount that shifted into built-up area (0.08% of cultivated area *annually*) was even smaller. In addition, among the cultivated land converted to other uses, 17% of the cultivated area was converted to forestry, 30% into grasslands and 16% to other areas. Among the different types of land, most of the newly converted cultivated land, 55% came from grasslands; 28% came from forested areas and around 20% came from wet lands, the reclamation of unused land and other uses (see gray bars). Hence, when looking at the big picture about the sources and uses of cultivated land in net terms, it is clear that most of China's newly converted cultivated land came from forests and grasslands and most of the cultivated land that was converted out of cultivated area went into built-up area (see black bars).

Changes in potential agricultural productivity and production due to land conversions

Using the results of the AEZ analyses in conjunction with our data that tell us the net changes of cultivated land, we can come up with an estimate of the net change in potential agricultural productivity due to the conversion of land into and out of cultivated area. When considering the effect of all conversions, we find that unlike the story being told by some policy officials, the effect of conversion of cultivated land is negligible. The average potential agricultural productivity during the 15-year study period fell by 2.2%. Aggregating over all of the cultivated area, the total production potential fell by 5855 billion kcal, or by only 0.3%.

While there is only a small change overall, our analysis requires us to further break down the net change by land type so that we can assess how much the conversion of cultivated land to different uses (e.g., to built-up areas) has affected total production potential (Table 3 and Fig. 4). In total the conversions of cultivated land to other uses led to a net loss of 34829 billion kcal or 1.8% of total potential productivity in 1986. Of this total amount, a decrease of 20489 billion kcal or about 59% of the total decreased production potential (or 20489/34829) is due to the conversion of cultivated land to built-up areas. The high percentage due to the conversion of built-up area is due in a large part to the fact that the land being converted into built-up area is higher quality than the other types of land. In a potential productivity sense, a large part for this higher quality is due to the fact that the converted land is in the south and east (so it can be cultivated during two or more seasons). Land in the south and east also is on less steep land and is in areas with more precipitation. In addition, of the total reduction in cultivated area due to conversion, 16% (or 5623 billion kcal) is due to conversion to forestry. As will be seen in the next section this figure would likely have been higher had the Landsat data been available through 2004 since the nation's Grain for Green program (or China's conservation set-aside program) did not begin until 1999.

At the same time that the conversion of cultivated land to other uses was reducing the production potential, the conversion of land from other uses to cultivated land has also led to increases in China's production potential. In total newly converted land accounted for 28971 billion kcal more in production potential. As a percentage of production potential in 1986, newly converted land raised production potential by 1.5%. Of the total, conversions from grasslands (48% or 13879 billion kcal) and forests (36% or 10335 million kcal) account for most of the increased production potential. Hence, although the quality of land that was converted into cultivated area was lower than the land converted into cultivated area (especially for that converted into built-up area), the increased land that could be cultivated in 2000 versus 1986 significantly offsets the fall in production potential due to conversion to built-up area.

When ranking China's provinces by the changing rates of production potential, we can see that there exists an obvious spatial distribution pattern (Table 3). The developed provinces located in the North China provinces, e.g., Beijing and Tianjin, account for a large share of the falling production potential. The eastern and southeastern provinces also account for a fraction of the fall. In contrast, the large shares of land reclaimed as cultivated land in Northeast China, Inner Mongolia and some of the inland provinces help boost production capability.

When taken together, our analysis demonstrates that between 1986 and 2000 China's food security has been only slightly diminished by cultivated land conversion. During the study period the quantity of cultivated land rose by 1.9%. The average potential productivity of land fell, but by only 2.2%. Hence, the quantity of land almost offset the fall in total production potential and we can conclude land conversion decreased the total potential output of China's land resources by only 0.3%.

Our results are in contrast to the works of some other researchers. For example, some papers conclude that the conversion of cultivated area will significantly affect production (Feng and Li, 2000; Tan and Peng, 2003). While these studies are valuable, their overall findings may be being driven by the regional focuses of their samples. In other words the nature of the samples may be one of the reasons for the different findings. For example, Tan and Peng (2003) study Nanjing; Feng et al. (2000) study Western China. In fact, as can be seen from our results, if we had centered our analysis on a certain subset of areas, such as Beijing or Shanghai, we would come to a different conclusion than if we had focused on Heilongjiang.

Cultivated land changes since 2000

While our paper so far has established, on the basis of Landsat data, that land conversions did not negatively

Table 3
Change of total production potential associated with changes in cultivated land by provinces, 1986–2000 (billion kcal, %)

Province	Total production potential in 1986	Increase	Decrease	Net change	Percentage change
Beijing	4120	23	837	−814	−19.75
Tianjin	6220	13	204	−191	−3.06
Hebei	72,600	396	1950	−1554	−2.14
Shanxi	34,600	268	237	31	0.09
Inner Mongolia	36,100	4940	1630	3310	9.17
Liaoning	34,000	1470	505	965	2.84
Jilin	31,400	1970	441	1529	4.87
Heilongjiang	53,300	6210	524	5686	10.67
Shanghai	9170	0	1010	−1010	−11.01
Jiangsu	114,000	240	5000	−4760	−4.18
Zhejiang	69100	313	3040	−2727	−3.95
Anhui	137,000	471	2110	−1639	−1.20
Fujian	48,100	543	772	−229	−0.48
Jiangxi	106,000	537	1030	−493	−0.47
Shandong	97,600	162	1430	−1268	−1.30
Henan	111,000	1500	1340	160	0.14
Hubei	149,000	721	2320	−1599	−1.07
Hunan	141,000	333	1160	−827	−0.59
Guangdong	90,600	267	3460	−3193	−3.52
Guangxi	113,000	1340	852	488	0.43
Hainan	16,100	191	352	−161	−1.00
Chongqing	56,300	87	396	−309	−0.55
Sichuan	176,000	417	1390	−973	−0.55
Guizhou	63,300	613	99	514	0.81
Yunnan	67,900	896	1090	−194	−0.29
Tibet	1940	0	4	−3	−0.16
Shaanxi	40,800	434	379	55	0.13
Gansu	32,000	553	174	379	1.18
Qinghai	2780	9	24	74	2.66
Ningxia	8540	1200	108	1092	12.79
Xinjiang	28,700	2750	883	1867	6.51
Taiwan	13,500	13	76	−63	−0.46
Total	19,65770	28,971	34,826	−5855	−0.30

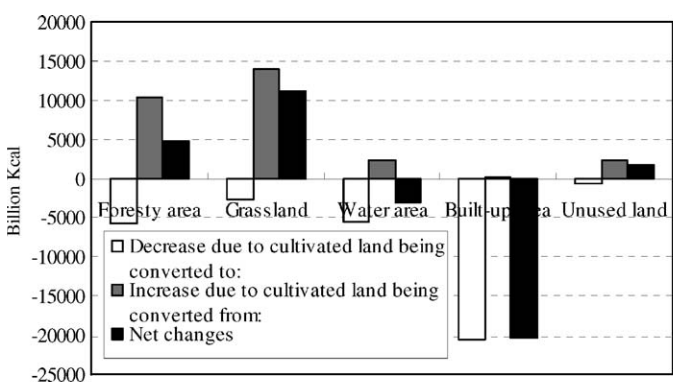

Fig. 4. Changes in total production potential (measured in million kcal) associated with changes in cultivated area in China, 1986–2000.

affect food security between 1986 and 2000, we have no Landsat data after 2000. Therefore, it could be that the recent concern by observers is purely being voiced about trends in more recent years. According to published data since 1997 (which are more consistent than a longer time series due to the fact that the Ministry of Land and Resources of China collected all of the post-1997 data themselves using a single, consistent set of definitions), it is true that cultivated land loss has accelerated. During the period 1997–2000, 0.5 million hectares of cultivated area were lost annually. During the period 2001–2003, 1.56 million hectares were lost annually. Perhaps it is on the basis of these figures that concerns over the effect of conversion of cultivated land on food security have appeared.

Decomposing the MLRC data, however, makes the focus of the issue clearer. A decomposition of national statistics after 2000 shows that the main reason for reductions in cultivated land is the nation's "Grain for Green" program that was launched in 1999. Between 2000 and 2003, nearly 70% of the total decrease in cultivated land was due to the land set-aside program (CCICED, 2004). In fact, between 1997 and 2003, there was little change in the rate of conversion of cultivated land into urban expansion and industry construction. Moreover, since China's leaders have continued to invest in land, the creation of newly cultivated area also continued to significantly offset part of the falls in the conversions of cultivated to non-agricultural uses (CCICED, 2004; Ho, 2001).

Hence, since the analysis shows that aside from Grain for Green there is no impact of land conversion on food security, the final question that needs to be answered is whether or not there any effect of Grain for Green on food security. While a complete analysis is beyond the scope of this paper, another paper (Xu et al., 2004) studies this precise question and show that the overall effect of Grain for Green on grain prices and imports between 2000 and 2003 is minimal. Between 1999 and 2003 forestry officials oversaw the conversion of more than 7 million hectares of cultivated land into forest land as part of the upper Yangtze River Basin and Yellow River Basin Protection plan (a plan that is designed to reduce floods and increase watershed retention that will have an overall productivity enhancing effect on China's agricultural sector—CCICED, 2004). Despite the large scale of the conversion program, the analyses in Xu et al. (2004) and our analysis demonstrate that the effect on national grain supply and demand balances has been almost imperceptible. Since officials made effort to target steeply sloped land in mountainous regions, the quality of the land that is being converted to forests is poor. The average yields on the converted land are less than 30% of the national average. When farmers retire their land, it also is documented that their production efforts on the rest of their land rises and there is an increase in yields that offsets the output lost due to the reduction in area. Hence, although wheat, maize and rice prices rose, on average, by 40% between 2003 and 2004, less than 5% of that rise is due to the conversion of land. In other words the price rises in the past year were due mostly to other factors, not the conversion of cultivated area. In return, the creation of a large forested area has already reduced soil erosion and improved the hydrological capacity of China's mountainous areas. In this way it is actually plausible that Grain for Green ultimately will have positive impacts on agricultural production in downstream regions along and have positive future effects on food security.

Moreover, as long as the geographic distribution of land conversions has not changed between the 1990s and post 2000 periods, there also is not any reason for concern about excess waste for irrational conversions of cultivated area. Landsat-based analysis show that most of the change is occurring in the coastal areas and around cities—exactly in the places where the conversion should be occurring. In other words, there is no evidence of excessive waste which would be indicated if there were massive conversions of land out of cultivated area in inland areas (which there are not).

Conclusions

Our study finds that after the 25 years of rapid economic growth, unlike the perception of many, there has not been a large shift of land, especially in a net sense, out of cultivated area. In fact, in terms of the overall retention of cultivated land, China's agriculture is actually doing well relative to other nations. Indeed, net cultivated land actually increased during the study period, 1986–2000. Our decomposition of cultivated land changes show that nearly half of lost cultivated land was due to cultivated land being converted to grassland (30%) and forest (17%). Of the remaining, nearly 40% was due to the shift to built-up area. However, there also was a considerable amount of newly cultivated land created, some shifting into cultivation from grassland and other from forestry areas.

Although the newly cultivated area rose, average potential agricultural productivity actually fell. The most important reason was due to the fact that the quality of land converted to built-up area from cultivated area was higher quality than that converted to cultivated area from other uses. Despite this, when examined in the aggregate for the entire period, the effect on total agricultural potential output was negligible.

When considering the main message to policy makers, one of the most important lessons of our study is that China's national food security was virtually unaffected by the conversion of cultivated land between 1985 and 2000. While we are unable to say how well planners have done in the past in managing the process of the conversion of land at the local level, given the future pressures to convert land that will certainly exist, it is absolutely certain that for the process to continue smoothly China needs careful management and planning to facilitate rational land use in both the short and long-run. Our work, however, suggests that when considering the concern about national food security, at least currently the ban on land conversion is not warranted. According to other work (e.g., Sonntag et al., 2005), at least for now China has retained its capacity to improve agricultural production through further conversion from other land uses and through increasing yields on existing cultivated land.

Although our results support the conclusion that the conversion of cultivated land into built-up area during recent years has not compromised China's ability to largely feed itself, this is no guarantee that this will continue into the future. In fact, according to the successful experiences of development in other countries, it is almost certain that there will be continuing pressure on the nation's cultivated land. The process of development is fundamentally one of shifting the population from rural and agriculture to urban and industry. It also is one that requires the construction of a modern infrastructure. When this process begins successfully, development means that the overall productivity in the economy sharply increases and wealth rises. Land of all types, including cultivated land, is a key input to the nation's industrial production and the investment into cities. Hence, the use of cultivated land inevitably will be shifted to other uses during this process. Although development in the future will require land, when the land is used rationally, the employment and creation of wealth associated with the new uses of land will be many times greater than if the land was left in agriculture.

In summary, then, the key to good development policy, in general, and food policy, in particular, is not to stop the conversion of land. Conversion is inevitable and desirable. Good policy management, however, requires that the process of conversion is done rationally and that the productivity of the remaining resources in the agricultural sector is improved. Although China raised productivity successfully in the past, additional investment into agricultural research and development is needed to ensure that these trends continue. Complementary investments into water, land and labor also are needed.

Perhaps the biggest challenge to China in its drive to become a modern, market-oriented economy is whether or not it will be able to develop a set of institutions that can promote sustainably more rational use of land. While it is beyond the scope of this paper to fully detail the policies steps that are needed, it is clear that several elements are needed to create an effective portfolio of land management policies. China needs to improve its urban planning skills and more effectively merge land use planning into its economic plans. Moreover, when good plans are developed, they also need to be implemented. The best plans in the world are useless if they are not incorporated into the processes that guide the expansion of factories, housing developments and roads. There is also scope for the expansion of the role of land markets in identifying the areas that should be developed and those that should be protected. The ultimate goal of China's government must be to find the harmonious balance between good planning and the forces of supply and demand.

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References

Albersen, P., Fischer, G., Keyzer, M., Sun, L., 2002. Estimation of Agricultural Production Relation in the LUC Model for China. IIASA, Luxemburg, Austria.

Anderson, K., Huang, J., Ianchovichina, E., 2004. Will China's WTO Accession Worsen Farm Household Incomes? China Economic Review 15, 443–456.

Ash, R.F., Edmonds, R.L., 1998. China's land resources, environment and agricultural production. The China Quarterly 156 (Special Issue: China's Environment), 836–879.

Brown, LR., 1995. Who Will Feed China? Wake-up Call for a Small Planet. W. W. Norton & Company, Norton, New York, 163pp.

Caradec, Y., Lucas, S., Vidal, C., 1999. Agricultural landscapes: over half of Europe's territory maintained by farmers. Retrieved May 2, 2005, from http://europa.eu.int/comm/agriculture/envir/report/en.

CCICED (China Council for International Cooperation on Environment and Development), 2004. China's Agricultural and Rural Development in the New Era: Challenges, Opportunities and Policy Options-Policy Recommendations and Executive Summary. Beijing, 23 pp.

Central Committee of the Communist Party of China and China State Council, 2004. Opinion on Improving the Overall Agricultural Productivity (Guan Yu Ti Gao Nong Ye Zong he Sheng Chan Neng Li De Yi Jian). Beijing, China. (in Chinese).

Chen, S., Lu, X., Zhou, C., 1999. Introduction of Geographical Information System. Science Press, Beijing, 240 pp.

Crook, F.W., 1993. Underreporting of China'S Cultivated Land Area: Implications for World Agricultural Trade. China International Agriculture and Trade Report RS-93-4. 33–39.

Deng, X., Liu, J., Zhuang, D., 2002. Modeling the relationship of land use change and some geophysical indicators: a case study in the ecotone between agriculture and pasturing in Northern China. Journal of Geographical Sciences 12 (4), 397–404.

Deng, X., Liu, Y., Zhao, T., 2003. Study on the land-use change and its spatial distribution: a case study in Ankang District. Resources and Environment in the Yangtze Basin 12 (6), 522–528 (in Chinese).

Evans, T.P., Kelley, H., 2004. Multi-scale analysis of a household level agent-based model of landcover change. Journal of Environmental Management 72, 57–72.

FAO, 1982. Assessment of Land Resources for Rainfed Crop Production in Mozambique. FAO, Rome.

Felleman, J., 1990. There's a GIS in your future. Government Information Quarterly 7 (3), 261–267.

Feng, Z., Li, X., 2000. The strategey of cultivated land and food supplies security: storing food in land—raising the comprehensive productivity of land resource of China. Geography and Territorial Research 16 (3), 1–5 (in Chinese).

Fischer, G., Sun, L., 2001. Model based analysis of future land-use development in China. Agriculture, Ecosystems and Environment 85 (1–3), 163–176.

Fischer, G., Chen., Y.F., Sun, L.X., 1998. The Balance of Cultivated Land in China During 1988–1995. IIASA, Luxemburg, Austria.

Fischer, G., van Velthuizen, H.T., Nachtergaele, F.O., 2000. Global agro-ecological zones assessment: methodology and results. IIASA, Luxemburg, Rome.

Fischer, G., Prieler, S., van Velthuizen, H., 2005. Biomass potentials of miscanthus, willow and poplar: results and policy implications for Eastern Europe, Northern and Central Asia. Biomass and Bioenergy 28 (2), 119.

Frolking, S., Qiu, J., Boles, S., Xiao, X., Liu, J., Zhuang, Y., Li, C., Qin, X., 2002. Combining remote sensing and ground census data to develop new maps of the distribution of rice agriculture in China. Global Biogeochemical Cycles 16 (4), 1091.

Hamamatsu, 2002. Decline in cropland in China, South Korea, and Japan—decline in highly productive cropland. Retrieved May 1, 2005, from www.nihonkaigaku.org/ham/eacoex/200prob/210envi/212food (in Japanese).

Heilig, G.K., Fischer, G., van Velthuizen, H.T., 2000. Can China feed itself? An analysis of China's food prospects with special reference to water resources. International Journal of Sustainable Development World Ecology 7 (3), 153–172.

Ho, P., 2001. Who owns China's land? Policies, property rights and deliberate institutional ambiguity. The China Quarterly 166, 394–421.

Huang, J., Bouis, H., 2001. Structural changes in the demand for food in Asia: empirical evidence from Taiwan. Agricultural Economics 26, 57–69.

Huang, J., David, CC., 1993. Demand for cereal grains in Asia: the effect of urbanization. Agricultural Economics 8, 107–124.

Huang, J., Rozelle, S., Rosegrant, M., 1999. China's Food Economy to the 21st century: Supply, Demand and Trade. Economic Development and Cultural Change 48, 227–252.

Huang, J., Rozelle, S., Chang, M., 2004. Tracking distortions in agriculture: China and its Accession to the World Trade Organization. The World Bank Economic Review 18 (1), 59–84.

Keyzer, M., 1998. Formulation and Spatial Aggregation of Agricultural Production Relationships Within the Land-use Change (LUC) Model. IIASA, Luxemburg, Austria.

Kok, K., 2004. The role of population in understanding Honduran land use patterns. Journal of Environmental Management 72, 73–89.

Laya, D., VanRanst, E., Herrero, J., 1998. A modified parametric index to estimate yield potentials for irrigated alfalfa on soils with gypsum in Quinto (Aragon, Spain). Geoderma 87 (1–2), 111.

Lin, H.Y., Kao, J.J., 1998. A vector-based spatial model for landfill sitting. Journal of Hazardous Materials 58, 3–14.

Liu, J., Liu, M., Deng, X., 2002. The Land-use and land-cover change database and its relative studies in China. Chinese Geographical Science 12 (2), 114–119.

Liu, J., Liu, M., Zhuang, D., 2003. Study on spatial pattern of land-use change in China during 1995–2000. Science in China (Series D) 46 (4), 373–384.

Milesi, C., Elvidge, C.D., Nemani, R.R., Running, S.W., 2003. Assessing the impact of urban land development on net primary productivity in the southeastern United States. Remote Sensing of Environment 86, 401–410.

Ministry of Land and Resources, 2004a. 2003 China National Report on Land and Resources. Beijing, China (in Chinese).

Ministry of Land and Resources, 2004b. Regulation on Implementing Protection of Cultivated Land Nationwide (Ge Di Yao Shi Xing Zui Yan Ge De Geng Di Bao Hu Zhi Du). Beijing, China (in Chinese).

National Resources Conservation, 2003. Urbanization and development of rural land. Retrieved May 3, 2005, from http://www.nrcs.usda.gov/technical/land/nri01/nri01dev.html.

Naughton, B., forthcoming. China's Economy: From Transition to Development. Oxford University Press, Oxford, UK.

NSBC (National Statistical Bureau of China), 1996 to 2000, 2004. China statistical yearbook. China Statistics Press, Beijing, (in Chinese).

Ogud, Y.Y.S., Takeuchi, S., Gawa, K., Tsuchiya, K., 2003. Monitoring of a rice filed using Landsat-TM and Landsat ETM+ Data. Advances in Space Research 32 (11), 2223–2228.

Palmera, J.F., Lankhorst, J.R.-K., 1998. Evaluating visible spatial diversity in the landscape. Landscape and Urban Planning 43, 65–78.

Ramankutty, N., Foley, J.A., Olejniczak, N.J., 2002. People on the land: changes in global population and croplands during the 20th Century. AMBIO: A Journal of the Human Environment 31, 251–257.

Seto, K.C., Kaufmann, R.K., Woodcock, C.E., 2000. Landsat reveals China's farmland reserves, but they're vanishing fast. Nature 406, 121.

Skole, D., Tucker, C., 1993. Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988. Science in China (Series D) 260, 1905–1909.

Smil, V., 1995. Who will feed China? China Quarterly. 143, 801–813.

Smil, V., 1999. China's agricultural land. China Quarterly 158, 414–429.

Sonntag, B., Huang, J., Rozelle, S., Skerritt, J., 2005. China's Agricultural and rural development in the early 21st Century. Australian Centre for International Agricultural Research, Canberra Austria.

Tan, S., Peng, B., 2003. Examination of cultivated land utilization to guarantee our grain security and its recent adjustment thoughtfulness. Economic Geography 23 (3), 371–374 (in Chinese).

Tian, H., Melillo, J.M., Kicklighter, D.W., Pan, S., Liu, J., McGuire, A.D., Berrien, M.I., 2003. Regional carbon dynamics in monsoon Asia and its implications for the global carbon cycle. Global and Planetary Change 37 (3–4), 201–217.

van Diepen, CA., 1993. Two alternative methods for evaluating regional crop yield potential in the European Community. Geoderma 60 (1–4), 359.

Verburg, P.H., Chen, Y., Veldkamp, T., 2000. Spatial explorations of land use change and grain production in China. Agriculture, Ecosystems and Environment 82 (1–3), 333.

Verburg, P.H., Veldkamp, A., Frescoa, L.O., 1999. Simulation of changes in the spatial pattern of land use in China. Applied Geography 19, 211–233.

Vogelmann, J.E., Helder, D., Morfitt, R., Choate, M.J., Merchant, J.W., Bulley, H., 2001. Effects of Landsat 5 thematic mapper and Landsat 7 enhanced thematic mapper plus radiometric and geometric calibrations and corrections on landscape characterization. Remote Sensing of Environment 78, 55–70.

Wicks, T.E., Smith, G.M., Curran, P.J., 2002. Polygon-based aggregation of remotely sensed data for regional ecological analyses. International Journal of Applied Earth Observation and Geoinformation 4, 161–173.

Woodcock, C.E., Macomber, S.A., Pax-Lenney, M., Cohen, W.B., 2001. Monitoring large areas for forest change using Landsat: Generalization across space, time and Landsat sensors. Remote Sensing of Environment 78, 194–203.

World Bank, 2000. World Development Report 2000/2001. Oxford University Press, World Bank, Washington, DC, 352 pp.

Xiao, X., Boles, S., Liu, J., Zhuang, D., Liu, M., 2002. Characterization of forest types in Northeastern China, using multi-temporal SPOT-4 VEGETATION sensor data. Remote Sensing of Environment 82 (2–3), 335–348.

Xiao, X., Liu, J., Zhuang, D., Frolking, S., Boles, S., Xu, B., Liu, M., Salas, W., Moore, B., Li, C., 2003. Uncertainties in estimates of cropland area in China: a comparison between an AVHRR-derived dataset and a Landsat TM-derived dataset. Global and Planetary Change 37, 297–306.

Xu, Z., Xu, J., Deng, X., Huang, J., Rozelle, S., Uchida, E., 2004. Grain for Green and Grain: A Case Study of the Conflict between Food Security and the Environment in China. Working Paper, Center for Chinese Agricultural Policy.

Yang, H., Li, X., 2000. Cultivated land and food supply in China. Land Use Policy 17, 73–88.

Zhang, X., Mount, T.D., Boisvert, R.N., 2000. Industrialization, Urbanization, and Land use in China. IFPRI, Washington, DC.