

# Cultivated Land Conversion and Bioproductivity in China

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## ABSTRACT

International experience shows that rapid economic growth is accompanied with a large shift of agricultural land to other uses. The overall goal of this study is to examine the changes of the area and bioproductivity of cultivated land in China where the size of economy doubled in every 8 years. Based on Landsat TM/ETM digital images covered China territory in the past 15 years and AEZ methodology, our study finds that, in contrast to many people expectation, China had recorded a net increase of cultivated land of 2.65 million hectares in 1986-2000, accounted for nearly 2% of cultivated land. We also found that average productivity of cultivated land declined by about 0.31% as the bioproductivity of new cultivated land converted from other uses is in general lower than that of cultivated land converted to other uses. Despite a decline in land bioproductivity in the past and a likely decline in total cultivated land in the future, their impacts on agricultural production will be minimal. China can maintain health cultivated land base for food and agricultural production in the long term.

Keywords: Cultivated land, land use changes, bioproductivity, China

## 1. INTRODUCTION

International experience shows that rapid economic growth is often accompanied with a large shift of land from agriculture to industry, infrastructure and residential use. For example, in Japan, cultivated land has been declining significantly during the last three decades. In the 1990s Japan lost of cultivated land at a rate of one percent per year<sup>1</sup>. A similar trend is found in South Korea since the 1970s<sup>1</sup>. The US is losing its agricultural land with a range of 0.1 to 0.3 percent per year to development and conservation set aside<sup>1</sup>.

Although starting later than the US and its East Asian neighbors, China has grown rapidly in recent years. China's economy in 2002 was about 8.5 times as what it was when the economic reform began in 1978. Such rapid economic growth has significantly improved the livelihood of China's population. During the reform era (1978-2002) GDP grew at an average annual rate of about 9%<sup>2</sup>. The growth in food and agricultural production also was substantial. During the reform era, agricultural GDP grew at around 5% annually, largely exceeding the annual population growth rate (1.2%) over the same period. Rising income and food production has considerably improved China's food security and substantially reduced the rate and severity of poverty. Interestingly, during the period of rapid economic growth, China has been a net food exporter (since the early 1980s) and net grain exporter (after the middle 1990s<sup>3</sup>).

Although China's economy grew rapidly, concern over national food security remained and, in fact, may have intensified. 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. In recent years, in the same way that occurred in Japan and Korea, urbanization and industrialization began to accelerate and

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cultivated land began to be converted to nonagricultural uses, such as for industrialization, the building of residences and the construction of infrastructure. Such trends are expected to continue into the future as China's growth is expected to double the nation's economic output during the first decade of the 21<sup>st</sup> century. Since these trends, including the conversion of cultivated land, have all occurred just as China's agriculture production hit a period over the last five years during which there have been five successive falls in grain sown area and production, grain security once again has become a top priority in national agricultural policy. Although prices of grain fell during most of the last five years, as soon as the price of China's major grains began to rise in late 2003, the issue of the effect of conversion of cultivated land into built-up area and its effect on grain production, imports and food security moved to the top of the policy agenda of China's national leadership. 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. When the price rises continued in February 2004, a directive came from the top leadership in March 2003 banning any further conversion, except for under several extreme conditions. Interviews with local leaders and commentaries in local and national periodicals show that different sets of actors have had strong reactions favoring and opposing the strong measures against continuing with the conversion of built-up area. Some claim it is critical to maintain national food security. Others say that it will cripple China's economic growth if the ban is kept in place for long.

Surprisingly, although the issue is so important and has such far-reaching potential consequences, there is almost no empirical research effort studying the economic consequences 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 for 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 land? What are the implications of cultivated land changes to nation's food security in the past and in the future?

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 examined based on Landsat TM/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 areas, we then calculate the corresponding changes in agricultural land bioproductivity, using a methodology that uses Agro-Ecological Zones (AEZ) to produce measures of bioproductivity. Our study finds that contrary to popular perceptions, 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 net fall in the bioproductivity of China's cultivated land. It is important to note, however, that the net decline over the study period was very small and it can be said with certainty that there was at most only a negligible effect on food security.

The paper is organized into 5 sections. Section two briefly introduces the methodology used in the study. Section three describes the unique dataset that we use in our analysis. The results are in the fourth section. The final section concludes and discusses the policy implications for the future management of China's cultivated.

## 2. METHODOLOGY

### 2.1 Land Use Models, 1-km area percentage data models

The vector data model and the raster data model are two of the most widely used models in spatial data analyses.<sup>1</sup> In a vector data model, each location or point is recorded as a single coordinate (x, y). A line is a series of ordered

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<sup>1</sup> [http://gis.washington.edu/cfr250/lessons/introduction\\_gis/spatial\\_data\\_model.html](http://gis.washington.edu/cfr250/lessons/introduction_gis/spatial_data_model.html).

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<sup>4-6</sup>. 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, such as slope and elevation along with some other aspect<sup>6</sup>.

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<sup>6</sup>. 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 have a number of advantages<sup>4-6</sup>. By combining the advantages of these two kinds of data models, Liu et al. further developed a 1-km area percentage data model (1-km APDM)<sup>7-8</sup>, or 1-km area with different land uses model, to detect and represent the land use changes on a 1 km x 1km grid scale. This model has been widely used in the past to analyze spatial and inter-temporal characteristics of land use change in China<sup>7-11</sup>.

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<sup>7,9</sup>. The procedures to generate the 1-km area percentage data are conducted in 5 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 the ArcGIS 8.02 software environment<sup>9-10</sup>. 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 LUT 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 LUC (the encroachment of urban land onto cultivated land).

## 2.2 Bioproductivity

There are several ways to estimate the potential productivity of cultivated land, or bioproductivity. As with any of the alternative methods, a number of assumptions are needed about the crops or mix of crops that can be produced on each plot of land. 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<sup>11-15</sup>.

The Food and Agriculture Organization of the United Nations (FAO), in collaboration with the International Institute for Applied Systems Analysis (IIASA), has developed one commonly used method of calculating bioproductivity, the Agro-ecological Zones (AEZ) methodology. The AEZ methodology serves 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<sup>11-13</sup>. In its simplest form, the AEZ framework contains three elements: selected agricultural production systems with defined input/output relationships, termed land utilization types (LUTs); geo-referenced land resources data (including climate, soil and terrain data); and procedures for calculating potential yields, matching crop/LUT environmental requirements (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 by 5 kilometers. As part of the agro-climatic characterization, Fisher et al. employed a water-balance model in each grid cell, based on monthly historical data from 1958 to 1988 to simulate when and for how long water is available to sustain crop growth<sup>12-13</sup>. 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 yield. 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<sup>13</sup>. 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 too susceptible to topsoil erosion<sup>13</sup>. In this study we follow the results on cultivated land production from IIASA as baseline values to estimate the changes of bioproductivity of cultivated land due to LUT conversions.

### 3. DATA

One of the strength of our study is the quality of data that we use to estimate cultivated land use change and bioproductivity. Satellite remote sensing digital images for our purposes are the most suitable data for detecting and monitoring LUC at global and regional scales. There are a number of choices. Satellite sensors, such as Advanced Very High Resolution Radiometer (AVHRR), Landsat Thematic Mapper (TM), and French SPOT system, have been used successfully for measuring deforestation, biomass burning and other land cover changes, including the expansion and contraction of deserts<sup>16</sup>. Remote sensing techniques also have been used widely to monitor the conversion of agricultural land to infrastructure (i.e., the process of urbanization).

In our study, we use a LUT dataset developed by the Chinese Academy of Sciences. Based on Landsat TM scenes with a spatial resolution of 30x30, our study's data are from satellite remote sensing data from the US Landsat TM/ETM images.<sup>2</sup> The database includes time-series data for three time periods: a.) the late 1980s, including Landsat-TM scenes for 1986-1989 (henceforth, referred to as 1986 data for simplification purposes); b.) the middle 1990s, including Landsat-TM scenes for 1995/1996 (henceforth, 1995); and c.) the late 1990s, including Landsat-TM scenes for 1999/2000 (henceforth, 2000). For each time period, we used more than 500 TM scenes to cover the entire country. Specifically, we use 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<sup>9-10</sup>. A hierarchical classification system of 25 land-cover classes was applied to the data.<sup>3</sup> 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 were validated against extensive field surveys<sup>7</sup>. The interpretation team from CAS conducted ground truth checks for more than 75,000 kilometers of transects across China. During the ground truthing more than 8,000 photos were taken using cameras equipped with global position system (GPS). The average interpretation accuracy for land-cover classification is 92.9% for the late 1980s and 97.6% for the late 1990s. The database from 1999/2000 was used for our analysis of current patterns of land cover in China. By comparing land cover patterns between the late 1980s and the late 1990s, we determined the change 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 by Liu<sup>9</sup>.

In order to obtain even more accurate estimates of land use, we also designed a matrix that will help us discount the areas in which there are thin ground objects. 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 time). 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

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<sup>2</sup> <http://www.reidc.ac.cn>.

<sup>3</sup> <http://www.reidc.ac.cn>

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

### 4.1 Changes in cultivated land

Using the methods and data described above, our study shows that China's the conversion of cultivated land to other uses was surprising 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 (Table 2, row 1, column 6). When compared to total cultivated area in 1986, the converted land accounted for 2.21% of total cultivated land (column 7). Conversion of this amount of land implies that the annual conversion of cultivated land to other uses was only 0.15% 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 conversions of cultivated land into other land use categories (Figure 1 and Table 2, columns 1 to 5). Among land converted out of agriculture, about 38% was converted to built-up areas. By far, most of the area is in the east coast of China. We also can see that smaller shares of cultivated land in the Loess Plateau and the Sichuan Basin were also converted into built-up areas. In addition to the area turned into industry, infrastructure and residences, 17% of the cultivated area was converted to forestry (in the south and southwest), 30% to grasslands (mostly in the northeast) and 16% to other areas.

Although considerable cultivated land was converted to other uses between 1986 and 2000, during the same time period even more land was converted from other uses into cultivated area (Table 2, row 2). Overall between 1986 and 2002, 5.71 million hectares of new cultivated land was created (column 6). As a share of cultivated land in 1986, the conversion of other land to cultivated land resulted in a gross expansion of 4.12%. Among the different types of land, most of the newly converted cultivated land, 55.23%, came from grassland; 27.76% came from forested areas and around 20% came from wet lands, the reclamation of unused land and other uses.

The mapping analysis also shows the distribution of the newly converted area (Figure 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 of 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 waste land were converted to cultivated area, although in some cases, the analysis shows that there is considerable conversions of one type of cultivated land (e.g., paddy) to other types of cultivated area (e.g., upland).

When looking at the aggregate record of China during the study period, we can see that in a large part the tendency to convert cultivated land into built-up area and other uses are in a large part offset by the conversion of grasslands, forestry and other land types into cultivated area. Hence, when taking the net gain (5.71 million hectares) from the net loss ((3.06 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 2.65 million hectares (Table 2, row 3). When compared to the base of cultivated area in 1986, China's farmers were cultivating 1.91% more land in 2000 than they were in 1986.

Comparing the maps in Figures 1 and 2, of course, shows that the location of land converted into cultivated area differs fundamentally from that converted from cultivated land into other uses, including built-up area. In Figure 3 we summarize the data by ranking the provinces by the net percentage of total cultivated area (using 1986 as a base) that was converted into or out of cultivated land. The results of such an analysis show in the case of more than half of provinces cultivated land falls. In general, cultivated land falls most sharply for the large municipalities and those provinces in southern and eastern China. It should be noted that Beijing and Shanghai are the only two provinces that experienced reductions of cultivated land that exceed 5%. In contrast, in one-thirds of provinces cultivated land rose. Most of the provinces that experienced net rises are in northeast China and in some parts of north China.

## 4.2 Changes in bioproductivity due to land conversions

Using the results of the AEZ analyses in conjunction with our data that tells us the net changes of cultivated land, we can come up with an estimate of the net change of in bioproductivity 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. In total, the bioproductivity of cultivated land decreased between 1986 and 2000 by 1505.98 million Kcal (Table 3). In percentage terms, this means that productivity during the 15-year study period only fell by 0.31%.

While overall there is only a small change, our analysis requires us to further break down the net change by land type, in general, so we can assess how much the conversion of cultivated land to built-up area has affected bioproductivity (Table 3). In total the conversions of cultivated land to other uses led to a net loss of 8756.09 million Kcal or 1.80% of total bioproductivity in 1986. Of this total amount, a decrease of 5153.25 million Kcal or about 58.85% of the total decreased bioproductivity (or 5135/8756) 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 bioproductivity 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 support two or more seasons), it is on less steep land in areas with more precipitation. In addition, of the total reduction in cultivated area due to conversion, 16.10% (or 1410 Kcal) is due to conversion to forestry, a figure that would be higher in 2004 since the nation's Grain for Green program (or a cultivated land conversion program) did not begin until 1999.

At the same time, the conversions of other uses to cultivated land have also led to the increase of cultivated land bioproductivity. In total, newly converted land accounted for 7250.11 million Kcal more in bioproductivity. As a percentage of bioproductivity in 1986, newly converted land raised bioproductivity by 1.49%. Of the total, conversions from grasslands (47.85% or 3469 Kcal) and forests (35.68% or 2587 Kcal) account for most of the increased productivity. Hence, although the quality of land that was converted into cultivated area was less 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 offset the fall in productivity due to conversion to built-up area.

When ranking China's provinces by the changing rates of bioproductivity, we can see that there exists an obvious spatial distribution patterns (Figure 4). The developed provinces located in the North China provinces, e.g., Beijing and Tianjin, account for a large shares of the falling bioproductivity. The eastern and southeastern provinces also account for a large fraction of the fall. In contrast, the large shares of land reclaimed as cultivated land in Northeast China, Inner Mongolia and some of inland provinces help boost productivity.

## 5. CONCLUSION

Our study finds that after the 25 years of rapid economy 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 retention of cultivated land, China's agriculture is actually doing well. Indeed, net cultivated land actually increased during the study period, 1986 to 2000. Decompositions of cultivated land changes show that nearly half of lost cultivated land was due to cultivated land converted to grassland (30%) and forest (17%). Of the remaining, most, indeed, nearly 40%, 125 were due to the shift to built-up area. However, there also was a considerable amount of newly cultivated land, some shifting from grassland and other from forestry area.

Although newly cultivated area rose, bioproductivity actually fell. The most important reason is due to the fact that the quality of land converted to built-up area from cultivated area is higher quality than that converted to cultivated area from other uses. Despite this, however, when examined in aggregate for the entire period, the effect on bioproductivity is negligible. Our study also finds that, despite the changes in land bioproductivity and potential decline of cultivated land in recent years (2000-2003) and in the future, China's national food security will remain high in the coming decades.

When considering the main message to policymakers, one of the most important lessons is that at least through 2000, there is not any real problem. It is true that land use needs strict management to facilitate rational land use in the short and long-run, but our work suggests that the current ban on land conversion is not warranted. Since the process of development is one of shifting the population from rural and agriculture to urban and industry, a complete ban on conversion, especially at the growth rates of China, may pose a serious threat to rapid development.

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Table 1. The classification system of land use categories used 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 meters high, with a canopy cover greater than 40%; land covered by trees with canopy cover between 10 to 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. Conversion of Cultivated Land in China, 1986-2000  
Land use (million hectares)

	Forestry area	Grassland	Water area	Built-up area	Unused land	Total	As percentage of 1986
Changes from cultivated land being converted to:	0.51	0.92	0.29	1.17	0.17	3.06	2.21
Changes from cultivated land being converted from:	1.58	3.15	0.23	0.07	0.67	5.71	4.12
Net changes	1.07	2.23	-0.06	-1.10	0.50	2.65	1.91

Data source: Author's data and calculations.

Table 3. Bioproductivity shifts (measured in million kcal) associated with changes in cultivated area in China, 1986 and 2000

	Land uses (million kcal)					Total	As percentage in 1986
	Forestry area	Grassland	Water area	Built-up area	Unused land		
Changes from cultivated land being converted to:	-1410	-672	-1371	-5153	-149	-8756	-1.80
Changes from cultivated land being converted from:	2587	3469	591	21	582	7250	1.49
Net changes	1177	2797	-780	-5132	432	-1506	-0.31

Data source: Author's data and calculations.

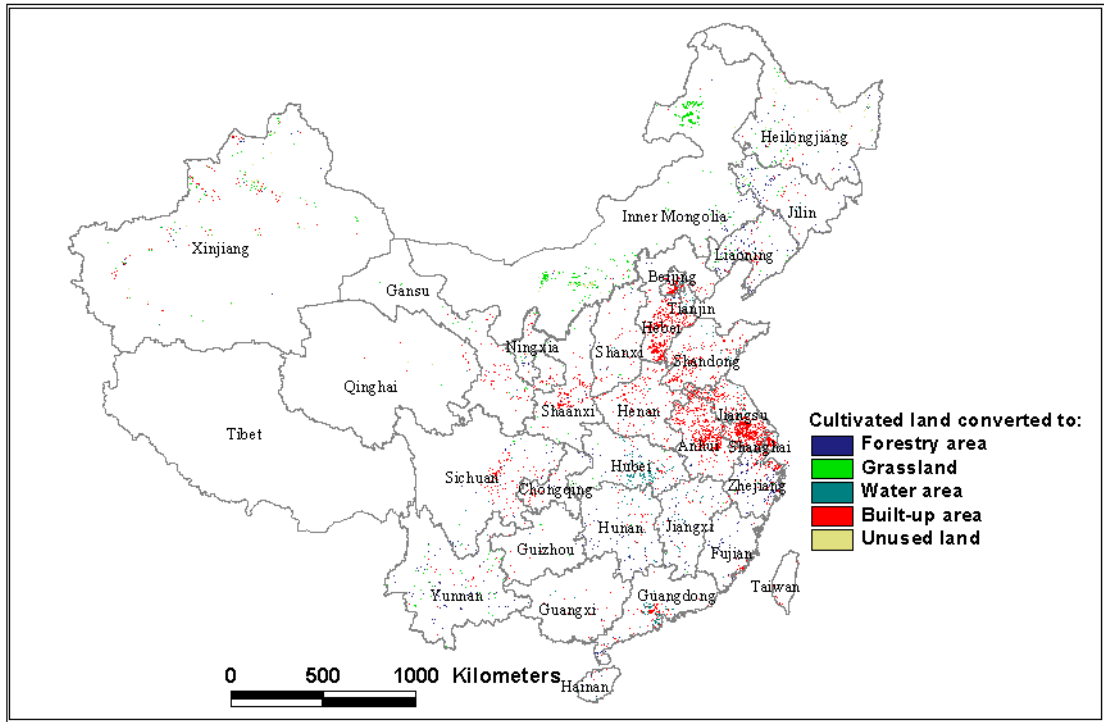


Figure 1. Distribution of land converted from cultivated land to other uses, 1986 to 2000.

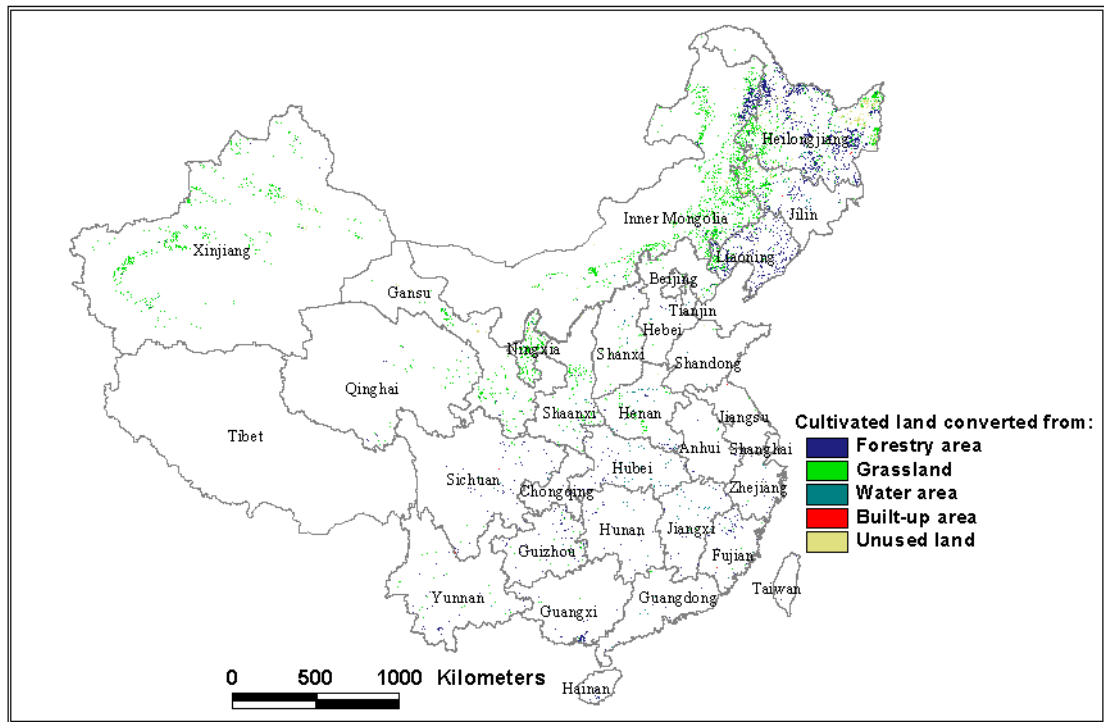


Figure 2. Distribution of land converted to cultivated land from other uses, 1986 to 2000.

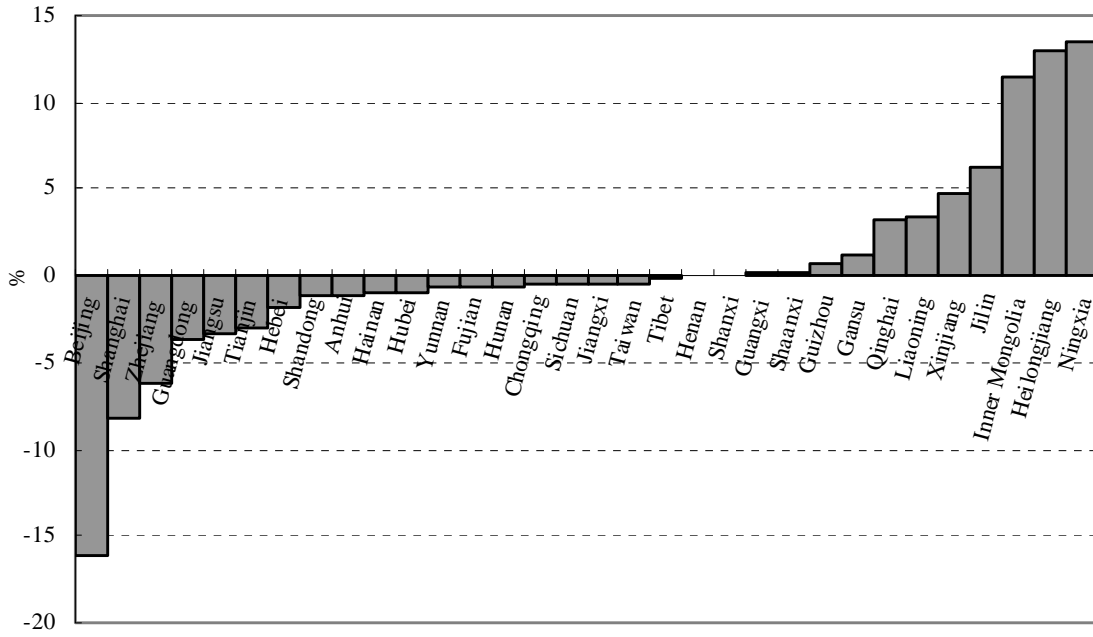


Figure 3. Percentage changes of cultivated land by province, 1986 to 2000.

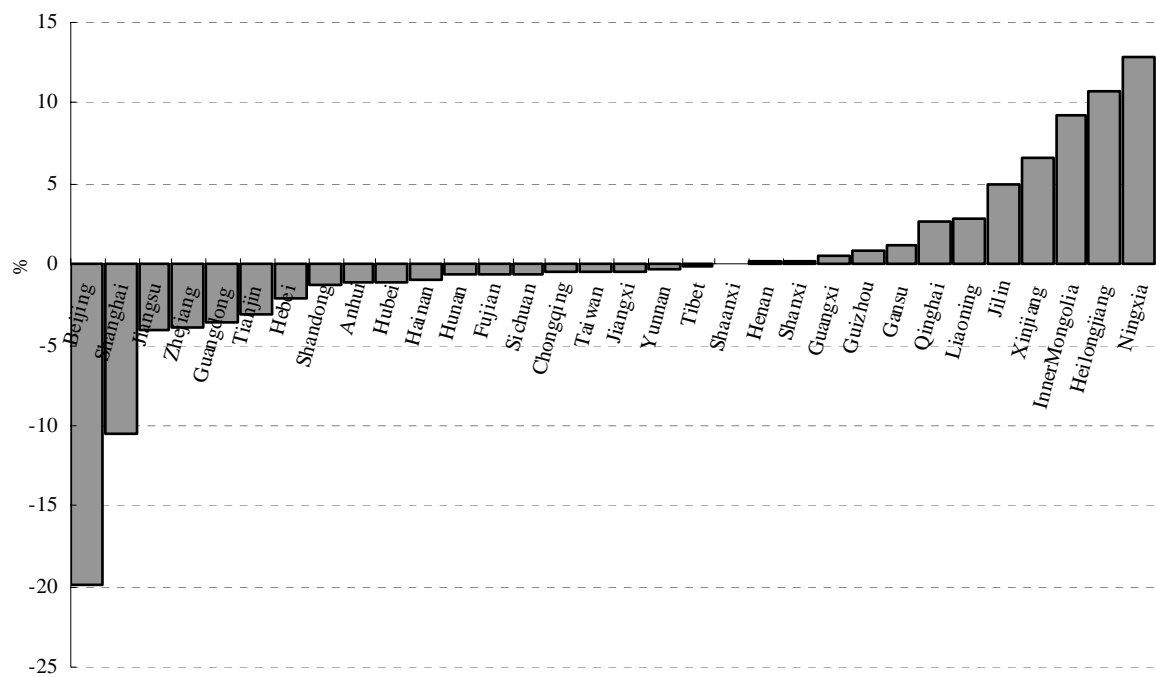


Figure 4. Percentage change of bioproductivity associate with changes in cultivated land by provinces, 1986-2000