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Rapid urbanization in China: A real challenge to soil protection and food security

Jie Chen*

State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China

Abstract

To feed its 1.3 billion population with a per capita cultivated land far below the world average, China is already facing a great challenge of land scarcity. Accelerated urbanization along with explosive economic growth has further worsened the shortage of agricultural land over the last two decades. Increasing concern over land is expressed in terms of soil availability for grain production and soil quality degradation. Based on official statistics and data derived from satellite imagery, dynamics of China's cultivated land over the past two decades is outlined and the causes and destinations of cultivated land loss are analyzed in this paper. Particularly, urbanization-related land-use changes and their spatial variation across the country are demonstrated. Furthermore, impacts of urbanization and associated waste disposals, consequent shifts of soil utilization on areal soil quality are expatiated. It is initially concluded that China's cultivated land is shrinking at a rather shocking rate. Although conversion to urban and industrial uses took up a comparatively small share of total cultivated land loss, urbanization should still be considered as a great threat to future agricultural production for several reasons. Urbanization is increasing the risk of soil pollution through waste disposal and acid deposition derived from urban air pollution. Facing rapid urbanization, China is making positive policy responses to the challenge of decreasing availability of cultivated land and offering unremitting efforts towards the goal of national food security.

Keywords: Urbanization; Cultivated land; Soil resource; Food security; China

1. Introduction

Urbanization, referring to a growth in the proportion of a population living in urban areas, is one of the major social changes sweeping the globe. According to the latest estimate and projection released by the Population Division, United Nations, the world's urban population continues to grow at a higher rate than the total population of the world, and 3 billion people or approximately 48% of the world population are now city dwellers (United Nations, 2004). Urbanization is progressing rapidly in the less developed regions and urban population is anticipated to grow an average 2.3% per year in the developing world between 2000 and 2030. Almost all of the world's total population growth in this period is expected to be absorbed by the urban areas of the less developed regions (Brockherhoff, 2000; United Nations, 2000, 2004; UNFPA, 2004) (Fig. 1).

As the most populous nation, China has the largest urban population in the world but a comparatively low urbanization level, approximately 10% lower than the world average and 30% lower than more developed regions (United Nations, 2004). On the other hand, China has been widely viewed as a case of under-urbanization, and urbanization has lagged rather behind its industrialization as a consequence of urban-restricting policies concerning migration toward cities before the economic reform (Chan, 1996; Chang and Brada, 2002; Zhang and Zhao, 2003; Liu et al., 2003). With the unprecedented economic growth, however, the country has been witnessing a dramatic growth of urbanization since 1978 when economic reform began. Statistics from the Ministry of Construction of China (abbreviated as MCC, hereafter) show that, the urbanization level in China increased from 17.9% in 1978 to 40.5% in 2003, demonstrating a growth twice as fast as the world average

* Tel.: +86 25 86881278; fax: +86 25 86881000.
E-mail address: jchen@issas.ac.cn.

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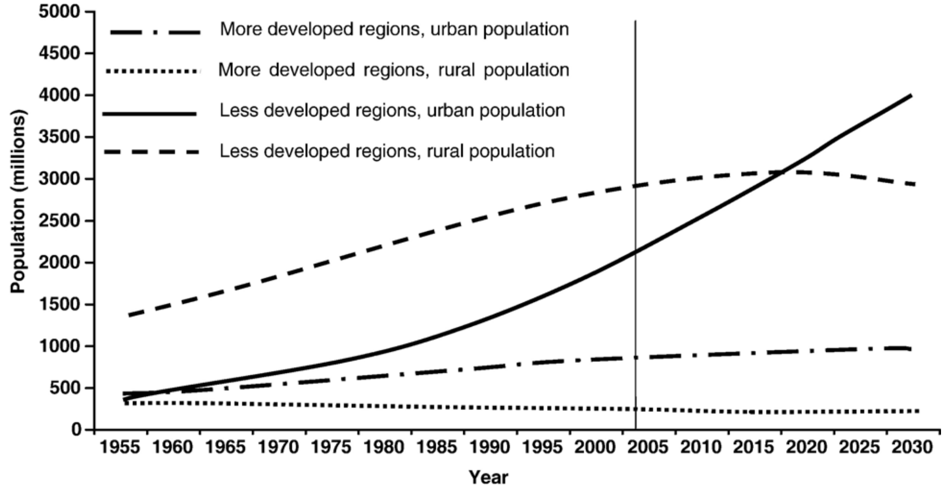

Fig. 1. Estimation and projection of the world's urban and rural populations, 1950–2030 (from United Nations, 2004).

of the same period (MCC, 2002–2004)[1] (Fig. 2). Recognizing urbanization's central role in further economic growth and social development, China will continue to give high priority to urbanization in the coming decades. China's urbanization level is projected to range between 48% and 50% by 2020 and the proportion of urban population is expected to exceed 60% by 2030.

Despite numerous benefits originating from urbanization, a rapidly urbanizing world including China faces intensified resource scarcity and environmental degradation. It is known that urbanization is dependent on a steady supply of natural resources including fresh water, fuel, land, food and all the raw materials (WRI, 1998; UNFPA, 1999; Hardoy et al., 2001; Hinrichsen et al., 2001). Along with rapid urbanization and city sprawl, there definitely are drastic increases both in natural resource demands and in the area from which these resources are drawn (O'Meara, 1999). Urbanization also leads to significant alterations of physical environment far beyond city limits, resulting in habitat loss, climatic changes, and accumulation and spread of wastes in the Earth's atmosphere, hydrosphere and pedosphere.

As the foundation of terrestrial ecosystems, soil not only functions as an indispensable physical base to provide humankind a majority of food, livestock feed, fibre and biotic fuel, but serves as both a source and a sink for green house gases and an integrated part of biogeochemical cycles (Yaalon, 2000; Bunning and Jiménez, 2003). With unique pedogenetic characteristics formed by the combined effects of environmental and biological factors over geological periods, soil could be considered as a non-renewable resource in a human time perspective (Amundson and Jenny, 1997; Amundson et al., 2003). Urbanization leads to conversion of a natural landscape to an urban area and intensifies competition between different land-use practices in space and time, thus posing direct and indirect influences on soil resources, and on food security (Blum, 1997).

2. Dynamics of cultivated land under accelerated urbanization

It is particularly true in China that the recognizable value of the soil resource has centered on agricultural land, since the country is feeding 22% of the global population on less than 9% of the world's cultivated land. According to the latest report released by the Ministry of Land and Resources (MLR, hereafter), the total cultivated land area in China shrank by 2.01% in 2003 over the previous year to 123.4 million ha accounting for 41% of the world average (MLR, 2004)[2] and the average cultivated land per capita cropped to 0.095 ha. Now only 12.8% of total national terrestrial surface is available for agricultural production (land-use structure in 2003 displayed in Fig. 3).

2.1. Shrinking of total cultivated land

Increasing concern over land scarcity is expressed in terms of soil availability for agricultural production which is worsened due to rapid population growth and accelerated urbanization and industrialization over the past two decades (Yang and Li, 2000; Lin and Ho, 2003; Zhang et al., 2004). Studies focusing on land composition and magnitude, extent, and driving factors of land-use changes, however, have been severely hampered by unreliability of official statistics (U.S. Embassy Beijing, 1996, 1998; Yang and Li, 2000; Lin and Ho, 2003). Based on the sets of statistics from different authorities, estimates of the amount of cultivated land ranged

[1] China's percent urban at mid-year of 2003 released in *World Urbanization Prospects (the 2003 revision)* is 38.6, which is presented as the official United Nations population projection at national level.

[2] The figures used here in terms of the world total and per capita cultivated land areas are cited from FAOSAT, which were updated in 2002, available through http://apps.fao.org/default.jsp.

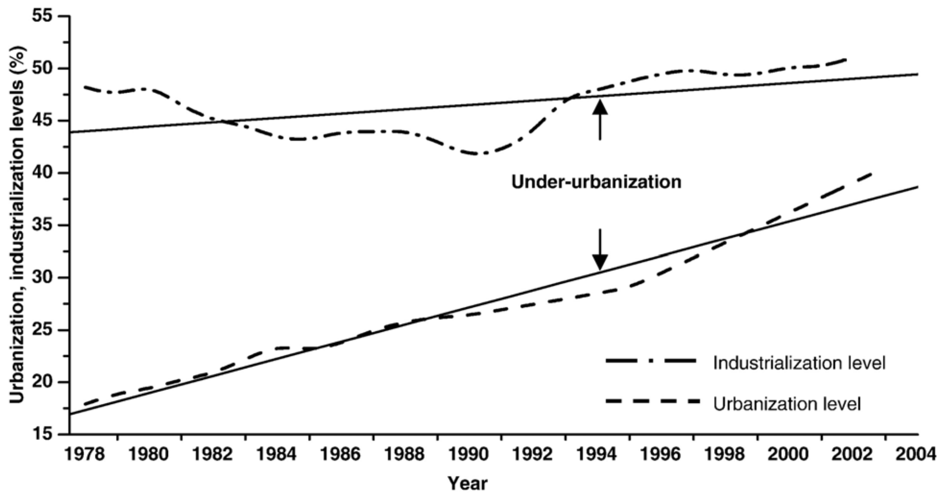

Fig. 2. Dynamics of urbanization and industrialization levels of China between 1978 and 2003 (data source: NBS, 1996–2003; MCC, 2002–2004).

widely, from less than 93 million ha to nearly 140 million ha, until a consensus was generally achieved that China's arable land totaled to some 130 million ha in 1996 when the nationwide land survey was conducted with availability of LANDSAT photography and the assistance of remote-sensing techniques (U.S. Embassy Beijing, 1996, 1998; Heilig, 1999; NBS, 1996–2003; Lin and Ho, 2003). Despite lack of comparable official figures in the terms of the total cultivated land between the different periods, it is commonly recognized that land-use changes have drastically transferred soil resources away from agricultural production. Using the base underestimation, the total cultivated land decreased by 4.42 million ha between 1978 and 1995. Based on the figures commonly adopted after the 1996 national land survey, it is found out that 6.72 million ha of arable land, or 5.1% of the country's total, was lost to industrial and urban destinations or other purposes in the 7-year period from 1996 to 2003 (Fig. 4). Comparing the two layers in Fig. 4, it is evident that loss of the cultivated land has significantly accelerated since the middle 1990s, especially during the first several years of the new century.

2.2. Causes and conversions of cultivated land loss

The low availability of the information on land-use patterns and uncertainties of the category definitions

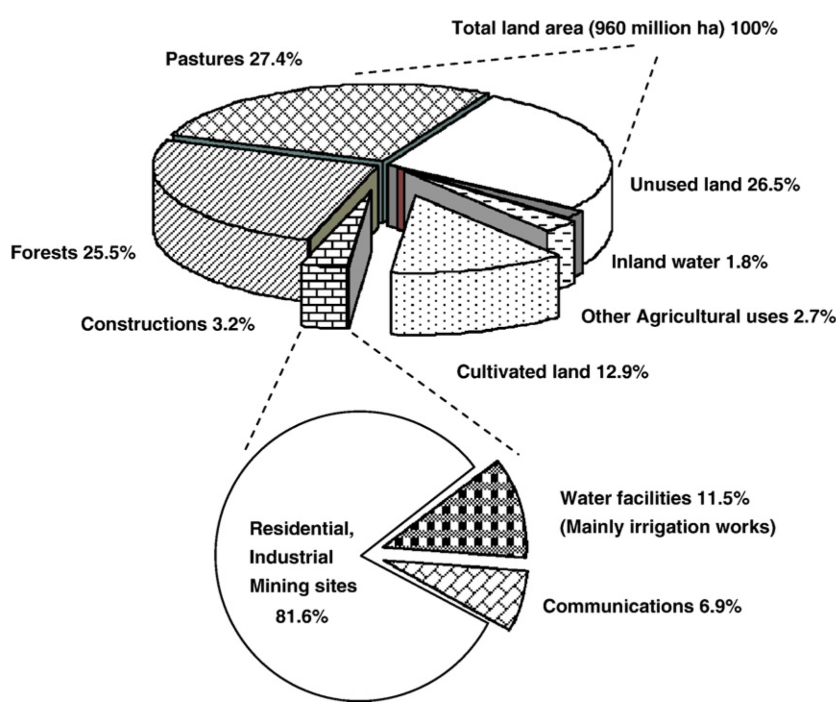

Fig. 3. Land-use structure of China, 2003 (data source: MLR, 2004).

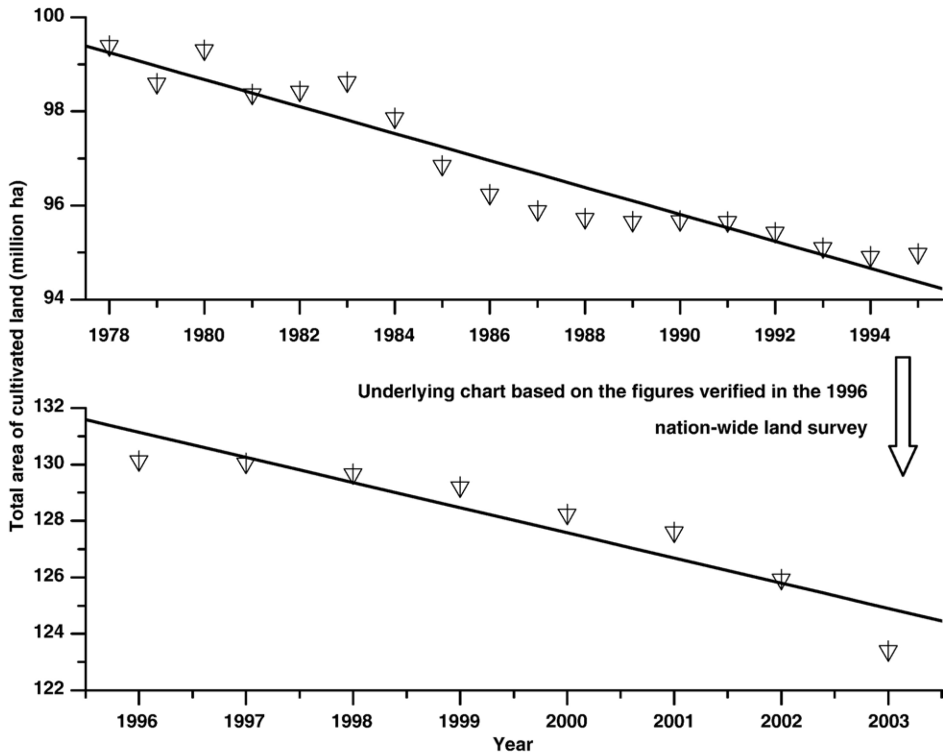

Fig. 4. Change in the total cultivated land of China between 1978 and 2003 (data source: NBS, 1996–2003; MLR, 2004).

significantly limit the accuracy of assessment of land conversions. Nevertheless, the data pieced together through the available sources still allow an in-depth investigation of the causes and conversions of cultivated land (NBS, 1996–2003; Yang and Li, 2000; Cai et al., 2002; Lin and Ho, 2003; Lu et al., 2003). The data in Table 1 show, between 1986 and 1995, agricultural restructuring, namely conversion of crop production to other agricultural purposes, such as orchards and cash-crop plantations, is the dominant cause leading to reduction in cultivated land, accounting for 62% of the total loss. Construction as one of four classified categories, is defined as conversion of cultivated land to urban and rural settlements, industrial and mining sites, communications and agricultural facilities. It accounts for 21% of the total loss of cultivated land. In the late 1990s, China started a vigorous initiative of "returning reclaimed land to ecology" to protect fragile soil-based ecosystems especially in the vast west. As a result, the conversion structure of cultivated land was significantly altered by the addition of the new transfer category. Since then, the ecological destinations (perhaps including part of conversion with ecological significance within agricultural sector) began to dominate the conversion of cultivated land and replaced agricultural restructuring as the top cause. Between 1997 and 2003, conversion for ecological purposes accounted for 54.2% of the land removed from agricultural production. Despite slight changes in the percentage, the areas of cultivated land annually occupied by construction significantly increased over time, from 142,700 ha in the period from 1986 to 1995 to 190,900 ha from 1997 to 2003.[3] Although land practices shifting within agriculture and competing between agricultural production (fishery ponds and poultry sheds exclusive) and ecological maintenance have been significantly altering land-use structures, they neither lead to reduction in amount of areal soil resources or change basic characters of soils as one kind of natural resource in terms of productive and ecological functions. In contrast, the conversion to construction results in irreversible loss of soil resources in the fullest meaning. To assess the dynamics of soil resources, therefore, particular attention should be paid to land development accelerated by economic growth.

2.3. Land converted to urbanization and its spatial variation across the country

The land claimed for construction is consistent with urbanization and industrialization over the past two decades. It is estimated that land used for urban sprawl and industrial development accounts for more than half of the total construction area converted from agriculture. Based on information derived from LANDSAT photography, the study by Tian and Zhuang (2004) concluded that, for the country as a whole, the soil landscapes under a variety of former uses

[3] Using a combination of data sets from different sources (Ministry of Agriculture of China, Tabulations of Chinese Agriculture, Agricultural Yearbook of China), Yang and Li (2000) made a higher estimate (about 200,000 ha) of the annual conversion from cultivated to construction use.

Table 1
Loss of cultivated land: causes and the conversions

	Unit: 1000 ha	Ecological conservation		Agricultural readjustment		Construction		Natural hazards	
		Area	%	Area	%	Area	%	Area	%
Period from 1986 to 1995									
1986	1108.3			684.6	61.8	252.6	22.8	171.1	15.4
1987	877.2			556.5	63.4	194.0	22.1	126.7	14.4
1988	676.3			394.7	58.4	122.2	18.1	159.4	23.6
1989	417.3			231.1	55.4	89.2	21.4	97.0	23.2
1990	346.4			207.7	60.0	82.7	23.9	56.0	16.2
1991	448.3			234.8	52.4	102.5	22.9	111.0	24.8
1992	707.3			452.9	64.0	155.5	22.0	98.9	14.0
1993	625.3			423.4	67.7	134.5	21.5	67.4	10.8
1994	785.1			511.1	65.1	133.1	17.0	140.9	17.9
1995	798.1			511.8	64.1	160.5	20.1	125.8	15.8
Total	6789.6			4208.6	62.0	1426.8	21.0	1154.2	17.0
Average	679.0			420.9	62.0	142.7	21.0	115.4	17.0
Period from 1997 to 2003									
1997	462.3	163.7	35.4	55.1	11.9	192.3	41.6	47.1	10.2
1998	575.4	164.6	28.6	70.0	12.2	176.2	30.6	164.6	28.6
1999	841.7	394.6	46.9	107.0	12.7	205.3	24.4	135.0	16.0
2000	1566.6	763.0	48.7	578.0	36.9	163.0	10.4	62.0	4.0
2001	830.1	590.7	71.2	45.0	5.4	173.7	20.9	30.6	3.7
2002	2028.7	1425.5	70.3	349.0	17.2	196.5	9.7	57.6	2.8
2003	2537.4	2237.3	78.6	364.1	11.6	427.8	8.0	50.4	1.8
Total	9153.0	5739.6	54.2	1535.4	15.4	1336.1	20.8	547.3	9.6
Average	1307.6	819.9	54.2	219.3	15.4	190.9	20.8	78.2	9.6

Data sources: Lin and Ho, 2003; Li, 2004.

including cultivated land, forest, grass and vegetable gardens together contributed 85.6% of the total acreage of urban sprawl between 1990 and 2000.

Geographically, soil resources, in terms of biotic productivity and suitability for agricultural uses, are unevenly distributed across the country. Approximately 90% of China's soil resources used for agricultural and forestry productions are concentrated in the monsoon-affected region covering less than half of the country's territory (Li et al., 2004). In East China, especially the coastal provinces with favorable climatic conditions for agricultural production, the soil resources are extremely scarce. The average cultivated land per capita is much lower than that in Central and West China. Most of the 670 counties with cultivated land per capita lower than 0.05 ha are located in the provinces of East China. As the cradle of China's agriculture, historically East China has intensively used soil resources for crop cultivation; agricultural soils account for 30% of the total land surface, nearly 10% higher than the Central and more than 20% higher than in the West of China. This contributes a greater share to the country's total grain production (Li et al., 2001; Guo, 2002; Lin and Ho, 2003). The spatial distribution of cultivated land per capita, multiple cropping index (MCI) and grain yields per unit across China in 2002 are shown in Fig. 5. As the heavily populated regions have more intensive economic activities, the proportion of land claimed by human settlements and economic infrastructures in East China has been well above the country average. Particularly since economic reform, China's eastern and coastal provinces, thanks to favorable policies and their accessibility to the outside world, have experienced vigorous economic growth leading to urbanization and industrialization significantly faster than that in interior counterparts. As a consequence, urban land-use has been increasing at a much higher rate. Fig. 6, created from the LANDSAT-based estimates by Tian and Zhuang (2004), displays the variations in proportion of urban land-uses (cities and towns, villages and scattered settlements exclusive) and expansion rates across the country.

Perhaps for aforementioned reasons, studies focused on land-use changes induced by urbanization and city sprawl have been concentrated in East China, especially in three metropolitan areas, namely Yangtze River Delta (YRD, hereafter), Pearl River Delta (PRD) and Beijing–Tianjin–Hebei (BTH) regions (Shen et al., 2001; Ho and Lin, 2004). Tan et al. (2005), using satellite imagery, estimated urban expansion and the consequent agricultural soil loss in the BTH region between 1990 and 2000. They indicated that the total urban area (including cities, county seats and designated towns) of the region increased by nearly 71%, from 2135.7 km^2 to 3651.8 km^2 between 1990 and 2000, resulting in an 18.7% drop of farmland per capita in the BTH region. It was concluded that the metropolises (Beijing and Tianjin) and county seats, rather than middle-size cities, were major contributors to the total loss of arable land. The preliminary results of land-use changes in the YRD region are exhibited in Fig. 7. It is clearly seen that the urbanized area had dramatic growth during the period from 1984 to 2003. The percent of total land area covered by the cities,

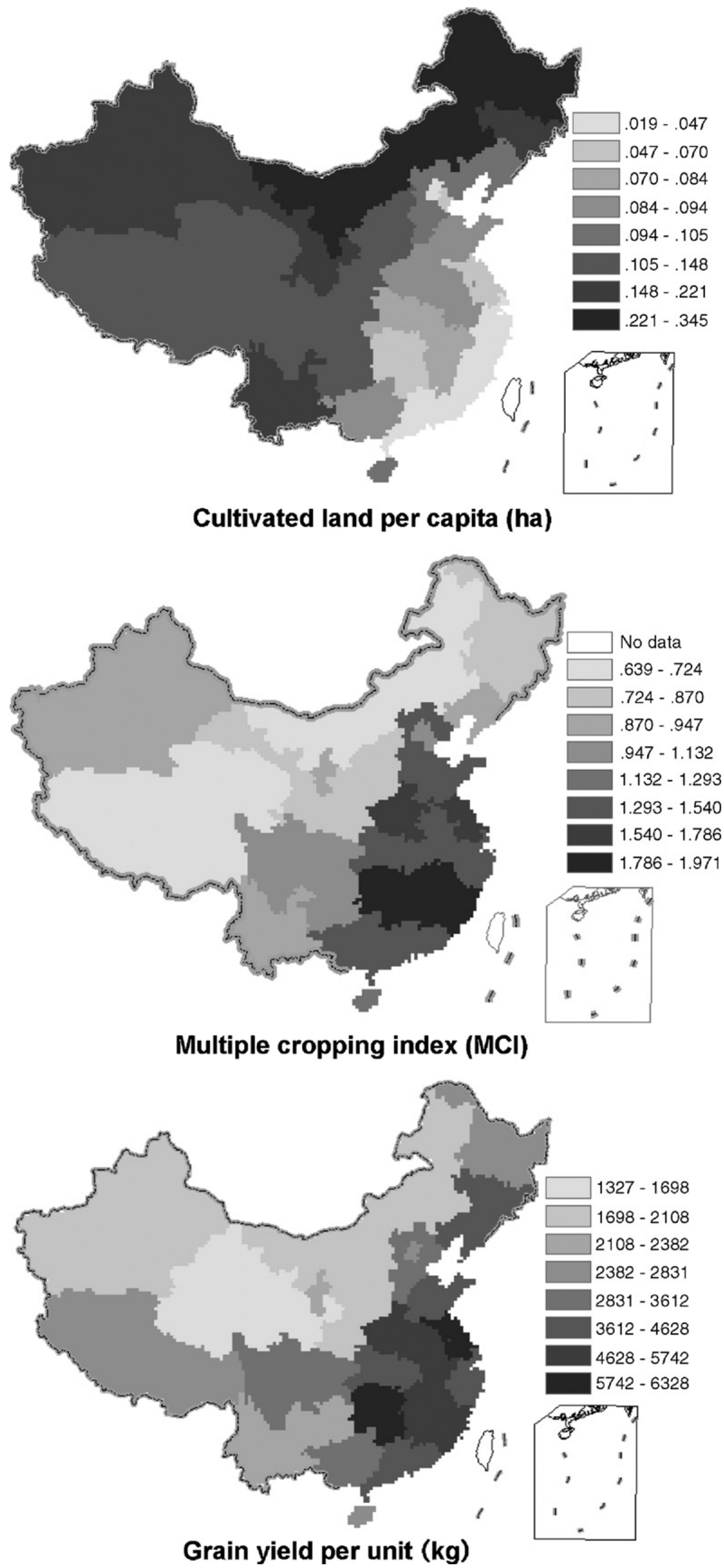

Fig. 5. Spatial variation of area per capita, utilization intensity and productivity of cultivated land (data source: NBS, 1996–2003).

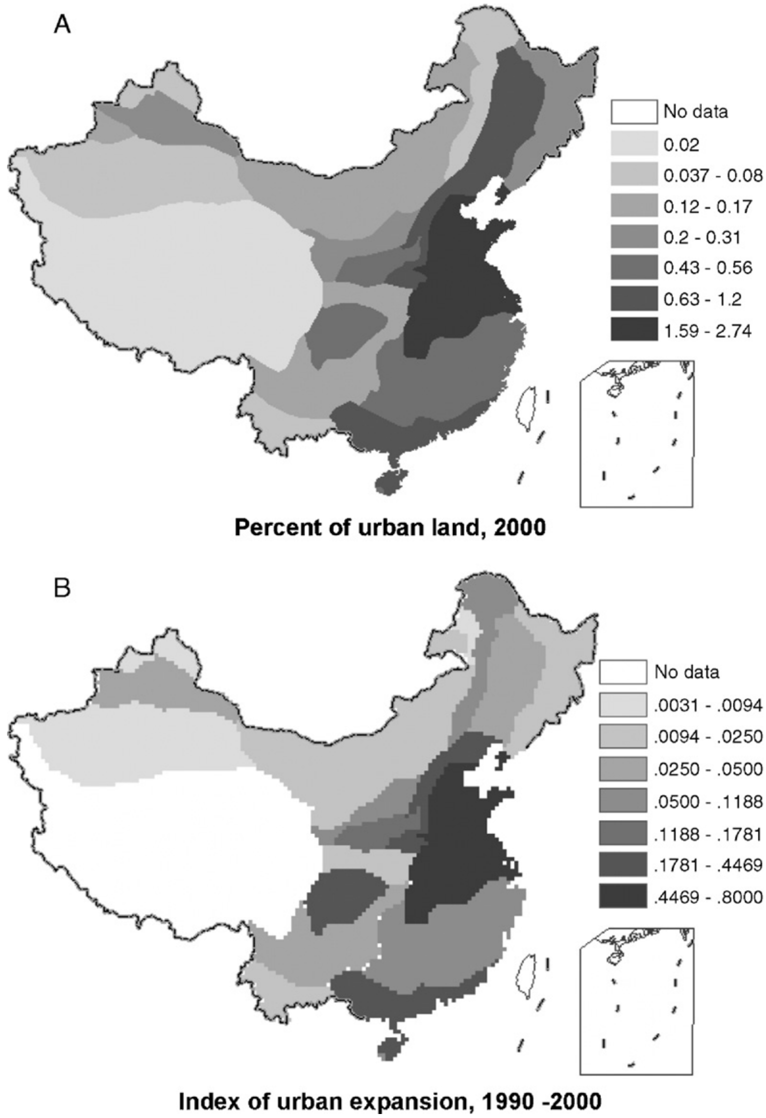

Fig. 6. Proportion of urban land and index of urban expansion in China. *Based on data source (Tian and Zhuang, 2004), percentage of urban land used here referring to proportion of urban built-up in total area land, while index of urban expansion standing for percentage of expanding area in total area land during the period from 1990 to 2000.

towns and villages increased from about 3.5% in the middle 1980s to 8.3% in 2003. Significantly differing from that in the BTH region, urbanization in the YRD region is characterized by extensive establishment of development zones in and near cities and drastic expansion of rural construction driven by the development of township–village enterprises (TVEs) (Ho and Lin, 2004). The lands encroached on by numerous development zones and rural construction (both settlements and enterprises), rather than a few big cities, account for the large share of agricultural land loss in the YRD region.

2.4. Excessive requisition and abuse of land

An increasing concern over the expansion of urban development into agricultural landscapes has been expressed in China since the country encouraged urbanization. Some are concerned that accelerated urban use of productive soil landscapes may threaten food security and environment sustainability, while others optimistically believe that, with good planning and management, a significant increase of urban population can be accommodated by limited increase of land area. For the country as a whole, however, a rapid growth of urban area has a paralleled growth of the urban population over the past decades. According to the statistics from the related authorities, between 1990 and 2003, the total built-up area of China increased by nearly 1.18 times, from approximately 1.28 million ha to 2.8 million ha, while urbanization level only increased by less than 54%, from 26.41% to 40.53% (NBS, 1996–2003; MCC, 2002–2004). The index of urban land development, defined as the ratio of increased rate of urban area to that of urban population, is employed to assess the efficiency of urban land-uses (Xiao, 1997; Yang and Han, 1998; Tan et al., 2005). For the past two

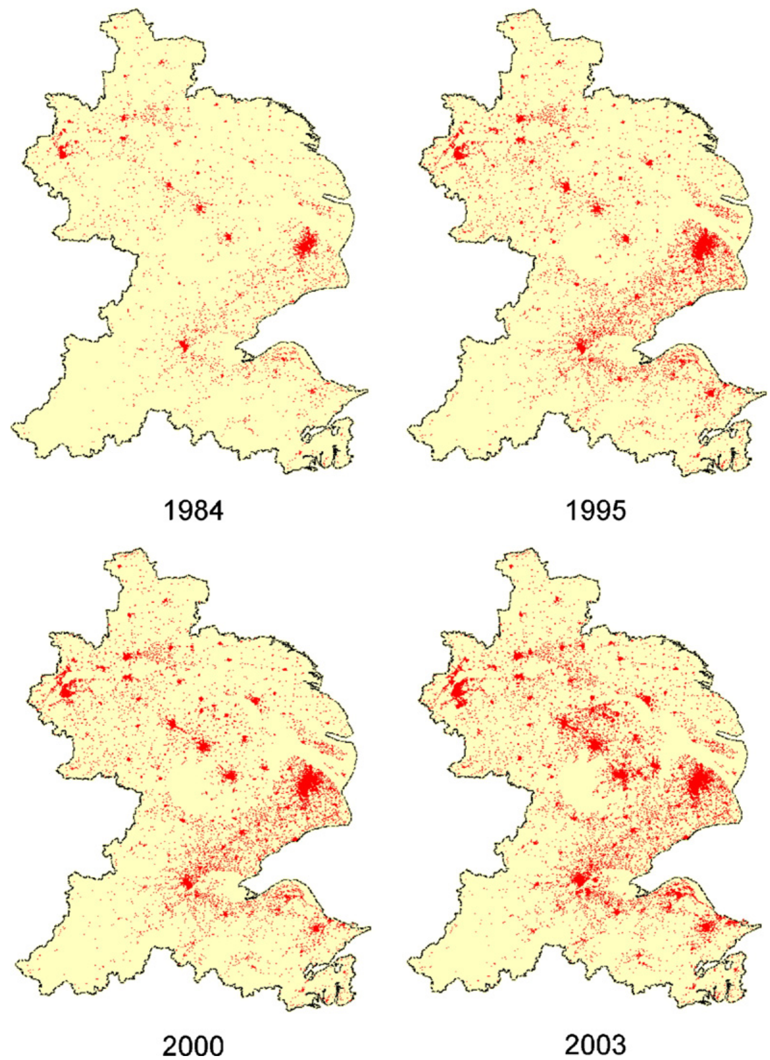

Fig. 7. Urban area estimates in Yangtze River Delta region (YRD) between 1984 and 2003 (isolated villages and settlements with an area smaller or equal to 0.08 km^2 are not displayed).

decades, the average index calculated based on the data released by official authorities was almost double the suggested desirable value (1.12), demonstrating a serious land abuse during urbanization. The economic development zones can be considered as typical examples of excessive requisition of lands. A recent MLR report revealed that development zones of various kinds across the country, including economic and technological development zones, industrial parks and high-tech zones, totaled 6741, taking up a planned area of 3.75 million ha, which is more than the present total built-up areas of 667 Chinese cities. According to MLR officials, more than 70% of these development zones were illegally built and nearly 65% of the total area abused.

3. Impacts of urbanization on soil quality

While dynamics of areal soil acreage during urbanization can be simply determined through spatial data analysis using a variety of physical approaches, detailed and quantitative assessment of urbanization's role in soil quality evolvement remains a great challenge, even though it has been commonly recognized that changes in land-use practices and material inputs associated with urbanization could significantly affect areal soil quality. Our current knowledge fails to establish reliable cause–effect relationships between urbanization and quality dynamics of affected soils. Consequently, a nation-wide assessment of urbanization influences on soil quality seems hitherto impossible in China. Numerous site-special studies and descriptive analysis focusing on interactions between urbanization (and urban activities) and areal soil environments, however, have been conducted. An introduction to soil quality dynamics associated with urbanization in the country may be made through the knowledge available.

3.1. Soil pollution associated with urban wastes

The total area of polluted cultivated soils in China is believed to be several times higher than previous estimates of about 10 million ha (U.S. Embassy Beijing, 1996; Chen et al., 2002a). According to the latest estimate by the experts from the Chinese Academy of Sciences (CAS), the acreage of the soils polluted by heavy metals alone accounts for 20 million ha, almost one-sixth of the cultivated land total, causing an annual grain yield loss of 10 million tons. In China, polluted soils are mainly distributed in the intensively cultivated areas and peri-urban zones. Untreated discharges of industrial and municipal refuses, inappropriate use of agrochemicals and urban wastes, and irrigation of sewage and polluted water are major causes of soil pollution.

With rapid urbanization and industrialization during the last two decades, generation of municipal solid waste (MSW) in China has increased at an average annual rate of about 9%, from 31.3 million tons in 1980 to 150 million tons in 2001 (Wang and Nie, 2001; Chen et al., 2002b). Due to the lack of facilities, only about 21% of MSW generated was processed. It was estimated that accumulated amounts of the untreated MSW had reached 7 billion tons in urban China by 2000.[4] Serious soil pollution might occur not only at and immediately around the landfill sites which occupied an estimated total acreage of more than 55,000 ha in the country, but in the vast peri-urban areas as a consequence of MSW land application under limited control (Wang, 1999).

Soil pollution has also been caused by industrial and municipal sewage and polluted surface water through irrigation and flooding events. Due to increasing industrial and municipal discharge, pollution threatens most of China's surface water resources. About 78% of the streams crossing urbanized regions have been so polluted that the water is no longer available for drinking. Due to rapidly decreasing availability of clean water supply, these polluted streams have been commonly used for irrigation. In the regions where water resources are seriously scarce, for example in the peri-urban areas of North China, urban sewage and industrial effluent have to be used to irrigate farmland, orchards and vegetable gardens. A nationwide investigation indicated that the area of the lands irrigated by polluted water and sewage was 3.62 million ha in 1995 (about 1.6 times higher than in the early 1980s), covering some 7.3% of the country's total irrigated lands and 10% of the total land area irrigated by surface water. Such lands irrigated directly by untreated urban sewage and industrial effluents accounted for 0.51 million ha (Wang and Lin, 2003).

Besides MSW and urban sewage, vehicle exhaust, atmospheric deposition, hazardous accidents and intensive use of agrochemicals can also significantly deteriorate the soil environment. Reportedly, soil pollution associated with urban and industrial sources accounts for one-third to half of the total polluted arable area in the country, with a concentrated distribution in the peri-urban zones. Numerous site-specific studies focused on soil pollution have been conducted in the most urbanized and industrialized regions of China, for examples, in BDH region (Mao and Lu, 2002; Chu et al., 2003; Ma et al., 2003; Wang and Lin, 2003; Wang et al., 2004), YRD region (Li et al., 2002; Zhou and Zhu, 2003; Wuzhong et al., 2004; Yang et al., 2004a) and PRD region (Weng and Chen, 2000; Wong et al., 2002; Cheung et al., 2003; Yang et al., 2004b; Zhou et al., 2004). Significant accumulations of a variety of pollutants including heavy metals, pesticide residues and persistent organic pollutants (POPs) were found in the peri-urban soils of these regions. A recent survey on soil quality carried out by the Institute of Soil Science, Chinese Academy of Sciences (ISSAS) revealed that about half of the area of paddy fields in the Taihu Lake watersheds of YRD region was polluted. Besides heavy metals, 15 kinds of polychlorinated biphenyls (PCBS) and organochlorine pesticides were detected in all of the tested paddy soils. In PRD region, about 50% of peri-urban areas of some cities suffered from soil pollution by heavy metals Cd, Hg, As, Cu, Pb, Ni, Cr and petroleum hydrocarbons. Serious status of soil pollution has led to an increasing concern over food quality safety (so-called FQS) in China. A spot check carried out in 2000 indicated that the concentrations of heavy metals in 30% of agricultural products produced in 7 out of 10 sampled peri-urban areas (of provincial capital cities) exceeded the permissible values of the National Standard for Food Safety.

3.2. Soil degradation associated with acid deposition

Air pollution associated with rapid urbanization and industrialization in China has become an environmental issue of widespread concern. Increasing energy production concentrated in urban and peri-urban areas is the major contributor to anthropogenic air pollution. Accounting for about three-quarters of energy production in China, coal consumption makes the country the largest source of soot and SO_2 emissions of the world (Larssen et al., 1999a; Li and Gao, 2002). As a consequence, China is suffering from severe acid deposition characterized by SO_2 as the key precursor. According to SEPA (2002–2004), in 2003 acid rain fell on 265 cities and annual average precipitation pH values equaled or was lower than 5.6 in 182 of the 487 cities monitored. The data indicated that acid rain pollution worsened nationwide and the area severely affected by acid rain increased, compared with previous years. With relatively higher concentrations of calcium and other base cations derived from air-borne soil particles, precipitation pH in most parts of North China has remained high despite more intense sulfur emissions (Larssen and Carmichael, 2000). The regions with annual average pH values of precipitation lower than 5.6 are mainly located south of Yangtze River, east of Qinghai–Tibet plateau, and in the Sichuan basin.

[4] Based on the data (MSW generation rate estimated at 285 kg/cap/year) released by World Bank in 1992, Henderson and Chang (1997) estimated that the total MSW generated was more than 300,000,000 tons/year, much higher than the official statistics of SEPA. More detail available through. http://www.ecowaste.com/swanabc/papers/hend01.htm.

Only a few northern cities have received acid rain pollution (He et al., 2002; SEPA, 2002–2004) (Fig. 8).

Concern over impacts of acid deposition on soil quality has emerged since 1980s. Due to both lower buffering capacity and higher precipitation acidity, soils distributed in South and Southeast China are much more subject to acidification and associated damage. Up to now the knowledge obtained fails to quantitatively determine the changes in physical, chemical and biotic characteristics of the soils exposed to acid deposition, partly because of the time-lag hysteresis between occurrence of acid rain and onset of any consequent soil responses and possible involvement of other causes of soil acidification in the natural conditions (Larssen et al., 1999b; He et al., 2002). However, more and more evidence from numerous site-special field investigations and laboratory leaching experiments strongly suggest that acid deposition is effectively inducing and accelerating soil degradation, especially in South and Southeast China where Ferrisols and Luvisols (commonly known as red and red-yellow soils) are mainly distributed.

First of all, it has been demonstrated that acid deposition significantly reduced stability of soil aggregates and increased structure destruction of some Ferrisol samples through enhancing decomposition of organic matter and mobilization of ferric oxides (Xu et al., 2002). The results suggest that acid rain not only lowers soil arability, but is responsible for increased soil erosion in the Ferrisol areas. As for soil chemistry, many studies indicate that, decreased pH of soil solutions by accumulated acid deposition could significantly enhance the release, mobilization and migration of elements in soil environments, thus leading to depletion of nutrients in cultivated soils (Qi et al., 2004; Gao et al., 2004; Xu et al., 2004a), increase in biotic availability of heavy metals in polluted soils (Guo et al., 2003a,b), and acceleration of aluminum transportation from low acid-buffering soils to other environmental phases (Larssen et al., 1999a,b; Bi et al., 2003; Xu et al., 2004b). Besides negative influences on physical and chemical features, acid rain can also affect soil microorganism and enzyme activities, resulting in significant changes in soil biodiversity, biomass carbon, and decomposition rate of organic matter as well (Guo et al., 2003c; Nie et al., 2003).

3.3. *Possible change of soil fertility resulting from utilization shifts*

Explosive economic growth and rapid urbanization have resulted in significant diversification of Chinese food composition over the past two decades. On the one hand, remarkable income increase had been encouraging demands for more animal protein, high-quality vegetables and fruits in addition to sufficient subsistence grains. For the country as a whole, the contributions of cereals and starchy roots to the average daily per capita calorie supply decreased by 17.4%

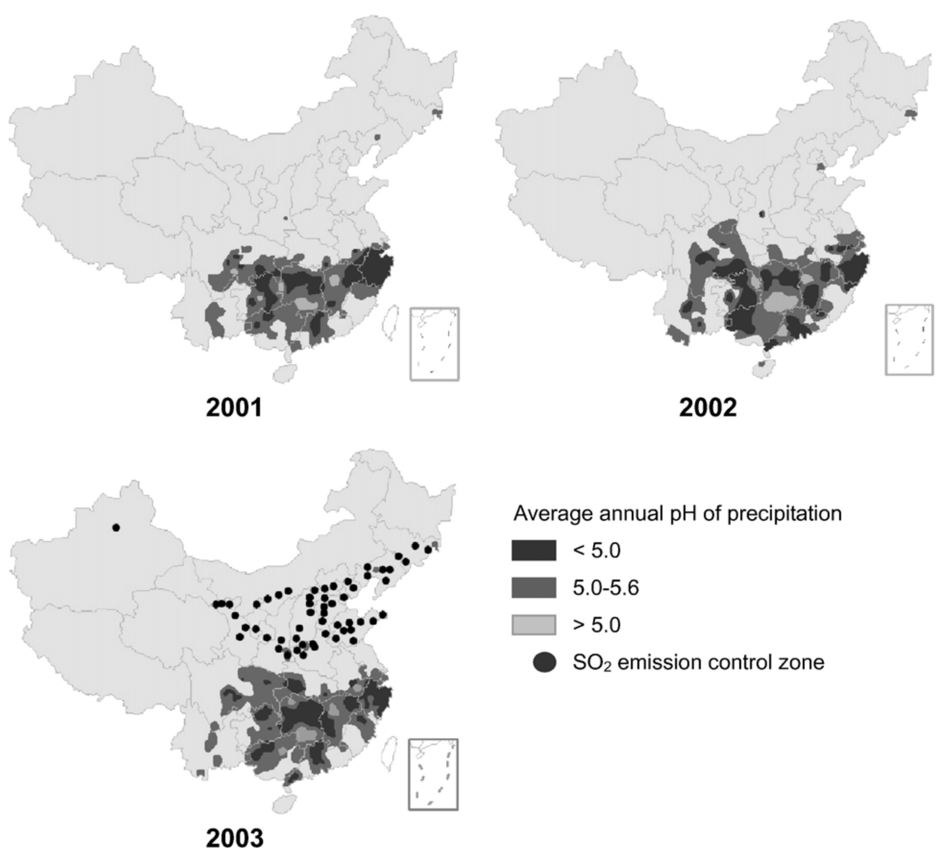

Fig. 8. Area affected by acid deposition in 2001, 2002, and 2003.

Table 2
Changes of average daily food calorie supply and contributing items in China between 1978 and 2002 (data source: FAOSTAT, 2004)

Items	Years (kcal/cap/day)												
	1978	1980	1982	1984	1986	1988	1990	1992	1994	1996	1998	2000	2002
Grand total	2247	2327	2514	2624	2622	2622	2709	2720	2809	2908	2977	2969	2951
Vegetal products	2108	2153	2327	2415	2372	2341	2399	2359	2374	2440	2433	2389	2333
Animal products	139	174	187	209	250	281	310	361	435	467	544	580	618
Cereals (excluding beer)	1554	1605	1763	1842	1807	1748	1793	1770	1700	1712	1665	1587	1457
Starchy roots	289	240	222	205	164	156	152	149	149	160	168	176	192
Sugar and sweeteners	41	53	66	65	68	83	78	75	63	80	87	63	69
Pulses	46	46	40	37	29	27	20	10	14	14	14	13	13
Oil crops	44	51	53	53	61	60	58	55	80	74	85	88	78
Vegetable oils	59	77	94	106	113	116	149	132	168	176	186	203	230
Vegetables	38	36	43	51	61	65	67	74	91	106	113	141	157
Fruits (excluding wine)	8	9	9	11	14	17	18	23	31	39	44	49	54
Alcoholic beverages	23	33	34	40	50	61	60	65	71	71	63	59	74
Meat	97	128	139	152	183	203	224	260	307	317	384	402	423
Animal fats	15	18	17	19	21	23	25	29	33	33	36	43	48
Milk (excluding butter)	7	7	7	8	10	11	12	13	14	16	16	19	25
Eggs	10	11	12	16	19	23	26	33	46	60	60	65	71
Fish, seafood	8	8	9	10	13	15	17	19	25	31	35	36	35
Others	3	3	3	4	4	5	5	8	9	11	13	15	16

and 13.5%, respectively, between 1980 and 2002, contrary to the contributions of vegetables and fruits that increased by 2.6 times and 5.0 times respectively during the same period, demonstrating a dramatic change of diet (more details shown in Table 2). On the other hand, accelerated urbanization is enlarging the markets of high-quality food products because the urban population in China normally has a much richer, more diverse diet than the rural population. During the 1970s, urban residents consumed more than twice as much meat as rural people (Torrey, 2004). The diet difference between the urban and rural population diminishes as rural income increases. In 2000, meat consumption per capita of urban residents was still 40% higher than rural residents, while average urban grain consumption per capita was only one-third of the rural consumption.

Changes of diet demands and market-oriented agricultural policy have led to strategic restructuring of China's agricultural system (Heilig, 1999). The emphasis is shifting from simple grain-focused production to more balanced composition of agricultural production. Consequently, soil resources formerly cultivated for subsistence crops like cereals and starchy roots are increasingly converted to more high-value crops and fresh water fishery. Between 1978 and 2002, the total acreage sown to grain crops decreased by 13.8%, from 120.6 million ha to 103.4 million ha, while the areas used for oil crops (from 6.2 to 14.8 million ha),

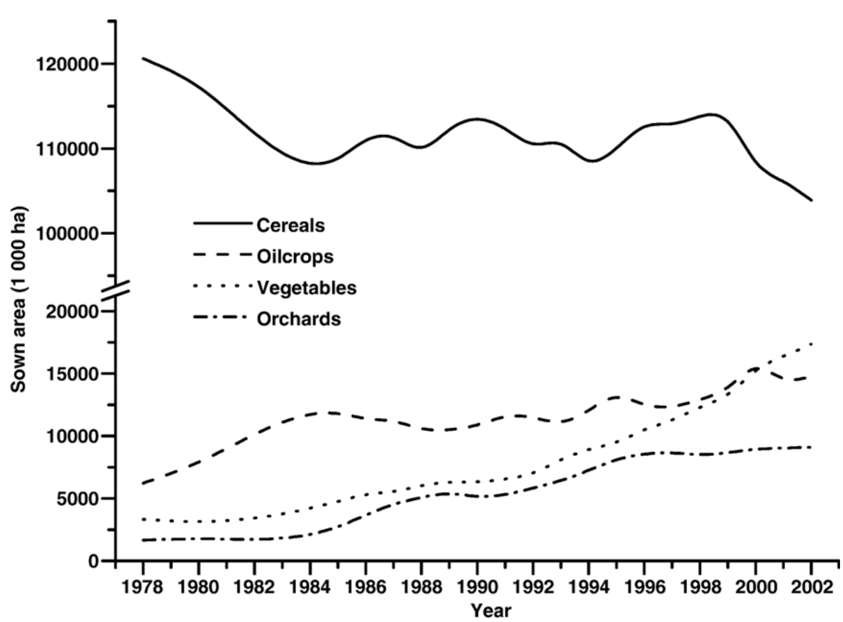

Fig. 9. Temporal variation of land areas for different agricultural production between 1978 and 2002 (data source: NBS, 1996–2003).

vegetables (from 3.3 to 17.4 million ha) and orchards (1.6 to 9.1 million ha) increased by 1.4 times, 4.2 times and 4.5 times, respectively (Fig. 9).

Changes in crop mix and agricultural outputs have profound influences on soil utilization and management, thus affecting soil fertility and material cycles within agricultural ecosystems. For instance, fruits and vegetables remove considerably more nutrients from the soils than cereal grains. Oil crops have a particular requirement for potassium. K content in soybean seeds is about 5 times higher than that in cereal grains (Shrotriya, 2000). The rather short growing period and the rapid biomass accumulation of vegetables and the rather undeveloped root system require a much higher soil nutrient release intensity than necessary for cereals. Shifts in crop mix need a different nutrient supply and a new balance of mineral elements in soil solution, thus oriented fertilizer application and soil management lead to changes in physical and chemical conditions of the soils. Due to easier access to markets, more developed infrastructure and higher capital availability, a large share of high-value agricultural production of China is concentrated in the urban and peri-urban areas. Of 18 cities sampled 90% of vegetables and 50% of meat supplies for the urban residents came from peri-urban agriculture. Urbanization leads to expansion of agricultural production in urban and peri-urban areas, enhancing development of efficient farming systems and intensive utilization of soil resources in these regions. Strong human activities and high material inputs, however, completely disturb the intrinsic material and energy cycles within a soil system, resulting in significant alternation in fertility potential and an increase in risk of pollution.

4. Challenge to food security and policy responses

With top priority given to agriculture, China has achieved great success in feeding its people in the past decades. Total supply of basic staples has shifted from a long-term shortage to a general balance against total demand; consequently, the number of undernourished people fell from 250 million in 1978 to 29 million in 2003. With a decreasing per capita availability of cultivated soils, however, China will face the challenge of reaching its food security goal (95% or even more of self-sufficiency rate before 2030 when the population will be at a projected maximum of 1.6 billion).

4.1. Analysis of land-related factors affecting grain production

Considering the major land-related factors limiting further rise in grain production, namely conversion of cultivated land, soil gradation and low availability of unused cultivable land, it can be clearly seen that China has to address land resource balance among economic development, grain production and ecological protection. China suffers the world's most serious land degradation, with more than 40% of its land area increasingly affected by soil erosion, salinization and desertification. Fully recognizant of the fact that inappropriate and intensified human activities have largely contributed to increased land degradation, China has stopped land reclamation in its vast west, and has reconverted 7.86 million ha of cultivated lead to ecological purposes between 1999 and 2003, despite an annual loss of grain production of 6.5 million tons. To ensure sustainable development and better ecological maintenance, China will continue its drive of "land for ecology" in the west in the coming decades. In addition to this loss of cultivated land, the policy toward local ecological and environmental conservation will also significantly reduce the availability of unused soils for grain production, which includes 7.34 million ha of which 75% occurs in the west. Agricultural restructuring, which greatly contributes to China's land-use change and shrinking of grain production area, is commonly considered as a strategy of diversified food production to improve the living standard and the nutritional level of people, thereby increasing food security of China.

Land converted to urban use is an important cause leading to the drop of cultivated land and arouses special attention. Between 1986 and 2003, a variety of construction activities removed more than 2.9 million ha from agricultural production, largely attributable to urbanization and industrialization. Despite only occupying about 2.4% of the cultivated land total, urbanization in the form of city sprawl and rural urbanization, is regarded as a serious challenge to future food security. First of all, urbanization leads to irreversible alteration in the physical and biotic character of the natural surface resulting in complete loss of soil productivity. Immediate re-conversion is impossible in the case of grain supply emergency. Secondly, urbanization progresses much more rapidly in densely populated regions where fertile soils have not been seriously degraded. Drop of grain production in these regions is mainly caused by loss of cultivated land to land development. For example, coastal provinces of Southeast China like Jiangsu and Guangdong, which were not obligated to return land to any ecological uses, witnessed grain output drops of nearly 30 million tons in 2003 from the 1998 level. Thirdly, it is just a beginning of land loss to urbanization. Along with explosive economic growth, land claimed for infrastructure is expected to continuously increase at a rapid rate. Some even believe that accelerated urbanization and industrialization will decrease cultivated area to the point where China can no longer feed its people in the next decades. Furthermore, in addition to conversion of soil resources away from productive purposes, impacts of urbanization on quality of existing or remaining soil resources have also been of great concern in China over the past two decades. Intensive human activity concentrated in urban areas and associated waste disposal from industrial and municipal sources have significantly affected soils and soil-based ecosystems through various ways, leading to decreases in output and quality of agricultural products.

4.2. Policy responses

To feed its future theoretical peak population of 1.6 billion, China needs to have a minimum cultivated land area of 107 million ha. Therefore, land-use has always been a top priority and a series of laws and regulations concerning protection of cultivated land, including the Agriculture Law, Land Management Law and Water and Soil Conservation Law, have been promulgated and perfected over the years. Besides the laws mentioned above, the Basic Farmland Protection Regulation, promulgated in 1994, has played a crucial role to control conversion of cultivated land with high productivity to non-agricultural purposes. Urbanization-related loss of cultivated land, however, still has been going on, and even accelerated since the late 1990s. In fact, the goal of cultivated land protection designed in 2001 (the country would secure a national cultivated land of at least 1.28 million ha before 2005) was not archived. In view of this, China repeated that it will spare no effort to protect its existing arable land resources, particularly “basic farmland”, from shrinking, while working to improve the efficiency of land use in urban and industrial development. Subsequently, the State Council issued a decree in 2004 stating its determination to increase land management reform by adopting the most strict land management rules to stop rampant misuse of land associated with urbanization. As the first step of the ongoing campaign against random land uses related to rapid urbanization, in the first half of 2004, related authorities closed 4735 development zones covering a total planned area of 2.4 million ha. And, since July 2003, approval of any proposal for development zones has been suspended. Local governments of all levels, who have authority to make decisions on land conversions, have been asked to strictly implement land management laws and regulations. For better land allocation among different purposes and a move towards sustainable land management along with rapid economic growth and urbanization, China is working to revise for the third time its National Overall Land Use Plan, which was worked out in the middle 1980s and revised in the late 1990s. The new revision will be finished before the end of 2006. According to the MLR authority, protecting cultivated land from loss to other uses, especially non-agricultural ones, will still remain as a top priority in this revision. Efforts to ensure quality of such lands, instead of a simple emphasis on keeping areas, will be included. With regard to soil pollution made worse by urbanization and industrialization, a legislative proposal of Law on the Prevention and Control of Soil Pollution has been submitted to the State Congress. It is quite hopeful that development of the law will be completed in the near future and stand with a series of available laws related to pollution control including Law on Environmental Protection, Law on the Prevention and Control of Water Pollution Law on the Prevention and Control of Environmental Pollution by Solid Waste and Law on the Prevention and Control of Atmospheric Pollution. Enforcement of soil pollution control will not only stop the possible drop of grain output, but also improve the quality of agricultural products.

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