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Review

# Water management and crop production for food security in China: A review

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ABSTRACT

Food security is a high priority issue on the Chinese political agenda. China's food security is challenged by several anthropogenic, sociopolitical and policy factors, including: population growth; urbanization and industrialization; land use changes and water scarcity; income growth and nutritional transition; and turbulence in global energy and food markets. Sustained growth in agricultural productivity and stable relations with global food suppliers are the twin anchors of food security. Shortfalls in domestic food production can take their toll on international food markets. Turbulence in global energy markets can affect food prices and supply costs, affecting food security and poverty. Policy safeguards are needed to shield food supply against such forces. China must make unremitting policy responses to address the loss of its fertile land for true progress towards the goal of national food security, by investing in infrastructure such as irrigation, drainage, storage, transport, and agricultural research and institutional reforms such as tenure security and land market liberalization. The links between water and other development-related sectors such as population, energy, food, and environment, and the interactions among them require reckoning, as they together will determine future food security and poverty reduction in China. Climate change is creating a new level of uncertainty in water governance, requiring accelerated research to avoid water-related stresses.



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'Agriculture is the base of China' and 'Food is the first necessity'.

"农业是中国的基础" "粮食是根本"
Historic Chinese maxims

## 1. Introduction

Despite a step-down in growth in 2008, real GDP in the East Asia and Pacific region is projected to grow at about 10% to 2009, compared with the world average of about 3.6% (World Bank, 2008). Growth in China is expected to exceed 11%, putting pressure on food prices. Increasing urbanization and affluence will put further pressure on food demand (Pingali, 2007). China's increasing appetite for energy and the surging demand for biofuel crops worldwide will worsen the situation. For instance, crude oil prices reached the $100 per barrel mark in early 2008. The surge in oil prices and government subsidies in several countries have stimulated the use of food crops for biofuels, increasing fertilizer and irrigation costs. There were unprecedented increases in the prices of maize (33%) and vegetable oils (50%) during 2007, and these price shocks were transmitted to other food cereals. Global wheat production fell below consumption as much wheat area was displaced by maize. Wheat stocks reached historic lows and wheat prices increased by about 30% (World Bank, 2008). Structural changes in global grain markets also increased rice prices, by around 40% between December 2005 and 2007, and thus endangered food security (EPW, 2008).

Turbulence in global energy and food markets can impact food security and poverty reduction in China (Diao et al., 2003). Sudden increases in food prices can greatly impact urban and non-agricultural households, and farmers in lagging rural areas and affect rural households in several ways (Huang et al., 2004b). Price changes can have diverse impacts across household types and regions due to heterogeneity in consumption behaviour and income sources, with possible implications for compensatory policies (Chen and Ravallion, 2004). The cost of protecting the livelihood and food security of these vulnerable households can be daunting, requiring as much as 0.5% of GDP in developing countries (World Bank, 2008).

Population growth, urbanization, industrialization, income and consumption growth, and changes in lifestyle brought about by global forces and market integration will pose ever greater challenges to maintaining food security in China. Biofuel projects will require more land and water resources, with impacts regarding resource allocation to food production (de Fraiture et al., 2007). Pro-poor agricultural technologies and transgenic food and cash crops might provide opportunities to enhance food security and benefit the poor farmers (Spielman, 2007).

Investments in infrastructure, and new policies and institutions are needed in China to achieve national food security goals and sustain the reductions in poverty that have been achieved in recent years. Water security must be assured and efforts must be made to limit the loss of fertile land to urbanization and industrialization. Given these issues and challenges, we review the role of land and water resources, and policies and institutions in promoting food security and reducing poverty in China.

## 2. Economic reform and food security

China embarked on its economic reform program more than 20 years ago when the government introduced the household responsibility system in agriculture. Price distortions were reduced and key land rights were reallocated from collective farms to rural households. Bold policies and institutional reforms were implemented to motivate greater production by rural households (Fan et al., 2004). The impacts on agricultural production, food security, and poverty reduction have been dramatic (Zhang and Kanbur, 2001). The reforms, which have lifted hundreds of millions of rural residents out of extreme poverty, stand as the "biggest antipoverty program the world has ever seen" and are claimed to have led to the "greatest increase in economic wellbeing [and food security] within a 15-year period in all of human history" (Sachs et al., 1994: 131).

Prior to implementing the reforms, much of China was a peasant agricultural society. Rapid economic growth was possible because the large agricultural sector contained vast surplus labour. China's reallocation of labour allowed all groups to gain, in contrast with reforms that have occurred in other former socialist economies (Donaldson, 2007). Economic reform often generates major gains and losses, and the distribution of impacts varies among social groups, with implications for social equity and the course of reform. Chinese peasants were a particularly important group from the perspective of food security and equity, and also from the perspective of economic reform.

During the 1980s and 1990s, agricultural productivity rose steadily and per capita grain output reached a level similar to that in developed countries. Many farmers shifted to higher valued crops and food exports grew significantly (FAO, 2003). With sustained growth in agriculture, rural incomes rose dramatically, lifting millions of people out of poverty permanently (Hussain and Hanjra, 2003, 2004). Despite these notable achievements, more than 100 million farmers and their families still live in poverty. The gap in rural and urban incomes remains wide and inequality in the rural economy has remained high since the mid-1990s (World Bank, 2005). Urbanization and increasing affluence are placing new demands on food production (Popkin, 2006), requiring more land and water. As a result, the overuse and degradation of resources have increased in major river basins (Molden et al., 2007).

## 3. Anthropogenic factors and food security

The challenge of maintaining food security, while the population and incomes increase is a classic research theme and a high priority issue on the Chinese political agenda. Five anthropogenic factors influence the pace of increasing food demands: population growth, urbanization, industrialization, changes in lifestyle and consumption, and shifts in political and economic arrangements (Heilig, 1997). All of these factors are at work in China. The challenge of maintaining food security will remain substantial, in part because China's endowment of land and water resources, on a per capita basis, is notably below the world average (Fig. 1).

In the next half century, China's population is expected to increase by about 300 million (Heilig, 1997) to 1.6 billion. Rural to urban migration, the growth of cities and industry, and changes in consumption patterns that accompany rising incomes will place additional pressure on land and water resources. The demand for meat and dairy products, which require substantially more water in production than grains, will continue increasing (Molden et al., 2007). At the same time, more land will be needed for transportation infrastructure, housing and energy generation to support the increasingly urban population.

Innovations in technology and policy will be needed to maintain food security in China. Resources must be used efficiently and carbon emissions must be reduced to maintain environmental quality. Producing crops for biofuel will divert resources from food production. Developing viable alternatives to fossil fuels that reduce or negate the demand for biofuels might reduce the pressure on land and water resources in ways that enhance efforts to maintain food security. Much will depend on the pace of technology development and how markets respond to the emerging pressures of climate change.

## 4. Land use changes

Land use changes in China are driven by the increasing demand for food (Heilig, 1997) and other economic and political factors (Lin and Ho, 2005). Land sales are an important source of local revenue in many areas. In 1996, about 67% of China's land was devoted to agriculture (Lin and Ho, 2003). The cultivated area was about 130 million ha, nearly 40% more than had been reported previously by local officials. The amount of cultivated land per capita was only 0.106 ha, much less than the world average of 0.236 ha. The per capita value has continued to decline with China's increasing population, despite a substantial development of new agricultural land in the country. For instance, between 1978 and 1996 the cultivated area decreased from 99.4 to 95.0 million ha (a net loss of 4.4 million ha) or 4.4% (Lin and Ho, 2005). Much of the loss was due to structural changes within agriculture, such as the conversion of paddy fields into orchards or fish ponds. However, a substantial portion of the loss was due to industrial and urban expansion (Ellis et al., 2000). Much of the loss occurred in the coastal and central regions, while the western region experienced a small gain in cultivated area.

Since the 1990s, the processes of agricultural restructuring, rural industrialization, urbanization and economic reforms have caused substantial farmland loss (Long et al., 2007a). The major sources of changes in cultivated area (Yang and Li, 2000) are given in Table 1.

The potential impacts of changes in cultivated area on food production and other ecosystem values vary with the sources of those changes. For instance, reclaiming low-quality land generally cannot offset the productivity lost when fertile land is converted to a non-agricultural use, as has occurred in southeastern China, where cropping intensities and population density are notably high, and the amount of arable land available per person is quite small (Lin and Ho, 2003). Cultivated area declined substantially in the Yangtze River Delta from 1987 through 2000, due largely to rapid municipal and industrial growth in areas near Shanghai, Nanjing, and Jiangsu, three of China's largest cities (Long et al., 2007b). The area in rice fields declined most notably, falling by about 12%.

The conversion of fertile land to non-agricultural uses is the primary threat to China's continued capacity to produce sufficient cereals (Lichtenberg and Ding, 2008). Cultivated area

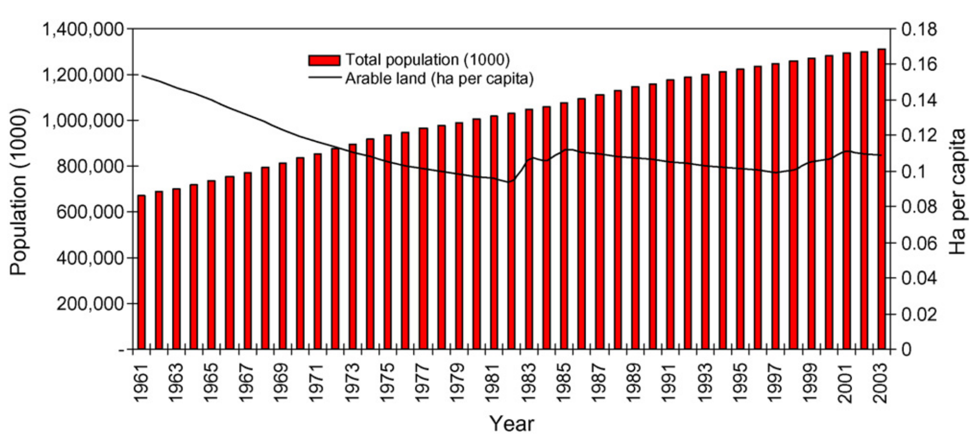


**Fig. 1 – Population and arable land resources in China.**

Table 1 – The major sources of changes in cultivated area in China.

| *Increase*: cultivated land converted from | *Decrease*: cultivated land converted to |
|---|---|
| Reclamation of newly cultivated land | Built-up area |
| Drainage from shallow water bodies, lake, swamps | Construction by rural collectives |
| Drainage of waterlogged land | Peasant housing |
| Conversion of land from forestry, grasses or horticulture through adjustment of agricultural structure | Forestry, grassland or horticulture |
| Rehabilitation of areas discarded by mining, construction, disasters, etc. | Loss due to disasters such as floods, mud flow, gully erosion, sand mining, land slides, and abandonment of cultivation |

has increased in some northwest and frontier provinces, partially offsetting losses in the southeast (Yang and Li, 2000). This gain, however, has not been achieved without environmental harm, as noted by the abandonment of damaged land in the major reclaiming provinces in the northwest.

Long-term studies in China have identified six prominent land degradation processes: desertification, secondary salinity, loss of agricultural use, deforestation, grassland degradation, and the loss of wetlands (Zhang et al., 2007).

The impact of cultivated land conversion on food security is contested. Satellite imagery analysis of changes in cultivated area and agricultural productivity in China between 1986 and 2000 depicts a net increase in cultivated area (+1.9%), which almost offsets the decrease in productivity or *bioproductivity* (−2.2%). Thus the conversion of cultivated land has not necessarily harmed China's national food security. Changes in cultivated area that have occurred more recently also have had little adverse effect on food security (Deng et al., 2006).

Others argue that China's cultivated area is declining at a shocking rate (Chen, 2007). Changes in agricultural area, and grain-sown area in particular, have occurred throughout China (Verburg et al., 2000), with implications that vary geographically. Hotspots of change are found in two areas: (1) in the Ordos and Loess plateau regions where land degradation is the primary land use change process, and (2) around the growing cities in eastern China. To maintain food production, all losses in agricultural area must be offset by more intensive cultivation of remaining areas. The increased production of vegetables and cash crops near cities in southeastern and eastern China enables greater use of labour, yet the decline in grain production might result in larger grain imports. Further intensification might threaten long-term sustainability of food production due to land degradation, pollution, and declining soil fertility. Additional threats include soil pollution through waste disposal, acid deposition from urban air pollution and an increased risk of flooding due to urbanization (Chen, 2007).

The transition toward intensive but more sustainable land use systems is more important for food security than further intensification alone. Maintaining environmental quality should therefore receive more emphasis than increasing production (Verburg et al., 2000). China must make unremitting policy responses to address the loss of its fertile land for true progress towards the goal of national food security (Chen, 2007). Such a program should have two critical elements: (1) eliminating arbitrage opportunities for farmland conversion, and (2) investing in institutions and infrastructure that optimize comparative advantage across regions. Arbitrage opportunities can also be reduced by investing in infrastructure such as irrigation, drainage, storage, transport; and institutional reforms such as land tenure security, land market liberalization, that improve returns to farming and enhance incentives for farmland retention, while also exploiting the comparative advantage of scarce land (Lichtenberg and Ding, 2008).

## 5. Food production

China has made impressive strides toward achieving food security. Since the late 1970s when China started rural economic reforms, grain production has increased substantially. From 1978 through 1997 total output increased by 189 million tons or 62%, despite a 7% decrease in the area planted in grain. Corn and wheat production doubled during 1978 through 1997, while rice output increased by about 50% (Yang, 1999). The momentum of land use changes started in the early 1980s was followed in the 1990s, however the grain production reached a new high. Continued gains in agricultural productivity are needed in China, where more than 300 million workers, or about half the labour force, remain in agriculture.

Total factor productivity in agriculture increased by 55% from 1979 to 1984, an unprecedented rate of increase in the developing world. Despite a slowdown in agricultural investments in the late 1980s and early 1990s, productivity increased by almost 50% from 1988 to 1996. The gains in productivity vary among provinces. For example, farm level data for Jiangsu province indicate a reduction in productivity from 1988 to 1996 due to a reduction in farm labour input and sown area (Carter et al., 2003). A true understanding of food security in China requires consideration of regional and provincial data.

Technology adoption accounted for an estimated 40% of the increase in rice productivity during 1980 to 1995, while institutional reforms accounted for 35% (Jin et al., 2002). Most of the increase in total factor productivity is attributed to wheat, corn, and rice (Jin et al., 2002). National and international investments in new technology and continued institutional and policy reforms will continue to be important.

China has adopted the goal of maintaining a high degree of cereals self-sufficiency. Yet projections of China's demand and supply of cereals between now and 2030 vary somewhat (Fan and Agcaoili-Sombilla, 1997). Per capita consumption of cereals is expected to increase slowly, from 380 kg in 1995 to 400 kg in 2030 (Alexandratos, 1997). The increasing demand for meat in China will contribute to stronger demand for grain. Supply can be enhanced by increasing the productivity of livestock, increasing the number of grazing animals, and

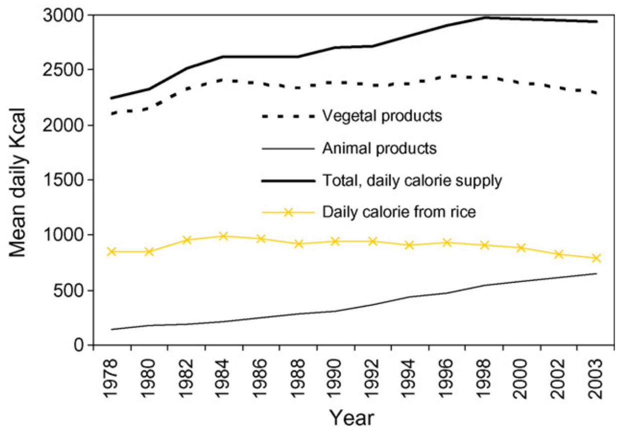


**Fig. 2 – Per capita daily calorie consumption in China.**

producing more poultry, which utilize feed more efficiently (Alexandratos, 2005).

China's per capita annual meat consumption (30 kg) is still below that of South Korea (32 kg), Japan (40 kg) and Malaysia (44 kg), but it continues to increase, and is expected to rival those of Europe and the United States (de Fraiture et al., 2007) (Fig. 2). Pork accounts for about 75% of China's meat consumption, and pork production has fewer impacts on land and water resources than beef production (Rozelle and Rosegrant, 1997). As incomes continue increasing in China, the demand for meat might diversify somewhat, thus increasing the demand for grains and placing greater pressure on land and water resources.

The nutritional transition in China limits the likelihood that *more* grain consumption could lessen pressure on land and water resources. Evidence from rural China shows that food consumption tends to converge or become similar for grains (WAN, 2005): total grain, fine grain, edible oil, poultry, sugar and aquatic products show convergence; animal fat and red meat show consumption divergence; and for commodities that converge, the speed of convergence is slow; rising incomes promote consumption divergence, indicating a trend towards more meat consumption (Fig. 3).

Despite changes in consumption patterns in the 1990s, a large share of household animal product expenditure is still on pork (which requires much less water than for producing beef). The shares of fish and poultry products in Chinese diets likely will increase substantially. Concerns with Avian flu may sway consumers away from poultry to red meat (beef requires several orders of water per kg than the poultry). The expenditure share on pork will decrease gradually as incomes increase and diet preferences change in both rural and urban areas (Ma et al., 2006) while red meat consumption may continue to increase especially for more educated, young and affluent consumers, intensifying pressure on water resources. This might impose a ''double burden'' on food security by increasing obesity and the occurrence of related health issues (Zhang et al., 2008) and thus merits the attention of food policy makers.

There are significant differences in the consumption of animal products across China (Jalan and Ravallion, 2002; Ma et al., 2006). Much of the increase in animal protein demand will come from affluent eastern areas, increasing the demand for land and water resources in an increasingly urban, richer, and eating food-away-from-home population (Ma et al., 2006). Estimates of food and nutrient intake elasticities from a prosperous area in northern China suggest that the relative contribution of grains and protein to calorie intake declines at higher incomes. Although income elasticities of total protein intake are low, the food-expenditure elasticity of animal protein intake is still relatively high, implying a switch to more expensive protein sources as food expenditure increase (Ye and Taylor, 1995).

Total factor productivity growth in major livestock products has been lower than in the grain sector since the economic reforms of the late 1970s (Rae et al., 2006). China has become a net exporter of pork and poultry and a net importer of beef. Increased consumption of livestock products, especially red meat, will increase per capita evapotranspiration demand for water, with implications for China's food security and global food markets (Carter and Rozelle, 2001).

## 6. Water resources management

With rapid urbanization and industrialization, water transfers from low-value agricultural uses to high-value industrial and domestic uses are increasing in China (Matsuno et al., 2007) and other countries (Molden, 2007). Water shortages are limiting agricultural development and urbanization in many parts of China (Loeve et al., 2007). A clear understanding of the issues and trends in agricultural water management is

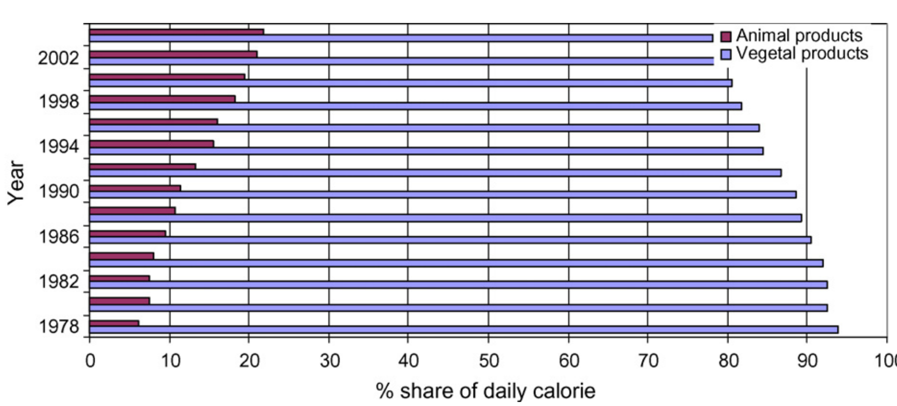


**Fig. 3 – Changes in diet preferences in China.**

essential to support a national development policy that focuses on food security. The government must determine the best policies for ensuring that increasing food demands are satisfied, while maintaining environmental quality and sustaining a desirable pace of economic development (Hongyun and Liange, 2007).

China's annual water supply is equivalent to 1856 $m^3$ per capita, or about 25% of the world's average. Supplies are particularly small in arid portions of the country, such as the Yellow River Basin (750 $m^3$ per capita) and the Hai-Luan basin (355 $m^3$ per capita). These average supplies are much smaller than the internationally accepted definition of water scarcity (1000 $m^3$ per capita). The average use rate of water in China increased from about 20% of available water resources in 2000 to 23% in 2004. The use rate will continue increasing in future, with increases in population and incomes (Hongyun and Liange, 2007).

The geographic distribution of water resources in China is uneven. An estimated 81% of water resources are found in the south, while most of China's arable land (64%) is in the arid north. Water availability per ha of cropland in the north is about 12% of the availability in the south. Similarly, the average supply of groundwater is about four times greater in the south than in the north. Excessive abstraction of groundwater occurs beneath 70% of the North China Plain (Kendy et al., 2004). In some areas, the water table has declined by 2 m per year since the early 1980s. The implications of over-pumping include higher pumping costs, wasteful energy use, salt water intrusion, increased soil salinity and waterlogging, soil compaction, and land subsidence (Zhen and Routray, 2002). Over-pumping in upstream areas of the Hai River Basin completely eliminates river flow in the lower reaches, and the Yellow River does not reach the sea in most years (Wang et al., 2006a).

Water pollution also influences food security. The volumes of degraded water in China might increase from 204 million $m^3$ in 2002 to 232 million $m^3$ in 2010 and 357 million $m^3$ in 2020 (Zhu et al., 2002). The paper industry, which is considered by some to be the largest source of rural pollution in China, accounts for 10% of wastewater discharges and 25% of chemical oxygen demand. Evidence from case studies (Yongguan et al., 2001) in heavily polluted cities such as Chongqing show that water pollution reduces GDP in local areas by about 1.2%. Damages in agriculture constitute the largest share of the costs (56%) while damages in the health and industrial sectors account for 20% and 18%, respectively. Many incentives and regulatory instruments have been proposed for water pollution abatement in China (Wang and Wheeler, 2005).

Sustained production from irrigated agriculture is vital to Chinese food security. China has one of the world's largest irrigated areas (59.3 m ha), which is about half of China's cultivated land and produces about 75% of the grain harvest. Irrigated area expanded from 45.0 m ha in 1978 to 54.5 m ha in 2004 (Hongyun and Liange, 2007). The use of higher energy inputs such as fertilizers also increased (Fig. 4).

A number of institutional and policy measures have been implemented to enhance the productivity of irrigated agriculture. Watering practices such as alternative wet/dry irrigation were meant to produce more rice with less water (Bouman et al., 2007; Surridge, 2004). Such practices have been promoted since the early 1990s and covered about 40% of the rice area by 2002. About 150 institutions collaborated on conducting research on such practices (Li and Barker, 2004).

Water management institutions offer financial incentives to water managers to encourage water savings (Wang et al., 2006b). Farmers have responded favorably to more reliable water supplies and abolition of agricultural taxes, sometimes relinquishing water to cities and industries. More pragmatic water policies such as water pricing have not been implemented for political reasons (Yang et al., 2003). International research organizations have collaborated with the Chinese government and research institutions on water-saving projects. The government has promoted the adoption of water saving technologies and provided financial support for infrastructure, with notable impacts on food security (Li, 2006). For instance, wet/dry irrigation for rice has positive impacts on yields, water productivity, fertilizer use efficiency and irrigation costs and returns (Moya et al., 2004). The

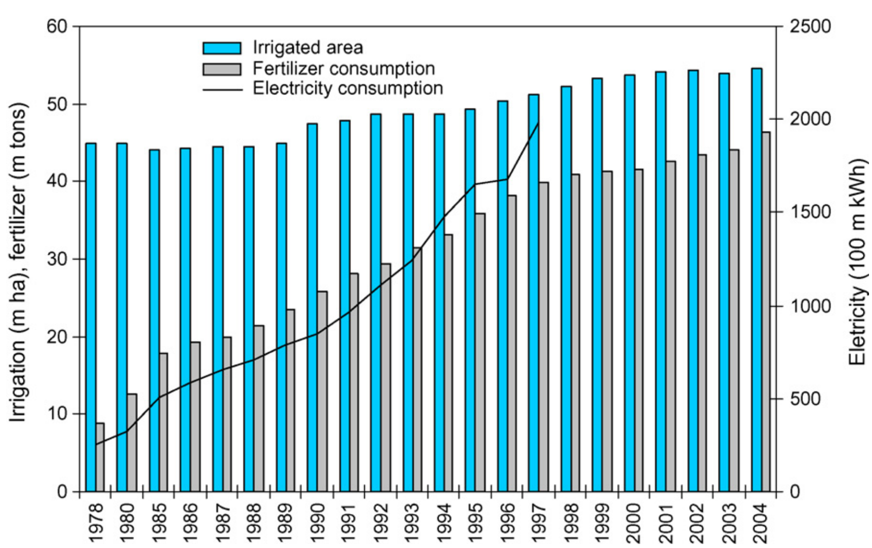


**Fig. 4 – Irrigation, fertilizer, and rural electricity consumption in China, 1978–1996.**

practice also helps reduce the spread of malaria by reducing mosquito populations (Qunhua et al., 2004).

Despite government efforts to promote water saving irrigation practices, there is limited evidence of widespread adoption and consequent water savings at the system or basin level (Loeve et al., 2004). Biophysical and socioeconomic issues constrain the rate and extent of adoption across regions. Highly divisible and low cost technologies have been more successfully adopted at the household level. At the community level such practices are adopted on a limited scale, due partly to policy failures and constraints to adoption such as information and financial support, extension programs, coordination failure in collective action, and the need for large fixed investments (Moya et al., 2004). The scope for increasing field level water savings and water productivity in rice production remains substantial. Future policies must focus on an incentive structure in which field level adoption and water savings can enhance water availability elsewhere, not only locally (Bluemling et al., 2007).

Enhancing water use efficiency without impacting better quality return flows remains the key to obtaining such water savings. The average efficiency of canal water delivery systems is only 30–40% compared to 70–90% in most developed countries. Some irrigation districts in Australia achieve 90% water use efficiency (Khan et al., 2008b). Increasing the total amount of water made available to crops for transpiration; and increasing the efficiency with which transpired water produces biomass (Kassam et al., 2007) can enhance water use efficiency and productivity. Inefficient water use results in low water productivity. Mean grain output per m$^3$ of water in China is just 0.85 kg, or about 50% of productivity in many developed countries, and less than 33% of productivity in Israel (2.32 kg/m$^3$). Efficient water use can enhance productivity but also deplete beneficial return flows, stressing the environment.

Boosting water productivity while protecting water resources and the environment requires a range of measures and policies:

- Scientific and technical measures to increase the water use ratio include: improving management, strengthening protection of water resources and the environment, and supporting more research of water conservation techniques (Feng et al., 2000);
- Water management plans comprising better water policies and institutions, demand management, pollution control, and water transfers across river basins, with pricing incentives that assign equal value to both local and imported water supplies (Shin, 1999);
- Substantial strengthening of local, community, and regional water quality management operations (Dasgupta et al., 2001), with funding to upgrade municipal wastewater treatment systems, and recharging of aquifers with treated effluents and flood water during rainy seasons for recovery during dry years (Khan et al., 2008a); and greater use of clean technologies and recycling by industries (Wang and Wheeler, 2005).
- On farm measures to protect irrigation water supplies from pollution include: the use of diversified agricultural buffer structures to reduce nutrient discharges, better drainage systems (Wichelns, 2006); better irrigation scheduling (Pereira et al., 2007); silt management in the lower reaches of irrigation systems (Chengrui and Dregne, 2001); soil conservation measures such as grass strips, bench terraces and straw mulching (Lu and Stocking, 2000); and conjunctive use of surface and groundwater in saline areas (Khan et al., 2008a).

## 7. Water transfers

Water transfers can address water scarcity for millions of people who would otherwise be living in water stressed basins (Molden, 2007). For instance, the South-North Water Transfer project could deliver 40–50 km$^3$ per year from the Yangtze River basin to the North China Plain, benefiting 300–325 million people (Berkoff, 2003). About 1.76 million m$^3$ daily could be delivered from the Wanjiazhai Reservoir on the Yellow River to the City of Taiyuan (Qingtao et al., 1999).

Water transfer projects may be economically feasible but their social and environmental impacts are contested. Most require population resettlement (Tan and Wang, 2003) and have impacts on the environment (Gunaratnam et al., 2002). Water transfers projects are based on political arguments rather than strictly based on food security concerns. Their objective is to improve the water environment in the water-stressed north China basin. These engineering measures must be complemented with appropriate water prices, investment policies, and legal measures (Xiaoping et al., 2004).

## 8. Fertilizer

The world's fertilizer use per ha increased from about 60 kg in 1960 to 110 kg in 2002 (FAO, 2007). In China, fertilizer use per ha increased from 10 kg in 1960 to about 330 kg in 2002, contributing significantly to growth in grain production (Fig. 5). Chemical fertilizer use increased rapidly with the rural economic reforms initiated in 1978, surpassing the use of organic fertilizer by 1982 (Liu and Chen, 2007).

The rapid increase in fertilizer use has been a key determinant of agricultural productivity growth in China during the past three decades (Fig. 6). The growth in grain yields during 1952–1993 was significantly determined by the use of fertilizer and new technologies aided by strong institutional support (Wang et al., 1996).

Fertilizer use rates vary with geography in China. The average use rate is about 300 kg ha$^{-1}$ in southeast provinces such as Guangdong, Fujian and Jiangsu, and about 100 kg ha$^{-1}$ in the northwestern provinces of Gansu, Guizhou and Qinghai (FAO, 2007). This skewness points to policy issues and infrastructure constraints on inter-provincial trade, as fertilizer production and imports are controlled primarily by the government. Policy reforms are needed to increase the use of phosphorus and potassium. Recommendations include increasing fertilizer production and imports, and allocating more fertilizer to areas with low application rates.

The increase in fertilizer and pesticide use has caused environmental problems such as groundwater pollution and eutrophication in many areas of China. Chemical fertilizer use will continue to increase in China due to continued positive

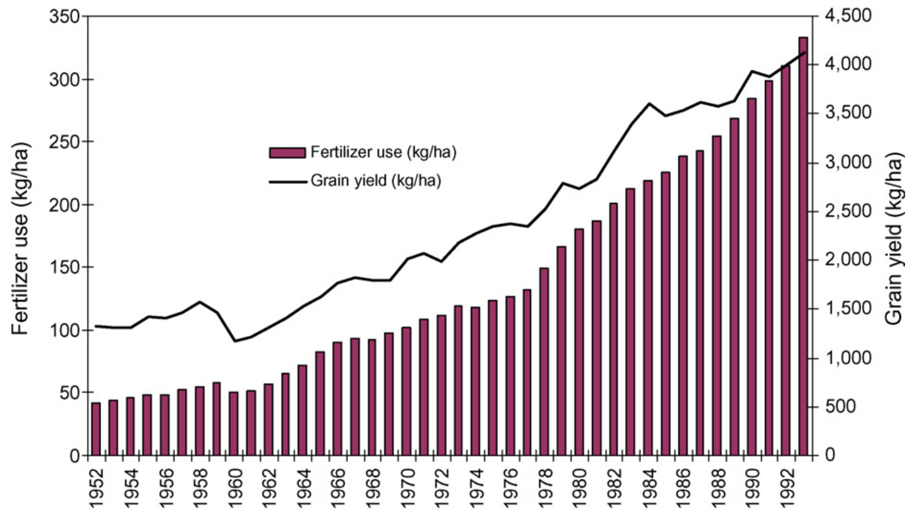


**Fig. 5 – Grain yield and fertilizer consumption per hectare in China, 1952–1993.**

yield responses. Balancing food production and environmental quality will become a major issue. Increasing fertilizer supply to areas with low usage can improve production and food security, and reduce groundwater pollution in areas with high use rates. China successfully sustained the productivity levels of wheat and rice over 100 years by meeting 50% of the nitrogen requirement from organic sources (Zhen et al., 2005). Balanced organic fertilizer use can have positive impacts on soil quality, with minimal effects on economic efficiency (Jacoby et al., 2002).

Environmental issues pertaining to agricultural chemicals can pose serious challenges to food security, human health and biodiversity (Hengsdijk et al., 2007). Key strategies to address the environmental and water pollution issues include (Liu and Chen, 2007):

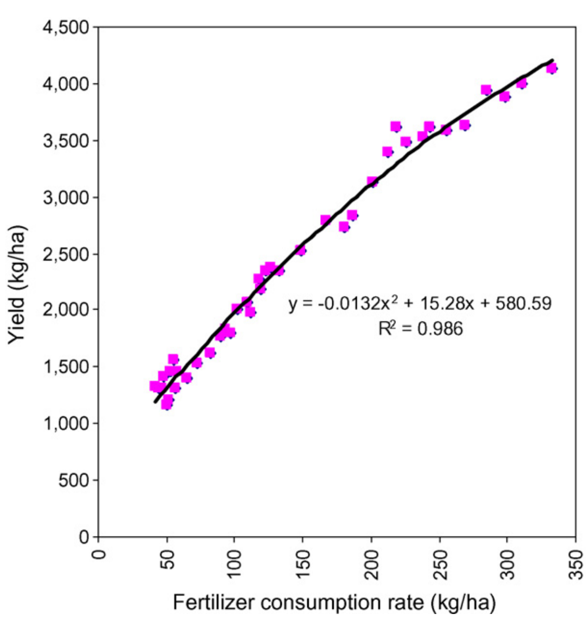


**Fig. 6 – Relationship between grain yield and fertilizer application in China, 1952–1993.**

- Improving the efficiency of crop absorption and adjusting chemical use rates,
- Developing crop varieties to fix nitrogen, to reduce fertilizer demand,
- Including legume crops in the cropping system to supplement nitrogen requirements,
- Adjusting N:P:K ratios to increase crop yield response to fertilizer,
- Balanced and integrated use of chemical and organic fertilizers, based on soil tests,
- Increasing fertilizer supply to areas with very low use rates,
- Improving farmer knowledge of soil fertility and fertilizer use through better extension and education,
- Adding environmental research objectives to conventional objectives of agricultural research,
- State support for collective and private investments in agricultural research and extension,
- Regulations on permissible limits on chemical concentration in drinking water, and
- Removing chemicals from water supplies.

## 9. Pesticides

Following the threat of crop losses from pest infestations during the 1960s and 1970s the availability of pesticides was increased. By the late 1980s smallholders in China applied pesticides regularly at rates higher than other rice producing countries in Asia (Widawsky et al., 1998). Application rates in some counties in eastern China in the 1990s were twice those of irrigated rice systems in the Philippines, where serious impacts to farmer health and productivity have been linked to pesticide use (Pingali et al., 1994). Pesticide use for other crops also increased by several orders of magnitude (Fig. 7). Field studies in China have shown that pesticides are over used; pest resistance has decreased the effectiveness of pesticides; and direct marginal contributions of pesticides to yields are low or negative, while associated negative externalities are high (Widawsky et al., 1998). Evidence shows that less developed countries with high levels of foreign direct investments in the primary sector use

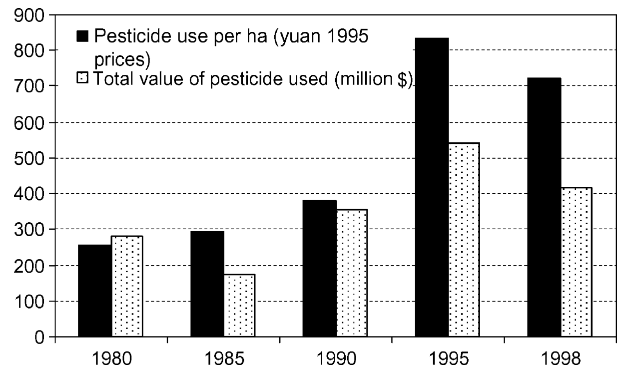


**Fig. 7 – Pesticide use in cotton production in China.**

more pesticides per hectare of cropland (Jorgenson, 2007). Together this poses a perplexing issue. With further liberalization of the Chinese economy, pesticide use will continue to increase. Government policies that promote pesticide use might be inappropriate, given the low incremental productivity and negative returns to pesticide use. China might reconsider its commitment to increase pesticide use in rice for greater food security. Investments in farmer education on biological pest control and improving host-plant resistance might generate larger net benefits (Widawsky et al., 1998).

## 10. Genetically modified food crops

Adoption of genetically modified (GM) food and cash crops can enhance food security while reducing pesticide use. For instance, GM cotton requires much less pesticide and has only a small impact on yields (Huang et al., 2002a; Shankar and Thirtle, 2005). Economy-wide assessments show that the impacts of GM cotton on China's production, trade and welfare outweigh public research expenditures. In addition, most of the gains accrue inside China, and can be achieved irrespective of anti-GM policies adopted in some developed countries (Huang et al., 2004a, 2002b).

The small and poor farmers may benefit from GM/Golden rice, due to higher vitamin content and reduced use of pesticides, which can contribute to improved health (Stein et al., 2008). Poor farmers in China cultivate a larger area of GM crops than small farmers in any other developing country. Chinese consumers have higher acceptance and willingness to buy GM food than residents of other countries (Huang et al., 2006), indicating the potential for increasing the use of GM food crops in China.

## 11. Ecological agriculture

Some researchers argue that organic farming or low-external input agriculture is environmentally sound, economically viable, and socially acceptable (Zhen et al., 2005). Others show that organic farming without proper use of fertilizers may lead to nutrient deficits in the soil, with negative environmental and economic impacts (Rahman, 2003). Chinese Ecological Agriculture (*daudi*) addresses the negative externalities associated with agrochemical use in grain production. Sustainable agriculture can also address food security concerns. The Chinese government first realized the need for such agriculture in the 1970s and 1980s, and emphasized replacing environmentally damaging factor inputs (chemicals) with traditional practices involving crop rotations, organic fertilizers, biological pest management, and recycling of wastes and farm residues. The initiative was termed as "green food" in 1993 with ISO65 standard including a total ban on chemical fertilizer use for such food production (Sanders, 2006). Green agriculture represents a typical, pragmatic Chinese solution to environmental problems caused by attempts to increase agricultural output to enhance food security in rural areas. However without sustained institutional and policy support the outlook for green farming remains uncertain.

## 12. Grain for Green program

The goal of the nation-wide cropland set-aside program known as "Grain for Green," started in 1999 is to reduce water and soil erosion by increasing forest cover. Participating farmers set aside all or part of their cultivated land and plant seedlings to grow trees. In return the government compensates them with in-kind grain, cash payments, and free seedlings. The program, which is designed to reduce cultivation on steep slopes, offers other benefits including increased and sustained income to participating poor farmers; reduced soil erosion; and greater environmental conservation in a cost effective manner (Uchida et al., 2007).

The main intention of the "grain for green" program was ecological recovery especially for controlling soil erosion for example in Hunan Province on the middle reaches of the Yangtze River. The program covered 15 million farmers in 25 provinces by the end of 2002 and will have set aside 15 m ha of cropland by 2010, an area larger than the Conservation Reserve Program in the United States (Uchida et al., 2007). However the long-term sustainability of the program remains uncertain should the government withdraw payment support once the program stops after 10 years (Hu et al., 2006). Although this effort significantly helped improved the watersheds to control rampant flooding on the river, it has put extra pressure on other areas to produce more grain from lesser use of resources at the national level.

## 13. Summary

The national development policy in China puts food security at its heart. China's food security is challenged by several anthropogenic and sociopolitical policy factors, including:

- Population growth;
- Urbanization and industrialization;
- Land use changes and water scarcity;
- Income growth and nutritional transition;
- Turbulence in global energy and food markets.

Population growth and urbanization will continue to put pressure on food demand. Feeding a larger and affluent population with higher preference for meat-based diets will pose significant challenges. Further challenges will arise from the increasing demand for biofuels, growing realisation to preserve ecological function and the increasing competition for land and water resources currently devoted to food production.

Implications for food policy are clear. Sustained growth in agricultural productivity and stable relations with global food suppliers are important anchors of food security. Shortfalls in domestic food production can impact international food markets. Turbulence in global energy markets can affect food prices and supply costs. Policy safeguards are needed to shield food supply against such forces.

Water resources are essential to agricultural and human development. China must implement policies to address the loss of fertile land, and it must invest in infrastructure such as irrigation, drainage, storage, and transportation. Further investments in agricultural research and institutional reforms such as tenure security and land market liberalization are needed. Policies and technical support are needed also to improve water use efficiency and protect water quality on the North China Plain, where groundwater levels are declining. Policies that support the production of genetically modified crops can improve the welfare of China's poor.

Increasing water scarcity and emerging signs of groundwater stress are driven by complex socioeconomic and geophysical factors, requiring further research. Any water crisis in the future may not be caused by physical scarcity of water, but more likely by inadequate or inappropriate water governance. Cross-sectoral policy responses are needed to address the linkages between water and other development-related sectors such as population, energy, food, environment, and the interactions among them.

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