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A FOOD SECURITY APPROACH TO ANALYSE IRRIGATION EFFICIENCY IMPROVEMENT DEMANDS AT THE COUNTRY LEVEL

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ABSTRACT

This paper used a food security approach in an attempt to analyse how much food will be needed in China in years 2030 and 2050; to produce that amount of food, at what scale should the irrigation area expand; to realize the development of that irrigation area, how much should the irrigation efficiency improve with the total irrigation water use kept within the range of the goals set up by the Chinese government; and what water management options should be adopted to improve the irrigation efficiency? The results show that there was US$ 3.1 billion worth of grain deficit in the year 2000 and there will be US$ 10.8 billion and US$ 3.2 billion of grain deficits in years 2030 and 2050 respectively at the medium population growth and irrigation area development scenarios. To meet the total food demand in years 2030 and 2050, 138 and 109 million ha of gross irrigated area are needed, which required 69% and 85% of surface water and groundwater irrigation efficiencies in 2030 and 63% and 83% of surface water and groundwater irrigation efficiencies in 2050 provided the total irrigation diversion is kept around 420 and 400 billion cubic metres marks respectively.

KEY WORDS: PODIUMSim model; food security; irrigation efficiency; water management; China

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RÉSUMÉ

INTRODUCTION

By 2025, 1.8 billion people will live in countries or regions facing physical water scarcity, this means that they will not have sufficient water resources to maintain their current level of per capita food production from irrigated agriculture – even at high levels of irrigation efficiency – and also to meet reasonable water needs for domestic, industrial, and environmental purposes (IWMI, 2007). Most countries in the Middle East and North Africa can be classified as being water scarce today. By 2025, these countries will be joined by Pakistan, South Africa, and large parts of India and China. To sustain their needs, water will have to be transferred out of agriculture into other sectors, making these countries or regions increasingly dependent on imported food (de Fraiture et al., 2007).

Food security issues are not that pressing in China for now but would heavily dominate the national political agenda in next twenty years as population will reach its peak by 2030. Much will depend on local production and global political and macroeconomic landscape and China's strategic positioning in the emerging world trade alliances. Local production will become a hostage to hydrology, at least in the major food producing areas such as the North China Plain and Yellow River Basin. Boosting crop productivity by increasing water use efficiency will be the main pathway to addressing the water and food security issues.

Agriculture is now the largest consumer of water, accounting for some 70% of total water use. The average water use efficiency is only 37%. As population continue to rise, irrigation will be called upon to provide an increasing share of total food production to meet the growing demand (Rozelle *et al.*, 1997). Water demand for domestic and industrial uses is projected to grow even more rapidly than agricultural water demand, particularly in developing countries (Shiklomanov 1998; Rosegrant *et al.*, 1998). A portion of the growing demand for water will be met through new investments in irrigation and water supply systems, and some potential exists for the expansion of non-traditional sources of water supply. However, in many arid or semiarid areas, the high economic and environmental costs of developing new water resources pose limits to water supply expansion. New water supplies will not be sufficient to meet growing demands. Achieving water savings in existing uses through increases in water use efficiency in agriculture has been suggested as the most readily available pathway to meet future food demand (Cai *et al.*, 2001); the required water use efficiencies are not known. Furthermore, climate change and human activities are making the hydrological cycle more and more complex, which thereby adds more uncertainty to future water availability and food production. Figure 1 shows schematically the complex interconnections of climate, land use, food production and water use as well as how human activities affect freshwater resources (both quantity and quality) and their management.

As one of the most populated and rapidly growing economies of the world, China is increasingly facing water shortage and food security challenges. The population in China reached 1.3 billion (excluding Hong Kong, Macau and Taiwan) in January, 2005, accounting for 21% of the world's total and is predicted to reach 1.47 billion by year 2030. Population growth increases the food demand. With the improvement of people's living standard, the dietary structure improves, including the increase in meat consumption, which requires several multiples of consumptive water to meet the same daily calorie needs.

Irrigated agriculture is the foundation for China's rural economic development and the population, arable land, climate and water resources conditions have made it the most important part of China's agricultural production. By the end of 2003, irrigated area in China was 55.90 ha, 3.5 times the size of that in 1949 and the irrigation area per capita was 0.65 ha, over 2 times the size of that in 1949. About 75% of grain and over 90% of cash crops in China are produced from irrigated area. Therefore, irrigation plays an important role in guaranteeing China's agricultural production, food security as well as economic and social stability, and in enabling China to support its 21% of the world population with just 6% of the world's renewable water resources and 9% of the world's arable land.

China's mean annual precipitation is 648 mm and mean annual water resources are 2,812 billion m^3, including an estimated 2,712 billion m^3 of surface water and 829 billion m^3 of groundwater (accounting for 728 billion m^3 of duplication between surface water and groundwater). However, the annual water resources per capita in China are only 2,200 m^3, about one-fourth of the world average, making China one of the water deficient countries of the world. In fact, drought, flood and water pollution has become the three most serious water problems in China due to the uneven spatial distribution of land and water resources and rapid industrialization and urbanization. The arable land in the north of China accounts for three-fifths of the national total; the water resources are only one-fifth of the total; while the arable land in the south of China accounts for two-fifth of the national total, the water resources make up four-fifths of the total. The per hectare water resources in the south is three times that of the north

(Figure 2). With increasing competition for water from domestic and industrial sectors, it has become more and more difficult to increase the water supply to agricultural production (Figure 3). As a result, finding some sustainable and optimal water management options has become one of the most imperative issues for the decision makers and natural resources managers.

WATER AND FOOD CHALLENGES IN CHINA

Food challenges

China's food security is of significant importance to not only guaranteeing its own sustainable national economic development and social stability, but also to guaranteeing the world's food security and stabilizing the world's grain market. With the transfer of water and land resources to non-agriculture sectors in recent years, whether China's water and land resources can sustain the national food security while keeping its rapid national economic development has become one of the concerns worldwide (Alexandratos, 1997; 2005). Some of the major challenges that China is confronting are detailed as follows.

Population: Feeding a growing and affluent population is the greatest challenge facing China. China's population increased from 673 million in year 1961 to 1282 million in year 2000 (FAOSTAT, 2007), nearly doubled within 40 years. The population would reach 1.47 billion by year 2030 and 1.42 billion by year 2050 at the medium variant scenario. At 400 to 450 kg of annual grain consumption per capita, the total grain demand will reach 588 to 660 million tons by year 2030. However, the current grain production is only about 400 million tons. Grain production must grow 50 - 65% to meet this additional demand. The future food supply and demand will be unbalanced if no effective measures are adopted; China will face enormous food security challenges.

Arable land and water availability: The loss of fertile land to urbanization and industrialization is a major threat to arable land. The arable land area in China is is projected to drop to 0.073 ha per capita by year 2020 and to below 0.067 ha per capita by year 2030, due to the rapid expansion of urbanization and industrialization. The total water availability in China is around 1,125 billion m^3 or 878 m^3 per capita. The average per capita water use is 428 m^3. It is indicated from some studies that the population in China will peak, 1.37 - 1.58 billion around the year 2030. Therefore, with the adoption of stringent water saving measures, the nationwide per capita water use can be kept below 500 m^3. However, in this case, the total water consumption will reach 790 billion m^3, approaching the bottom line of utilizable water resources. As a result, there can be increasingly acute contradictions between continuous population growth and limited land and water resources.

Climate change: Global climate change poses an even greater threat to food security. Even though there are many uncertainties in the prediction of future climate change, global climate change is widely accepted. Global warming could accelerate the global hydrological cycle, and therefore change the frequency of drought and flood disasters. Climate change will pose potential threat to the sustainable use of water resources in the north of China in the future. It is predicted that the temperature in the north of China will increase by around one centigrade by year 2030 and by 1.3 to 1.4 centigrade by year 2050. Global warming will have adverse impacts to the water resources in the north of China. The total water availability in Haihe and Luanhe river basins will be reduced by 4.7% and 4 - 6% in the whole area of North China. The runoff in Haihe and Luanhe river basins will be reduced by 12% in the coming 30 years due to climate change (Zhang, 2002). Therefore, global climate warming will inevitably exert adverse impacts to the precipitation, water resources and its regional allocation, as well as water availability, especially in the north of China. Food production will be particularly sensitive to climate change, because crop yields depend in large part on prevailing climate conditions (temperature and rainfall patterns); there will be winners and losers, the gains may not offset the loses.

In the meantime, climate change will impact the production and yield of crops from arable land. The impact on yield will mainly result from the change of the frequency of extreme climate events, rather than the change of average climate conditions. Secondly, temperature will directly influence photosynthesis and breath velocity, the two crucial processes to crop growth, while crop productivity depend on the combination of these two processes.

Water challenges

With population growth the scramble for water for food would intensify further. The total water exploitation in China has increased from 100 billion m^3 per year to 560 billion m^3 per year and the per capita water use has increased from 187 m^3 to 428 m^3 since the year 1949 (Hongyun *et al*, 2007). In the last two decades, the groundwater extraction increased by about 2.5 billion m^3 per year, from 57.2 billion m^3 in 1970's, to 74.8 billion m^3 in the 1980's and to 107 billion m^3 in the year 2000. The proportion of groundwater use to total water use increased from 14% in year 1980 to 20% in year 2000. The total water use in China in the year 2000 was 550 billion m^3, 376 billion m^3 of which was used for agriculture. Table I shows the nation-wide water use in China in the year 2000. Historical agricultural water use since 1949 is shown in Figure 4. Various water management options, like improving water use efficiency and water productivity, transferring water from south to north, and treating and reusing sewage water and reallocating water have been adopted to address the scarcity and uneven spatial and temporal distribution of water resources in China. The National Medium-and-Long-term (2006 - 2020) Scientific and Technical Development Programme states that the two development goals of irrigated agriculture are: (i) to increase the command irrigation area from current 55.9 million ha to 60.0 million ha while keeping the total agricultural water use between 400 and 420 billion m^3; (ii) to improve the water use efficiency from present 0.43 to 0.65 (ratio total used by crop to the total water delivered) and the water productivity from current 1.0 kg/m^3 to 1.5 kg/m^3. Given the competition for water from domestic and industrial sectors and the need to produce more food from available land and water resources, the development of, the development of future irrigated agriculture must focus on water conservation to increase the efficiency and productivity of the available water resources.

Against this backdrop, a food security approach is used to estimate the irrigation water use efficiency that must be achieved to meet the national food production target in the future, subject to a constraint on the availability of water resources in China. The insights may be useful for policy makers.

METHODOLOGY OF ANALYSING WATER FOR FOOD

For this study the Policy Dialogue Model Simulation (PODIUMSim) developed by the International Water Management Institute (IWMI) in collaboration with the International Commission on Irrigation and Drainage (ICID) under Country Policy Support Programme (CPSP) was used. It is an interactive policy planning and scenario analysis tool, which explores the trade-offs and future demands on water resources on a national scale. It is intended to foster dialogue and stakeholder participation, and provide a basis for multi-sectoral planning and analysis. It is not intended to be used as a quantitatively reliable predictive tool, but is provided as an awareness raising exercise useful to explore the complex interactions of water scarcity, food security, and environment needs, in the light of increasing populations and changing national diets (IWMI, 2007). However, PODIUMSim does not represent complete water flows in a hydrological system but it represents system water demands (current or forecasted) and remaining water balance as environmental or the return flow (Khan *et al.*, 2005). PODIUMSim consists of four major components: Crop Consumption, Crop Production; Water Demand; and Water Supply. With an interface in Microsoft Excel, it can generate future scenarios at sub-national level, such as river basins or at administrative boundaries (IWMI, 2003). Different scenarios can be developed for food consumption and demand, with an interval of five years.

The food demand scenarios are simulated in the model on the basis of population and per capita dietary consumption for the basin or country. Similarly, the scenarios for food production are simulated on the basis of rainfed and irrigated area and yield in the basin or the country. Policy options can then be simulated to improve the water use efficiency of the cultivated area, the possibility of expansion of irrigated area or rainfed area, and increasing cropping intensity or importing more food in order to meet the future food security for the population of the basin or the country. Projections for future years are determined in relation to base year by the expected changes in the key variables over this period.

PODIUMSim enables users to set goals, such as food production for an adequate per capita consumption, and explore ways of reaching that goal: through expanding irrigated area or rainfed area, increasing cropping intensity, improving irrigation efficiency or importing more food. Likely scenarios can also be developed with respect to growth in population, changes in diets and developments in agriculture and water resources to ensure food security and sustainable water use. Therefore, to derive responses corresponding to future food supply and food demand, present study attempted to answer the following questions:

- how much food should be produced under various population growth scenarios?
- to produce that amount of food, at what scale should the irrigated area expand?
- to realize the development of that irrigated area, how much improvement in irrigation efficiency would be needed subject to a constraint on the total irrigation water use within the range of the goals set up by the Chinese government?
- what kind of water management options should be adopted to meet that irrigation efficiency gains?
- how much food would have to be imported to feed the population, if there are no new investments in developing additional water resources?

Crop consumption estimation

This component first estimates the food requirement, the feed requirements, and the seeds/waste/other uses separately for 11 crop categories and then aggregate to obtain grain, non-grain and total crop requirement. Figure 5 shows the flow chart to estimate crop requirements for a given level of nutritional requirements.

Food requirement: The major drivers of food requirement estimation are:

- population growth;
- per person daily calorie requirement growth;
- changes in the composition of daily calorie supply, i.e., changes in the daily calorie

supply from grains, oil crops, fruits and vegetables and other crop products as a percent of total calorie supply;

- the changes in daily consumption of crop products such as rice, wheat, maize, other cereals, pulses, oil crops, roots and tubers, vegetables, sugar, fruits.

The growth or changes of the drivers satisfies the constraint that the absolute difference of calorie requirement and calorie supply, i.e., |calorie requirement – calorie supply from crop consumption|, of crop categories of grains, oil crops, fruits/vegetables and other crops should be less than 5 kcal. The food requirement of i^{th} crop or crop category is estimated as:

Food consumption of i^{th} crop = Total population × Consumption/capita/day of i^{th} crop × 365 (1)

Feed requirement: The major drivers of feed requirement estimation are:

- population growth;
- total calorie requirement growth;
- growth in per person calorie supply from animal products in the total;
- the changes in feed conversion ratios, i.e., the quantity of different crop products for supplying the required calorie supply from animal crop products.

The feed consumption of i^{th} crop or crop category is estimated as:

Feed consumption of i^{th} crop = Total population × animal products calorie supply/pc/day ×365 ×feed conversion ratio of crop i (2)

Seeds/waste/other uses: The quantity of seeds/waste and other uses of crop as a percentage of total crop consumption is a driver for estimating the total crop requirement.

Total requirement of crop i:

Total consumption of crop i = (Food consumption of crop i+ Feed consumption of crop i) / (1- (Seeds/waste/other use of crop i as % of total consumption)). (3)

In addition to the food crops, the annual requirement of cotton (lint equivalent) was also estimated.

Grain, non-grain and all crop requirements: The total crop requirements of grains, non-grains and all crops of the scenario year are estimated as the aggregate value of crop products based on the base year export prices. The base year export prices are used only as a means of aggregating the quantity of different crop products. Let R_{bi} and P_{0i} are the total quantity of consumption of crop i in year t and the base year unit export prices of crop i. Then:

Grain crop requirement = $\Sigma\, R_{bi} \times P_{0i}$, $i \in$ (Rice-milled equivalent, wheat, maize, other cereals, pulses) (4)

Non-grain crop requirement = $\Sigma\, R_{bi} \times P_{0i}$, $i \in$ (Oil crops, roots and tubers, vegetables, sugar, fruits, cotton) (5)

Crop production estimation

The major improvement in PODIUMSim over the standard version is its capacity to capture the spatial variability in production potential of several crop categories. The model estimates crop production for 11 crop categories (rice, wheat, maize, other cereals, pulses, oil crops, roots and tubers, vegetables, fruits, sugar, cotton) in both irrigation and rainfed condition.

First, the growth of net and gross crop area and net and gross irrigated area are specified. This gives the changes of total crop areas under irrigated and rainfed conditions for two seasons and cropping intensities:

Overall cropping intensity = gross crop area/ net crop area (6)

Irrigated cropping intensity = gross irrigated area/ net irrigated area. (7)

Second , the seasonal irrigated cropping patterns, i.e., the irrigated crops areas are specified. The changes in irrigated crop areas in the two seasons satisfy the following constraints:

- first-season total irrigated crop area ≤ net irrigated area;

- change in first season irrigated crop area ≥ change in net irrigated area;
- change second season irrigated area = change in gross irrigated area – change in first season irrigated area.

Third, the seasonal rainfed cropping patterns, i.e., rainfed crop areas, are specified. Changes in rainfed crop areas satisfy the following constraints:

- first-season total rainfed crop area ≤ net crop area - net irrigated area;
- change in first season rainfed crop area ≥ changes in (net crop area – net irrigated area);
- change in second season rainfed area = changes in (gross crop area – gross irrigated area)-changes in first season rainfed crop area

Fourth, the growth of irrigated and rainfed crop yields are specified. The production of i^{th} crop is:

$$\text{Total production-crop}_i = \Sigma \text{ area-crop}_{ij} \times \text{yield-crop}_{ij} \; j \in (\text{first season, second season}) \quad (8)$$

Irrigation water demand estimation

PODIUMSim was used for estimating the irrigation water demand, to produce the required quantity of food in future based on crop water requirements. The PODIUMSim captures the variation of crop water requirements temporally by monthly estimations and spatially by river basins level estimations.

Crop Water Requirement: The model estimates crop water requirement for each crop. First it determines the time (months) of the growth period using the starting date (month and day) of the season and the length of the growth period and also the effective rainfall for each month using P75. Next it estimates the crop water requirement for each growth period using effective rainfall, *Et*, crop coefficients (*kc*) and percolation in paddy areas. Crop- water requirement (CWR) of the paddy crop is estimated as:

$$CWR^{Paddy} = Paddy\ Area \times \left(\sum_{j \in Growth\ period} \left(kc_j^{Paddy} \times Et_j^P - Effective\ rain\ fall_j \right) + deep\ percolation \right) \quad (9)$$

and the crop-water requirement of other crops is estimated as:

$$CWR^{other\,crops} = \sum_{i \in other\,crops} Area_i \left(\sum_{j \in Growth\,periods} \left(c_j^{Paddy} \times Et_j^P - Effective\ rain\ fall_j \right) \right) \quad (10)$$

Then total irrigation water requirement of a basin is estimated as:

$$Irritgation\ water\ requirement = \sum_{j=1}^{2} (1 - GWIA_j) \left[\frac{CWR_j^{paddy} + PER_j}{SEP_j} + \frac{\sum_{i \in other\,crops} CWR_{ij}}{SEOC_j} \right] + \sum_{j=1}^{2} GWIA_j \left[\frac{CWR_j^{paddy} + PER_j + \sum_{i \in other\,crops} CWR_{ij}}{GE_j} \right] \quad (11)$$

Where:

IA_{ij} – irrigated area of i^{th} crop in j^{th} season

CWR_{ij} – crop water requirement of i^{th} crop in j^{th} season

PER_j – Percolation requirement for paddy in j^{th} season

$GWIA_j$ – Groundwater irrigated area as a percent of total irrigated area in j^{th} season

SEP_j – Surface project irrigation efficiency for paddy in j^{th} season

$SEOC_j$ – Surface project irrigation efficiency for other crops in j^{th} season

GE_j – Ground water project irrigation efficiency in j^{th} season

PER_j – Percolation requirement for paddy in j^{th} season

SCENARIOS DEVELOPMENT

There are many factors that affect the total food demand and food supply in China. Population and urbanization are the two major factors, which determine the per capita food consumption. While the food supply capacity relies mainly on arable land area, cropping pattern, cropping density, irrigation water availability, as well as irrigation efficiency factors. Future food supply and food demand scenarios are developed on the basis of the base year 2000.

China's population is projected to peak in year 2030, to 1451 million (UNPD, 2004). In this paper three scenarios at low, medium and high growths were developed based on the projections from the United Nations Population Division (UNPD, 2007) and the Food and Agriculture Organization (FAOSTAT, 2007) (Table II and Figure 6). The changes in population size and diets are used for estimating the total food demand.

The arable land area in China in the year 2000 was 128 million ha and is going to drop to 122 and 118 million ha by year 2030 and 2050 due to the rapid urbanization and industrialization (CAE, 2000). However future irrigation area will increase owning to the expansion and improvement of irrigation infrastructure and adoption of various water-saving technologies. Future arable land area and scenarios for the development of irrigation areas at various levels in the coming years 2010, 2030 and 2050 are shown in Table III. Water uses by various sectors in the year 2000 are shown in Figure 7. These are used for estimating the total food supply.

RESULTS AND DISCUSSION

Food consumption

Food consumption is made up of food grain, feed grain, and seeds/waste/other uses. The food grain consists of paddy rice, wheat, maize, pulses and other cereals. The daily calorie supply per capita in the base year 2000 was 2,974 Kcal, 57.2% and 54.0% from grain products in urban and rural areas respectively and 19.5% from animal products. It is going to reach to 3,383 Kcal, 46.4% and 43.7% from grain products in urban and rural areas respectively and 29.0% from animal products, by year 2030; and 3,686 Kcal, 40.3% and 30.8% from grain products in urban and rural areas respectively and 37.8% from animal products, by year 2050, all at a medium population variant scenario. The total food grain consumption in the base year 2000 was 291 million tons, 44% from rice, 25% from wheat and 27% from maize. However, with the change of people's dietary structure, more meat will be consumed in the future, which would increase the consumption of maize, one of the major sources of feed, and reduce the consumption of starchy food, like rice and wheat correspondingly. Trends for the change of food consumption at medium population growth scenario are shown in Figure 8. Compared with the total food consumption, there will be an acute increase in the total feed consumption due to more demand for meat in the coming decades (Figure 9), which would reach 202 and 300 million tons respectively in years 2030 and 2050. The increased consumption of meat based diets will require much more water than would be required to supply the same daily calories from direct consumption of cereals.

Food production

Suppose the yield of paddy rice will increase from 6.6 ton/ha in 2000 to 9.6 ton/ha by year 2030 and to 12.2 ton/ha by year 2050 due to the improved agronomic skills, its total production will increase from 201 million tons in year 2000 to 249 million tons in year 2030 and to 287 million tons in year 2050 at medium irrigation area development scenario, even though its harvested area decreasing slightly year by year. However, the total production of wheat, maize, other cereals and pulses at the same scenario will increase from 75, 108, 12 and 4.5 million tons in the year 2000 to 105, 147, 16 and 5.4 million tons in year 2030 and to 133, 185, 18 and 6.4 million tons in year 2050 respectively due to the increase of both harvested area and yield. Out of which, the irrigated yields of wheat, maize, other cereals and pulses are supposed to increase from 3.7, 5.3. 2.8 and 1.8 tons/ha in the year 2000 to 5.3, 7.7, 4.1 and 2.6 tons/ha in year 2030 and to 6.8, 9.8, 5.3 and 3.3 tons/ha in year 2050. In particular, the total production of vegetables, roots and tubers, fruit and cotton will increase tremendously due to change in people's dietary preferences, from 276, 45, 62 and 4.0 million tons in the year 2000 to 469, 66, 84 and 6.4 million tons in year 2030, and to 673, 88, 105 and 8.9 million tons in year 2050 respectively supposing their irrigated yields will increase from 20.8, 4.8, 12.0 and 1.1 tons/ha to 30.0, 7.0, 17.0 and 1.6 tons in year 2030 and to 38.4, 8.9, 22.0 and 2.1 tons in year 2050. Details for crop production in the year 2000, 2030 and 2050 at the medium irrigation area development scenario are shown in Figure 10. As vegetarian diets require less water per calorie than meat based diets, a transition towards these diets may help to reduce the pressure on water resources.

Food surplus or deficit

Since it is difficult to compare the total food surplus or deficit in terms of production (Million tons) of individual crops, the food deficit and surplus are converted to equivalent financial values (US$ billion) using the base year export prices (FOB) of different crops (US$/ton). There was US$ 3.1 billion of grain deficit in the year 2000 and there will be US$ 10.8 billion and US$ 3.2 billion of grain deficit in year 2030 and 2050. In addition, there will be more deficits in the other crops, including vegetables, roots and tubers, sugarcane, fruit and cotton in year 2030, which will increase from US$ 48.1 billion in the year 2000 to US$ 59.0 billion in year 2030. However, there will be US$ 26.1 billion of surplus of these crops in year 2050 due to the adjustment of cropping pattern. Details of crop production, consumption, and surplus or deficit for this scenario in the year 2000, 2030 and 2050 are shown in Figure 11. Model results predict that there will be huge food deficit in years 2030 and 2050 for the integrated scenarios of high population growth and low irrigation area development. The financial value of total grain deficit will reach US$ 21.0 and US$ 29.8 billion respectively and the total crop's deficit will reach US$ 128.0 and US$ 136.3 billion respectively in years 2030 and 2050 (Figure 12). Therefore, tangible and feasible measures should be adopted to meet the food demand in the future.

Irrigation water demand

The total net irrigated area of China in the year 2000 was 55.4 million ha, including 30.4 million ha of paddy rice and 25.1 million ha of other crops. The estimated irrigation efficiency was 43% for surface water and 70% for groundwater, and the percolation requirement for paddy was 160 mm. Thus the total irrigation requirement is calculated with the irrigated area of different crops and the water use efficiency, which was 381 billion cubic metres, 34.4 billion cubic metres more than the actual irrigation water diversion in 2000, which means 34.4 billion cubic metres of water deficit in irrigated agriculture. More water will be required for irrigated agriculture even with the increase in irrigation efficiency, for both surface water and groundwater in the future due to the adjustment of cropping pattern (more irrigated areas for vegetable, fruit, and roots and tubers) and expansion of irrigated area, The total irrigation requirement will reach 433 billion cubic metres in year 2030, with 54% and 78% of irrigation efficiency from surface water and groundwater respectively. As there will be slight increase in the irrigation area in all the scenarios (from 58.3 million ha in year 2030 to 58.9 million ha in year 2050 at the medium irrigation area development scenario) and relatively large increase in the irrigation efficiency is required (62% irrigation efficiency for surface water and 83% for groundwater), the total irrigation requirement in year 2050 must decrease compared with year 2030; it will be around 379 billion cubic metres.

Water productivity

Water productivity is generally defined as the amount of crop output in physical terms (crop yield in kilogram) or monetary terms (crop yield times its price in financial or economic terms) divided by the amount of water consumed (evaporated from the soil or transpired by the plant, i.e. the evapotranspiration that include 'green' water (effective rainfall) for rain-fed areas and both 'green' water and 'blue' water (diverted water from water systems) for irrigated areas.) - in other words, the crop per drop. Based on the yields and water consumptions in years 2000, 2030 and 2050 derived from the PODIUMSim model, the corresponding water productivities of various crops can be calculated. Table IV shows the water productivities of some typical crops in 2000, 2030 and 2050. It could be seen from this table that the current water productivities of paddy rice and irrigated maize is relatively high, around 1.01 kg/m^3 and 1.31 kg/m^3 respectively and will reach 1.46 kg/m^3 and 1.89 kg/m^3 respectively in year 2030, and 1.86 kg/m^3 and 2.41 kg/m^3 respectively in year 2050. The calculated overall water productivity of irrigated cereals is 1.15 kg/m^3 in year 2000, and is predicted to reach 1.69 kg/m^3 in year 2030 and 2.19 kg/m^3 in year 2050, which is in rough consistency with the values given from the National Scientific and Technical Development Programme.

Gains in irrigation efficiency to meet the future food security

The food security situation will become dire around the year 2030 due to population growth, and pressure on land and water availability. There are two options to meet the total food demand: increasing per hectare yield or expanding the harvested area. Since yields are higher in irrigated agriculture, expanding the irrigation area will inevitably be a better pathway. However, the total water available for irrigation is limited due to the water competition from domestic and industrial sectors, so improving the water use efficiency and keeping the irrigation water use within the development goal set up by the Chinese government should be the promising options. Suppose the total irrigation water diversion is 420 billion cubic metres in year 2030 and 400 billion cubic metres in year 2050 under conditions without considering the impact of climate change on total water availability, and the irrigated yields are kept the same, the gross irrigated area have to reach 138 and 109 million ha respectively to meet the total food demand; irrigation efficiency needs to increase to 69% for surface water and 85% for groundwater in year 2030 and 63% for surface water and 83% for groundwater in year 2050. This is a huge challenge for the irrigated agriculture in China, particularly considering the water and food needs in year 2030. As a result, various management options, like converting some of the flood irrigation area to sprinkling or micro irrigation areas, increasing the reuse of return flows, and technologies, practices and policies promoting water conservation at basin scale to help achieve real water savings should be adopted in the future (Blanke et al., 2007; Bluemling et al., 2007).

CONCLUSIONS

Population growth and economic development are putting immense pressure on land and water resources for food as well as industrial and urban uses in China. Enhancing water use efficiency in food production will be a key pathway to future food security. The required water use efficiencies are not known. Against this backdrop, this paper used a food security approach for estimating the irrigation efficiency gains at the country level that must be achieved to meet the national food security goal, subject to a constraint on total water withdrawals. The PODIUMSim model results indicated that total grain demand for China would increase from 427 million tons in 2000 to 609 million tons by 2030 and 714 million tons by 2050. The estimated financial value of food production in 2030 and 2050 will be US$ 600 and US$ 816 billion, US$ 111 and US$ 327 billion higher than the food production in 2000; even though the arable land area decreased from 128 Mha in 2000 to 122 Mha in 2030 and 118 Mha in 2050, due to the adjustment of cropping pattern and implementation of the policy of returning cultivated land to forest and pasture. There would be US$ 10.8 billion and US$ 3.2 billion worth of grain deficits in year 2030 and 2050 at the medium population growth and medium irrigation area development scenarios. Therefore, to meet the total food demand in year 2030 and 2050, 138 and 109 million ha of gross irrigated area need to be reached respectively, which requires 69% and 85% of surface water and groundwater irrigation efficiencies in year 2030 and 63% and 83% of surface water and groundwater irrigation efficiencies in year 2050 provided the total irrigation diversion is maintained at 420 and 400 billion cubic metres respectively. Achieving these gains in irrigation efficiency at the country levels is a formidable task, requiring further intensification of land and water use which will put pressure on the environment. While the potential exists in many areas, in some areas particularly in the north China the scope is rather limited as land and water resources are almost fully allocated. Needed are the technologies, policies, and water management practices that promote water conservation to achieve real gains in water use efficiency.

PODIUMSim is strong on food security but does not fully address the water management problem and is best applicable to understand country level water and food needs. It can not deal with the externalities such as virtual water trading within and outside the country to evaluate production and environmental tradeoffs. The authors propose a global food security, virtual water trade, and environmental stress analysis using an integrated food security and economic approach.

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REFERENCES

Alexandratos N. 1997. China's consumption of cereals and the capacity of the rest of the world to increase exports. Food Policy 22: 253-267.

Alexandratos N. 2005. Countries with rapid population growth and resource constraints: issues of food, agriculture, and development. Population and Development Review 31: 237.

Blanke A, Rozelle S, Lohmar B, Wang J, Huang J. 2007. Water saving technology and saving water in China. Agricultural Water Management. 87, 139-150.

Bluemling B, Yang H, Pahl-Wostl C. 2007. Making water productivity operational--A concept of agricultural water productivity exemplified at a wheat-maize cropping pattern in the North China plain. Agricultural Water Management. 91, 11-23.

Cai X, Ringler C, Rosegrant M.W. 2001. Does efficient water management matter? EPTD Discussion Paper No. 72, International Food Policy Research Institute.

Chinese Academy of Engineering (CAE), 2000. The Key Consultation Project ‘Agricultural Water Demand and Water-saving and Efficient Agricultural Development in China, P167 (in Chinese).

Chinese Academy of Engineering (CAE), 2001. Assessment on China’s current water resources and analysis on its trend of supply and demand, Vol. 2 of the proceedings of Study on the strategy of sustainable water resources development, China Water Power Press (in Chinese);

de Fraiture C, Wichelns D, Rockström J, Kemp-Benedict E, Eriyagama N, Gordon LJ, Hanjra MA, Hoogeveen J, Huber-Lee A, Karlberg L. Looking ahead to 2050: scenarios of alternative investment approaches. In *Comprehensive Assessment of Water Management in Agriculture. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. Chapter 3, pp.91-145*; D. Molden, Ed.; London: Earthscan: Colombo: International Water Management Institute, 2007.

Hongyun H, Liange Z. 2007. Chinese agricultural water resource utilization: problems and challenges. Water Policy 9(S1): 11-28.

International Water Management Institute (IWMI), 2003. User’s manual of PODIUMSim- Policy Dialogue Model: Version II, A Water and Food Security Planning Tool. April 2003.

International Water Management Institute (IWMI), 2007. The global PODIUM, interactive water & food security planning scenario tool. http://podium.iwmi.org/podium.

Khan S, Mu J, Jamnani MAR, Hafeez M, Gao Z. 2005. Modelling water futures using food security and environmental sustainability, Proceedings of MODSIM05, International Congress on Modelling and Simulation, 12-15 December 2005, Melbourne, Australia, P1963-1969.

Kundzewicz ZW, Mata LJ, Arnell NW, Döll P, Kabat P, Jiménez B, Miller KA, Oki T, Sen Z, Shiklomanov IA. 2007. Freshwater resources and their management. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, Eds., Cambridge University Press, Cambridge, UK, 173-210.

Ministry of Water Resources (MWR), 2000. China Water Bulletin, http://www.mwr.gov.cn/xygb/szygb/qgszygb/20000101000000415341.aspx (in Chinese);

Oki T. 2005. The hydrologic cycles and global circulation. Encyclopaedia of Hydrological Sciences, M. G. Anderson, Ed., John Wiley and Sons, Chichester.

Rosegrant MW, Ringler C. 1998. Impact on food security and rural development of transferring water out of agriculture. Water Policy 1(6): 567-586.

Shiklomanov IA. 1998. World water resources: a new appraisal and assessment for the 21st Century. IHP report. Paris: UNESCO.

Rozelle S, Rosegrant MW. 1997. China's past, present, and future food economy: can China continue to meet the challenges? Food Policy. 22, 191-200.

The United Nations Food and Agriculture Organization (FAO), 2007. FAOSTAT. www.apps.fao.org (accessed January 09, 2007), henceforth FAO (2007).

The United Nations Population Division (UNPD), 2004. World Population to 2300. New York.

The United Nations Population Division (UNPD), 2007. http://esa.un.org/unpp/ (accessed December 18, 2007), henceforth UNPD (2007).

Zhang Y. 2002. Challenges confronted by China’s water conservancy in the 21st century. Shanghai Science and Technology, http://www.stcsm.gov.cn (in Chinese).

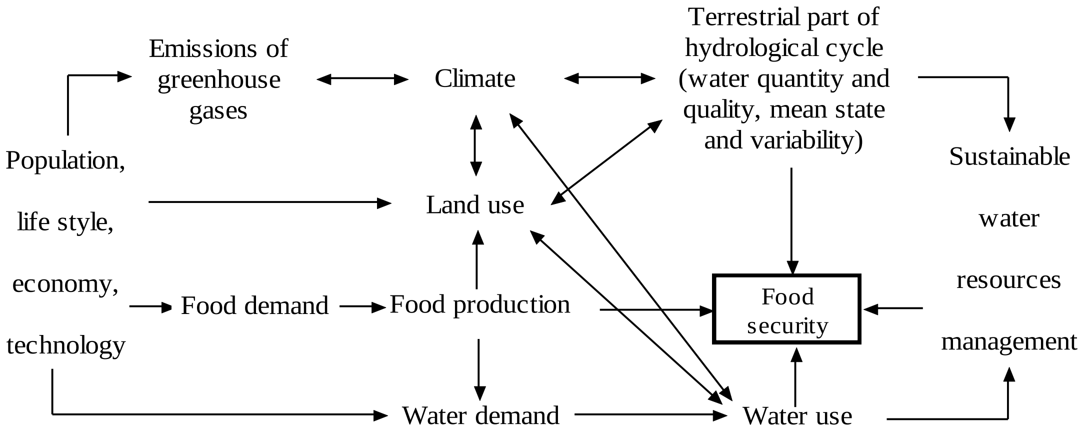

Figure 1. Impact of human activities on freshwater resources and food security

(Source: modified after Kundzewicz *et al.*, 2007 and Oki, 2005

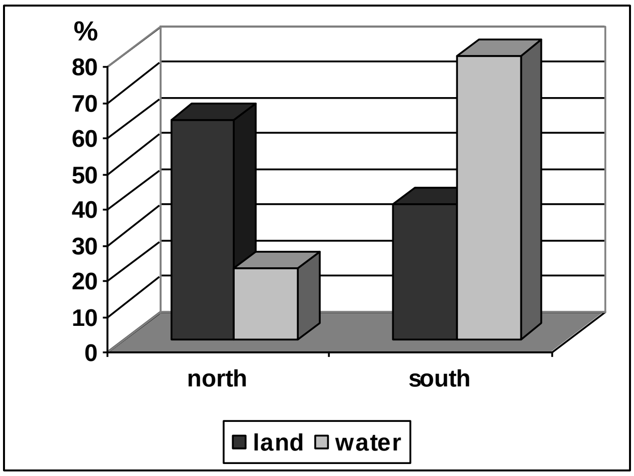

Figure 2. Uneven land and water distribution across China

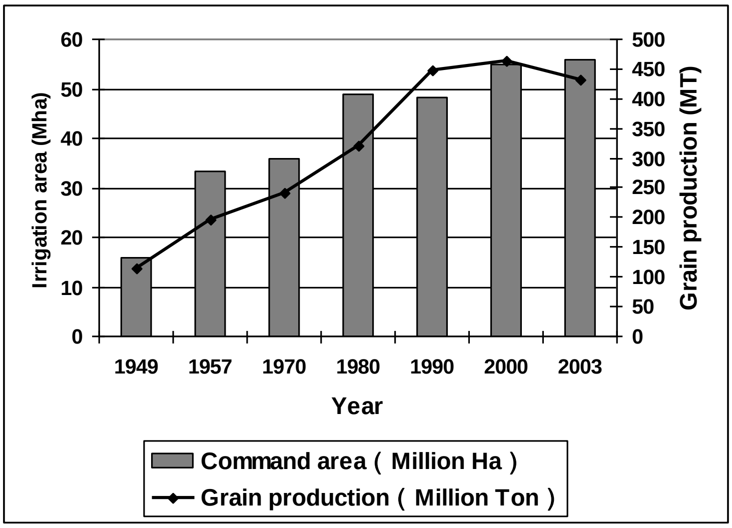

Figure 3. Irrigation area and gross grain production

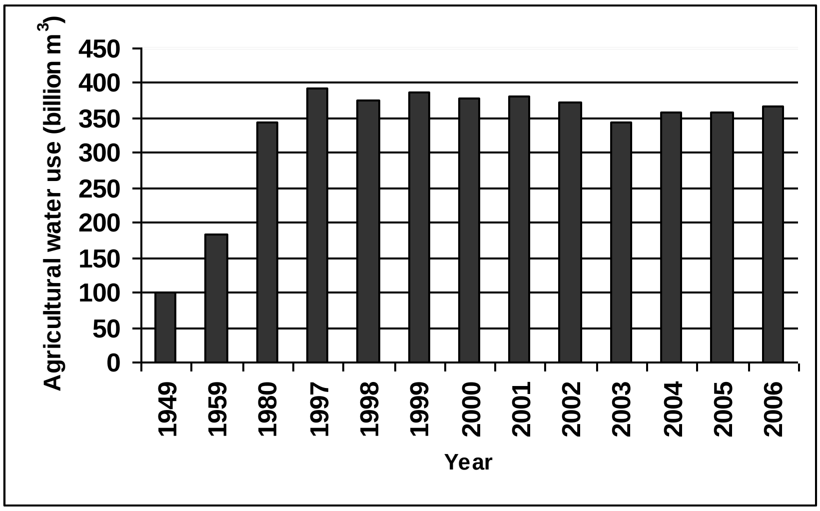

Figure 4. Variation of agricultural water use since the year 1949

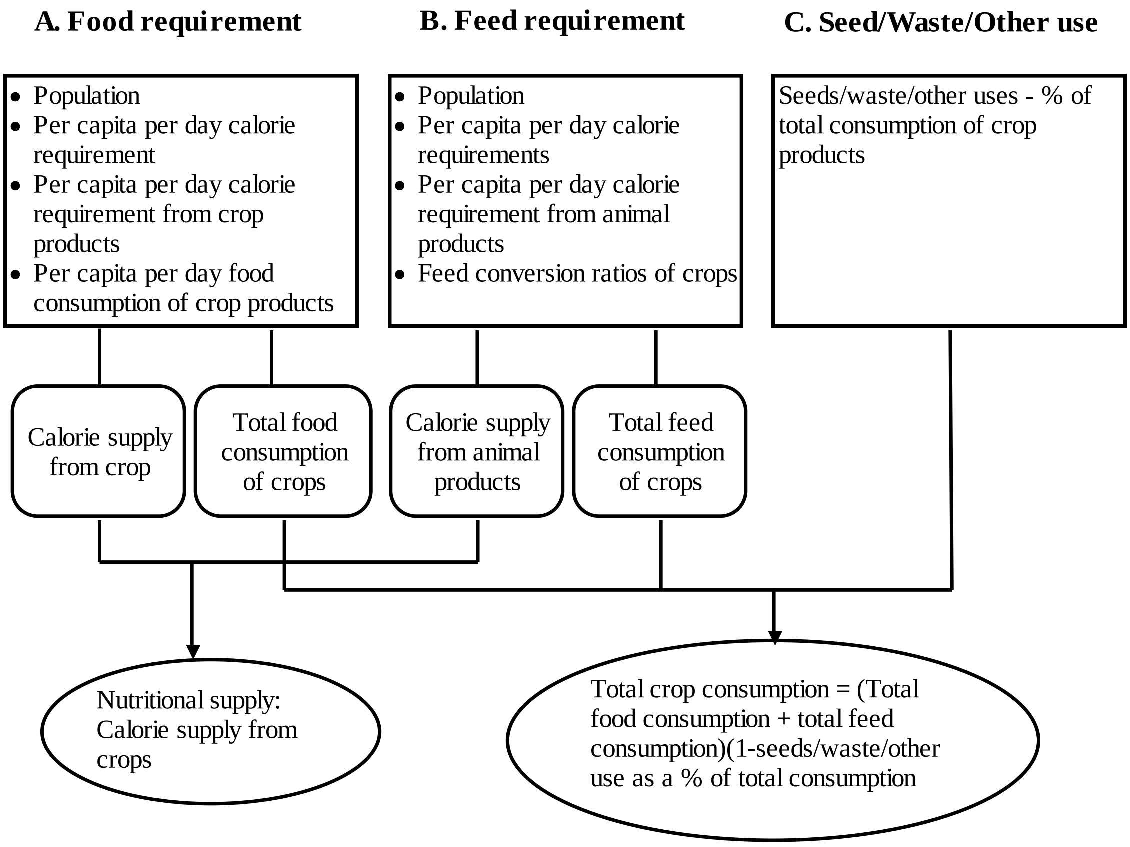

Figure 5. Flow diagram of consumption component

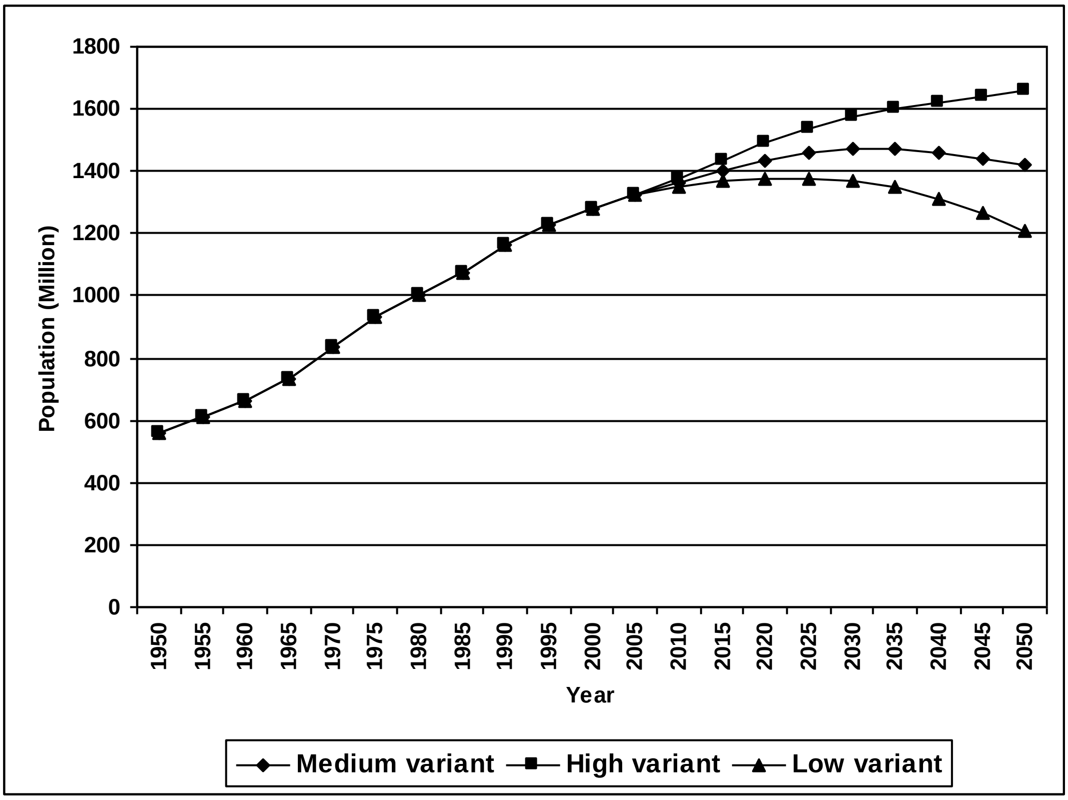

Figure 6. Population scenarios of China, 1950-2050, by projection variants

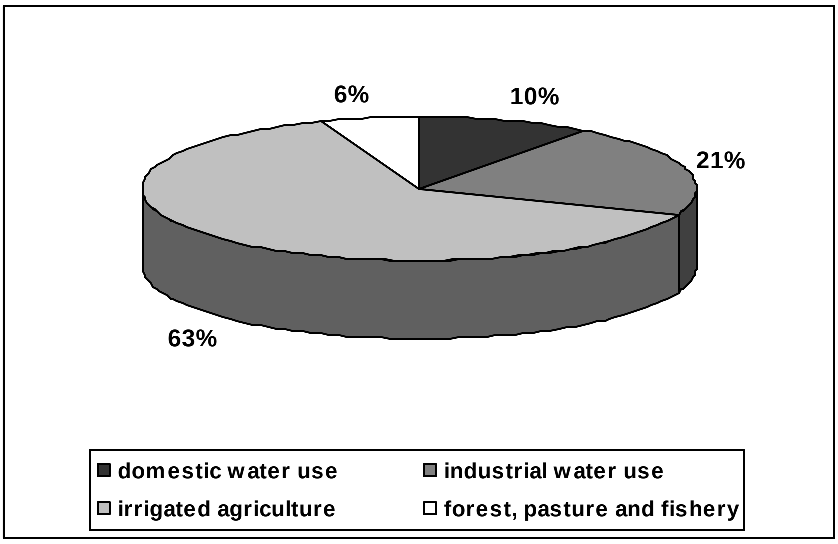

Figure 7. Percentage of various water uses in the year 2000

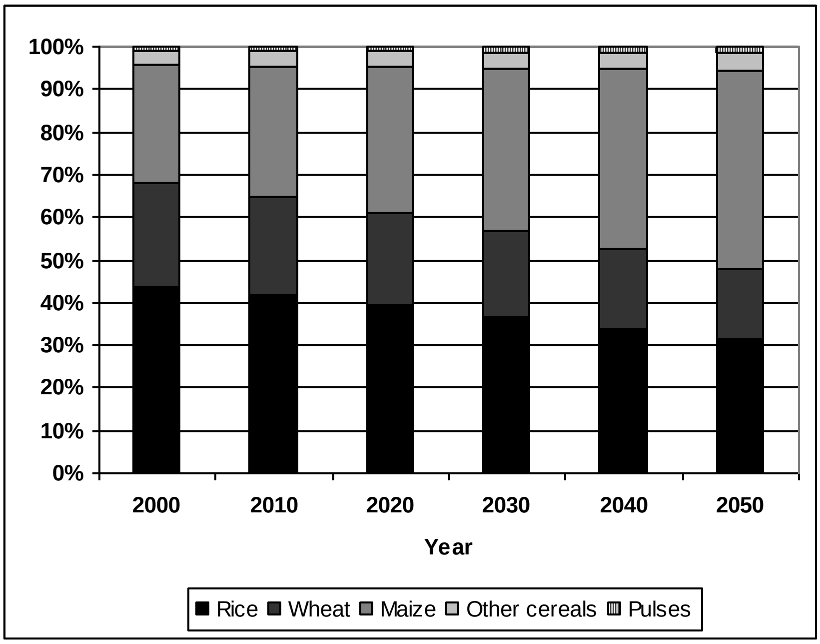

Figure 8. Distribution of food consumption in the future at medium population growth scenario

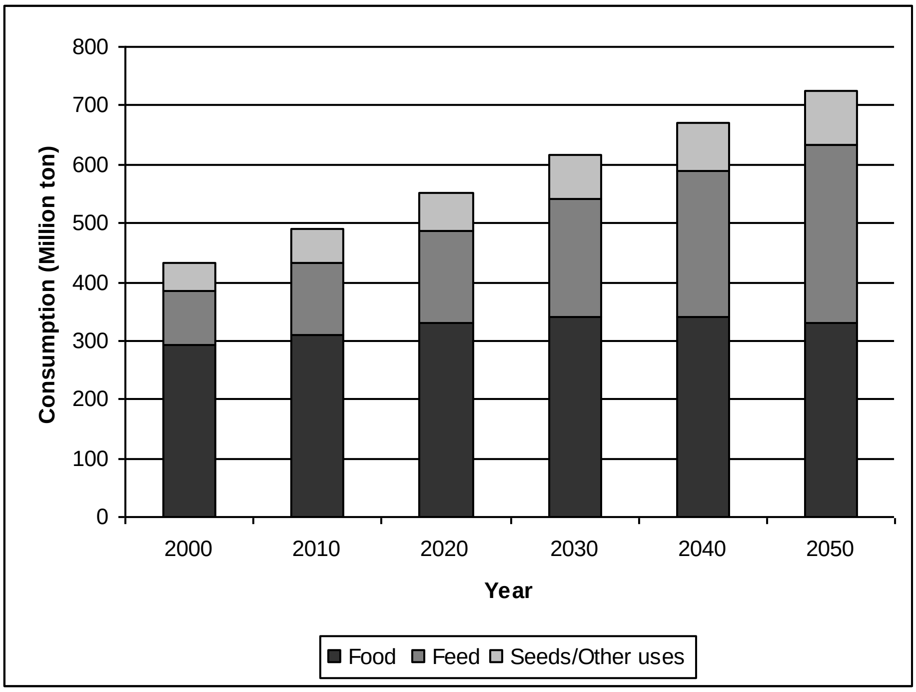

Figure 9. Total grain consumptions in the future at medium population growth

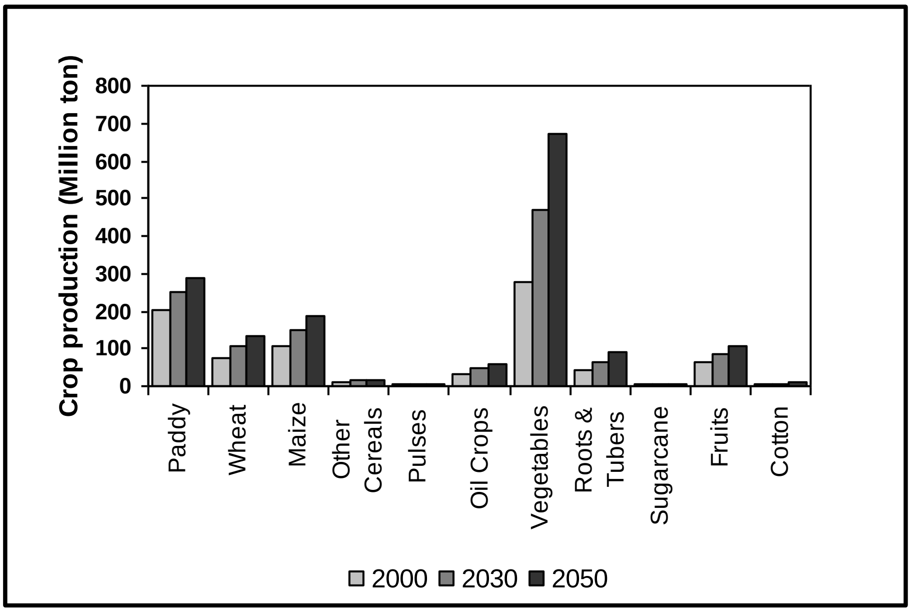

Figure 10. Crop productions in the year 2000, 2030 and 2050 at medium irrigation area development scenario

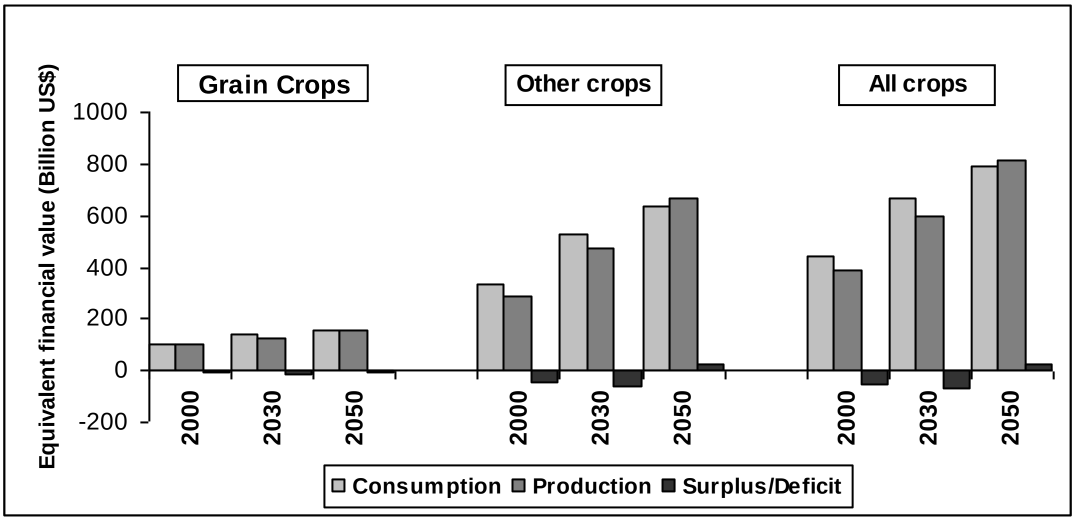

Figure 11. Crop production, consumption and surplus or deficit in the year 2000, 2030 and 2050 at medium population growth and irrigation area development scenarios

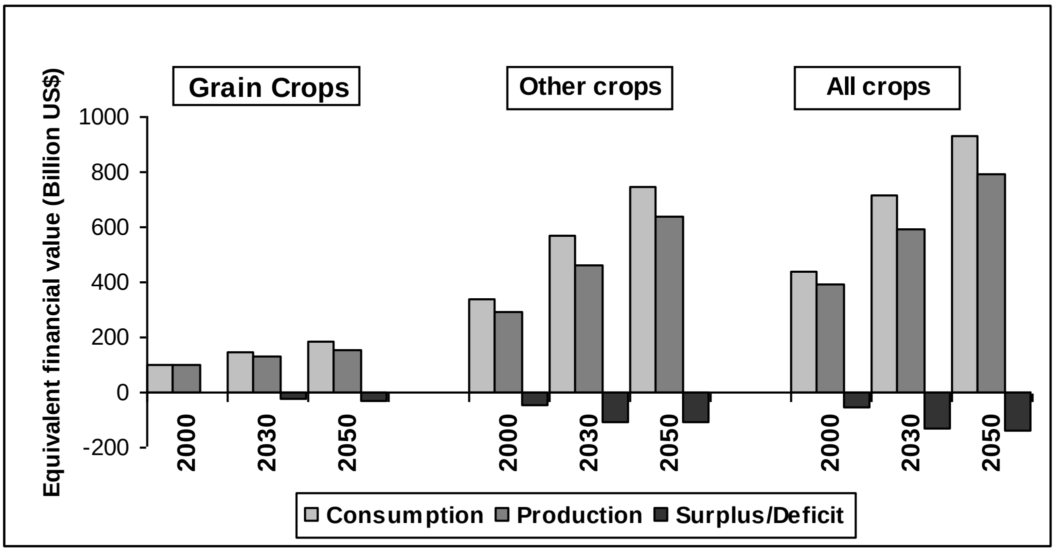

Figure 12. Crop production, consumption and surplus or deficit in the year 2000, 2030 and 2050 at high population growth and low irrigation area development scenarios

Table I. Nation-wide water use in the year 2000

Water use items		Water use (billion m^3)	Percentage to the national total
Total national water use		549.8	100
Domestic use (urban)		28.6	5.2
Industrial use		113.8	20.7
Agricultural use	Total	375.5	68.3
	Irrigation	346.4	63.0
	Rural domestic	29.1	5.3
Forest irrigation and wetlands		31.9	5.8

Source: Ministry of Water Resources, 2000.

Table II. Scenarios for population growth (million)

Scenarios	1980	2000	2010	2020	2030	2040	2050
Low variant			1,349	1,376	1,370	1,312	1,211
Medium variant	999	1,282	1,362	1,432	1,470	1,460	1,420
High variant			1,374	1,489	1,576	1,620	1,660

Source: Past and current population are derived from FAOSTAT (2007) and projections for future population are after the United Nations Population Division (2007) and FAOSTAT (2007).

Table III. Arable land and irrigation area development (million ha)

Year		1980	2000	2010	2030	2050
Arable land area		99.7	128.3	126.1	122.0	117.8
	High development scenario			56.7	59.7	60.9
Irrigation area	Medium development scenario	48.9	55.4	56.1	58.3	58.9
	Low development scenario			55.4	57.1	57.6

Sources: 1. The annual decrease rate for arable land area is derived from Chinese Academy of Engineering (CAE) (2000; P. 167)

2. Scenarios for the development of irrigation area are derived from Chinese Academy of Engineering (CAE) (2001).

Table IV. Water productivity of some typical crops with and without irrigation in year 2000, 2030 and 2050 (kg/m^3)

Water productivity	2000		2030		2050	
Crops	Irrigated	Rainfed	Irrigated	Rainfed	Irrigated	Rainfed
Paddy	1.01	/	1.46	/	1.86	/
Wheat	0.76	3.94	1.10	4.41	1.41	4.76
Maize	1.31	1.65	1.89	1.85	2.41	1.99
Other cereals	0.65	0.86	0.94	0.97	1.20	1.04
Pulses	0.58	0.52	0.83	0.58	1.06	0.62
Oil crops	0.56	0.76	0.81	0.85	1.04	0.92