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AN EMPIRICAL ANALYSIS AND FORECASTING OF GRAIN PRODUCTION IN CHINA

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Abstract

Great concerns are now emerging over China's future food security as its rapid economic growth might have adverse impacts on food supply and demand in the world. In this paper, the regression model of crop yield per unit land area in the scale of county is presented, which takes into account the agricultural technology and climate factors, such as the consumption of chemical fertilizers, the rate of irrigation, the total power of agricultural machinery, temperature, precipitation and cloudiness. Based on the relations between the above factors and the expected economic growth, scenarios for these factors and cultivated areas are set for the years up until 2025. Then an estimation of grain production all over the country is made according to these scenarios. The results show that total grain production in China will arrive at 530 million tons in 2015 owing to the increase in crop yield as the result of agricultural technology development despite the decline in cultivated areas. After 2015, however, a decline may take place, suggesting an increasing shortage of food supply.

KEYWORDS: *Food supply and demand in China, Grain production in China, Environmental modeling, Regression model, Crop yield*

1. Objectives

A major question about China's sustainable development is how she can secure food production to support her increasing population in the trend of rapid industrial development, and this is a matter of great concern for the world. Since the establishment of the new Chinese state, the nation maintained self-sufficiency in grain in spite of a burgeoning population. In 1995, however, China became a grain-importing nation. At the same time the report of Lester Brown (Brown, 1995) was published, bringing the problems of Chinese grain supplies to the attention of the world.

The issue of food obviously has both supply and demand aspects. The primary determining factor in demand is population. Another key factor is changing in eating habits due to an improving

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standard of living: increased consumption of meat, in particular, causes the increase in demand for feed grain. On the other hand, supply is determined by yield per unit of cultivated land (referred to below as "yield") together with total cultivated land area.

According to China's national statistics for the period immediately after World War II, there was a sharp rise in yield due to increased usage of fertilizers and other agrochemicals. In many nations the yield increased faster than agricultural land area shrank, providing an overall increase in production. There are limits to the production growth that can be achieved through these methods, however, and the warning bell sounded by Brown *et al.* was that eventually production would be unable to keep pace with population growth. In recent years, however, Chinese grain production levels have continued to grow due to favorable climatic conditions and the high-pricing strategy of the government, reaching some 500 million tons in 1996 (CNSB, 1997). This level represents attainment of the official goal for the year 2000 a full four years in advance, and demonstrates that Chinese efforts to increase grain production are progressing smoothly. Views on whether or not a grain crisis will occur depend on whether the supply-and-demand problem is considered for a single nation alone, or on the global level. In the case of Japan, for example, there would be no crisis even if self-sufficiency were not possible, as long as required grain could be imported. If a nation like China having enormous population, however, becomes a grain importer due to poor domestic harvests caused by unfavorable weather, the effect on the world grain market would be enormous.

Many studies have been conducted based on various data and projection models in order to predict the future food situation in China as well as to determine its potential impact on the world food market. They include studies made by Brown, OECF, USDA (U.S. Department of Agriculture), World Bank and the Chinese Academy of Agricultural Science (Brown, 1995; Tsuji, *et al.*, 1995; ERS/USDA, 1996; Fang, *et al.*, 1996; Liu, 1991; Hu, 1996). Most of these studies except the domestic study of China show that China will increase its grain imports. The magnitude of imports, however, is different among the studies, resulting from the difference in the model structure, macroeconomic assumptions and used data. Furthermore, the difference in supply prediction is larger than that in demand side. Regression and linear extrapolation models are commonly used in those studies based on past trends and/or the experiences of other countries that seem to be alike with China in various aspects. However, all of models were built in the country or province scale and they have limitations in taking into account the actual local situation of the different areas of vast China. Another problem is that some models were developed just according to time series data of grain production or expert's judgement but not explicitly taking into account the agricultural technology and climate factors, which have an important bearing on crop yield. For example, OECF report (Tsuji, *et al.*, 1995) extrapolates forecasts based on past trends in per-province yield and cultivated land area, and neglects analysis of factors determinant in production tonnage.

An objective discussion of food problems requires a predictive analysis of grain supply and demand, and the essential first step for this is to identify absolute limitations on production capacity. In other words, it is essential to forecast future grain production tonnage, which in turn requires prediction of changes in yield due to technical progress and trends in cultivated land area. Here, for China, with its enormous land area, the bottom-up approach is needed, consisting of summation of data for the various regions. In terms of the above consideration, this paper first divides China into nine agricultural regions, while organizing data for each region including grain production tonnage in county units, and related factors such as agricultural technology level, agricultural state and meteorology. Then multivariate analysis is applied to analyze relationships between these factors and yield for each agricultural region, and empirical equations are derived. Next, scenarios are developed for these determining factors and the changes in cultivated land area, and they are used to forecast grain production capacity for China as a whole. Then, discussions are made of the validity of the analysis methodology and uncertainties in the forecasts.

The method of analysis for supply forecasting adopted in this paper is almost in line with the authors' previous paper published in Japanese (Toyoda, *et al.*, 1997) except the following points. Firstly, the present analysis uses the cultivated land area data from Chinese statistical yearbooks while the previous analysis used the data from satellite observation; this change is made in order to ensure consistency with other data, which are derived from Chinese statistical yearbooks. Furthermore, the present analysis is improved in that it uses numerical data instead of the grade data, and the time frame of the prediction is expanded to the year 2025 instead of 2010 in the prior study. In addition, this paper presents an analysis of possible demand-supply gaps in the future.

2. Determination of experiential expressions of yield

2.1 Analyzed regions and units of observation

Grain production tonnage is greatly influenced by natural characteristics on the micro-level in each region. It is therefore desirable to use the data for the smallest geographical units for which relevant data can be collected. The present paper uses the 2,187 individual counties and cities

Table 1. Agricultural regions of China and their agricultural characteristics

Region	Province	Agricultural climate condition	Main crop	Multiple crop system
Northeast China Region	Heilongjiang,Jilin,Liaoning	Q=1000～3400℃ W=500～700mm	Wheat,Corn, Largebeans, Potato	1harvest/year
Inner Mongolia Region	Neimenggu,Ningxia	Q=2000～3000℃ W=200～500mm	Wheat,Corn, Potato	1harvest/year
Huang-huai hai Region	Beijing,Tianjin,Hebei, Shandong,Henan,	Q=4000～4500℃ W=500～800mm	Wheat,Corn	3harvest/2year
Loess plateau Region	Shanxi,Shaanxi, Gansu	Q=3000～4300℃ W=400～600mm	Wheat, Coarse grain	3harvest/2year or 1harvest/year
Lower reaches of the Yangtze river Region	Shanghai,Jiangsu,Zhejiang, Anhui,Fujian,Jiangxi, Hubei,Hunan	Q=4500～6000℃ W=800～2000mm	Rice	2harvest/year
South China Region	Guangdong,Guangxi	Q=6500～9500℃ W=1500～2000mm	Rice	3harvest/year
Southwest China Region	Sichuan,Guizhou,Yunnan	Q=3000～5000℃ W=800～2000mm	Rice	2harvest/year
Xingjiang Region	Xinjiang	Q=2600～4500℃ W<250mm	Wheat, Coarse grain	1harvest/year
Tibet Region	Qinghai	Q=1000～2000℃ W=200～1500mm	Wheat,Corn, Coarse grain	1harvest/year

Note:Q is 10℃ above accumulation temperature for one year.W means annual precipitation

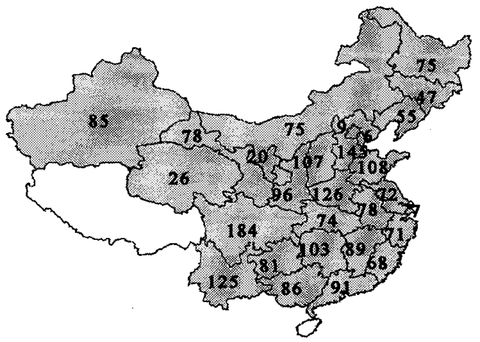

Figure 1. The numbers of observation point in each province, city or autonomous region

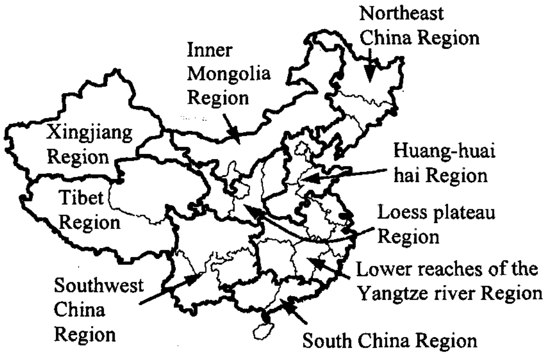

Figure 2. The breakdown by agricultual regions

making up China as observation points, in that the compiled data related to grain production tonnage and determining factors are available. It should be noted that China just published her agricultural data in the scale of county for 1988,1989,1990 and 1991(CNSB, 1989-1992): they are the newest data available today although they are rather old and short in time series. On the other hand, for analyzing the change trend of agricultural situation, data in the scale of province are used as per-county data are not available for them.

Determining factors chosen in this analysis to explain grain production tonnage are consumption of chemical fertilizers F, effective irrigation ratio I, total power of agricultural machinery M, and weather condition (mean annual atmospheric temperature T, mean annual precipitation P, and mean annual cloudiness C). Here, effective irrigation ratio is defined as the percentage of cultivated land area which is irrigated to the total cultivated land area, and the total power of agricultural machinery expressed in terms of W/ha represents the level and usage state of mechanical agricultural facilities. The effective irrigation area is the cultivated land area that is located in relatively flat land. In normal years, it is normally irrigated as it has established irrigation processes and equipment and developed certain water sources.

The Chinese land area is extremely large and the agricultural characteristics diverse: frigid climate in the north and warm climate in the south, dry regions to the west and moist plains to the east. Each region is thought to respond to its specific natural conditions with specific crops and techniques. As a result, the agricultural characteristics of China can be divided into the nine agricultural regions as shown in Table 1. Multivariate analysis is applied on the data for observation units (counties, cities) in each of these regions, and the experiential expressions representing grain production tonnage is developed. Here, however, the Tibet Autonomous Region and Hainan Province are omitted in the analysis due to the lack of relevant data. Figure 1 indicates the numbers of observation point in each province, city or autonomous region, and Figure 2 indicates the breakdown by agricultural regions.

2.2 Analysis methodology

(1) Model expression

As determining factors for yield, variables representing agricultural practices (F, I, and M) and weather conditions (T, P, and C) are adopted. Then the following two regressive expressions are tested as model expressions representing yield, and the one which fits better to the actual data is adopted for each region. The determining factors are listed in Table 2.

$$V_i = K \times F_i^a \times I_i^b \times M_i^c \times T_i^d \times P_i^e \times C_i^f$$
$$V_i = a_0 + a_1 F_i + a_2 I_i + a_3 M_i + a_4 T_i + a_5 P_i + a_6 C_i$$

Table 2. Yield and its determing factors

Variable / Factor	Variables used				
	Description	Factors	Symbol	Unit	Data type
Described factor		Yield of grain crop	V	kg/ha	statistics data
Determining factors	agricultural technology level	consumption of chemical fertilizers	F	kg/ha	
		effective irrigation ratio	I	%	
		total power of agricultural machinery	M	W/ha	
	meteorology Condition	mean annual temperature	T	K	mesh data
		mean annual precipitation	P	T	
		mean annual cloudiness	C	%	
	Constant	Constant	K		

(2) Observation point data

Observation point (county, city) data are sorted out through the following procedure. Firstly, the averaged data for the years 1989, 1990, 1991 and 1992 (CNSB, 1989, 1990, 1991, 1992) are used for agricultural practices (*i.e.*, F, I and M). With respect to weather condition data (*i.e.*, T, P, and C), mesh data from the Global Ecosystem Database 92 (NOAA/EPA, 1992) are used to generate averages for each city and county by overlaying administrative boundaries with it. If there are mismatches between mesh boundaries and administrative boundaries, the adjusting method shown in Figure 3 is

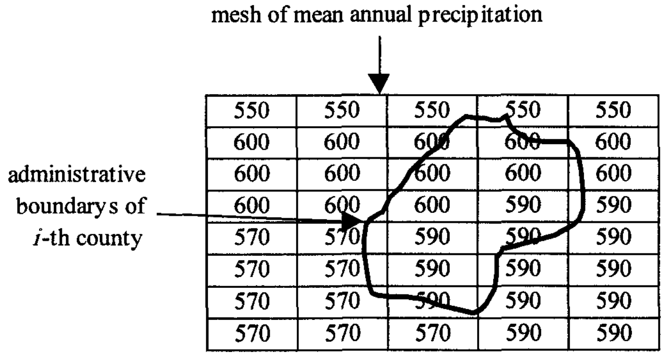

Figure 3. Overlaying between administrative boundaries and mesh boundaries. Example: mean annual precipitation of i-th county = (600×5+590×5)÷10 = 595(mm)

applied. It means when multiple administrative areas are included with a given mesh, the mesh is assigned to the administrative area occupying the largest share of that mesh.

2.3 Analysis results

The results of regression analysis are indicated in Table 3. By significant test, it is shown that for almost all regions the applied fertilizer and effective irrigation ratio has a 5% significance. Weather factors (mean annual temperature, precipitation and cloudiness) show a 5% significance just

Table 3.The results of regression analysis on yield

Region	Province	R	consumption of chemical fertilizers F(kg/ha)	effective irrigation ratio I(%)	total power of agricultural machinery M(W/ha)	mean annual temperature T(K)	mean annual precipitation P(mm)	mean annual cloudiness C(%)
Northeast China Region	Heilongjiang, Jilin,Liaoning	0.77	**	**	-	-	-	**
Inner Mongolia Region	Neimenggu, Ningxia	0.90	**	**	-	-	**	-
Huang-huai hai Region	Beijing,Tianjin, Hebei,Shandong, Henan,	0.85	**	**	**	-	**	**
Loess plateau Region	Shanxi,Shaanxi, Gansu	0.80	**	**	**	-	-	-
Lower reaches of the Yangtze river Region	Shanghai,Jiangsu, Zhejiang,Anhui, Fujian,Jiangxi, Hubei,Hunan	0.70	**	**	**	-	-	-
South China Region	Guangdong, Guangxi	0.86	*	**	**	-	-	**
Southwest China Region	Sichuan,Guizhou, Yunnan	0.81	**	**	**	*	-	-
Xingjiang Region	Xinjiang	0.62	**	**	-	-	-	-
Tibet Region	Qinghai	0.73	**	-	-	-	-	-

*10%significance **5%significance

Table 4. The regression expression in each aguricultural region

Agricultural regions	Regression expression
Northeast China Region	$V = -10008.06 + 7.58\ F + 12.96\ I + 215.44\ C$
Inner Mongolia Region	$V = -354.81 + 4.50\ F + 33.99\ I + 4.07\ P$
Huang-huai hai Region	$V = 0.26 \times F^{0.23} \times I^{0.21} \times M^{0.09} \times P^{0.57} \times C^{0.78}$
Loess plateau Region	$V = 196.03 \times F^{0.24} \times I^{0.07} \times M^{0.19}$
Lower reaches of the Yangtze river Region	$V = 647.05 \times F^{0.09} \times I^{0.29} \times M^{0.04}$
South China Region	$V = 680.49 + 0.48\ F + 44.00\ I + 0.02\ M + 30.43\ C$
Southwest China Region	$V = 531.35 \times F^{0.16} \times I^{0.20} \times M^{0.07}$
Xingjiang Region	$V = 406.00 \times F^{0.20} \times I^{0.30}$
Tibet Region	$V = 1647.34 \times F^{0.16}$

in certain regions, but not for all regions. Table 4 shows the regression expression resulting from the use of only factors with 5% or 10% significance. Correlation coefficient R is greater than 0.6 for all regions.

3. Yield forecasts

3.1 Future scenarios of determining factors

Future yield is forecasted by applying the scenarios given below for determining factors in the above grain production tonnage expression. Assumptions are made for each factor, and the prediction result for each scenario depends on these assumptions. The forecasted year is until 2025. It should be noted that forecasts over even longer periods of time are of course possible, but the reliability of the given scenario degrades rapidly.

(1) Applied fertilizer and applied agricultural machinery

Data for these factors are not available on a per-county, per-year basis, so each county is assumed to share the growth of the province to which it belongs. The elasticity coefficient (ε) for the annual increase rate of applied fertilizer and applied agricultural machinery to the growth rate of GDP is determined for the years 1987 to 1996 (CNSB,1988-1997), and used as the value applicable for all counties within the province. Future applied fertilizer and applied agricultural machinery are forecasted for each county from the scenario of future GDP growth rate (r_{GDP}) and the constant elasticity coefficient values obtained for the past. The per-province GDP growth rate, in principle, is assumed to follow the past trend for that province, with overall proportional adjustments to maintain a national growth rate of 8% through 2000, 7% in the period of 2000 to 2010 and 5% thereafter. Here, however, the upper limitation of applied fertilizer is given according to the average amount of fertilizer applied per unit area of wheat and rice in Japan in 1994 (JAF, 1997):

$$F_t = F_0 \times (1 + r_{GDP} \times \varepsilon_1)^t \quad \text{[kg/ha]}$$

$$M_t = M_0 \times (1 + r_{GDP} \times \varepsilon_2)^t \quad \text{[W/ha]}$$

(2) Effective irrigation ratio

Prediction of the irrigation ratio requires referencing current water resources and land resources data, adjusting for societal parameters. It is difficult to accurately quantify the amount of water resources available for irrigation due to mobility of water between regions, annual variation and limits to the usage of underground water sources. The expansion of irrigation is also greatly affected by problems of socioeconomic cost and benefit, and it is unclear whether or not obtainable water resources can be automatically allocated to specific land areas (Alexandrators, 1995). While it is difficult to set the irrigation ratio, one scenario used here calls for a continuing expansion through 2000 at the same rate in effect from 1987 to 1996 (average annual growth rate r_I), and no change from that time, taking account of the increasing water need of industry and people's daily life. Here again, counties are assumed to grow at the same rates as their provinces because of the reason that per-county per-year data are unavailable:

$$I_t = I_0 \times (1 + r_I)^t \quad [\%]$$

(3) Meteorological conditions

Yield forecasts assume no change in overall meteorological conditions. The effect of meteorological conditions must be taken into account separately if there is, for example, significant climate change resulting from the global warming.

3.2 Results of yield forecasts

Table 5 indicates the per-province forecasts of yield based on the above scenario. The minimum, mean and maximum forecasts are also shown for each province in Table 5. Here, the minimum and maximum forecasts of a province refer to the values of the counties, which exhibit the minimum and maximum values among the counties belonging to that province. The yields in all provinces have increasing trend until 2025 due to increases in applied fertilizer and the applied agricultural machinery accompanying GDP growth in China. Beijing, Tianjin, Liaoning, Jilin, Shanghai and Shandong emerges as the higher group, while Inner Mogolia, Guizhou, Gansu, Qinghai and Ningxia provinces will keep the lower level in the future.

Table 5. The results of yield forecasts of Provinces (Unit:kg/ha)

Province	Year	1995	2000	2005	2010	2015	2020	2025	Province	Year	1995	2000	2005	2010	2015	2020	2025
	mean	5297	5720	5868	5998	6010	6022	6035		mean	4671	5054	5228	5329	5926	5988	6052
Beijing	min	3741	4040	4274	4331	4340	4349	4358	Shandong	min	3297	3673	3994	4063	4516	4564	4612
	max	6211	6707	6343	6565	6579	6592	6606		max	6143	6315	6411	6509	7236	7312	7390
	mean	4136	4641	5022	5357	5998	6061	6095		mean	3723	4234	4404	4492	4996	5051	5106
Tianjin	min	3698	4150	4491	4859	5502	5600	5620	Henan	min	2070	2442	2611	2660	2959	2991	3024
	max	4519	5071	5487	5938	6723	6827	6853		max	5952	6814	6942	7072	7865	7952	8039
	mean	3624	3993	4244	4453	5028	5144	5248		mean	4205	4436	4480	4500	4506	4512	4518
Hebei	min	655	727	783	844	974	1022	1073	Hubei	min	1830	1966	1998	2002	2004	2006	2008
	max	5048	5595	5715	5862	6538	6629	6722		max	5302	5477	5488	5498	5504	5510	5516
	mean	3177	3460	3678	3902	4007	4109	4209		mean	4676	4940	4994	5034	5050	5064	5078
Shanxi	min	1685	1836	1954	2080	2141	2204	2269	Hunan	min	3447	3695	3715	3734	3743	3753	3763
	max	5433	5697	5855	6017	6094	6172	6251		max	5258	5471	5499	5526	5541	5556	5571
	mean	2340	2594	2638	2686	2711	2738	2766		mean	4462	4462	4505	4559	4608	4666	4736
Neimenggu	min	648	713	715	718	719	720	722	Guangdong	min	3006	3014	3029	3057	3083	3113	3149
	max	5267	5484	5592	5823	5829	5936	6053		max	6641	6740	7090	7248	7318	7660	7808
	mean	5096	5453	5627	5795	5838	5880	5923		mean	3760	3771	3778	3789	3808	3838	3872
Liaoning	min	3847	4063	4149	4241	4265	4290	4315	Guangxi	min	1939	1940	1946	1972	1997	2026	2062
	max	7481	7654	7654	7654	7654	7654	7654		max	5761	5807	5999	6229	6431	6669	6948
	mean	4790	5023	5194	5374	5472	5568	5662		mean	3644	3933	4078	4177	4223	4266	4307
Jilin	min	3114	3228	3297	3371	3412	3455	3499	Sichuan	min	1399	1476	1560	1649	1700	1752	1806
	max	6235	6589	6879	7067	7174	7285	7432		max	5292	5539	5591	5644	5673	5702	5732
	mean	3197	3431	3614	3829	3954	4090	4237		mean	3054	3430	3544	3661	3560	3548	3536
Heilongjiang	min	1652	1797	1929	2084	2163	2244	2333	Guizhou	min	1801	1842	1904	1968	2033	2101	2172
	max	4472	4808	5141	5552	5790	6048	6329		max	4475	4649	4805	4866	4919	4932	4955
	mean	5429	5436	5441	5494	5537	5560	5573		mean	3523	3892	4100	4276	4364	4458	4544
Shanghai	min	5262	5286	5340	5375	5418	5411	5425	Yunnan	min	1394	1431	1525	1624	1730	1843	1964
	max	5547	5576	5590	5594	5607	5549	5672		max	5421	5678	5855	6078	6139	6202	6265
	mean	4839	5134	5164	5176	5183	5190	5197		mean	3052	3374	3578	3754	3809	3865	3921
Jiangsu	min	3694	4010	4129	4137	4143	4149	4154	Shaanxi	min	1313	1483	1619	1767	1826	1888	1951
	max	5410	5598	5610	5622	5629	5637	5645		max	5177	5672	5762	5853	5888	5922	5957
	mean	4578	4876	4967	5026	5062	5097	5129		mean	2367	2555	2681	2811	2817	2822	2828
Zhejiang	min	2617	2809	2913	3019	3096	3175	3255	Gansu	min	538	583	613	645	647	648	649
	max	5392	5765	5976	6196	6353	6504	6542		max	5031	5310	5587	5815	5821	5826	5832
	mean	4332	4685	4805	4884	4911	4936	4958		mean	3020	3039	3050	3061	3068	3073	3081
Anhui	min	2445	2707	2797	2889	2939	2958	2969	Qinghai	min	1462	1471	1477	1482	1489	1495	1503
	max	5153	5272	5429	5469	5490	5511	5533		max	3550	3572	3585	3599	3605	3618	3633
	mean	4669	4849	4906	4946	4972	4999	5026		mean	2457	2677	2833	2981	3031	3076	3112
Fujian	min	3870	4105	4165	4194	4216	4239	4262	Ningxia	min	688	708	718	730	735	740	746
	max	5360	5540	5578	5616	5647	5677	5708		max	3498	3899	4190	4334	4334	4359	4398
	mean	4563	4802	4880	4911	4918	4923	4928		mean	4010	4137	4230	4323	4377	4426	4468
Jiangxi	min	4037	4278	4409	4500	4503	4507	4510	Xinjiang	min	1747	1814	1874	1935	1973	2012	2052
	max	5258	5267	5275	5282	5286	5291	5295		max	4909	4922	4953	5012	5104	5154	5192

4. Cultivated land area forecasts

4.1 Method

Rapid industrialization and urbanization in China has led to a continuing reduction in cultivated land area. Forecasts of cultivated land area must include not only potential area (lands scheduled to be converted to cultivated land area by the government by 2025), but also reductions in cultivated land area due to economic development and soil degradation. Considerable diversity in speeds of urbanization and soil degradation as well as other natural conditions between different regions, however, makes it difficult to forecast cultivated land area. Therefore, the present analysis simply extrapolates past trends for each province to forecast future cultivated land area. Forecasts of grain production tonnage are not merely based on cultivated land area, but also multiple crop index and the ratio of total sown area to cultivated land area.

4.2 Data

A number of sources (Alexandrators, 1995; CNSB, 1987-1997) indicate that the cultivated land area data given in Chinese statistical yearbooks is about 20-30% less than actual cultivated land area. If this is true, then the data for yield, land use index and invested materials and equipment given in the yearbooks are inflated. The forecasts in this paper do not correct this possible error in yield data, and therefore cultivated land area of China Statistical Yearbook are naturally used as source data. The uncertainties of forecast in cultivated land area will be discussed in 6. Reduction in cultivated land area is due to two factors. The first is the conversion of cultivated land to other uses such as factories, housing and roads as a result of economic development, and it is demonstrated by "capital construction + village collective construction + peasant construction" in China Statistical Yearbook. The second is the loss of cultivated land due to soil degradation such as erosion, salt damage, disaster, climate and terrain change, resulting in conversion to forestry or animal husbandry, and it is represented by the difference between total annual reduction and primary reduction in China Statistical Yearbook. The data about reduction in cultivated land area demonstrated above have been published since 1991 in China Statistical Yearbook.

4.3 Estimation of per-province cultivated land area

The per-province cultivated land areas are estimated by using SD model (STELLA II) as demonstrated in Figure 4, based on the following assumptions. Firstly, the potentially cultivable

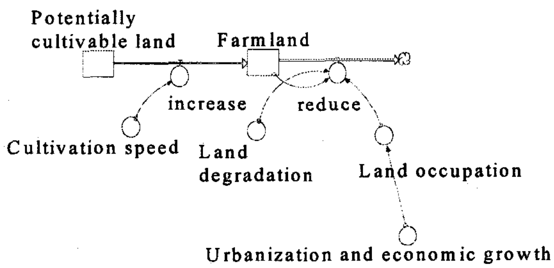

Figure 4. The model of cultivated land area forecasts

land at present is assumed as the upper limit that the accumulated total of newly cultivated land can not exceed. Here, however, as no data for potentially cultivable land are available in China Statistical Yearbook, we use the land resources map of China in 1: 1,000,000 scale (LANDSAT data of 1985) which is considered to represent the actual land use situation in China (Shi, 1991). More specifically, the potentially cultivable land at present is defined as the potentially cultivable land in 1985 minus the land newly cultivated from 1985 to 1995 (Shi, 1991; CNMA, 1991-1995). Future cultivation speed (1000ha/year) for each province is assumed to remain constant at the average value of those from 1991 to 1995 (CNMA, 1991-1995) on the condition that the accumulated total of the cultivated land can not exceed the potentially cultivable land of that province. Furthermore, the rates of transformation of cultivated land area to other uses are assumed to be proportional to the rate of GDP growth. Here, the elasticity coefficients are determined for the reductions for 1991 through 1995. Per-province GDP growth rates are assumed to follow the prior per-province trends, adjusted proportionally for a national growth rate of 8% through 2000, 7% in the period of 2000 to 2010 and 5% thereafter. Moreover, loss of cultivated land due to soil degradation is set based on reduction rates for 1991 through 1995. The forecasts for 2000, 2005, 2010, 2010, 2015, 2020 and 2025 are given in Table 6.

Table 6. The Forecasts of cultivated land area of Provinces(Unit:1,000ha).

Province \ Year	Year book	Present analysis					
	1995	2000	2005	2010	2015	2020	2025
Beijing	400	389	380	371	365	359	354
Tianjin	426	421	417	414	412	410	408
Hebei	6,517	6,474	6,437	6,400	6,373	6,347	6,320
Shanxi	3,645	3,597	3,554	3,508	3,461	3,415	3,369
Neimenggu	5,491	5,395	5,312	5,233	5,173	5,115	4,919
Liaoning	3,390	3,304	3,228	3,153	3,090	3,029	2,970
Jilin	3,953	3,906	3,864	3,822	3,788	3,754	3,720
Heilongjiang	8,995	9,003	9,017	9,031	9,057	9,084	9,109
Shanghai	290	257	232	209	195	181	169
Jiangsu	4,448	4,336	4,236	4,140	4,064	3,989	3,916
Zhejiang	1,618	1,508	1,414	1,326	1,257	1,192	1,130
Anhui	4,291	4,234	4,188	4,142	4,114	4,084	4,054
Fujian	1,204	1,164	1,125	1,084	1,048	1,013	980
Jiangxi	2,308	2,265	2,226	2,187	2,155	2,123	2,093
Shandong	6,696	6,539	6,400	6,264	6,155	6,049	5,922
Henan	6,806	6,663	6,529	6,398	6,279	6,163	6,049
Hubei	3,358	3,239	3,130	3,025	2,933	2,844	2,758
Hunan	3,250	3,168	3,094	3,021	2,958	2,896	2,837
Guangdong	2,317	2,043	1,811	1,609	1,443	1,298	1,170
Guangxi	2,614	2,461	2,320	2,187	2,067	1,953	1,848
Sichuan	6,190	6,082	5,987	5,894	5,822	5,747	5,657
Guizhou	1,840	1,821	1,806	1,791	1,784	1,776	1,768
Yunnan	2,871	2,778	2,588	2,411	2,284	2,105	1,966
Shaanxi	3,393	3,139	2,907	2,693	2,502	2,324	2,159
Gansu	3,483	3,477	3,472	3,468	3,466	3,464	3,462
Qinghai	590	592	595	597	600	603	610
Ningxia	807	808	810	812	815	817	820
Xinjiang	3,128	3,036	2,955	2,881	2,822	2,767	2,717
total	94,971	92,097	90,032	88,072	86,480	84,900	83,254

Note: Tibet and Hainan provinces are not included

4.4 Estimation of per-county cultivated land area

The per-province cultivated land areas are allocated to individual cities and counties through the following procedure. Firstly, the cultivated land area of the county *c* in the province *p* for the year *y*, $A_{p,c}^{(y)}$, are determined from 1991 data through the following expression (CNSB,1991):

$$A_{p,c}^{(y)} = A_p^{(y)} \times (A_{p,c}^{(1991)} / A_p^{(1991)})$$

Where $A_p^{(y)}$ is the cultivated land area of the province *p* for the year *y*.

Then the ratio of grain crop area to total agricultural crop area is assumed to follow the same average annual growth rate as from 1987 to 1995 through the year 2000, and then remain constant based on an assumption that a dramatic change from the current level is unlikely to take place. Moreover, counties belonging to the same province are assumed to share the average annual growth rates of that province as per-county data is not available for long periods of time.

5. Forecasts of grain production tonnage

5.1 Deviation from trend variation, and forecast uncertainty

In forecasting grain production tonnage, we must pay attention to the trend production tonnage, P_A, and the deviation from it, P_D. Here, P_A is the normal production tonnage achieved under normal weather conditions and with normal technical advancement. Chen, *et al.* analyzed Chinese grain production tonnage data from 1978 to 1996, and showed that the temporal change in P_A could be approximated by two order multinomial expressions for the variable *x* (Chen, *et al.*, 1997). Here, *x* is defined in the following way: *x*=0, 1, and 2 for the years 1978, 1979, and 1980, and so forth. The expression for P_A as determined through the least square method is shown in Figure 5.

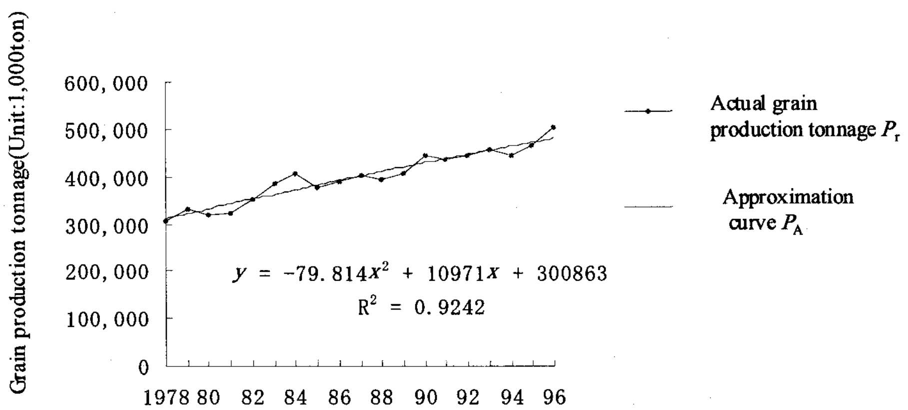

Figure 5. The temporal change of Chinese grain production tonnage and its approximation curve

P_D indicates the deviation from the normal production tonnage due to natural disasters and other causes, and is minus in the event of such a disaster. It is determined from the difference between actual grain production tonnage P_r and P_A:

$$P_D = P_r - P_A$$

Then the deviation rate J for production tonnage can be defined as:

$$J = P_D / P_A \times 100$$

When $J<0$, it is assumed to represent a decrease in production tonnage due to disaster, with damage increasing as J decreases. If $J>0$, it is assumed to represent weather conditions favorable to agricultural production. The value J for Chinese grain production tonnage is indicated in Table 7 (1978 to 1996), and its standard deviation δ is 4.0%. We forecast the deviation for grain production tonnage from the trend production tonnage by using this deviation rate δ.

Table 7. The deviation rate J for Chinese grain production tonnage from 1978 to 1996(Unit;1,000ton)

year	Actual grain production tonnage	Trend grain production tonnage	Deviation from actual grain production tonnage	Deviation rate J(%)
1978	304,770	307,851	-308	-1.00
1979	332,120	320,468	1165	3.64
1980	320,560	332,630	-1207	-3.63
1981	325,020	344,338	-1932	-5.61
1982	354,500	355,593	-109	-0.31
1983	387,280	366,392	2089	5.70
1984	407,310	376,738	3057	8.11
1985	379,110	386,630	-752	-1.94
1986	391,510	396,067	-456	-1.15
1987	402,980	405,050	-207	-0.51
1988	394,080	413,579	-1950	-4.71
1989	407,550	421,654	-1410	-3.34
1990	446,240	429,274	1697	3.95
1991	435,290	436,440	-115	-0.26
1992	442,660	443,153	-49	-0.11
1993	456,490	449,410	708	1.58
1994	445,100	455,214	-1011	-2.22
1995	466,618	460,564	605	1.31
1996	504,535	465,459	3908	8.40
Standard deviation δ				4.00

5.2 Trend grain production tonnage P_A

Forecasting of the trend grain production tonnage for the year y, $P_A^{(y)}$, is conducted by multiplying the yield $V^{(y)}$ by the total cultivated land area $A^{(y)}$, multiple crop index $S^{(y)}$ and ratio of grain crop area to agricultural crop area $L^{(y)}$ for the year y. Here, the index $S^{(y)}$ is the ratio of total cultivated land area which is planted with crops, and 1991 values in the county scale (CNSB,1992)are calculated and used throughout the analysis because they are not expected to change significantly in the present and future.

$$P_A^{(y)}=V^{(y)}\times A^{(y)}\times S^{(y)}\times L^{(y)}$$

The results of the above process are given in Table 8, which also presents OECF forecasts and actual data in 1990 for comparison (Tsuji, *et al.*, 1995; CNSB, 1996). Production tonnage for China overall will reach 521 million tons in 2000, and keep slight increasing until 2015 to reach about 530 million tons, then turn to decreasing to 520 million tons in 2025. Considering that tonnage in 1996

Table 8. The Forecasts of trend grain production tonnage P_A(Unit:1,000ton).

Year / Province	1995		2000		2005		2010		2015	2020	2025
	Present analysis	CNSB	Present analysis	OECF	Present analysis	OECF	Present analysis	OECF	Present analysis	Present analysis	Present analysis
Beijing	2,892	2,600	3,026	3,060	2,996	3,000	2,992	2,960	2,951	2,910	2,870
Tianjin	2,120	2,080	2,381	2,520	2,552	2,610	2,708	2,590	3,023	3,043	3,047
Hebei	28,551	27,390	32,662	25,260	34,458	27,410	35,946	29,910	40,424	41,196	41,846
Shanxi	10,476	9,170	12,870	8,830	13,519	9,050	14,154	9,330	14,339	14,507	14,657
Neimenggu	12,012	10,550	13,684	13,700	13,693	15,690	13,727	16,660	13,690	13,665	13,271
Liaoning	16,528	14,240	19,354	17,500	19,539	17,450	19,694	17,220	19,453	19,217	18,979
Jilin	20,088	19,920	24,028	21,330	24,612	21,440	25,180	21,280	25,396	25,611	25,793
Heilongjiang	25,075	25,520	30,648	28,220	32,419	28,160	34,498	27,850	35,775	37,161	38,664
Shanghai	2,217	2,100	1,996	1,910	1,794	1,660	1,614	1,460	1,502	1,397	1,300
Jiangsu	34,057	32,860	35,471	30,490	34,852	29,900	34,130	29,390	33,551	32,979	32,418
Zhejiang	16,529	14,310	16,551	14,430	15,770	13,660	14,935	12,940	14,248	13,592	12,967
Anhui	29,057	25,810	31,464	21,410	31,962	21,070	32,183	20,170	32,138	32,046	31,946
Fujian	10,763	9,200	10,439	8,900	10,206	8,970	9,922	9,080	9,640	9,370	9,108
Jiangxi	18,000	16,070	17,783	16,210	17,726	16,610	17,511	16,920	17,270	17,027	16,804
Shandong	43,072	42,460	46,273	43,970	46,774	47,160	46,649	48,160	50,983	50,635	50,097
Henan	35,839	34,670	39,453	37,160	40,207	40,160	40,168	39,890	43,844	43,506	43,172
Hubei	24,617	24,640	24,312	24,120	23,679	24,700	22,970	25,260	22,300	21,651	21,023
Hunan	28,250	26,920	28,605	26,410	28,162	26,520	27,682	26,660	27,181	26,687	26,205
Guangdong	17,547	17,350	14,827	17,930	13,240	18,230	11,867	17,920	10,725	9,732	8,869
Guangxi	14,664	15,080	12,251	17,010	11,639	19,540	11,070	19,910	10,526	10,013	9,544
Sichuan	43,220	43,650	46,129	44,500	46,920	45,790	46,996	46,290	46,768	46,484	46,053
Guizhou	8,437	9,490	9,406	9,910	9,641	11,230	9,881	12,690	9,561	9,487	9,414
Yunnan	13,496	11,890	13,699	12,070	13,450	13,460	13,076	14,490	12,653	11,920	11,358
Shaanxi	13,229	9,130	15,191	12,040	14,831	12,900	14,303	13,850	13,455	12,657	11,905
Gansu	6,722	6,440	7,346	8,480	7,707	9,870	8,083	11,040	8,095	8,107	8,119
Qinghai	1,536	1,140	1,516	1,330	1,528	1,450	1,540	1,590	1,546	1,552	1,568
Ningxia	1,689	2,030	1,835	2,120	1,933	2,160	2,028	2,210	2,067	2,100	2,129
Xinjiang	8,341	7,190	7,931	9,100	7,875	9,760	7,828	9,160	7,750	7,674	7,599
total	489,022	466,620	521,132	483,070	523,683	503,050	523,334	511,240	530,854	525,926	520,724

Note: Tibet and Hainan provinces are not included was about 500 million tons, this is a relatively good match. A breakdown by province shows that production tonnage is expected to increase for provinces in North China, Northeast China and Northwest China, but a decrease is expected in Shanghai, Jiangsu, Zhejiang, Fujian, Jiangxi,Gangdong, Gangxi Hubei and Xinjiang provinces. Production tonnage in other provinces, which are located in South China and Southeast China except Xinjiang Autonomous Region, remains almost at the same level. In spite of an increase of yield in most regions, there are still provinces, which show a drop in total production tonnage because of the rapid reduction in cultivated land area due to urbanization and soil degradation. This tendency is especially pronounced in the coastal provinces where economic development is most active. Results are slightly higher than those from the OECF, presumably due to differences in calculation of yield and assumptions used in the cultivated land area scenario.

5. 3 Grain production tonnage P_r (consideration for weather effects)

The grain production tonnage P_r, is obtained from the trend production tonnage P_A as calculated in 5.1 above and adjusted for weather conditions with deviation P_D:

$$P_r = P_A \pm P_A \times \delta / 100$$

Results show total Chinese grain production tonnage for 2000 is 500 to 542 million tons, 503 to 545 million tones for 2005, 502 to 544 million tons for 2010, 509 to 552 million tons for 2015, 505 to 547 million tons for 2020 and 500 to 542 million tons for 2025.

6. Discussions: Uncertainties in forecasting

There are several crucial questions with the uncertainties of the forecasts obtained through this analysis.

(1) *Uncertainties with the cultivated land area estimation.* As stated in the above, there are already substantial discrepancies between the data from different sources: it is reported that the cultivated land area given in Chinese statistical yearbooks is about 20-30% less than that estimated by satellite data. Table 9 shows the difference of cultivated land area at province scale in 1985 between those from Chinese statistical yearbooks and from the map of land resources of China in 1: 1,000,000 scale (LANDSAT data of 1985) (Shi, 1991). We can make an analysis based on the land data from satellite observation instead of those from statistical yearbooks. In that case, the yield data should be 20-30% lower than those presented in this analysis on the condition that the grain production and other data available in the statistical yearbooks are correct. This will produce similar results to those presented in this paper. However, if we just use the satellite data while assuming the yield forecast presented in this analysis, the national grain production might be 20-30% larger than our results.

(2) *Uncertainties with the irrigation scenario.* In China about half of cultivated land area is irrigated, and accounts for 80% of grain production. Promotion of irrigation in China is a key measure in achieving expanded grain production there, but irrigation today faces a number of

Table 9. The difference of cultivated land area at province scale in 1985 between from Chinese statistical yearbooks and from LANDSAT data

Province \ Data Source	1985 Yearbook	1985 Landsat	Ratio (Yearbook/Landsat)
Beijing	421	574	0.73
Tianjin	447	646	0.69
Hebei	6,603	6,777	0.97
Shanxi	3,761	5,724	0.66
Neimenggu	4,930	6,512	0.76
Liaoning	3,586	4,471	0.80
Jilin	3,999	5,351	0.75
Heilongjiang	8,931	12,254	0.73
Shanghai	340	340	1.00
Jiangsu	4,604	5,611	0.82
Zhejiang	1,777	2,378	0.75
Anhui	4,422	6,553	0.67
Fujian	1,261	1,784	0.71
Jiangxi	2,369	2,800	0.85
Shandong	7,038	9,372	0.75
Henan	7,033	8,839	0.80
Hubei	3,585	4,552	0.79
Hunan	3,342	4,334	0.77
Guangdong	2,599	3,779	0.69
Guangxi	2,572	4,290	0.60
Sichuan	6,367	9,459	0.67
Guizhou	1,873	3,732	0.50
Yunnan	2,777	4,630	0.60
Shaanxi	3,627	5,522	0.66
Gansu	3,491	4,980	0.70
Qinghai	564	703	0.80
Ningxia	795	1,184	0.67
Xinjiang	3,083	4,093	0.75
total	96,197	131,244	0.73

Note: Tibet and Hainan provinces are not included

problems. Existing irrigation facilities require improvements due to damage and aging, and irrigation water is being diverted to make up for shortages of industrial and city water supplies. The forecasts developed by this analysis assume a simple scenario of the increase in the irrigation ratio, but this assumption may not be appropriate and requires independent verification. If we assume a drastic improvement in irrigation system, then it might bring about an increase in production.

(3) *Validity of extrapolating the past trend data to the future.* This analysis develops a simple forecast for cultivated land area based on past per-county trends, but in fact each county will vary due to differing speeds of urbanization and soil degradation, and natural conditions. These factors, both individually and in composite, must be taken into account.

(4) *Uncertainties with multiple crop index scenario.* Although the multiple crop index has reached the high level about 157% in whole China in 1991, many Chinese researchers have an idea that it could be raised to 160-170%(Wang, 1997; Liu, 1991; Shi, 1991). If it is possible, the forecasts of our scenario, in which multiple crop has been set as the constant value of 1991, will increase about 3 to 13% in the future.

(5) *Uncertainties with technological progress.* It is doubtless that technological progress plays a key role in improving food production in China. The yield improvement could arise from advances in such technical factors as mechanization of agriculture, promotion of irrigation, the use of inorganic

plant fertilizers and the introduction of hybrid crops. The first three factors are taken into consideration in our regression equation assuming that the upper limitation of applied fertilizer per unit area is given by the current Japanese level. With respect to the last factor, FAO has pointed out that modern biotechnology is not expected to influence crop production greatly before 2010 because it will take long time from laboratory to the market and need great investment (Haen, *et al.*, 1998). Moreover, there are other uncertainties about the date of introduction, degree of diffusion of hybrid crops. Therefore, introduction of hybrid crops is not taken into account in this paper. However, development in this field might take place around or immediately after 2010. In rice production, considerable progress is being made in research of two-line hybrid varieties, the first of which is now being planted in a 10 Km^2 test field in China. The two-line system could yield 10 to 30% more than the three-line system now in use (Liu, *et al.*, 1991). It suggests that introduction of hybrid crops could cause 10 to 30% increase in the yield compared with our forecast.

(6) *Possible climatic Change.* Global climatic change may have a major impact on agricultural production. According to the IPCC WG2 Report (WMO/UNEP, 1996), 2*CO2 CGM experiments in China indicate that the winter monsoons will grow milder and summer monsoons stronger. The amount of precipitation in high-rainfall regions will increase, and the regions themselves will expand toward the north and west. If these predictions come true, grain production tonnage will rise in the water-short west and north, and the danger of flooding will become severe in the south. The GCM scenario used, however, expects that 2*CO2 will be reached between 2025 and 2050. This paper treats a time prior to this range, and therefore no evaluation of the impact of climatic changes is provided.

(7) *Uncertainties with government policies.* The policy of the Chinese government has a major effect on agricultural production. Increases in grain production tonnage in recent years have been affected by government policy in the form of increases in grain purchase prices, leading to expansions in cultivated land area. This analysis does not consider these measures.

(8) *Uncertainties with the feedback of market.* It is necessary to take into account the effect arising from feedback of market when the shortage of grain production occurs. However, this effect can not be simply discussed only by the balance of demand and supply in China, but also by taking into account the world grain market and other factors. This requires much complicated economic analysis and it is beyond the scope of this paper.

7. Consideration about Chinese food security

Questions about food security in China should be discussed on the basis of demand-supply gap analysis. The simplest estimate of the total grain demand in China is presented in Table 10. Here, future population is based on the prediction of United Nations (United Nations, 1995), and different estimates for annual grain consumption per person are presented by using the actual value of 1995 and predicted values by different authors (OECF, Brown, *et al.* and the Chinese Academy of Science). There are significant gaps among the estimates, depending upon the assumptions adopted for per capita consumption. However, it is easily noted that demand-supply gap will become significant after 2010 even in the lowest demand case, suggesting the relevancy of the warning by Brown *et al.* In fact, demand is expected to be increasing in proportion to the increasing population despite the decreasing cultivated land area, and the yield can not be increased in a pace as we assumed. The risk of grain crisis in China is rising and its impact on the world food market will be enormous. However, the present study has identified some crucial uncertainties in prediction, suggesting the need for further investigations on the questions such as actual cultivated land area, multiple crop index, irrigation ratio, *etc.*

Table 10. The amount of grain demand based on population prospects by U.N.

Population Scenario \ Year			2000		2005		2010	
population prospects by U.N.(1,000person)	Scenario	High	1,304,902		1,370,579		1,426,541	
		Middle	1,285,894		1,341,412		1,382,463	
		Low	1,259,067		1,294,471		1,320,989	
Author \ Item			Grain consumption for one pereon per year (kg/person·year)	Total damand tonnage (million ton)	Grain consumption for one pereon per year (kg/person·year)	Total damand tonnage (million ton)	Grain consumption for one pereon per year (kg/person·year)	Total damand tonnage (million ton)
Actual value in 1995	Scenario	High		502.7		528.0		549.6
		Middle	385	495.4	385	516.8	385	532.6
		Low		485.1		498.7		508.9
OECF	Scenario	High		467.8		524.2		585.4
		Middle	358	461.0	382	513.1	410	567.3
		Low		451.4		495.1		542.1
Lester R. Brown	Scenario	High		522.0		548.2		570.6
		Middle	400	514.4	400	536.6	400	553.0
		Low		503.6		517.8		528.4
The Chinese Academy of Sciences	Scenario	High		522.0		558.5		592.0
		Middle	400	514.4	408	546.6	415	573.7
		Low		503.6		527.5		548.2
Grain production tonnage of present analysis Pr				500.3～542.0		502.7～544.6		502.4～544.3

Population Scenario \ Year			2015		2020		2025	
population prospects by U.N.(1,000person)	Scenario	High	1,482,581		1,541,175		1,596,364	
		Middle	1,421,408		1,459,753		1,492,550	
		Low	1,343,390		1,362,058		1,372,035	
Author \ Item			Grain consumption for one pereon per year (kg/person·year)	Total damand tonnage (million ton)	Grain consumption for one pereon per year (kg/person·year)	Total damand tonnage (million ton)	Grain consumption for one pereon per year (kg/person·year)	Total damand tonnage (million ton)
Actual value in 1995	Scenario	High		571.2		593.7		615.0
		Middle	385	547.6	385	562.4	385	575.0
		Low		517.5		524.7		528.6
OECF	Scenario	High		608.4		632.5		655.1
		Middle	410	583.3	410	599.1	410	612.5
		Low		551.3		559.0		563.1
Lester R. Brown	Scenario	High		593.0		616.5		638.5
		Middle	400	568.6	400	583.9	400	597.0
		Low		537.4		544.8		548.8
The Chinese Academy of Sciences	Scenario	High		622.7		662.7		702.4
		Middle	420	597.0	430	627.7	440	656.7
		Low		564.2		585.7		603.7
Grain production tonnage of present analysis Pr				509.6～552.1		504.9～547.0		499.9～541.6

8. Conclusions

Major conclusions of the present study are as follows:

(1) Data related to grain production tonnage, agricultural technology, agricultural state and meteorology, in county and city units for each region, are prepared and multivariate analysis applied to develop an experiential relationship between yield and factors describing production tonnage. Results show a high correlation for applied chemical fertilizer amount and effective irrigation ratio, and a lower correlation for usage of agricultural machinery. Meteorological factors show a significance of about 5% for about half of the regions, but no significance was found for China overall.

(2) The future grain production tonnage capacity of China is forecasted, indicating an increase in yield in all regions, with total production for China reaching 500 to 542 million tons in 2000, and keep the same level until 2025. The increase in grain production tonnage is lower than the increase in yield.

(3) Based on the discussion about the uncertainties of the forecasts, the validity of the analysis techniques and the reliability of the forecasts are discussed. Demand-supply gap in the future is also discussed, suggesting the need for further studies on crucial determining factors such as cultivated land area, irrigation and agricultural practices.

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