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Effect of Cropland Occupation and Supplement on Light-temperature Potential Productivity in China from 2000 to 2008

YANG Xiaohuan[1], CHENG Chuanzhou[1, 2], LI Yuejiao[1, 2]
(*1. State Key Laboratory of Resources and Environmental Information System, Institute of Geographic Sciences And Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China;*
2. Graduate University of the Chinese Academy of Sciences, Beijing 100049, China)

Abstract: There are more people but less land in China, so food safety has always been a most important issue government concerned. With continuous population increase, economic development and environment protection, cropland occupation and supplement are unavoidable. It not only leads to the variation of cropland area, but also makes the light-temperature potential productivity per unit area different due to regional climate differentiation, therefore impacts the total potential productivity and food output eventually. So, it is necessary to analyze the climate differentiation between occupation and supplement cropland areas and to study its impact on total potential productivity, which is significant to reasonably develop natural resources and instruct agricultural arrangement. This study firstly discussed the variation and distribution of occupation and supplement croplands in China from 2000 to 2008, then analyzed the climate differentiation between occupation and supplement cropland areas and its effect on light-temperature potential productivity. The results demonstrate: 1) From 2000 to 2008, the cropland variation presented occupation in the south and supplement in the north, but overall decreased. Supplement cropland was mainly from ecological reclamation (77.78%) and was mainly distributed in Northeast China and Northwest China with poor climatic and natural conditions. Occupation cropland was mainly used for construction (52.88%) and ecological restoration (44.78%) purposes, and was mainly distributed in the Huang-Huai-Hai Plain, and the middle and lower reaches of the Changjiang (Yangtze) River with better climatic and natural conditions. 2) The climate conditions were quite different in supplement and occupation cropland areas. The annual precipitation, annual accumulated temperature and average annual temperature were lower in the supplement cropland area, and its average potential productivity per unit was only 62% of occupation cropland area, which was the main reason for the decrease of total potential productivity. 3) Cropland occupation and supplement led to the variation of total potential productivity and its spatial distribution. The productivity decreased in the south and increased in the north, but had a net loss of 4.38315×10^7 t in the whole country. The increase of cropland area was at the cost of reclaiming natural forest and grassland resources, and destroying natural ecological environment, while the decrease of cropland area was mainly due to a lot of cropland occupied by urban-rural construction, which threatened the sustainable use of cropland resources.

Keywords: cropland; cropland occupation; cropland supplement; climate condition; light-temperature potential productivity; China

1 Introduction

There are more people but less land in China, so food safety has always been a most important issue government concerned (Wen, 2007). Cropland and agricultural climate resources basically determine regional agricultural development and ensure food safety (Yin *et al.*, 2006a; 2006b; 2007; Fang *et al.*, 2009). With continuous population increase, economic development and environment protection, cropland occupation and supplement are unavoidable. It not only leads to cropland area variation, but also makes the light-temperature potential productivity (LTPP) per unit area different due to regional climate differentiation, therefore impacts the total poten-

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Corresponding author: YANG Xiaohuan. E-mail: yangxh@lreis.ac.cn

tial productivity and food output eventually. So, it is necessary to analyze the climate differentiation in occupation and supplement cropland areas and to research its impact on total potential productivity, which is significant to reasonably developing natural resources and instructing agricultural arrangement.

In recent years, scientists have carried out a lot of studies on the effect of land use/cover change (LUCC) on potential productivity. Diana (1999) estimated the decrease in cropland productivity due to deforestation in Amazon area by using LUCC model and Generalized Least Square (GLS) formula. Chen *et al*. (2002) made a qualitative analysis on cropland productivity variation by comparing the loss of soil nutrient in cropland due to LUCC to actual food output. Gao *et al*. (2004) estimated net primary productivity (NPP) with global production efficiency model (GLO-PEM) in the northern China from 1979 to 1998, and analyzed the effect of climate and LUCC on NPP in the same period. Liu Jiyuan *et al.* (2005) analyzed the LTPP variation due to the LUCC process in China in the 1990s. Xu *et al.* (2007) estimated the effect of climate fluctuation and LUCC process on cropland potential productivity in Northeast China form 1991 to 2000. And Zhao *et al.* (2007) analyzed the effect of LUCC on cropland natural potential productivity in North China from 1990 to 2000 by using 1 km × 1 km land use data and meteorological data.

The studies mentioned above made important contribution to the basic theories, models and application practices, which will lay foundation for the future researches. However, there were few studies on the spatial difference between occupation cropland area and supplement cropland area, as well as the studies on the relationship between total LTPP and cropland occupation and supplement in a national scale. The spatial difference of natural environment is significant in China (Yang and Ma, 2009). The climate differentiation in occupation and supplement cropland areas is obvious as well (Shi and Yang, 2010).

To quantitatively analyze the effect of cropland occupation and supplement on LTPP from 2000 to 2008, this study firstly calculated the LTPP by using meteorological observation data and satellite retrieval data from 2000 to 2008, and then analyzed the climate differentiation in occupation and supplement cropland areas and the variation of total potential productivity by using 1 km × 1 km land use variation data from 2000 to 2008.

2 Data Sources and Methods

2.1 Data sources

2.1.1 Meteorological observation data

Based on such daily observation data as temperature, precipitation and sunshine hours from more than 700 stations of the National Meteorological Bureau of China from 2000 to 2008, 1 km × 1 km spatial grid data were obtained by interpolating with Spline function. Through projection transformation to match the spatial cropland data, those grid data were used to calculate the LTPP.

2.1.2 Solar radiation data

Daily solar radiation data were inversed by hourly data of geostationary meteorological satellite (GMS-5) according to the radiative transfer model, and then converted to 1 km × 1 km spatial data with resample method. The error of the spatial data is less than 1% compared with those observation data.

2.1.3 Cropland variation data

The cropland change data used in this study came from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences. They consisted of 1 km × 1 km cropland change data in two periods (2000 to 2005 and 2005 to 2008), which include information such as the fate of occupation cropland and the source of supplement cropland. The original 1∶100 000 land use data were extracted from remote sensing information in Landsat TM/ETM. Since small ground features were not excluded in the cropland, the cropland area mentioned in this study is actually a gross area.

2.2 LTPP calculation method

The LTPP refers to the maximum crop output determined by natural light-temperature conditions while water, soil, seed and other agricultural techniques are suitable (Huang, 1985; Li, 1988; Wang and Liang, 2002). After reviewing prevalent potential productivity models (Loomis and Willians, 1963; Hanks, 1983; Deng, 1986; Kiniry and Bockholt, 1998; Dang *et al*., 2000; Zhou and Guan, 2000; Van *et al*., 2003; He *et al*., 2004; Hurtt *et al*., 2006; Backalenko *et al*., 2008; Aleander *et al*., 2009) at home and abroad, and comparing the advantages, disadvantages, application ranges and parameter selection of those models (Wang, 2009), the Deng-Genyun-Model was adopted to calculate the photosynthetic potential productivity and the Sun-Huinan-Model was used to calculate the LTPP. Deng-Genyun-Model, focusing on the investigation and identification of the light energy utilization, is suitable for large-scale calculation of photosynthetic potential productivity. Furthermore, the data for Deng-Genyun-Model were easier to get. Experimental results in Shandong Province also showed that the precision of this model was relatively high. Sun-Huinan-Model, considering many factors such as biological significance, physical meaning, data availability, data consistency and so on, selected frostless period as the temperature modified function. This model can reflect the effect of the temperature on the potential productivity. What is more, it achieved a unified of utility and accessibility.

$$Y_T = Y_Q \times f(T) \tag{1}$$

$$Y_Q = \frac{1\times10^5}{C} \times F \times Q \times E \tag{2}$$

where Y_T refers to LTPP (kg/ha); Y_Q refers to the photosynthetic potential productivity; *f*(*T*) equals to *n*/365, and *n* is the number of frostfree days in a year; *C* is the energy conversion coefficient (kcal/kg), with a mean value of 4.25×10^3 kcal/kg for most of crops, referring to the chemical energy associated with 1 g dry matter; *F* is the light utilization rate, which is 1.4%, 1.4% and 1.1% for rice, corn and wheat, separately, and can reach 2% in the future under the tendency of agricultural development; *E* is the economic coefficient and mainly ranges from 0.35 to 0.50 (0.42 for rice, 0.40 for corn and 0.35 for wheat); and *Q* is the total solar radiation during crops growing period (kcal/ha). In this study, despite of crop classification, the LTPP was calculated by assigning 2% to *F* and 0.40 to *E* (Liu Yang *et al*., 2005; Lin, 2006; Gao *et al*., 2009; Liu, 2009). To remove the effect of climate variation on the potential productivity, the climate data used in this study were mean values from 2000 to 2008.

The 1 km × 1 km LTPP data, climate data and cropland variation data were overlaid together and spatial statistic by province and cropland occupation/supplement classification was made.

3 Results

3.1 Variation and distribution of occupation and supplement croplands

Statistics has been made according to the source of supplement cropland and the fate of occupation cropland. In the increased cropland of 2.7225×10^6 ha, 2.1174×10^6 ha came from ecological land reclamation (ELR, including woodland, grassland and lake reclamation), accounting for 77.78%; 6.008×10^5 ha from wasteland reclamation (WR), 22.06%; and 4.3×10^3 ha from construction land reclamation (CLR), 0.16%. In the decreased cropland of 3.9180×10^6 ha, 2.0718×10^6 ha was occupied by the urban-rural construction land (CO), accounting for 52.88%; 1.7546×10^6 ha by ecological restoration (ER, including woodland, grassland and lake restoration), 44.78%; and 9.16×10^4 ha was due to cropland abandonment (CA), 2.34%. So supplement cropland was mainly from ecological reclamation and was mainly distributed in Northeast China and Northwest China (Fig. 1, Table 1). Occupation cropland was mainly used as construction land and ecological restoration land, and was mainly distributed in the Huang-Huai-Hai Plain and middle and lower reaches of the Changjiang (Yangtze) River (Fig. 1, Table 1).

From 2000 to 2008, the spatial distribution of cropland presented a pattern of occupation in the south and supplement in the north of China (Fig. 1, Table 1). In terms of the quantity of cropland occupation and supplement, construction contributed a net decrease of 2.0675×10^6 ha of cropland, ecological reclamation did a net increase of 3.628×10^5 ha, and wasteland reclamation did a net increase of 5.092×10^5 ha. Totally, the cropland decreased 1.1955×10^6 ha in China from 2000 to 2008 (Table 1).

3.2 Climate differentiation between occupation and supplement croplands

Figure 2 shows the spatial distribution of average climate conditions in China from 2000 to 2008, including annual sunshine hours, annual precipitation, annual accumulated temperature and average annual temperature. The climate conditions are quite different between occupation and supplement cropland areas (Table 2). The annual sunshine hours were 671.67 h higher in cropland supplement area than occupation area; the annual precipitation was 632.28 mm lower in the supplement area than the occupation area; the annual accumulated temperature was 1351.37℃ lower in the supplement area than the occupation area; and the average annual temperature was 5.83℃ lower in the supplement area than the occupation area. In general, as a result of the spatial differentiation between occupation and supplement cro-

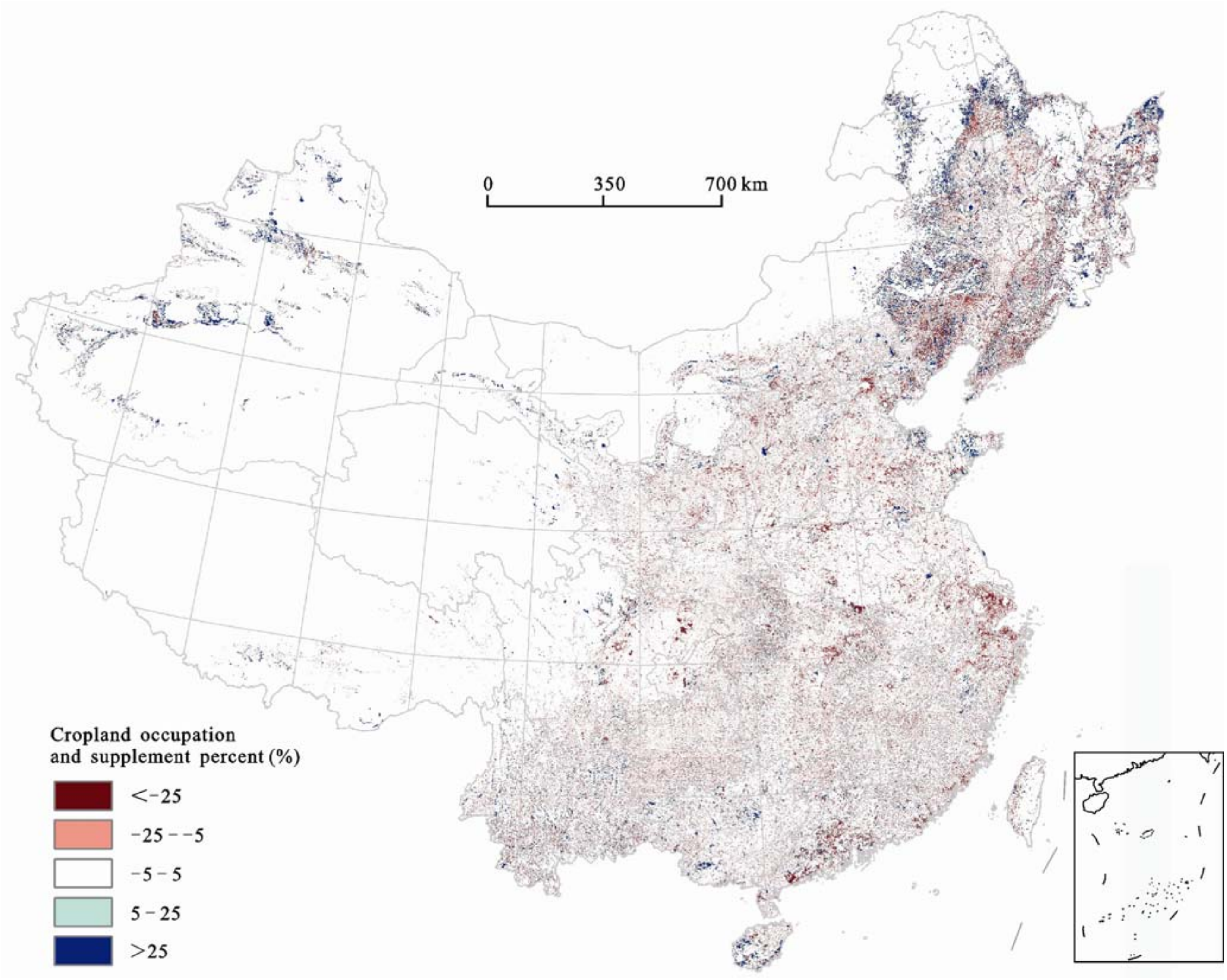

Fig. 1 Cropland occupation and supplement percent in China from 2000 to 2008

plands, the cropland occupation area has a better climate condition and the cropland supplement area has a poor climate condition which is not good for agricultural production and has a significant impact on the LTPP.

3.3 Effect of cropland occupation and supplement on LTPP

3.3.1 Spatial distribution of LTPP

The LTPP in China has an obvious latitudinal and longitudinal distribution (Fig. 3). In the east-west direction, the LTPPs in the east and the west of Heihe-Tengchong line are quite different. In the west, most areas belong to plateau and desert climate with poor natural condition, lower temperature, less precipitation and the LTPP is lower than 6 000 kg/ha. In the east, especially in the southeastern costal area with subtropical monsoon climate, the LTPP is much higher, all above 25 000 kg/ha. In addition, in the Sichuan Basin, the Yunnan-Guizhou Plateau, the middle and lower reaches of the Changjiang River with subtropical monsoon climate, the productivity is higher as well, mostly above 20 000 kg/ha. In the north-south direction, the productivity shows an increase trend from north to south. Especially in the eastern part, the productivity gradually increases from the Northeast Plain, the North China Plain, to the middle and lower reaches of the Changjiang River, since the Northeast Plain is in a middle temperate monsoon climate with lower temperature, the North China Plain is in a warm temperate climate with higher temperature and insufficient precipitation, and the middle and lower reaches of the Changjiang River is in a subtropical monsoon climate with the highest temperature and sufficient

Table 1 Classification statistics of cropland occupation and supplement in all provinces of China from 2000 to 2008* ($\times10^4$ ha)

Province	Cropland supplement				Cropland occupation				Total
	ELR	CLR	WR	Subtotal	ER	CO	CA	Subtotal	
Jiangsu	0.97	0.02	0.00	0.99	4.64	26.44	0.00	31.08	−30.09
Guangdong	0.17	0.00	0.00	0.17	3.88	21.00	0.00	24.88	−24.71
Zhejiang	1.61	0.07	0.00	1.68	2.99	22.58	0.01	25.57	−23.89
Shaanxi	2.52	0.00	0.42	2.94	20.26	4.11	0.08	24.45	−21.51
Shandong	5.69	0.09	3.53	9.31	4.51	24.13	0.46	29.10	−19.79
Sichuan	0.27	0.00	0.00	0.27	8.98	7.33	0.03	16.35	−16.08
Henan	1.43	0.06	0.14	1.64	5.93	9.93	0.00	15.87	−14.23
Hubei	0.66	0.00	0.07	0.73	8.61	4.83	0.01	13.45	−12.73
Shanxi	0.91	0.00	0.00	0.91	7.30	4.96	0.00	12.26	−11.35
Anhui	1.51	0.00	0.00	1.51	2.02	10.38	0.00	12.41	−10.89
Fujian	0.44	0.00	0.00	0.44	1.08	9.85	0.00	10.93	−10.50
Chongqing	1.58	0.00	0.01	1.59	5.76	4.92	0.00	10.69	−9.10
Ningxia	3.74	0.00	1.56	5.30	9.12	2.08	2.96	14.16	−8.86
Hebei	2.34	0.01	0.57	2.92	1.57	9.57	0.07	11.20	−8.28
Shanghai	0.19	0.00	0.00	0.19	0.30	6.96	0.00	7.26	−7.07
Yunnan	0.83	0.00	0.00	0.84	5.20	2.43	0.00	7.63	−6.80
Hunan	0.26	0.00	0.00	0.26	2.81	3.29	0.01	6.11	−5.85
Beijing	0.21	0.01	0.00	0.21	0.17	5.16	0.00	5.33	−5.11
Tianjin	0.23	0.00	0.00	0.23	0.44	3.65	0.00	4.09	−3.87
Liaoning	3.45	0.00	0.39	3.84	3.13	4.01	0.08	7.22	−3.38
Guangxi	0.31	0.02	0.00	0.33	1.04	1.86	0.00	2.90	−2.56
Jiangxi	5.50	0.05	0.06	5.60	2.52	5.31	0.16	7.99	−2.39
Gansu	6.60	0.00	7.92	14.53	13.73	2.14	0.80	16.68	−2.15
Guizhou	6.86	0.01	0.02	6.89	8.38	0.45	0.00	8.83	−1.94
Hainan	0.36	0.00	0.25	0.61	0.92	0.57	0.00	1.49	−0.88
Tibet	0.07	0.00	0.00	0.07	0.00	0.14	0.00	0.14	−0.07
Qinghai	1.69	0.00	0.02	1.71	0.49	0.45	0.03	0.97	0.74
Jilin	8.06	0.00	1.80	9.86	2.27	2.32	0.14	4.73	5.13
Inner Mongolia	44.17	0.01	5.15	49.33	28.22	2.42	1.74	32.38	16.95
Heilongjiang	28.10	0.07	9.42	37.59	12.31	2.33	1.15	15.80	21.79
Xinjiang	81.03	0.01	28.73	109.76	6.86	1.56	1.44	9.86	99.90
Total	211.74	0.43	60.08	272.25	175.46	207.18	9.16	391.80	−119.55

Notes: ELR, ecological land reclamation; CLR, construction land reclamation; WR, wasteland reclamation; ER, ecological restoration; CO, construction land; CA, cropland abandonment. * Excluding Hong Kong, Macau and Taiwan

heat and precipitation. The Qinling-Huaihe line corresponds with 25 000 kg/ha value. Temperature determines the latitudinal distribution of LTPP in China.

Table 2 Climate conditions in occupation and supplement cropland areas in China from 2000 to 2008

Area	Annual sunshine time (h)	Annual precipitation (mm)	Annual accumulated temperature (℃)	Average annual temperature (℃)
Supplement area	2663.17	374.75	4049.82	8.22
Occupation area	1991.50	1007.03	5401.19	14.05

3.3.2 Variation of LTPP caused by cropland occupation and supplement

From 2000 to 2008, total LTPP increased 3.34994×10^7 t as a result of cropland supplement (Table 3). The increases in LTPP resulting from ELR, CLR and WR account for 79.93%, 0.22% and 19.85%, respectively. On the other hand, the total LTPP decreased 7.73309×10^7 t as a result of cropland occupation. The decreases in LTPP resulting from CO, ER and CA account for 58.76%, 39.84% and 1.40%, respectively.

In the eight years, the total LTPP had a net loss of

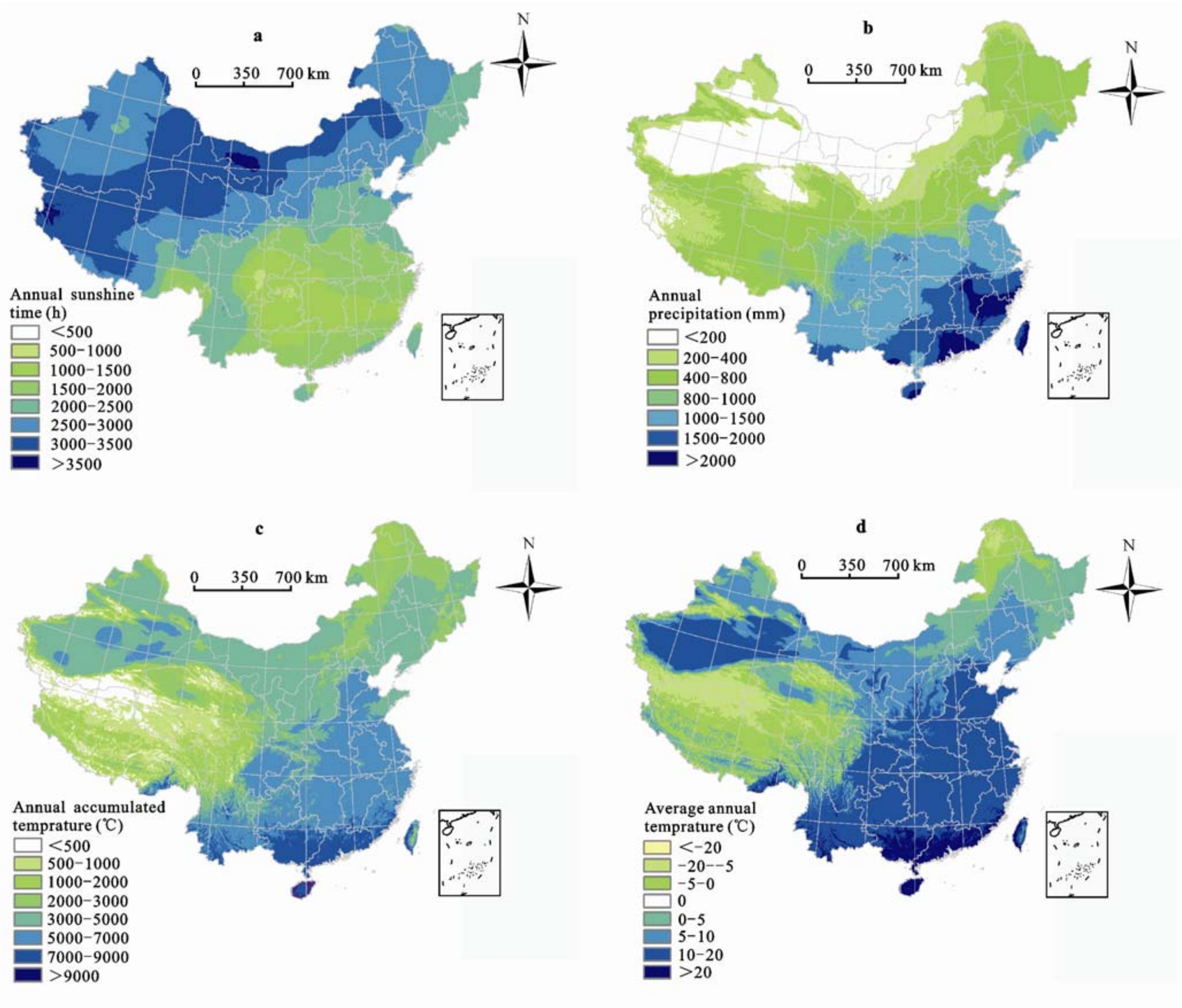

Fig. 2 Overall distribution pattern of climatic conditions in China from 2000 to 2008

4.38315×10^7 t as a result of the climate differentiation between cropland occupation and supplement areas. The average LTPP per unit area was 19.74 t/ha in occupation cropland while 12.27 t/ha in supplement cropland, only 62% of the former. Each type of cropland occupation had a higher LTPP per unit area than that of cropland supplement (Table 4).

From Table 5, it can be seen that from 2000 to 2008, the total LTPP increased mainly in Xinjiang, Heilongjiang, Inner Mongolia, Jilin and Qinghai provinces, of which Xinjiang increased the most by 1.07469×10^7 t. And it decreased in most of provinces, with the higher values in Jiangsu, Guangdong, Zhejiang and Shandong provinces. In the whole country, the LTPP decreased 7.73309×10^7 t for the cropland occupation and increased 3.34994×10^7 t for the cropland supplement, therefore, China had a net loss of 4.38315×10^7 t in the study period (Table 5).

4 Discussion and Conclusions

4.1 Discussion

The areas with increased total LTPP are mainly distributed in Northwest China and Northeast China, which belong to plateau climate, steppe climate or desert climate with poor natural environment. The increase of LTPP is at the cost of reclaiming natural wood and grass resources, and destroying natural ecological environment. It is a result of requiring cropland instead of Gobi which plays a buffer role between oasis and desert, th-

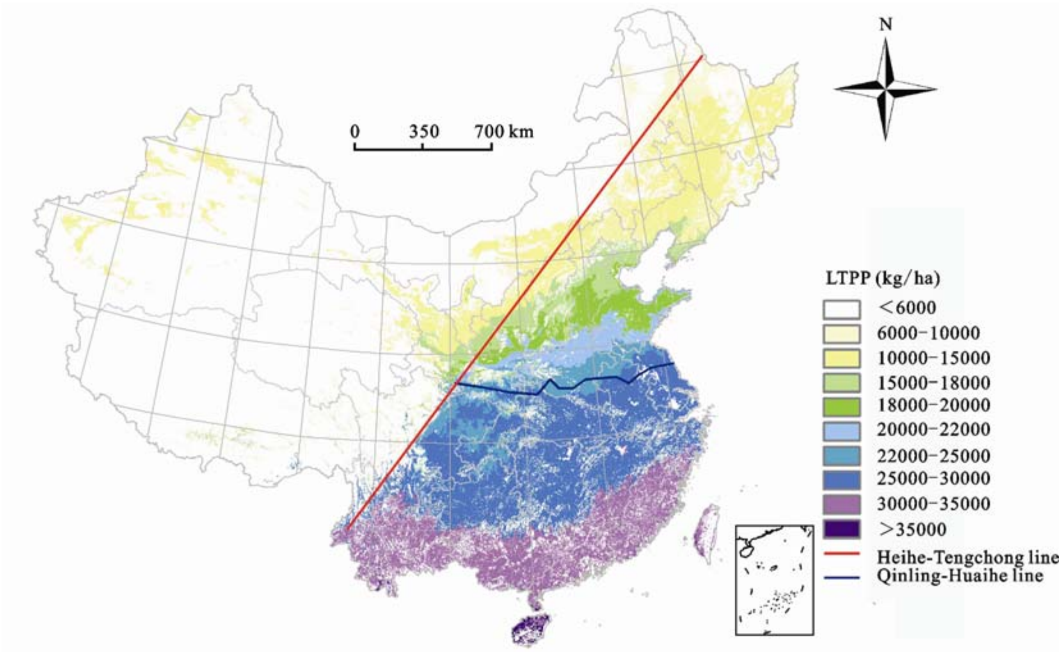

Fig. 3 Spatial distribution of average annual light-temperature potential productivity (LTPP) in China from 2000 to 2008

Table 3 Total increment and decrement of LTPP led by cropland occupation and supplement in China from 2000 to 2008 ($\times 10^4$ t)

Increment				Decrement				Total
ELR	CLR	WR	Subtotal	ER	CO	CA	Subtotal	
2677.57	7.48	664.89	3349.94	3080.62	4543.79	108.68	7733.09	−4383.15

Table 4 Average LTPP per unit area in cropland occupation and supplement areas in China from 2000 to 2008 (t/ha)

Cropland supplement				Cropland occupation				Mean
ELR	CLT	WR	Mean	ER	CO	CA	Mean	
12.65	17.40	10.89	12.27	17.56	21.93	11.89	19.74	16.67

Table 5 Variation of total LTPP led by cropland occupation and supplement in all provinces of China from 2000 to 2008* ($\times 10^4$ t)

Province	LTPP increment	LTPP decrement	Variation	Province	LTPP increment	LTPP decrement	Variation
Jiangsu	17.59	754.20	–736.62	Ningxia	71.43	169.59	–98.16
Guangdong	4.51	683.96	–679.45	Gansu	160.88	247.80	–86.92
Zhejiang	35.02	590.27	–555.25	Beijing	3.36	84.97	–81.61
Shandong	125.27	540.62	–415.35	Guangxi	9.72	87.15	–77.43
Sichuan	4.95	375.20	–370.25	Tianjin	3.85	72.05	–68.20
Shaanxi	48.97	411.94	–362.97	Jiangxi	165.98	227.38	–61.40
Hubei	18.49	355.00	–336.51	Guizhou	181.59	234.70	–53.11
Henan	30.67	339.06	–308.39	Liaoning	47.46	94.09	–46.63
Anhui	37.70	316.01	–278.32	Hainan	13.63	37.33	–23.69
Fujian	12.93	261.92	–248.99	Tibet	0.72	2.60	–1.88
Chongqing	38.84	252.71	–213.87	Qinghai	17.13	12.88	4.25
Yunnan	25.24	236.99	–211.75	Jilin	114.41	55.30	59.11
Shanxi	16.79	182.38	–165.59	Inner Mongolia	532.04	336.67	195.37
Hunan	7.01	165.39	–158.39	Heilongjiang	384.51	166.65	217.86
Shanghai	0.65	157.71	–157.06	Xinjiang	1176.00	101.30	1074.69
Hebei	42.60	179.26	–136.66	Total	3349.94	7733.09	–4383.15

Note: * excluding Hong Kong, Macau and Taiwan ough it is barren. If the development of Gobi is improper, it can lead to oasis directly adjoining desert and would damage the ecological environment irreversibly. The increase of cropland in Inner Mongolia is mainly at the cost of developing grass resources and also breaks up the ecological balance. The LTPP decreases in most of provinces, mainly in Jiangsu, Guangdong, Zhejiang and Shandong provinces as a result of occupying high quality cropland.

The analysis above demonstrates that, on one hand, the cropland occupation and supplement areas are not equal; on the other hand, the LTPP per unit area differs due to climate differentiation, so both of them directly limit the food production capacity. Therefore, this study strongly suggests that government should strengthen macro-control, take effective measures, strictly control cropland occupation for non-agricultural use, especially high quality cropland occupation, and further protect basic cropland to ensure cropland non-decreasing, unchanged and improved.

4.2 Conclusions

All in all, we can draw the conclusions as follows:

(1) From 2000 to 2008, the trend of cropland variation presents occupation in the south and supplement in the north in China, but overall decreased. Supplement cropland was mainly from ecological reclamation (77.78%) and was mainly distributed in Northeast China and Northwest China with poor climate and natural conditions. Occupation cropland was mainly used as construction land (52.88%) and ecological restoration (44.78%), and was distributed in the Huang-Huai-Hai Plain, the middle and lower reaches of the Changjiang River with better climate and natural conditions.

(2) The climate conditions were quite different in supplement and occupation cropland areas. The annual precipitation, annual accumulated temperature and average annual temperature were lower in supplement cropland area, and its average potential productivity per unit area was only 62% of occupation cropland, which was the main reason for the decrease of total potential productivity.

(3) Cropland occupation and supplement leads to the variation of total potential productivity and spatial distribution. The productivity decreased in the south and increased in the north, but had a net loss of 4.38315×10^7 t in the whole country. The increase of cropland area was at the cost of reclaiming natural wood and grass resources, and destroying natural ecological environment; while the decrease of cropland area was mainly due to a lot of cropland occupation by urban-rural construction land, which threatens the sustainable use of cropland resources.

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