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Modelling scenarios of land use change in northern China in the next 50 years

HE Chunyang, LI Jinggang, SHI Peijun, CHEN Jin, PAN Yaozhong, LI Xiaobing
(Key Laboratory of Environmental Change and Natural Disaster, Ministry of Education of China, Beijing Normal University; College of Resources Science and Technology, Beijing Normal University, Beijing 100875, China)

Abstract: Modelling scenarios of land use change and their impacts in typical regions are helpful to investigate the mechanism between land use and ecological systems and process the land use allocation under the ecological security. A system dynamics (SD) model with the aim to modelling scenarios of land use change and assessing ecological impact in northern China in the next 50 years is developed here. The accuracy assessment with the historic data from 1990 to 2001 indicated the SD model is robust. After the different "what-if" scenarios controlled by GDP, population, market, and technology advancement were built, the different scenarios of land use change in northern China from 2000 to 2050 were simulated with their ecological impact assessed. The result suggested that such factors as GDP, population, market and technology have a strong relationship with land use structural change in northern China. It also indicated that such measures as strict controlling of population increase, importing some food to keep the supply-demand balance in the region, and improving agricultural technology will be the guarantee of regional sustainable development with fast economic growth and the obvious land use structural improvement at the same time.
Key words: northern China; land use; scenarios simulation
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1 Introduction

Land use modelling is a useful tool to analyze the land use cause, process and result, to recognize the impact of land use system change on ecological environment, and to support the land use planning and policy (IIASA, 1998; Costanza *et al*., 1998). Modelling scenarios of land use change and their impact in typical regions are helpful to investigate the mechanism between land use system and ecological system and process the land use allocation under the ecological security (Cai, 2001; Zhang *et al*., 2001; Leng *et al*., 1999; Shi *et al*., 2002).

System Dynamics (SD) is a methodology for the research of structure, function and dynamic behaviors of feedback systems; it is built on cybernetics, system theory and information theory. A prominent characteristic of system dynamic models is its ability to reflect the interaction between structure, function and dynamic behaviors of complex systems, performing dynamic reality simulation, then studying the dynamic behaviors and trends of the system under different scenarios which can support the decision making process (Wang, 1993). Many researches had proved that SD model could simulate the behaviors of complex land use systems; it is a good tool for scenario land use research (Van *et al*., 1999; Li *et al*., 2002; Zhang, 1997; Zhang *et al*., 1999; Bai, 2000; Yao *et al*., 2000; Wang *et al*., 1997). Using the SD model, Li and Simonovic modelled many manners of floods from snowmelt in North American prairie watersheds. Results indicated that simulated values match observed data very well (Li and Simonovic, 2002). Zhang Hanxiong established an SD model for the simulation of dynamics of soil erosion in the loess

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Author: He Chunyang (1975-), Ph.D., specialized in the study of remote sensing application and land use/land cover change. E-mail: hcy@ires.cn
Corresponding author: Li Jinggang, E-mail: sharp@ires.cn

hills of Shanxi and Shaanxi provinces (Zhang, 1997; Zhang *et al.*, 1999). But there has been no literature on SD models using key driving factors in typical areas to generate scenarios to predict the future land use and assess its ecological impact.

The 13 provinces (autonomous regions, municipalities) of northern China consisting of Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Jilin, Liaoning, Heilongjiang, Shaanxi, Gansu, Ningxia, Qinghai and Xinjiang lie between longitude 73°-136°E and latitude 31°-54°N and span the humid, semi-humid, semi-arid and arid zones. This region features climatically an obvious regional difference and transition with diverse vegetation types. There are large areas of cultivated land, forest, grassland and desert, most of them are located in Grassland and Farming-pastoral Zone of North China, and the ecological environment there is vulnerable. Because of irrational land use in recent years, many ecological problems, such as soil sandification, vegetation degradation, and frequent sandstorms, are very prominent. These impeded the economic development and social advancement of local regions (Li *et al.*, 2004). Currently, the Chinese government is implementing the "Western Development" and "Revitalizing Northeast Old Industrial Base" strategies. So, modelling scenarios of land use change and their impacts in northern China in the near future obviously have important theoretical and practical significance to the assessment of the potential impact of land use systems on the ecosystem.

Considering the issues mentioned above, based on the reconstruction of the land use/cover change and its change pattern in the last 20 years of the 13 provinces of northern China (Li *et al.*, 2004), we firstly established a regional land use scenario change SD model. Then under different system conditions, we modelled the land use structure in different socio-economic scenarios and assessed their ecological and environmental impacts in the next 50 years of northern China. The aim of this work is to provide a foundation for the understanding of the responses of regional land use to ecological security and future development of tempo-spatial land use models satisfying ecological security requirements.

2 Regional land use scenario change SD model

Though land use change is the synthesized consequence of physical and human processes, some researchers have shown that in short time scales, human activity may play a leading role in regional land use change (Lambin *et al.*, 2001), therefore in our SD model (Figure 1), we ignored physical factors, such as climate change, and only took human factors as the major driving forces for land use change. The basic goal of the SD model in this article is to simulate the land use structural change in different socio-economic scenarios and to assess ecological and environmental impacts in the next 50 years of the study area.

In this SD model, the 13 provinces of northern China were treated as a regional system. The simulation was conducted under two different conditions, one closed, the other open. In the

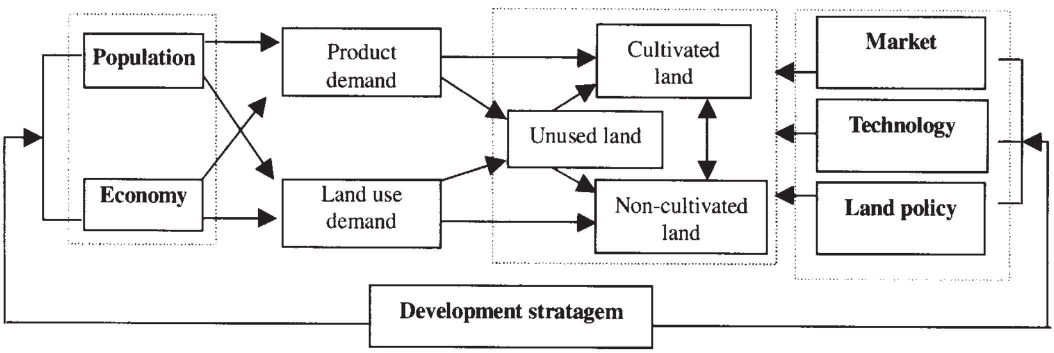

Figure 1 The framework of regional land use scenario change SD model

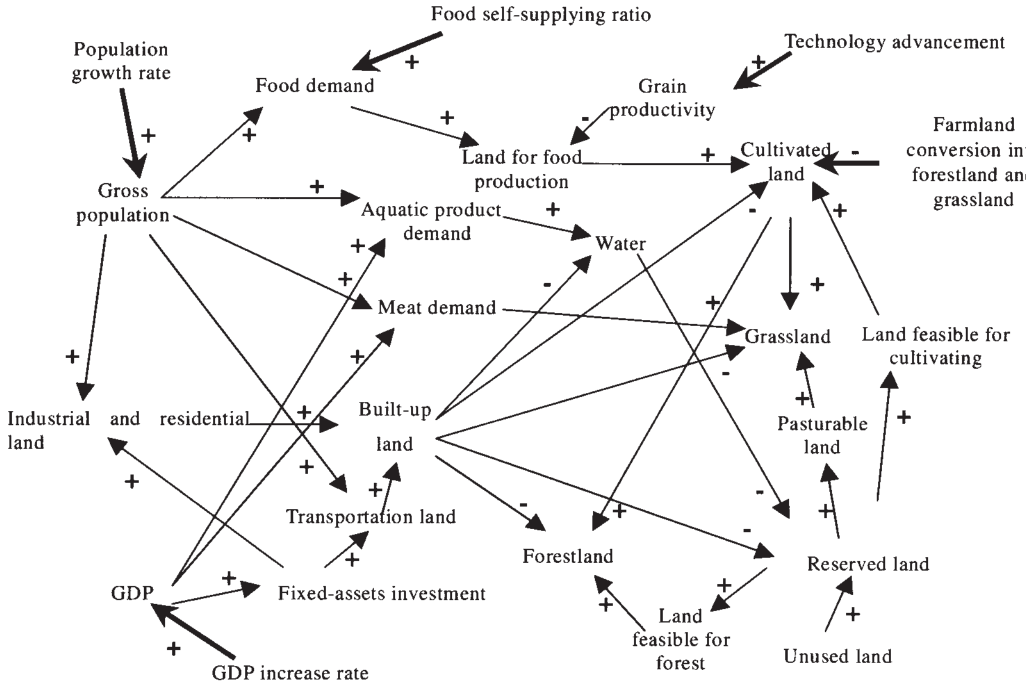

Figure 2 The diagram showing cause-consequence framework of regional land use scenario SD model

closed condition, there is no exchange of material and energy between the system and its environment, food self-supplying ratio is 1, and food supply and demand in the system is balanced. In the case of open condition, the circumstance is just the opposite; the food self-supplying ratio is not always equal to 1, without market exchange, food supply and demand will deviate from balance. More concretely, the model contains two sub-systems, namely social economy and land use (Figure 1). In the background of the national macro development strategy, population, economy (GDP), market (food self-supplying ratio), land policy, and technology advancement (grain productivity) are five basic driving forces of the land use sub-system; they act together to meet the balance of supply and demand, and hence adjust land use structure.

Based on Figure 1, we first analyzed the reciprocal relationship among sub-systems and factors, and then constructed a cause-consequence diagram (Figure 2). In this diagram, "+" stands for positive feedback relation, " —" stands for negative feedback relation. Afterwards, we implemented the whole model using graphical interfaces software for system dynamic simulation called Stella 5.0 developed by High Performance System Company (http://dynamic.hps-inc.com/(lztemnjrahtrmobncn55msrz)/community/presentations/STELLA.aspx#).

3 Modelling scenarios of land use change and assessing their ecological impact in northern China in the near future

Because of the lack of data, this model only simulated the change of 7 kinds of land use, namely cultivated land, forestland (including orchard), grassland, built-up land, transportation land, water and unused land. The tempo spectrum here is from 1990 to 2050. Data in 1990-2000 was for settings of parameters, model adjustment and result validation. Reality simulation is in 2001-2050, in this phase, we supposed different socio-economic scenarios for land use structural modelling and its ecological impact assessing.

Table 1 Accuracy assessment of simulated results in northern China from 1990 to 2001*

	Time	Cultivated land /km^2	Forestland /km^2	Grassland /km^2	Built-up land /km^2	Transportation land /km^2	Water /km^2	Unused land /km^2
Forecast result	1996	587,666.75	911,168.47	1,821,834.11	92,593.08	23,307.51	168,122.22	1,749,948.98
	1999	576,631.47	928,793.20	1,818,779.92	95,627.04	23,978.40	169,520.17	1,741,310.91
	2000	572,336.01	935,772.07	1,817,907.97	96,672.43	24,276.39	170,062.48	1,737,613.77
	2001	566,104.58	940,268.20	1,821,645.75	97,736.99	24,622.05	170,653.03	1,733,610.50
Historical data	1996	581362.42	914818.53	1839733.75	95190.25	23728.95	169774.5663	1730032.654
	1999	577154.63	921905.21	1823324.14	96252.41	24400.65	170699.486	1740904.594
	2000	572367.47	927690.01	1817279.98	96622.35	24575.27	170861.366	1745244.674
	2001	567420.83	940656.74	1818347.66	97066.588	24723.508	170839.41	1735586.384
Relative error	1996	1.07	0.40	0.98	2.80	1.81	0.98	1.14
	1999	0.09	0.74	0.25	0.65	1.76	0.70	0.02
	2000	0.01	0.86	0.03	0.05	1.23	0.47	0.44
	2001	0.23	0.04	0.18	0.69	0.41	0.11	0.11

* Historical data sources: China Land Resources Alamnac. 2000, 2001, 2002, edited by the Ministry of Land and Resources of P. R. C; Land resources survey dataset of China, edited by Liu Yucheng *et al*.

3.1 Model simulation in 1990–2000

The main purpose of the simulation from 1990 to 2001 is based on the historical data to adjust the model and to check up the model's availability. This model took 1990 as a benchmark year, using Stella5.0 on PC, step-width $dt = 1$, applying Euler algorithm for integral calculation. The validation results (Table 1) showed that parameters with a relative error less than 1% account for 78.57% of all model parameters; less than 2%, account for 96.43%; and less than 5%, reach 100%. It can be concluded that the simulation result is reliable. We can use it for the scenario land use reality simulation research for the 13 provinces of northern China (Zhang, 1997; Zhang *et al*., 1999).

3.2 Scenarios simulation from 2000 to 2050

3.2.1 Settings of simulation scenarios   Based on the simulation with the historical data from 1990 to 2001, and on the conditions of current actuality in the 13 provinces of northern China and prospective development in the whole of China, the effect of land use policy was firstly considered. According to *The Soil and Water Conservation Law of People's Republic of China* (http://www.chinawater.net.cn/law/w01.htm), it was presumed that the cultivated land with a gradient larger than 25 degree should have been restored to forest or grassland unconditionally by 2010. Then, the different "what-if" scenarios controlled by GDP, population, market, and technology advancement were built, and the different scenarios of land use change in northern China from 2000 to 2050 were simulated with the land use SD model under an open and a closed condition separately. Furthermore, considering the water area in northern China is very small, we took a protective scheme, namely the water area should maintain the level of 2000 in the future 50 years, or in other words, remain unchanged.

(1) GDP increasing rate

It was reported from National Bureau of Statistics of China that the proportion of the study area's economy to that of the whole country appeared to decrease over the past 10 years, and the economic increase rate was 1%-2% lower than the national average level (http://www.stats.gov.cn). In the meantime, the development stratagem of the Chinese government indicates that if the national economic increase rate is kept at about 7.2% in the following 20 years, the national GDP in 2020 will be 4 times more than the GDP in 2000; and if the national economic increase rate is kept at about 4.7% from 2020 to 2050, then the national GDP in 2050 will be more than four times of that in 2020. So we set the following 3 scenarios for the economic increase rate in the next 50 years in the study area: (1) the economy developing at a high rate exceeding the development plan (E_1), the economy increase rate is 7.5% in the first 20 years, and 5.0% in the latter 30 years; (2) the economic developing at a stable rate according to the development plan (E_2), the economic increase rate is 7.2% in the first 20 years, and 4.7% in the latter 30 years; and (3) the economy developing at a low rate below the development plan (E_3), the economic increase rate is 7.0% in the first 20 years, and 4.5% in the latter 30 years.

(2) Population growth rate

The average population growth rate in the 13 provinces of northern China was a little lower than the average national rate, but the difference was not very obvious and the changing tendencies were the same. Thus we referred to data of the 5th national population census, and used the forecasts developed by the State Commission for Population and Family Planning of China (P_1: high rate), China Population Information and Research Center (P_2: middle rate) and United Nations (P_3: low rate) for the Chinese population in the future 50 years (http://www.cpirc.org.cn) for the setting of population development modes for northern China from 2000 to 2050.

(3) Market adjustment

In order to simplify the model, the market adjustment factor and system condition are reflected by the food self-supplying ratio. It is reported from National Bureau of Statistics of China that if the per capita food demand was 400 kg/a, the food self-supplying ratio rose from 1.07 in 1990 to 1.24 in 1998, and then fell to 0.95 in 2000 in northern China (http://www.stats.gov.cn), so the region was converting from a food exporting area to an importing area. As a response, the food self-supplying ratio of northern China was set as the following 3 modes: (1) open and export mode (G_1), the food self-supplying ratio was 1.15, which indicated that the food production not only can satisfy the regional demand itself but also export some food to external world; (2) closed and balance mode (G_2), the food self-supplying ratio was 1, that signified that the region acts as a closed system which has no material and energy exchange with external world, and only depends on itself to meet food supply-demand balance; (3) open and import mode (G_3), the food self-supplying ratio was 0.85, there was material and energy exchange between the region and the external world, and the region can import food to meet regional food supply-demand balance.

(4) Technology advancement

Also to simplify the model, the technology advancement factor is mainly reflected by the grain productivity. With institutional encouragement and technological advances, the grain productivity (per unit area grain yield) of China rose rapidly from 2749 kg/ha in 1980 to 4350 kg/ha in 1996 (http://218.56.33.82/aicwww/zhxx/qtxx/ls21zhanwang.htm). The mean annual increase was 6.7 kg. However the grain productivity in the study area had an obvious zonal difference. In most of the provinces, such as Shanxi, Inner Mongolia, Shaanxi, Gansu, the grain productivity was obviously lower than the average national level. Meantime, because of the impact of natural disasters, and market and policy factors in recent years, the grain productivity in most provinces of northern China has witnessed a negative increasing trend, even the traditional grain-producing area like the 3 northeastern provinces was not exempt (http://www.stats.gov.cn). Considering most of the 13 provinces in northern China are located in arid or semi-arid zones, the land quality is very poor, and there are many natural hazards, so to raise the grain productivity in the future will be very difficult and will largely rely on technology advancement. In light of the above situation, the grain productivity in the future in northern China was set as the following 2 modes: (1) the regional grain productivity maintains the existing level of 2000 in the next 50 years (S_1); and (2) the regional grain productivity can hold an increasing tendency in the future 50 years due to the technology advancement factor, but the annual mean increasing rate will decrease progressively from 1.5% of the first 10 years to 0.1% of the last 10 years, in other words, the increasing rate will decline 0.1% every 10 years (S_2).

Based on the above set parameters and different combinations of every parameter, we obtained 54 varieties of land use driving scenarios in the next 50 years in northern China. However considering the representativeness and practical purpose of the scenarios as well as the limited space of the article, we only selected 6 scenarios (Table 2) for analysis.

Table 2 Land use driven scenarios in northern China in the next 50 years

System condition	Condition declaration	Scenario declaration	
Closed	Closed and balanced	Scenario A	Economy and population increase at a high rate, grain productivity above the existing level in 2000 ($E_1P_1G_2$ S_2)
		Scenario B	Economy and population increase at a low rate, grain productivity at the existing level in 2000 ($E_3P_3G_2$ S_1)
Open	Open and import	Scenario C	Economy and population increase at a high rate, grain productivity above the existing level in 2000 ($E_1P_1G_3$ S_2)
		Scenario D	Economy and population increase at a low rate, grain productivity at the existing level in 2000 ($E_3P_3G_3$ S_1)
	Open and export	Scenario E	Economy and population increase at a high rate, grain productivity above the existing level in 2000 ($E_1P_1G_1$ S_2)
		Scenario F	Economy and population increase at a low rate, grain productivity at the existing level in 2000 ($E_3P_3G_1$ S_1)

3.2.2 Ecological impact appraisal of land use system in different scenarios The ecological benefit assessment of the land use systems is an extremely complex problem. The land use change in northern China will bound to exert complicated impact on water resources, water environment, soil and water loss, and biodiversity in this region. In order to assess the ecological impact of land use system in different scenarios and investigate the land use allocation satisfying ecological security requirements, from the view of the intensity of ecological service function (Shi, 2002), we merged all land use types into 3 classes: (1) ecological function land, including forestland, grassland and wetland; (2) productive and residential land, including cultivated land, built-up land, and transportation land; and (3) mixed function land, including unused land chiefly. We attempted to assess the ecological impact of land use system in different scenarios in northern China in the next 50 years by analyzing the structural change of the above 3 kinds of land use classes.

3.2.3 Results analysis The simulation results of scenarios given in Table 2 are shown in Table 3. The ecological impact appraisal of the land use system in every given scenario is given in Table 4. From these simulations and appraisal results, we can see that:

(1) When the whole system is under closed and balanced conditions, if the economy develops rapidly and population increases at a high rate, and the grain productivity is higher than the existing level (scenario A), then in the next 50 years the built-up land and transportation land in the region will keep on increasing. In the meantime, because of the implementation of ecological engineering and the occupation of built-up land and transportation land, the cultivated land in the region will have an obvious decreasing trend in the first 10 years of the 21st century, but forest shows some increase, however, the grassland will maintain the same. With the continuous increase in food demand driven by economic development and population increase, after 2010 cultivated land will begin to increase, in about 2030 cultivated land will reach its highest level since 2000. Then the maintenance of the regional development will result in a decrease in unused land and grassland by a big margin.

If there is technology advancement, the persistent increase in grain productivity can basically alleviate the pressure of the regional grain demand, so the increase of cultivated land from 2010 will end around 2030, and change into decrease from 2030, in 2050 cultivated land will be near the level of 2010. Viewing from the ecological impact of land system, from 2000 to 2050 the percentage of the regional productive and residential land will raise from 12.95% to 13.43%, the mixed function land fall down from 32.45% to 29.79%, and ecological function land raise from 54.6% to 56.78%. These indicate that in this scenario, because the persistent technology advancement alleviated the enormous pressure from the regional economic development and population increase, the percentage of the regional productive and residential land in 2050 will

Table 3 Land use structural prediction under different scenarios in northern China in the next 50 years

Scenario	Year	Cultivated land /km^2	Forestland (including orchard) /km^2	Grassland /km^2	Built-up land /km^2	Transportation land /km^2	Unused land /km^2
A	2000	572,336.01	935,772.07	1,817,907.97	96,672.43	24,276.39	1,737,613.77
	2010	521,481.41	987,627.85	1,813,252.24	106,092.60	27,453.32	1,728,080.66
	2020	524,889.11	1,038,056.39	1,801,179.78	114,436.06	32,938.53	1,672,488.20
	2030	528,685.75	1,067,158.52	1,796,007.88	120,394.51	40,625.77	1,631,115.64
	2040	525,392.87	1,079,695.54	1,793,042.01	124,459.95	52,048.60	1,609,349.10
	2050	520,022.96	1,079,427.46	1,790,540.74	128,236.01	70,622.78	1,595,138.11
B	2010	524,202.45	986,192.90	1,813,981.69	105,592.53	27,273.55	1,726,744.96
	2020	562,203.32	1,010,102.89	1,798,955.74	113,021.50	32,103.06	1,667,601.57
	2030	581,849.83	1,027,728.64	1,793,291.20	118,054.36	38,410.72	1,624,653.34
	2040	587,086.99	1,038,152.80	1,792,068.72	120,742.73	47,234.28	1,598,702.55
	2050	587,603.70	1,038,770.44	1,790,578.56	123,424.26	60,919.99	1,582,691.12
C	2010	521,481.41	987,627.85	1,813,252.24	106,092.60	27,453.32	1,728,080.66
	2020	446,909.26	1,069,563.02	1,808,591.38	114,436.06	32,938.53	1,711,549.83
	2030	449,322.06	1,109,326.53	1,803,449.29	120,394.51	40,625.77	1,660,869.90
	2040	446,501.50	1,127,304.59	1,801,443.61	124,459.95	52,048.60	1,632,229.82
	2050	441,897.30	1,130,294.26	1,799,517.24	128,236.01	70,622.78	1,613,420.48
D	2010	524,202.45	986,192.90	1,813,981.69	105,592.53	27,273.55	1,726,744.96
	2020	477,813.73	1,052,722.90	1,806,476.92	113,021.50	32,103.06	1,701,849.98
	2030	494,524.50	1,084,175.62	1,803,252.43	118,054.36	38,410.72	1,645,570.45
	2040	498,963.91	1,100,737.81	1,803,113.14	120,742.73	47,234.28	1,613,196.21
	2050	499,374.84	1,105,464.60	1,802,348.12	123,424.26	60,919.99	1,592,456.26
E	2010	583,067.04	961,291.45	1,804,808.78	106,092.60	27,453.32	1,701,274.89
	2020	603,689.69	1,001,256.78	1,794,685.73	114,436.06	32,938.53	1,636,981.28
	2030	608,049.44	1,027,969.92	1,789,092.24	120,394.51	40,625.77	1,597,856.19
	2040	604,284.24	1,039,809.42	1,786,003.28	124,459.95	52,048.60	1,577,382.58
	2050	598,148.62	1,039,123.72	1,783,428.32	128,236.01	70,622.78	1,564,428.62
F	2010	602,842.24	949,391.60	1,802,423.46	105,592.53	27,273.55	1,696,464.70
	2020	646,592.92	968,619.85	1,791,635.20	113,021.50	32,103.06	1,632,015.55
	2030	669,175.15	980,214.14	1,784,906.28	118,054.36	38,410.72	1,593,227.42
	2040	675,210.07	987,843.03	1,783,190.53	120,742.73	47,234.28	1,569,767.43
	2050	675,832.56	987,103.12	1,781,460.80	123,424.26	60,919.99	1,555,247.34

only increase by less than 5% in contrast to that in 2000. The percentage of the ecological function land will increase by about 2% because of the implementation of the ecological measures such as "farmland conversion into forestland and grassland".

However, without technology advancement and grain productivity at the present level, if the whole system is under closed and balanced condition, then even if the economy develops, population increases at a low rate (scenario B), the regional food demand pressure will still be very high, and cultivated land will increase substantially after 2010 and exceed the existing level of 2000 after 2030. In the meantime, the regional ecological function land percentages of every year will all be lower than that of scenario A at the same time, and the effect of ecological projects will be worse than that of scenario A. These indicated that technology advancement has a powerful effect in alleviating the pressure from high-speed economic development and population growth to keep the supply-demand balanced in the region, to guarantee the implementation of ecological engineering, and to improve land use structure at the same time.

(2) When the whole system is under open and import conditions, if the economy develops and population increases at a high rate, and meantime, the grain productivity is higher than the existing level (scenario C), then even if there is huge food demand pressure and more demand of built-up land and transportation land, cultivated land in the region will still have an obvious

Table 4 Ecological benefit assessment of the land use systems in different scenarios

Function	Year	Closed and balance		Open and import		Open and export	
		Scenario A (%)	Scenario B (%)	Scenario C (%)	Scenario D (%)	Scenario E (%)	Scenario F (%)
Ecological function land	2000	54.60	54.60	54.60	54.60	54.60	54.60
	2010	55.49	55.48	55.49	55.48	54.85	54.58
	2020	56.21	55.65	56.94	56.58	55.40	54.74
	2030	56.66	55.87	57.58	57.11	55.80	54.83
	2040	56.84	56.04	57.88	57.42	55.96	54.94
	2050	56.78	56.03	57.90	57.49	55.90	54.89
Mixed function land	2000	32.45	32.45	32.45	32.45	32.45	32.45
	2010	32.27	32.25	32.27	32.25	31.77	31.68
	2020	31.23	31.14	31.96	31.78	30.57	30.48
	2030	30.46	30.34	31.02	30.73	29.84	29.75
	2040	30.06	29.86	30.48	30.13	29.46	29.32
	2050	29.79	29.56	30.13	29.74	29.22	29.04
Productive and residential land	2000	12.95	12.95	12.95	12.95	12.95	12.95
	2010	12.23	12.27	12.23	12.27	13.38	13.74
	2020	12.55	13.21	11.10	11.63	14.03	14.79
	2030	12.88	13.79	11.40	12.16	14.36	15.42
	2040	13.11	14.10	11.63	12.46	14.58	15.75
	2050	13.43	14.42	11.97	12.77	14.88	16.06

decrease before 2020 and keep stable after 2040. This is because unlike the first two scenarios, the region can import food through the market to satisfy its demand. Technology advancement can also alleviate the regional food demand pressure, and the effect of the ecological engineering is very significant. At the same time, regional forest can have sustained increase and grassland can maintain stabilization after 2015. Viewing from the ecological impact of land use system, in 2050 the percentage of productive and residential land will be only 11.97%, which is about 0.6% lower than that of 2000, but the percentage of ecological function land can increase considerably, being 57.49%, the highest among the 6 scenarios.

Without the consideration of the technology advancement, the grain productivity at the present level and the whole system being open, then even if the economy develops and population increases at a low rate (scenario D), there will also be some food demand pressure, but the regional system can import some food to satisfy its demand through the market. The implementation of ecological projects will also have a very significant impact, so in 2050 the productive and residential land proportion can still maintain the level of 2000 and the ecological function land proportion can reach 57.49%. These indicated that, through the market adjustment mechanism, strict control of population growth and the construction of ecological projects, there would be obvious improvement in land use structure.

(3) When the whole system is under open and export conditions, if the economy and population increase at a high rate and the grain productivity is higher than the existing level (scenario E), then the built-up land and transportation land demand will keep on increasing in the next 50 years. At the same time, because the region is undertaking the duty of food exportation, regional food yield will face extremely high pressure. Although technology advancement can alleviate this pressure to some extent, before 2030 the cultivated land area will keep the increasing tendency and start to decrease because of the decrease of the technological factor after 2030. In 2050 the cultivated land area will still be above the level of 2000. Viewing from the ecological impact of the land use system, in this scenario, productive and residential land percentage will be obviously higher than that of scenario A, but ecological function land percentage will be obviously lower than that of scenario A. This indicates that even if technology advancement can act very powerfully, because of the huge food demand and cultivated land loss

pressure, it will still be difficult to implement ecological project.

(4) When the whole system is under open and export conditions, if there is lack of technology advancement, namely the grain productivity keeps at present level (scenario F), although the food production pressure will have be alleviated to a certain degree, because the region is undertaking the duty of food export, regional cultivated land demand and grain production will still face extremely high pressure. Under this situation, the cultivated land area will keep on increasing and reach the highest value among the 6 scenarios in 2050. When viewing from the ecological impact of the land use system, productive and residential land percentage will reach the highest among the 6 scenarios in 2050, but the ecological function land will be the lowest. So the regional land use structure will appear a deteriorating tendency. This further proves the importance of the 4 factors, namely, population, GDP, market and technology advancement in the maintenance of the reasonable land use structure.

From the above analysis, it can be concluded that such factors as GDP, population, market and technology advancement have strong effect on land use structural change in northern China. The simulation results of all the scenarios also indicated that such measures as strict control of population growth, importing some food to keep the supply-demand balanced in the region and improving agricultural technology can guarantee the regional sustainable land use structure and fast economic development in northern China.

4 Results and discussion

(1) This paper used system dynamic principles and methods, and after the different "what-if" scenarios driven by economy (GDP), population, market (food self-supplying ratio), land use policy and technology advancement (grain productivity) were built, the different scenarios of the land use change model in northern China from 2000 to 2050 were simulated based on their ecological impact assessment. The accuracy assessment with the historical data from 1990 to 2001 indicated that the land use SD model was robust, the parameters with relative error less than 1% account for 78.57%, less than 2% account for 96.43%, and less than 5% reach 100%. This indicates that the SD model has very high validity and can be used to help understanding these currently complex driving activities in land use system and assessing the potential ecological effect of land use system in vulnerable ecosystem in some ways.

(2) The model simulation and ecological assessment results in northern China in the next 50 years suggested that such factors as economy, population, market and technology advancement have strong effects on land use structural change in northern China. It also indicated that such measures as strict control of population growth, importing food to keep the supply-demand balanced in the region and improving agricultural technology are the guarantee to the regional sustainable development, rapid economic development and the obvious land use structural improvement at the same time.

(3) Land use system is a complex system under the synthesized effects of physical and human factors. In this land use SD model, only the social driving forces were considered, so the model is only a preliminary and simplified model, and there is still some room for improvement. In fact, the effect from such factors as climate, resource commitment (example: water resource) and others on land use structural change is mostly obvious. At the same time, as for these socio-economic driving factors with the possible change from socio-economic growth form at different stages, the simulation rationality and accuracy from 1990 to 2001 will be partly, even wholly, not applicable to the regional future conditions. So the simulation result in this paper is only one type of the possible "scenario results", which mostly reflects a kind of prospective situation on one special condition, and has some uncertainties. Because of the uncertainties, the simulation result differs greatly from the practical situation. When appreciating the land use scenario simulation result, this point must be sufficiently considered. Seeing from the above view, it is very necessary in our future work to enhance the responding ability of the current SD model to

the driving factors complexity in land use system.

(4) The actual and potential ecological effect and backfeed process coming from the land use system change is an extremely complex problem. In this paper, we did an ecological assessment on land use scenario change in northern China in the next 50 years from the view of the intensity of ecological service function. In fact this work is only one trail, which does not essentially involve the ecological effects of soil and water loss, water resource and biodiversity. So it is also the place of our work needing to be improved. But obviously, the actual and potential ecological effect assessment coming from the land use system change must be highly taken into account in current land use system change studies.

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