Chin. Geogra. Sci. 2008 18(1) 033–040
DOI: 10.1007/s11769-008-0033-5
www.springerlink.com

Long-term Dynamics of Cultivated Land Resources and Their Driving Forces of Guyuan City in Upper Reaches of Jinghe River

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Abstract: The land use patterns in Guyuan City, Ningxia Hui Autonomous Region of China, have changed greatly over the years, due to population growth and farming and stock raising development. This study, using 50-year statistical data of cultivated land and 14-year spatial data of land use pattern, analyzed the developmental stages, the character, and the spatial variance of farmland in the city, and discussed the driving forces of cultivated land changes based on empirical and conceptual statistical models. First, the change of cultivated land area went through different stages of rapid increase, fluctuating change, decrease and rapid decrease from 1949 to 2004, additionally, social and economic policies in different stages had an important impact on farmland variance. Second, from 1986 to 2000, the quantity of cultivated land increased, but its quality decreased. Third, social and economic factors are determinant factors in cultivated land transition. Five constructed paths explain cultivated land transition. Factors that have direct or indirect effects on farmland include the economy (X_{eco}), the population (X_{pop}), agricultural output (X_{agr}), and scientific input (X_{sci}). The sequence of impact was X_{eco}>X_{pop}>X_{sci}>X_{agr}. Among all these impacts, X_{eco} was the major positive one, and X_{pop} was the major negative one. It is urgent to take measures or adopt a policy to stop the vicious cycle in eco-environment and agriculture production. Otherwise, negative patterns of farmland use will increase, and high-quality cultivated land will continue to decline.

Keywords: cultivated land transition; driving forces; national policy; economic development; population; scientific input

1 Introduction

Cultivated land is a kind of fundamental and important natural resources. It helps to meet the human need for production, subsistence, and other basic necessities. The dynamics of cultivated land are closely linked with food security and human existence (Yu and Lu, 1996; Zhou et al., 2003), therefore, it is an emphasis of the studies on land use/cover change and sustainable land use (Irwin and Geoghegan, 2001; Xie et al., 2005; Gellrich et al., 2007). Guyuan City is located in the western part of the Loess Plateau, at the upper reaches of the Jinghe River. This region has a long history of agricultural development and a larger area of cultivated land per capita. However, agriculture production is affected by low temperature, sparse vegetation, and serious soil and water erosion. The main purpose of land use in Guyuan City is to acquire raw materials directly from land, thus the level of economic development there is continuously lower (Li et al., 2001). As a result of the burden of population growth, peasants destroy vegetation to reclaim cultivated land and make relatively little effort to change production in the farmland area. Irrational land uses result in soil erosion and extensive cultivation. If these problems are not resolved, both the agricultural production and ecological environment will be destroyed, which will endanger human survival and the residential environment. Therefore, it is important to

Received date: 2007-06-20; accepted date: 2007-11-25
Foundation item: Under the auspices of Major State Basic Research Development Program of China (No. 2002CB111506), National Natural Science Foundation of China (No. 30670374), Sixth Framework Programme of European Union (Priority 1.1.6.3) (No. 003874-2)
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monitor cultivated land dynamics, to analyze spatial and temporal variance, and to discover the driving forces. This research uses empirical and conceptual models to analyze historical data and remote sensing data in an effort to determine the social economic and environmental driving forces (Aspinall, 2004; Li et al., 2006), with the aim of providing support for regional decision-making regarding the rational utilization of cultivated land.

2 Study Area and Method

2.1 Study area

Guyuan City is located in the south of the Ningxia Hui Autonomous Region of China, in the source area of the Jinghe River. It is situated between 35°14′–37°04′N and 105°09′–106°58′E, and includes Guyuan proper and four counties (Fig. 1). The population was 1.51×10^6 in 2004. The city covers a total area of 14,421km^2, with 3793.6km^2 of cultivated land and 0.23ha per capita. The major landform is loess hill, with numerous ditches and gullies. The altitude ranges from 1500m to 2000m. The three main soil types are black loessial soil, sierozem, and mountain blown soil. The basic features of the climate include long sunshine time, strong radiation, wide temperature range, short and variable frostless period, drought, concentrated rainfall, and extreme evaporation. Annual sunshine time ranges from 2200h to 2700h. The average annual air-temperature is 5.2℃ to 7.3℃. Annual precipitation is between 250mm and 820mm. The mean precipitation is less than 500mm in 80% of the total area, and the aridity index is 1.00 to 2.05. Drought is the main natural disaster, and hail, frost, and sandstorms also occur frequently (Dai et al., 1990; Peng et al., 1986).

2.2 Data and method

Historical cultivated land data, population data, and relative social and economic data were obtained from the *Yearbook of South Ningxia Mountain Area—Guyuan 1949–1992*, the *Yearbook of Guyuan 1993–2000*, and the *Handbook of Brief Economic Information in Guyuan from 2001–2005* (National Bureau of Statistics of China, 1993; 2001; 2006). Both cultivated land data and social indices were put into a temporal database of different counties and the city.

The annual variance rate of cultivated land was applied to describing the transition process. Land use data covering 1986 to 2000 at the scale of 1∶250,000 were used to explore farmland spatial dynamics. These land use data came from the resources and environment data warehouse of the Chinese Academy of Science. The land uses were classified into six first-level types, i.e., farmland, forestland, grassland, construction land, water area and unused land, and then into 18 second-level types, namely, mountainous dryland, hilly dryland, plain dryland, slope farmland over 25°, woodland, shrubbery land, open forestland, other forestland, high coverage grassland, medium coverage grassland, low coverage grassland, water system, bottomland, town, rural inhabitancy, other construction area, sandy land and bare land. In this study, the statistical analysis of cultivated land area was based on the first level, and the spatial transition analysis was based on the second level.

Furthermore, to pick up socio-economic driving factors and extract their major effects on farmland transition, principle component analysis (PCA) was employed. This preliminary process depended on historical data, interviews with local peasants and expert opinions. Finally, 18 independent variables representing society, economy, and environment were selected for the analysis.

Fig. 1 Location of study area in Ningxia Hui Autonomous Region

When principle components and their loading were obtained, we applied multiple regression analysis (MRA) and the structural equation model (SEM) to determining the relationship between those components and farmland. Additionally, a cause-and-effect diagram was constructed to illustrate direct and indirect effects. SEM is a statistical technique for testing and estimating causal relationships using a combination of statistical data and qualitative causal assumptions (Guo et al., 2003). PCA, MRA, and SEM were normalized, and all processes utilized statistical software SPSS.

3 Results and Analyses

3.1 Temporal variation of cultivated land

From 1949 to 2004, cultivated land area in Guyuan City increased by 31,316ha. In 1997, it reached its maximum value of 443,727ha. The minimum of 339,673.3ha emerged in 1991. In the past 55 years, the change of cultivated land area went through four periods of fast increase, fluctuating change, decrease, and rapid decrease.

In the first period (1949–1957), cultivated land in Guyuan increased rapidly, with an annual expanding speed of 3.8%. The maximum value reached 14.2%. At that time, owing to land reform, local peasants obtained farmland and livestock, which actively sped up the expansion of farmland area.

In the second period (1958–1978), fluctuation occurred in the change of cultivated land area, with an annual changing rate of –1.97% to 4.70%. During this stage, as the government advocated economic development, especially industry, some cultivated lands were abandoned or occupied by crude industry, and some cultivated lands were transformed into small blast furnaces or reservoirs. Despite the negative events during this period, the cultivated land area in Guyuan continued to increase slowly under the guidance of the traditional agricultural policy of “taking grain as the key link”. Some beneficial policies of agriculture also acted as an impetus, such as remitting agricultural taxes in newly cultivated land over a three-year period.

In the third period (1979–1995), cultivated land descended from 410,967ha to 339,287ha, with an annual decrease rate of 1.07%. Agricultural economic reformation and agricultural development spread out in China in this period, raising peasants’ income. Rural land management shifted from a collective right to a contracting right. On the one hand, land management became more flexible, hence peasants could increase their income through non-agricultural management, such as livestock feeding or orchard planting. And many rural labor forces moved to urban and township enterprises. Their enthusiasm to cultivate land declined. On the other hand, the rural residential area expanded with population growth. Rural infrastructure construction increased with economic development. Therefore, large area of cultivated lands were occupied at this time. Several studies based on Participatory Rural Appraisal (PRA) and the geographic information system (GIS) also indicated the descending process of farmland during this period (Zhen et al., 2007; Hao et al., 2007).

In the fourth period (2001–2004), the cultivated land area in Guyuan decreased from 463,390ha to 353,956ha, with an annual decrease rate of 4.23%. Obviously, it was affected by the national policy of returning cultivated land to forest and grass. Statistical data revealed that both reducing area and decreasing rate of farmland accelerated after 2002. Transition areas from farmland to forest or grass occupied the biggest part of total farmland loss (99.2% in 2002, 64.8% in 2003, and 94.6% in 2004). Since the late 1990s, a series of ecological projects have been carried out, and Guyuan was one of the regions to implement such projects. Hence, in the fourth stage cultivated land reduction was led by ecological projects.

The period of 1996–2000 was not considered in the analysis of temporal variation of cultivated land due to some statistical error. In 1996 and 1997, cultivated land increased at the amazing rate of 36.2%, which was even higher than the increase rate of the early 1950s. This deviant pattern was probably due to the continuous lower offset of statistical data in cultivated land. Since the 1990s, many studies based on remote sensing or GIS have emphasized land use or cultivated land changes in China. Some researchers have compared the differences in statistical data of cultivated land, national soil survey data, detail data of land resources survey, and remote sensing data (Guo, 2006; Feng et al., 2005; Bi and Zheng, 2000). They concluded that since the 1980s it is likely that local cultivated land has been underestimated in statistical data. If so, a sudden tremendous increase may not have occurred.

3.2 Spatial transition of farmland

The spatial transition of farmland in Guyuan between

1986 and 2000 is listed in Table 1, which shows the transition in quantity between farmland and other land use types (first-level classification).

From 1896 to 2000, 11,293ha of farmland was turned into other land uses at an annual variation rate of 0.15%. Farmland mainly changed into grassland, forestland, and construction land. Hilly dry land and plain dry land were the two types that reduced most. Hilly dryland dropped by 8689ha, and plain dryland by 2704ha. The hilly dryland mainly transited into low coverage grassland (53.6%), open forestland (18.2%), and medium coverage grassland (17.1%). The major plain dryland transition was mainly into low coverage grassland (34.2%), rural residential area (11.0%), and open forestland (10.4%). Slope farmland and mountainous dryland experienced little change. There were 39,518ha of other land use types changing to cultivated land, with a mean variation rate of 0.64% per year. The major input transition of farmland was grassland, involving a total of 38,442ha. And among the input transitions of farmland, low coverage grassland occupied 74.2%, and the medium coverage grassland occupied 25.6%. Most of the increased farmlands were from hilly dryland. In fact, the farmland area expanded from 1986 to 2000 because many mutual conversions occurred between low coverage grassland and hilly dryland, and turning grassland into farmland is faster than the reverse transformation. However, farmland quality deteriorated in this period for rural residential areas and construction land occupied plain dryland with good condition. Production per area in plain dryland was greater than that in mountainous dryland or hilly dryland.

Table 1 Farmland transition in quantity between 1986 and 2000 (ha)

	Total	Forestland	Grassland	Water land	Construction land	Unused land
Farmland to other land use types	11293	2946	7066	155	1103	24
Other land use types to farmland	39518	256	38442	820	–	–
Farmland net change	28225	–2690	31376	665	–1103	–24
Farmland area in 1986	339287 (389842)					
Farmland area in 2000	465886 (528462)					

Note: Comparison data in brackets come from interpretation of remote sensing image, which is greater than the statistical data for the same period

In general, the order of prominent inter-transitions between farmland and other land uses are grassland to farmland (38,442ha), farmland to grassland (7066ha), farmland to forestland (2946ha), farmland to construction land (1103ha), and water area to farmland (820ha). Rank-order of net transition proportion is: grassland to farmland, farmland to forest, and farmland to construction land. The spatial variation of farmland indicates that local peasants still expand cultivated land at the expense of grassland. About 97.3% of the newly increased farmland come from grassland. The policy of turning farmland into forests causes forestland to grow in some places. But the increase is insufficient in quantity, and ecological imbalance and environment deterioration continue. With the booming economic development and increasing population, more and more farmland will be turned into urban and rural construction land. Most farmland that becomes construction land is plain dryland with good condition. As a result, agricultural production will be reduced, and the local region will suffer ecological deterioration in the long run.

3.3 Selection and analysis of driving forces

A history review revealed that policies imposed considerable influence on farmland transition, especially before 1971 and after 1996. Consequently, attempting to conduct statistical analysis based on this entire period from 1949 to 2004 would result in a major error. Some researches considered that the historical data of farmland from 1971 to 1996 maybe lower than the actual ones, however this series of data were consecutive, and the data indicated accurate trends that would not seriously affect the results of the analysis. Therefore, in the analysis of driving forces of farmland change, we used data from 1971 to 1996.

There are various factors influencing cultivated land changes. Social and natural factors like national policy, institution, population, economy, science and technology input, per capita income, agricultural production, land use policy, slope, and even disasters significantly affect the dynamics of farmland from the long-term perspective (Liu et al., 2005; Li, 2002; Zhang et al., 2006). Historical data, local peasants' interviews, and expert opinions were used to select 18 independent variables to conduct principle component analysis. These variables were total population (x_1), GDP (x_2, yuan (RMB)), the first industry output (x_3, yuan), the secondary industry output (x_4, yuan), industry output (x_5, yuan), the tertiary industry output (x_6, yuan), agricultural population (x_7), urban population (x_8), grain production (x_9, t), large livestock (x_{10}), urbanization level (x_{11}), fixed assets investment (x_{12}, yuan), crop production per unit area (x_{13}, t/ha), agricultural machine (x_{14}), rural income (x_{15}, yuan per capita), precipitation (x_{16}, mm), mean air temperature (x_{17}, ℃), and sunshine hours (x_{18}, h). Table 2 presents the driving factors' main results of the PCA.

The coefficient of correlation matrix indicates that a significant positive correlation existed among these driving factors, and their common effects on farmland could be explained. Both the Kaiser-Meyer Olkin measure (or KMO test) and the Bartlett tests reached significant levels, showing that commonalities exist among all the variables, they are suitable for PCA. Table 2 indicates that the eigenvalues of the first three components are 13.036, 1.910, and 1.013; and their variances were 72.4%, 10.6%, and 5.6% respectively. Their cumulative rate of contribution to the total variance was 88.7%, and they could simplify and represent information regarding the total 18 variables. The first component—the social and human synthetic factor—includes economy, population, agricultural input, and agricultural production. In the first component loading, the large values include x_2, x_6, x_4, x_{11}, x_8, x_1, x_{15}, and x_5. The second component involves the natural factors of temperature x_{17} and sunshine hour x_{18}. The third component—the rain factor—includes only x_{16}.

Table 2 Main results of principle component analysis in Guyuan

	% of variance	% of cumulative	Component			
			1	2	3	Communality
x_2	72.4	72.4	0.992	–0.094	–0.006	0.994
x_6			0.984	0.077	0.027	0.976
x_4			0.972	0.100	0.035	0.956
x_{11}			0.967	0.151	0.027	0.959
x_8			0.966	0.145	0.032	0.954
x_1			0.959	0.041	0.051	0.923
x_{15}			0.958	–0.014	–0.033	0.920
x_5			0.958	0.078	0.017	0.924
x_7			0.946	0.030	0.051	0.898
x_{14}			0.941	0.055	0.093	0.897
x_{12}			0.903	0.120	–0.011	0.830
x_{10}			0.876	0.103	–0.066	0.783
x_3			0.861	–0.402	–0.070	0.908
x_{13}			0.857	–0.386	–0.136	0.903
x_9			0.771	–0.453	–0.160	0.825
x_{17}	10.6	83.0	0.208	0.843	0.200	0.794
x_{18}			0.175	0.714	–0.130	0.557
x_{16}	5.6	88.7	0.072	–0.261	0.940	0.958
Eigenvalue			13.036	1.910	1.013	

3.4 Quantitative analysis of driving forces

Based on PCA, the stepwise method was first applied in order to build multiple regression models between cultivated land (Y, dependent variable) and three PCA components (X_1, X_2, and X_3, independent variables, or components. The regression equation was:

$$Y=-2.1\times10^{-15}-0.817X_1 \qquad \text{Sig.}F=0.000 \qquad (1)$$

Stepwise regression analysis first obtained the independent variable with the highest correlation in the equation. Then coefficients of partial correlation were used to determine the entering orders of independent residuals after entering independent controlled variables. The criterion of entering the equation was determined by the F-test. All three components were included in the analysis, but only X_1 was entered in the model, X_2 and X_3 were omitted. The adjusted R^2 value was 0.653, and it had statistical significance with an ANOVA test value of 0. Thus, the results could be accepted.

Table 3 Model summary and ANOVA test

R	R^2	Adjusted R^2	Std. error of estimate	F	Sig.
0.817	0.667	0.653	0.589	48.053	0.000

Coefficients of regression results are presented in Table 4. The negative value of the standardized coefficient for component 1 indicated a negative relationship between the social and human synthetic factor and farmland. In other words, cultivated land would eventually decrease with population and economic increases. The elimination of components 2 and 3 indicates that during the research period the influence of social and human factors was far greater than that of the natural factors in causing farmland change.

Table 4 Model coefficients

	Unstandardized coefficent		Standardized coefficent	t	Sig.
	B	Std. error	Beta		
Constant	-2.1×10^{-15}	0.116		0.000	1.000
X_1	–0.817	0.118	–0.817	–6.932	0.000

In order to explore detailed causal relationships in the cultivated land transition, a structure equation model was employed. First, the 15 factors were divided into groups. Then PCA was applied again to reducing the dimensions and to eliminating intercorrelation to obtain group components or factors that represented different groups (Li et al., 2004): population (X_{pop}, x_1, x_7), economy (X_{eco}, x_2, x_3, x_4, x_5, x_6), agriculture production (X_{agr}, x_9, x_{10}, x_{13}), peasants' income (X_{inc}, x_{15}), and scientific input (X_{sci}, x_{12}, x_{14}). After structure equation analysis of the group components, we determined five remarkable paths and equations.

$$Y= -3.1\times10^{-15}+2.123X_{eco}-1.462X_{pop}-0.698X_{agr} \quad R^2=0.725 \quad Sig.F=0.000 \tag{2}$$

$$X_{eco}= -1.2\times10^{-16}+0.594X_{pop}+0.345X_{out} \quad R^2=0.825 \quad Sig.F=0.000 \tag{3}$$

$$X_{inc}= -7.4\times10^{-17}+1.327X_{eco}-0.394X_{pop} \quad R^2=0.971 \quad Sig.F=0.000 \tag{4}$$

$$X_{sci}=6.97\times10^{-19}+0.976X_{eco} \quad R^2=0.953 \quad Sig.F=0.000 \tag{5}$$

$$X_{agr}= -5.7\times10^{-16}+0.103X_{sci}+0.798X_{pop} \quad R^2=0.798 \quad Sig.F=0.000 \tag{6}$$

The results of the SEM model and its coefficients reached a significance level of 0.001. The value of adjusted R^2 was 0.725 with a residual of 0.524, and the equation passed the collinerity test. It was determined that the SEM model could be established and explained five significant paths: X_{eco}→cultivated land, X_{pop}→cultivated land, X_{agr}→cultivated land, X_{pop}→X_{eco}→cultivated land, and X_{pop}→X_{agr}→cultivated land. The two insignificant paths were X_{eco}→X_{sci}→X_{agr}→cultivated land and X_{agr}→X_{eco}→cultivated land (Fig. 2).

Next, the direct impact, the indirect impact, and the total impact of these variables were calculated (Table 5). Four variables (X_{eco}, X_{pop}, X_{agr}, and X_{sci}) had direct or indirect impacts on cultivated land transition. The im-

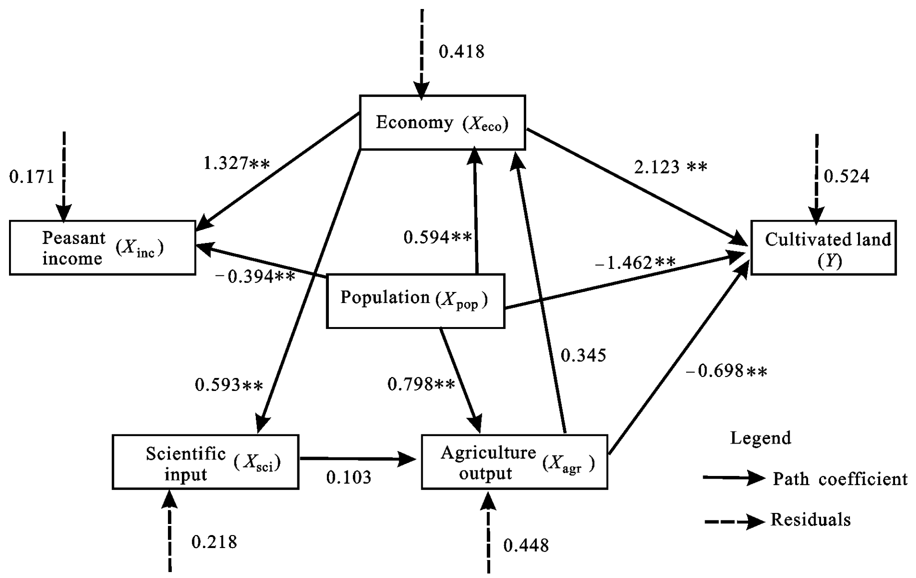

Fig. 2 Cause and effect diagram and path coefficient on cultivated land transition

pact of peasants' income (X_{inc}) was not observed in the model. The sequence of total impact on cultivated land was X_{eco}>X_{pop}>X_{sci}>X_{agr}. The results indicated the influence of all the variables, with X_{eco} having the greatest positive effect (2.054), and X_{pop} having the greatest negative effect (–0.758). The impacts of the other variables were small, with 0.034 for X_{agr} and –0.072 for X_{sci}.

Table 5 Decomposition table of cause and effect

Variable	Type of action	Coefficient
X_{eco}	Direct effect	2.123**
	Indirect effect	–0.068
	Total	2.054
X_{pop}	Direct effect	–1.462**
	Indirect effect	0.704**
	Total	–0.758**
X_{agr}	Direct effect	–0.698**
	Indirect effect	0.732
	Total	0.034
X_{sci}	Indirect effect	–0.072

Note: ** significant at a level of 0.001

Considering the real situation in Guyuan, we attempted to explain the SEM model results. Regarding the economy as a driving force, the results were compatible with local long-term development, which depended mainly on the agriculture industry. Historical data indicated that from 1949 to 1970, agricultural output occupied more than 90% of GDP; from 1971 to 1991, it occupied over 50%. And in 2004, more than one third of GDP was derived from agriculture. Low production levels indicated that economic development will involve more and more cultivated land.

When considering the population as a driving force, results indicated that it both directly and indirectly impacts farmland. First and foremost, population growth needs to expand rural residential areas and have relevant fundamental construction, usually resulting in the occupation of cultivated land. Hence, its direct negative impact on farmland was unavoidable in rural areas. Second, population growth accompanied an increase in the demand for grain, which further caused cultivated land expansion. This effect on farmland was a positive one. Generally speaking, however, a rapid increase in population appearred to have a negative impact.

No major difference was apparent between the direct and indirect impacts of X_{agr}. Its total impact was small (0.034), indicating that increased agricultural production requires the expansion of cultivated land, but the interaction was not strong. Historical data indicated that the annual growth rate of grain yield per area was about 9% and that it weakened the relation between agricultural output and cultivated land. It was determined that the path coefficient of X_{pop} to X_{agr} (0.798) was greater than that of X_{sci} to X_{agr} (0.103). Therefore, it can be concluded that due to the low level of technology in agriculture production, grain production still depended on the population variable.

4 Conclusions

Through statistical analysis of the spatial and temporal data of cultivated land, and regression analysis of influence factors, we conducted an in-depth analysis of the cultivated land change and driving force factors in Guyuan City of Ningxia Region.

The historical data indicated that the dynamics of cultivated land went through four stages of rapid increase, fluctuating change, decrease, and rapid decrease from 1949 to 2004. And in some special stages, policy acted as the dominant driving force.

The land use maps in 1986–2000 indicated that remote sensing data on farmland revealed the same tendency as statistical data. Spatial transition of cultivated land in detail showed that low and medium coverage grasslands were transformed into hilly dryland, and that plain dryland was turned into rural residential areas and construction land from 1986 to 2000. The quantity of cultivated land increased, but its quality decreased in the period.

PCA was employed to classify and reduce variables' dimensions. The results revealed that in 1971–1996, social and economic variables have imposed the biggest influence on cultivated land. An additional SEM model was used to discuss the cause and effect of the variables. We determined five significant construction paths: X_{eco} →cultivated land, X_{pop}→cultivated land, X_{agr}→cultivated land, X_{pop}→X_{eco}→cultivated land, and X_{pop}→X_{agr}→cultivated land. The sequence of impact was X_{eco}>X_{pop}>X_{sci}>X_{agr}. Among all paths, X_{eco} had the greatest positive impact, and X_{pop} had the greatest negative impact. It is urgent to take measures or adopt policies to change or optimize economic structure and control population growth. If such steps are not taken, total cultivated land area will increase, and high-quality cultivated land will decline continuously.

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