

Research on the Influencing Factors of Non-grain Cultivation of Cultivated Land in Sichuan Province

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Abstract. To address the increasingly severe issue of non-grain cultivation of cultivated land in Sichuan Province, this study aims to systematically identify its key driving factors. Based on panel data from 21 prefecture-level cities across the province spanning from 2020 to 2022, a comprehensive indicator system encompassing five major dimensions—economic, demographic, production conditions, policy, and natural factors—was constructed. A multi-model cross-validation was conducted by integrating the geodetector model, panel model, generalized linear model, and geographically and temporally weighted regression model. The study revealed that the consumer price index for urban residents, the proportion of cultivated land within the cultivated land protection target, and the altitude of cultivated land exert significant inhibitory effects on non-grain cultivation. Conversely, Soil biodiversity exhibits a significant positive driving effect, which is conducive to promoting the cultivation of non-food crops. Additionally, factors such as annual precipitation and soil pH value also exhibit significant influences. The findings provide a quantitative basis for formulating differentiated cultivated land protection policies and optimizing agricultural layout in Sichuan Province. It is recommended to strengthen policy implementation and dynamic monitoring to ensure regional food security and the sustainable utilization of cultivated land.

1. Introduction

Since the 18th National Congress of the Communist Party of China, General Secretary Xi Jinping has repeatedly emphasized the need to protect cultivated land with the same care as protecting giant pandas. The results of the Third National Land Survey reveal a significant decline in cultivated land area in Sichuan Province, with a prominent issue of non-grain cultivation of cultivated land. This problem not only concerns food security but also affects the sustainable development of agriculture. Although non-grain cultivation may yield short-term economic benefits, in the long run, it will severely threaten the region's self-sufficiency in food supply. Therefore, systematically studying the formation mechanism of non-grain cultivation of cultivated land in our province, establishing a scientific monitoring and evaluation system, and accurately identifying key driving factors have become crucial tasks for advancing cultivated land protection at present.

Existing research indicates that the non-grain cultivation of cultivated land is primarily influenced by three aspects: socio-economic factors, individual farmer factors, and natural conditions. Among these, socio-economic factors have been the most thoroughly studied^[1]. Multiple studies have confirmed that economic development and structural transformation significantly

impact cultivated land utilization patterns. For instance, Tan et al. (2024) found that the digital inclusive finance index and its dimensional indicators all have a significant positive impact on farmland use efficiency^[2]. Liu et al. (2025) discovered that the non-cultivation phenomena of both sloping farmland and terraced fields are the results of the combined effects of multiple factors, yet the key influencing factors vary across different regions³. Arowolo (2018) developed that agricultural income and input costs are major driving forces⁴. Chang (2022) through redundancy analysis, concluded that over 90% of non-grain cultivation in Xuzhou City can be explained by socio-economic factors. As the direct operators of cultivated land, farmers' behavioral decisions are of crucial importance⁵. Xin et al. (2024) found that farmers' age, gender, and per capita farmland area affect their willingness to make decisions regarding farmland transfer⁶. Mu (2022) indicated that the utilization of water resources is related to the structure of grain production and the efficiency of factor allocation⁷. Kou et al. (2025) pointed out that at the current stage, the coordinated regulation of farmland "non-grain" cultivation faces contradictions in multiple aspects such as objectives, subjects, resources, and institutions⁸. Ma et al. (2025) found that regional industrial upgrading, educational resource sharing, and the degree of government-led innovation have significant impacts on land use

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efficiency⁹. Bednár et al. (2018) demonstrated that slope, soil thickness, and precipitation all have significant impacts¹⁰.

Overall, existing research has covered multiple levels in terms of spatial scale, yet there remains a notable lack of systematic integration of the three types of factors. Regarding research methods, linear regression is predominantly employed for socio-economic factors, binary choice models are favored for analyzing farmer-related factors, and qualitative analysis is heavily relied upon for natural factors. The integration among these methods needs to be enhanced. In summary, while existing research has laid an important foundation for understanding the non-grain cultivation of cultivated land, most of it is still confined to a single dimension. This study innovatively constructed a multi-model cross-validation analytical framework integrating Geodetector, panel models, generalized linear models, and geographically and temporally weighted regression models. Through complementary validation among different model approaches, this framework not only enhanced the robustness of the analytical results and effectively captured the spatial heterogeneity characteristics of factors influencing the conversion of farmland from grain to non-grain crops, but also significantly reduced estimation biases that may arise from single-model applications, thereby providing a more reliable scientific basis for identifying key driving factors.

2. Research data and methods

2.1. Construction of the Indicator System and Data Sources

Based on the current research status at home and abroad regarding the influencing factors of the non-grain production of cultivated land, this study constructs an index system for the influencing factors of non-grain production of cultivated land from five aspects: economic level, demographic factors, production conditions, policy regulation, and natural factors. Among them, $X_1 - X_{15}$ represent all the secondary indicators under the primary indicator of economic level, $X_{16} - X_{21}$ represent all the secondary indicators under the primary indicator of demographic factors, $X_{22} - X_{27}$ represent all the secondary indicators under the primary indicator of production conditions, X_{28} and X_{29} represent all the secondary indicators under the primary indicator of policy regulation, and $X_{30} - X_{53}$ represent all the secondary indicators under the primary indicator of natural factors. The indicators and their symbols are shown in **Table 1**.

The study collected data on the non-grain cultivation rate of cultivated land and related influencing factors from 21 prefecture-level cities in Sichuan Province during 2020-2022, covering aspects such as economy, population, production conditions, policy regulation, and natural factors.

Table 1. Index system of influencing factors for the non-grain production of cultivated land

Secondary Indicator(Unit)	Symbol
Per capita GDP (¥)	X1
Gross output value of the primary industry (¥100 million)	X2
Gross output value of the secondary industry (¥100 million)	X3
Gross output value of the tertiary industry (¥100 million)	X4
Per capita added value of the private economy (¥)	X5
Local general public budget revenue (¥100 million)	X6
Local general public budget expenditure (¥100 million)	X7
Consumer Price Index for urban residents	X8
Grain Consumer Price Index for urban residents	X9
Urban-rural per capita disposable income ratio	X10
Urban-rural per capita consumption expenditure ratio	X11
Urban-rural per capita living space ratio (of current housing)	X12
Urban-rural per capita minimum living allowance ratio	X13
Total RMB deposits of financial institutions (¥100 million)	X14
Total RMB loans of financial institutions (¥100 million)	X15
Registered population at the end of the year (ten thousand people)	X16
Resident population at the end of the year (ten thousand people)	X17
Population mobility (ten thousand people)	X18
Urbanization rate of resident population	X19
Proportion of employees in the primary industry (%)	X20
Rural employed population (ten thousand people)	X21
Total power of agricultural machinery (10000 kw)	X22
Amount of fertilizer applied in agriculture (10000 t)	X23
Rural electricity consumption (100 million kwh)	X24
Irrigated area of cultivated land (1000 ha)	X25
Actual cultivated land area at the end of the year (mu)	X26
Total grain output per unit area (10000t/ha)	X27
Proportion of cultivated land within permanent basic farmland	X28
Proportion of cultivated land within the targets of cultivated land protection	X29
Annual average temperature (°C)	X30
Annual precipitation (mm)	X31
Annual average relative humidity (%)	X32
Annual sunshine duration (h)	X33
Distance from urban center (km)	X34
Coverage rate of water resources on cultivated land	X35
Coverage rate of urban-village roads on cultivated land	X36
Coverage rate of rural roads on cultivated land	X37
Coverage rate of rural residential areas on cultivated land	X38
Coverage rate of urban agglomeration areas on cultivated land	X39
Contiguity degree of cultivated land	X40
Altitude of cultivated land	X41
Slope of cultivated land	X42
Restorable land types	X43
Grade of cultivated land	X44
Soil texture	X45
Soil depth	X46
Soil organic matter content	X47
Soil pH value	X48
Soil biodiversity	X49
Soil cropping system	X50
Soil texture - Loam	X51
Soil texture - Clay	X52
Soil texture - Sandy soil	X53

2.2. Data Processing

The non-grain production rate of cultivated land is employed to characterize the phenomenon of non-grain production of cultivated land in Sichuan Province. Using the cultivated land area in 2019 $C_{k,2019}$ as the base period, the non-grain production rate of cultivated land for a certain year is defined as the ratio of the non-grain production area of cultivated land in that year to the cultivated land area in 2019.

To ensure the accuracy and validity of subsequent analyses, this study conducted systematic preprocessing of the original data. First, missing data were imputed using

the nearest-neighbor method for variables such as rural electricity consumption and annual sunshine hours. Second, continuous variables were classified via equal-interval, quantile, and hierarchical clustering methods, with a comparative analysis of their respective strengths and weaknesses. Finally, given that cultivated land soil in Sichuan Province comprises three textures (loam, clay, and sand) forming a compositional dataset (summing to 100%), centered log-ratio transformation was applied to address multicollinearity among soil texture variables.

3. Establishment of the Models for Influencing Factors of Non-Grain Cultivation of Cultivated Land

3.1. Establishment of the Geodetector Model

The geodetector is a statistical method designed to explore spatial heterogeneity and uncover the underlying driving forces behind it. Its fundamental principle posits that if an independent variable exerts a significant influence on a dependent variable, their spatial distributions should exhibit a tendency towards consistency. In the context of our study, different administrative regions in Sichuan Province demonstrate varying rates of non-grain production of cultivated land, accompanied by corresponding disparities in economic levels, demographic factors, production conditions, and other relevant aspects across these regions. Given that both the independent and dependent variables possess distinct spatial distribution characteristics, the geodetector can be employed to identify the factors influencing the rate of non-grain production of cultivated land in Sichuan Province. The formulas for spatial stratified heterogeneity and factor detection within the geodetector framework are presented as follows:

$$q_{it} = 1 - \frac{\sum_{h_i=1}^{L_{it}} N_{h_i} \sigma_{h_i}^2}{N \sigma_t^2} \quad (1)$$

Where, q_{it} represents the explanatory power of the i -th factor X_i on the non-grain production rate of cultivated land Y_i in the t -th year, with a value range of $[0,1]$. A larger q_{it} indicates a stronger explanatory power of the i -th factor on the non-grain production rate of cultivated land in the t -th year. h_{it} denotes the classification of the i -th factor in the t -th year, which is divided into L_{it} categories. If the factor is a continuous variable, discretization processing is required. N represents the total number of samples in the entire region, with the same sample size for each year. N_{h_i} represents the number of samples corresponding to the h -th category of the i -th factor in the t -th year. σ_t denotes the variance of the non-grain production rate of cultivated land in the entire region in the t -th year, while σ_{h_i}

represents the variance of the non-grain production rate of cultivated land corresponding to the h -th category of the i -th factor in the t -th year.

3.2. Establishment of the Panel Model

Based on the available data, the non-grain production rates of cultivated land for different years and administrative regions can be obtained. Such data, which encompass both time-series and cross-sectional dimensions, are referred to as panel data. Taking per capita GDP, the gross output value of the primary industry, and the per capita added value of the private economy as independent variables, and the non-grain production rate of cultivated land as the dependent variable, the following panel model is proposed for construction:

$$y_{kt} = \beta_0 + \sum_{i=1}^r \beta_i x_{ikt} + \mu_k + \gamma_t + \varphi_{kt} \quad (2)$$

Where y_{kt} represents the non-grain production rate of cultivated land in the k -th administrative region in the t -th year; x_{ikt} denotes the value of the i -th factor in the k -th administrative region in the t -th year; β_0 is the intercept term, and β_i is the regression coefficient of x_{ikt} . In practice, the factors that we can control are limited, and there may also exist certain unobservable factors. μ_k represents the individual effect, which is an unobservable factor at the regional level; γ_t is the time effect, an unobservable factor at the temporal level; and φ_{kt} is the random disturbance term.

3.3. Establishment of the Generalized Linear Model

The Generalized Linear Model (GLM) represents an extension of traditional linear models, wherein the overall mean is dependent on the linear predictor through a non-linear link function. Consider the linear model as follows:

$$y_i = \beta_0 + \sum_{k=1}^r x_{ik} \beta_k + \varepsilon_i, i = 1, 2, \dots, n \quad (3)$$

Where, n denotes the number of samples, y_i represents the dependent variable for the i -th sample, X_{ik} is the k -th independent variable for the i -th sample, β_0 is the intercept term, β_k is the regression coefficient for the k -th independent variable, r is the number of independent variables, and ε_i denotes the random error.

The GLM is founded upon three fundamental definitions:

Definition 1: Let $\mu = E(y|X)$ denotes the conditional expectation of the dependent variable y

given the independent variables X . The linear predictor operator is defined as

$\eta = X'\beta$, and the function $g(\mu) = \eta = X'\beta$ is termed the link function.

Definition 2: Denote the estimated value of y as $h(X, \beta)$. The estimated value of y is the expected value of the conditional probability $\Pr(y|X, \beta)$, which can be expressed as $h(X, \beta) = E(y|X, \beta)$.

Definition 3: The conditional probability distribution of y belongs to a certain exponential family of distributions, that is the probability distribution of $\Pr(y|X)$ follows the following form:

$$\Pr(y|X, \beta) = b(y) \exp\{\eta'T(y) - a(\eta)\} \quad (4)$$

Where, $b(y)$ and $T(y)$ are functions of y , while $a(\eta)$ is a function of η . The forms of these three functions are unknown and represent an abstract way of expression. Generally, $T(y) = y$.

3.4. Establishment of the Geographically and Temporally Weighted Regression model

The Geographically and Temporally Weighted Regression (GTWR) model fully accounts for both temporal and spatial factors by integrating geographical spatial coordinates with time, thereby forming a three-dimensional spatiotemporal coordinate system (u_i, v_i, t_i) . The model's expression is as follows:

$$y_i = \beta_0(u_i, v_i, t_i) + \sum_{k=1}^r x_{ik} \beta_k(u_i, v_i, t_i) + \varepsilon_i \quad (5)$$

$$\varepsilon_i \sim N(0, \sigma^2), i = 1, 2, \dots, n$$

Where, n represents the number of sample points, and r denotes the number of independent variables. (u_i, v_i, t_i) represents the spatiotemporal coordinates of the i -th sample point y_i is the dependent variable for the i -th sample point, while x_{ik} is the k -th independent variable for the i -th sample point. $\beta_0(u_i, v_i, t_i)$ represents the intercept term. $\beta_k(u_i, v_i, t_i)$ is the regression coefficient for the k -th independent variable of the i -th sample point, and ε_i denotes the random error.

4. Solution of the models for influencing factors of non-grain cultivation of cultivated land

4.1. Solution of the Geodetector Model

Based on the principles of the geodetector, utilizing the three classification methods, we conducted nine separate

analyses by applying these methods to the data from 2020 to 2022 in sequence. Subsequently, we compared and organized the results obtained from different classification methods. If there is more than one classification method that results in a p-value less than 0.1 for a certain variable in a given year, then select the classification method with the largest q-value. Through this process, we identified the significant factor variables influencing the non-grain cultivation of cultivated land for each year and their explanatory power, which are presented in **Table 2**.

For different datasets, among the equal-interval method, quantile method, and systematic clustering method, the quantile method demonstrated the best classification performance. If a variable significantly affects the non-grain cultivation rate in a certain year, it is considered an influencing factor for the non-grain cultivation of cultivated land in Sichuan Province. When a variable significantly impacts the rate over multiple years, the set of results with the largest value is selected. Ultimately, the influencing factors for the non-grain cultivation land in Sichuan Province and their explanatory power are determined. According to **Table 2**, ranked by explanatory power, the factors are as follows: the Consumer Price Index for Urban Residents, the proportion of employees in the primary industry, as well as the amount of agricultural fertilizer applied and the degree of contiguous cultivated land patches.

Table 2. Table of annual solution results from geodetector

Year	Variable	Method	q-value	p-value	Rank
2020	X10	Equal interval 5 Quantile 4	0.477	0.091	4
	X11		0.553	0.014	1
	X32		0.516	0.073	3
	X37	Systematic clustering 3	0.548	0.053	2
	X41		0.351	0.032	6
	X49		0.430	0.095	5
2021	X8	Equal interval 5	0.775	0.092	1
	X28	Equal interval 3	0.541	0.097	2
	X40	Quantile 3	0.322	0.076	3
2022	X8	Quantile 3	0.312	0.082	8
	X20	Quantile 5	0.571	0.045	1
	X23	Equal interval 3	0.318	0.044	6
	X29	Quantile 5	0.569	0.047	2
	X31	Quantile 4	0.561	0.020	3
	X38	Quantile 4	0.463	0.060	4
	X39	Equal interval 4	0.369	0.076	5
	X40	Quantile 3	0.317	0.080	7
	X41	Systematic clustering 3	0.249	0.083	9

4.2. Solution of the Panel Model

The panel model explores the influencing factors of non-grain cultivation of cultivated land in Sichuan Province based on proportional data. To address the issues of a large number of variables and a small sample size, we progressively eliminated variables with weak correlations with the dependent variable or those that were statistically insignificant. Ultimately, we determined to use a time fixed-effects model for analysis, which yielded favorable fitting results. The findings obtained from this data and methodology are shown in **Table 3**.

Table 3. Optimal regression results from the time fixed-effects model

Variable	Regression Coefficient	t-value	p-value
X5	-0.297	-2.740	0.013
X20	-17.531	-7.820	0.000
X27	-0.952	-2.970	0.008
X32	-0.001	-5.960	0.000
X37	-0.208	-5.000	0.000
X40	1.784	2.840	0.010
X41	1.181	6.120	0.000
$Z_{\gamma 2021}$	-1.817	-4.240	0.000
$Z_{\gamma 2022}$	-1.891	-5.020	0.000
cons	45.635	3.780	0.001

In **Table 3**, $Z_{\gamma 2021}$ and $Z_{\gamma 2022}$ respectively represent the magnitudes of change in the time effects for the years 2021 and 2022 relative to 2020, while “cons” denotes the constant term (the time effect for the year 2020). As shown in **Table 3**, at a significance level of 0.05, the regression coefficients of all variables are statistically significant. The variables that have a significantly positive impact on the non-grain cultivation rate of cultivated land in Sichuan Province are X_{40} and X_{41} while the variables that have a significantly negative impact are X_5 , X_{20} , X_{27} , X_{32} and X_{37} .

4.3. Solution of the Generalized Linear Model

Based on the preliminary indicator system constructed according to **Table 1**, to avoid multicollinearity, variable selection was conducted by calculating correlation coefficients and the Variance Inflation Factor (VIF). The finally selected indicators are consumer price index for urban residents X_8 , grain consumer price index for urban residents X_9 , ratio of subsistence allowances per capita between urban and rural areas X_{13} , annual precipitation X_{31} , annual precipitation X_{36} , coverage rate of cultivated Land by Urban, Rural, and Village Roads, and soil thickness X_{46} .

The indicator variables used to establish the generalized linear model include X_8 , X_9 , X_{13} , X_{31} , X_{36} and X_{46} . The estimates of each indicator coefficient are presented in **Table 4**. The parameter estimation of the GLM reveals that Consumer Price Index for Urban Residents and annual precipitation have passed the significance test. This indicates that these two indicators—the Consumer Price Index for Urban Residents and annual precipitation have a significant impact on the non-grain cultivation rate in Sichuan Province. The influence of other indicator variables on the non-grain cultivation rate in Sichuan Province is relatively minor.

Table 4. Estimation of GLM

Variable	Coefficient	SE	Wald	P-value	95% CI	
					Lower	Upper
cons	-18.231	10.847	2.825	0.093*	39.492	3.029

X8	0.169	0.075	5.124	0.024**	0.023	0.316
X9	0.020	0.066	0.086	0.769	-0.111	0.150
X13	-0.557	0.557	1.002	0.317	-1.648	0.534
X31	0.001	0.000	6.819	0.009***	0.000	0.002
X36	-0.001	0.008	0.033	0.857	-0.017	0.014
X46	0.001	0.006	0.023	0.878	-0.012	0.014

4.4. Solution of the GTWR Model

Based on the preliminary indicator system constructed according to **Table 1**, to mitigate the impact of multicollinearity on the spatiotemporal geographically weighted regression model, further variable selection is necessary. By calculating the correlation coefficients between variables and the VIF, indicators with high correlation with the dependent variable and low VIF values are retained. The finally selected indicators include X_6 , X_8 , X_9 , X_{13} , X_{29} , X_{34} , X_{36} , X_{41} , X_{47} , X_{48} , X_{49} and X_{53} . Specifically referred to as local general public budget revenue, consumer price index for urban residents, grain consumer price index for urban residents, ratio of subsistence allowances per capita between urban and rural areas, proportion of cultivated land within the target of cultivated land protection, distance from the urban center, coverage rate of cultivated land by urban, rural, and village roads, elevation of cultivated land, soil organic matter content, soil pH value, soil biodiversity soil texture-sandy soil.

By employing the GTWR model, we analyzed the evolving impacts of 12 indicators on the non-grain cultivation rate across various regions in Sichuan Province. The significant influencing factors for each region are presented in the **Table 5**. There are 21 prefecture-level cities in Sichuan Province. If a certain factor has a significant impact on 11 or more prefecture-level cities, it is considered to be an influencing factor for the conversion of cultivated land to non-grain uses in Sichuan Province. The results in **Table 6** can be derived based on **Table 5**.

5. Analysis and Summary of the Solution Results for the Influencing Factors Model

The influencing factors obtained from the four models were collated (reference 错误!未找到引用源。 for variable symbols), and the results are shown in **Table 7**. In the analysis of multiple models, the consumer price index for urban residents, the proportion of cultivated land within cultivated land protection targets, the elevation of cultivated land, and soil biodiversity all demonstrated significant impacts in three or more models. Notably, the coefficient direction of the consumer price index for urban residents differed between the panel model and the generalized linear model. Considering that the generalized linear model’s treatment of panel data as cross-sectional data may lead to estimation bias, the results from the panel model were prioritized. Overall, the primary directions and magnitudes of influence on the conversion of cultivated land to non-grain uses in Sichuan Province are as follows: Positive influencing factors: annual

precipitation > soil biodiversity; Negative influencing factors: consumer price index for urban residents > proportion of cultivated land within cultivated land protection targets > elevation of cultivated land. Additionally, some factors have clear directional impacts but their magnitudes remain uncertain, including the coverage rate of cultivated land by urban, rural, and village roads (negative), soil texture-sandy soil (negative), and soil pH value (positive).

Table 5. Solution Results of the GTWR Model for Various Prefecture-Level Cities

City	Significant influencing factors
Chengdu	X6, X8, X9, X29, X34, X36, X41, X53, X47, X48, X49
	X8, X9, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X13, X34, X36, X41, X53, X47, X48
	X6, X8, X9, X29, X34, X36, X41, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Zigong	X6, X8, X9, X13, X29, X34, X36, X53, X47, X48, X49
Panzhihua	X6, X8, X9, X29, X36, X41, X53, X47, X48, X49
Luzhou	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Deyang	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Mianyang	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Guangyuan	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Suining	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Neijiang	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Leshan	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Nanchong	X6, X8, X9, X29, X34, X36, X41, X53, X47, X48, X49
Meishan	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Yibin	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Guang'an	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Dazhou	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Ya'an	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Bazhong	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Ziyang	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Aba Prefecture	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Ganzi Prefecture	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49
Liangshan Prefecture	X6, X8, X9, X13, X29, X34, X36, X41, X53, X47, X48, X49

Table 6. Solution Results of the GTWR Model

Significant variables	Indicator
X6	Local general public budget revenue
X8	Urban consumer price index
X9	Urban residents' grain consumption price index
X13	Ratio of per capita subsistence allowance funds between urban and rural areas
X29	Proportion of cultivated land within the target of cultivated land protection
X34	Distance from the city center
X36	Coverage rate of cultivated land by urban, rural, and village roads
X41	Altitude of cultivated land
X53	Soil texture - sandy soil
X46	Soil organic matter content
X48	Soil pH value
X49	Soil biodiversity

Table 7. Summary of solution results for the influencing factors model

Variable	Geodetector	Panel model	GLM	GTWR
X6				✓
X8	✓ (0.774)	✓ (-)	✓ (+)	✓
X9	✓ (0.477)			
X10	✓ (0.553)			
X11				✓
X13				
X19	✓ (0.571)			
X23	✓ (0.318)			
X28	✓ (0.541)			
X29	✓ (0.569)	✓ (-)		
X31	✓ (0.561)		✓ (+)	
X32	✓ (0.516)			
X34				✓
X36		✓ (-)		✓
X37	✓ (0.548)			
X38	✓ (0.463)			
X39	✓ (0.369)			
X40	✓ (0.322)			
X41	✓ (0.351)	✓ (-)		✓
X45		✓ (-)		✓
X47				✓
X48		✓ (+)		✓
X49	✓ (0.430)	✓ (+)		✓

6. Conclusion

Based on a comprehensive multi-model analysis, this study identifies key factors influencing the conversion of cultivated land to non-grain uses in Sichuan Province: the consumer price index for urban residents, the proportion of cultivated land within cultivated land protection targets, the elevation of cultivated land, and soil biodiversity. Among these, the consumer price index for urban residents, the proportion of cultivated land within protection targets, and the elevation of cultivated land exhibit significant negative impacts, while soil biodiversity demonstrates a significant positive influence, meaning it is conducive to promoting the cultivation of non-grain crops. Based on these research findings, the following policy recommendations are proposed: First, implement differentiated farmland protection measures: Set up a subsidy-price linkage in areas with notable price impacts. Second, guide industrial structure optimization: Develop eco-agriculture in biodiversity-rich zones and cold-resistant crops in high-altitude areas based on local conditions. Third, establish precise spatial management and control: Build a GIS monitoring system for classified regional management to strictly curb farmland's shift from grain to non-grain crops. Fourth, refine incentive and restraint mechanisms: Include farmland protection in local government assessments, offer targeted subsidies to farmers, and establish a fund for soil improvement and restoration.

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