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Article

Understanding Recessive Transition of Cultivated Land Use in Jilin Province, China (1990–2020): From Perspective of Productive-Living-Ecological Functions

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Abstract: Jilin Province is an important commercial grain production base in northeast China, and it has seen significant transition in cultivated land use in recent years. This study constructed a measurement system for the recessive transition of cultivated land use in Jilin Province based on the perspective of "three-function synergy" (productive, living, and ecological functions). It discussed the temporal and spatial evolution characteristics of the recessive transition of cultivated land use from 1990 to 2020, identified the turning point of the cultivated land transition trend, and built a model of recessive transition of cultivated land in Jilin Province. After analyzing the results, we came to the following conclusions: (1) The turning point of the "three-function synergy" of the recessive morphology of cultivated land in Jilin Province occurred earlier than the mutation point of the recessive transition of cultivated land, and there was a certain temporality in the recessive transition of cultivated land compared with the functional change of cultivated land; (2) the degree of recessive transition of cultivated land in Jilin Province showed a spatial distribution characteristic of being higher in the west and lower in the east; (3) the recessive transition of cultivated land use in Jilin Province could be divided into transition stages characterized by "low stage slow rise period", "middle stage significant increase period", and "high stage steady growth period"; (4) Jilin Province should adopt differentiated and diversified management of cultivated land to achieve a comprehensive management model that emphasizes quantity, quality, and ecology.

Keywords: cultivated land recessive transition; productive-living-ecological functions; transition mode; path selection; Jilin Province

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1. Introduction

With the intensification of land resource utilization, human research on land resources, especially the development and utilization of cultivated land resources, has become increasingly deep [1]. Land-use transition, as an important piece of content of land system science research, has become an important scientific frontier [2,3]. Land-use transition theory is a theoretical framework for studying land-use changes, emphasizing that, in different historical periods and different stages of socio-economic development, the patterns, structures, and methods of land use will undergo major changes, forming different stages of land-use transition [4,5]. Through research, Long Hualou proposed the theory of regional land-use transition patterns [6,7], which reveal the essence of regional land-use transitions. Long Hualou believes that land use morphology includes dominant morphology (whose change can cause explicit land-use transition) and recessive morphology (whose change can cause implicit land-use transition). Dominant morphologies are presented through the quantity and structure of land use, while recessive morphologies are special morphologies which rely on the dominant morphology, including the land use features in the aspects of quality, property rights, management mode, input, output, and function [8]. Regional land-use transition is actually a comprehensive manifestation of the dominant and recessive morphologies of different types of land use [9]. The transformation of land use types affects the morphology of land use and needs to be balanced through a land-use transition. Land-use transition is essentially a process of alleviating land type conflicts representing different sectoral interests by changing land use morphologies [10].

Cultivated land-use transition is derived from the theory of land-use transition, and it can be defined as the trend change or inflection of the morphology of cultivated land use (including dominant and recessive morphologies) in a long-time series in a certain region [11,12]. Consequently, cultivated land-use recessive transition is the change or inflection from one recessive morphology of cultivated land use to another over a period of time, driven by economic and social change, as well as innovation, in a certain region. Currently, there have been abundant research results on the transition of cultivated land use at home and abroad [9]. Based on different spatio-temporal scales and different research perspectives [13,14], combined with data analysis and field research, a variety of systematic studies have been conducted, and they obtained a large number of enlightening research conclusions and a rich method system. Most studies on the transition of cultivated land use start from the area, share, and spatial pattern changes of cultivated land [15], focusing on the transition process of the dominant morphology of cultivated land composed of the quantity structure and spatial pattern of cultivated land [16–18]. With the continuous enrichment of research content, research considering both the dominant and recessive morphologies of cultivated land have gradually increased. Most of them were analyses of the spatial differentiation laws of cultivated land-use transitions [19]. Some studies built frameworks and conducted evaluation analyses from the transition of regional cultivated land–function forms [20]. A small number of studies proposed the green transition of cultivated land use or analyzed the changes in the form of cultivated land while considering the background of regional urban and rural development stages [21–23]. From the perspective of research areas, most of the studies were mainly at the national, provincial city, or specific regional level, with the research units mostly being provinces, cities, and counties. A very small number of studies used administrative villages as research units for analysis and discussion [24]. The recessive morphology of cultivated land is difficult to quantify comprehensively and diversely, so current research on the systematic analysis and discussion of the direction and pattern of the transition, of the recessive morphology of cultivated land, is still relatively scarce. Current research focuses more on the analysis of the process and the driving mechanisms of the transition of the use of the recessive morphology, and there are still deficiencies in the theoretical framework and analytical methods of research on the recessive morphology of cultivated land.

There are currently two main views, in academia, on the definition of the transition morphology of cultivated land use: one is the dominant and recessive morphologies derived from Long Hualou's theory of regional land use transition patterns; the other is spatial form and functional form, where spatial form refers to the quantity and spatial structure of cultivated land, and functional form refers to the multifunctional expression of cultivated land use [25]. We believe that the function of cultivated land is one of the attributes of the recessive morphology. As the quality, output and management methods of cultivated land can change with the function of cultivated land, the recessive morphology of cultivated land should, therefore, be the multifunctional expression of cultivated land use.

The foundation of grain production lies in cultivated land, and the use of cultivated land is closely related to food security [26]. The "Opinions of the CPC Central Committee and the State Council on Doing a Good Job in Promoting Rural Revitalization in 2023" once again emphasized the importance of consolidating the foundation of food security, in all aspects, and strengthening the material basis of storing grain in the ground and in technology. As an important grain production area in China, the Northeast region shoulders the important mission of ensuring national food production safety [27]. Jilin Province is an important commodity grain production base in the Northeast region. In 2020, the total area of cultivated land in Jilin Province was 737.38 hectares, accounting for

39.38% of the total land area of Jilin Province. In recent years, Jilin Province has undergone a significant transition in cultivated land use, especially considering the conversion from dry land to paddy fields [28]. Therefore, in this study, Jilin Province, a typical region with a significant transition in cultivated land use and an important grain producing area, was selected as the study area.

Based on the perspective of productive, living, and ecological functions, we built a measurement system for the recessive transition of cultivated land use and the quantification of the recessive morphology of cultivated land. It accurately depicted the process characteristics of the recessive transition of cultivated land use from the perspective of temporal changes and spatial evolution. The conclusions of the study can provide a decision-making basis for local decision-makers to optimize the utilization and management of regional cultivated land in land resource management practice, as well as promote socio-economic transformation by taking advantage of land resources. The study will provide technical support for exploring the optimization and transformation of the utilization of cultivated land in Jilin Province, as well as building a "green-friendly" safe food production pattern by integrating the objectives of regional economic development, food production safety, and ecological environmental protection.

2. Materials and Methods

2.1. Study Area

Jilin Province is located in the central part of Northeast China (40°52′~46°18′ N, 121°38′~131°19′ E), adjacent to Liaoning Province, Inner Mongolia Autonomous Region, and Heilongjiang Province.

As an important commodity grain production base in the Northeast region, the province administers 8 prefecture-level cities and 1 autonomous prefecture, covering an area of about 187.4 thousand square kilometers. The terrain feature of Jilin Province is higher in the southeast and lower in the northwest (Figure 1); it has high temperatures and heavy rain in the summer, as well as cold and dry weather in the winter. There are many rivers within the province, but the distribution of water resources is uneven. The soil types are mainly dark brown soil and chernozem. Analyzing from the perspective of industrial structure, in 2019–2020, the added value of primary industry in Jilin Province was 26.568 billion yuan, a 20.64% increase; the added value of secondary industry was 19.14 billion yuan, a 4.63% increase; the added value of tertiary industry was 12.742 billion yuan, a 2.02% increase. The industrial structure shows the structure of "Primary-Secondary-Tertiary".

2.2. Data Source

The research takes Jilin Province as the research area and 47 counties in Jilin Province as the research units. Vector boundary data and land-use data are from the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) (https://www.resdc.cn (accessed on 15 April 2023)); socio-economic statistical data are from the Jilin Statistical Yearbook, Jilin Yearbook, China Urban Statistical Yearbook, China County Statistical Yearbook, and the statistical bulletins of national economic and social development of each county (district) from 1991 to 2021.

2.3. Construction of Indicator System

Based on the concept and connotation of the recessive transition of cultivated land use, the recessive morphological features of cultivated land use were characterized from the perspectives of productive, living, and ecological functions. Following the principles of systematicity, suitability, and feasibility—and considering the stability of indicators and the availability of data—combined with the features of cultivated land resources in Jilin Province and the opinions of experts in agriculture, land, geography, ecology, and other fields, the evaluation indicators system of cultivated land's recessive transition comprehensive index was constructed from multi-dimensional perspectives of production, life, and ecology. This included the production value of cultivated land, the level of agricultural contribution, economic carrying capacity, food security function, ecological security importance, and landscape value [29].

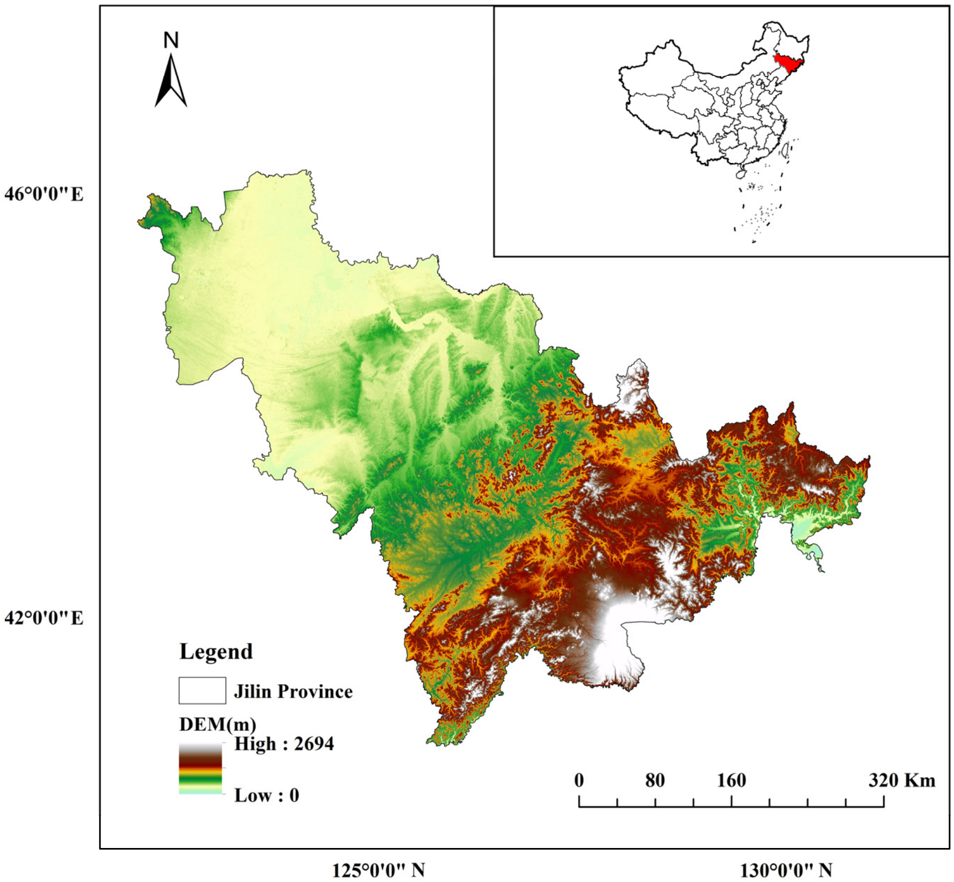

Figure 1. Location of the study area.

The extremal difference method was used to standardize the data [30,31]. The formulas are as follows:

When the character of the indicator is "+":

$$Y_{Aj} = \frac{X_{Aj} - min(X_{Aj})}{max(X_{Aj}) - min(X_{Aj})} \tag{1}$$

When the character of the indicator is "−":

$$Y_{Aj} = \frac{max(X_{Aj}) - X_{Aj}}{max(X_{Aj}) - min(X_{Aj})} \tag{2}$$

where A represents a county (district), A = 1, 2, ..., m; j represents an indicator, j = 1, 2, ..., n; Y_{Aj} is the standardized indicator value.

The overall entropy method, the CRITIC method, and AHP (the Analytic Hierarchy Process) were used, in combination, to determine the weights of the indicators [32,33].

The overall entropy weight method can effectively avoid the interference of human factors in the subjective weighting method, and it can avoid the processing defects in the general entropy method. The formulas are as follows:

$$P_{Aj} = \frac{Y_{Aj}}{\sum_{A=1}^{m} Y_{Aj}} \tag{3}$$

$$E_j = -[ln(m)]^{-1} \times \sum_{A=1}^{m} [P_{Aj} \times \ln(P_{Aj})] \tag{4}$$

$$W_{1j} = \frac{1 - E_j}{\sum_{j=1}^{n} 1 - E_j} \quad (5)$$

where P_{Aj} is the weight of the indicator value for the j indicator of the A county (district); E_j represents the entropy value of the j indicator; W_{1j} is the weight of the j indicator calculated by the overall entropy method.

The CRITIC method can handle the contrast intensity and conflict relationship between indicators simultaneously, thus reducing the influence of strong collinearity on the results. The formulas are as follows:

$$V_j = \sigma_j / \overline{y}_j \quad (6)$$

$$R_j = \sum_{i=1}^{m} (1 - r_{ij}) \quad (7)$$

$$C_j = V_j \times R_j \quad (8)$$

$$W_{2j} = \frac{C_j}{\sum_{j=1}^{m} C_j} \quad (9)$$

$$W_j = \frac{W_{1j} + W_{2j}}{2} \quad (10)$$

where V_j is the coefficient of variation of the j indicator; σ_j is the standard deviation of the j indicator; $\overline{y}_j$ is the mean of the j indicator. r_{ij} is the correlation coefficient between evaluation indicators i and j; R_j denotes indicator conflictivity; C_j is the information content of indicator j; W_{2j} is the weight of the j indicator calculated by the CRITIC method; W_j represents the objective weight of the j indicator.

Combining the characteristics of Jilin Province and expert opinions, we used the AHP method to determine the subjective weights and pass the consistency test. We used the average of the objective and subjective weights as the combined weights. The indicators, the combined weights, and the meanings are shown in Table 1.

Table 1. Jilin Province cultivated land-use recessive morphology evaluation indicators system.

Criterion Layer	Weights	Indicator Layer	Weights	Indicator Interpretation	Unit	Character
Productive Function	0.4268	Grain output rate	0.1151	Grain yield/Grain-sown area, reflects the grain production capacity of cultivated land	kg/hm^2	+
		Average agricultural output value of cultivated land	0.1452	Total agricultural output value/Cultivated land area, reflects the production value of cultivated land	$yuan/hm^2$	+
		Power of agricultural machinery on average cultivated land	0.1065	Total power of agricultural machinery/Cultivated land area, reflects the mechanization level of cultivated land	kW/hm^2	+
		Contribution of cultivated land to agriculture	0.0600	Total agricultural output value/Total output value of agriculture, forestry, animal husbandry, and fishery, reflects the contribution of cultivated land to agriculture	%	+

Table 1. *Cont.*

Criterion Layer	Weights	Indicator Layer	Weights	Indicator Interpretation	Unit	Character
Living Function	0.3165	Grain guarantee rate	0.0855	Grain yield/Total population, reflects food security function of cultivated land	kg/person	+
		Cultivated land carrying labor capacity	0.0764	Cultivated land area/Number of rural agricultural labor force, reflects degree of employment security for cultivated land	hm^2/person	+
		Guarantee rate of agricultural output value	0.0746	Total agricultural output value/Agricultural population, reflects economic carrying capacity of cultivated land	yuan/person	+
		Ability of agricultural machinery to replace labor force	0.0801	Total power of agricultural machinery/Number of rural agricultural labor force, reflects ability to optimize farming methods	kW/person	+
Ecological Function	0.2567	Average fertilizer application amount on cultivated land	0.0656	Fertilizer application amount/Cultivated land area, reflects ecological carrying capacity of cultivated land	kg/hm^2	−
		Proportion of cultivated land landscape area	0.1026	Cultivated/Total land area, reflects importance of ensuring ecological security of cultivated land	%	+
		Cultivated land Ecosystem diversity index	0.0569	-∑ blnb, b is the ratio of planting area to crop area for each variety of crops, reflects cultivated land ecosystem restoration capacity	/	+
		Fragmentation of cultivated land landscape	0.0316	[(Road mileage + Railway mileage)/Total land area] × correction factor correction factor is the power of e (cultivated land area/total land area), reflects landscape level of cultivated land	/	−

"+" indicates that the indicator is positive for the cultivated land recessive transition; "−" indicates that the indicator is negative.

2.4. Mutation Point Identification

To identify the trend characteristics of the transition of cultivated land use in Jilin Province, the multidimensional time series mutation point detection and segmented linear regression method were used to identify the mutation points of the recessive transition of cultivated land use in Jilin Province: high-value area, medium-value area, and low-value area. By use of the R segmented package, the segmented linear regression method was used to fit the scatter plot of the sequence and calculate the trend turning point. The mutation point is significant if p value < 0.05 through the F-statistic test [34,35].

2.5. Spatial Aggregation Analysis

Global spatial autocorrelation and local spatial autocorrelation analyses were used to reveal the spatial correlation landscape and spatial aggregation characteristics between counties in Jilin Province [36]. The value range of Global–Moran's I is [−1,1]. If the value > 0, it indicates spatial positive correlation. If the value < 0, it is spatially negatively correlated. If the value is close to 0, there is no spatial aggregation feature, and it is randomly distributed. After confirming the existence of clustering characteristics in the space, we conducted a local spatial autocorrelation analysis. More specifically, we used the

Local Spatial Association Index (LISA) to describe and visualize the spatial distribution, and we discovered the spatial correlation pattern of the recessive transition comprehensive index of cultivated land.

2.6. Coupling Coordination Analysis

Coupling degree is used to describe the dynamic association relationship of coordinated development between two or more systems, and it can reflect the degree of mutual dependence and restraint between systems [37]. This study used the coupling degree to quantify the coupling relationship of mutual game and cooperation among the "three-function synergy" of cultivated land (Table 2) [38]. Coordination degree refers to the magnitude of the benign coupling in the coupling interaction relationship, thus characterizing the quality of the coordination status. Referring to related research results and considering the actual use of cultivated land in Jilin Province, a coupling coordination model of productive–living–ecological functions of recessive morphology of cultivated land use was constructed, and types were classified (Table 3) [39].

Table 2. Coupling degree type division.

Coupling Degree	Coupling Degree Type	Interpretation
C ∈ [0.0, 0.3)	Low-level coupling stage	There is a mutual game among the "three-function synergy" of cultivated land, when C = 0, the "three-function synergy" in an unrelated state and developing towards disorder.
C ∈ [0.3, 0.6)	Antagonistic stage	The interaction among the three-function synergy of cultivated land is strengthened, resulting in the emergence of advantageous functions and the weakening of other functions.
C ∈ [0.6, 0.8)	Running-in stage	The three-function synergy of cultivated land have begun to cooperate with each other, showing a benign coupling trend.
C ∈ [0.8, 1.0]	High-level coupling stage	The benign coupling among the three-function synergy of cultivated land is strengthened and developing in an orderly direction, when C = 1.0, the three-function synergy achieves benign resonance coupling and tends towards a new ordered structure.

Table 3. Coordination degree type division.

Coordination Degree	Coordination Degree Type	Interpretation
D ∈ [0.0, 0.2]	Severe incoordination	There is an overdeveloped function that inhibits the development of other functions.
D ∈ (0.2, 0.4]	Moderate incoordination	There are dominant functions, and other functions are limited in their performance.
D ∈ (0.4, 0.5]	Basic coordination	The development of advantageous functions is slowing down, while other functions are gradually developing.
D ∈ (0.5, 0.8]	Moderate coordination	The development of the three-function synergy of cultivated land is basically balanced and synchronized.
D ∈ (0.8, 1.0]	High coordination	The development of the three-function synergy of cultivated land is coordinated and mutually promoted.

Based on the reference to the relevant research results and combining with the actuality of this study, the coupling coordination degree measurement model is constructed, and the specific calculation formula is as follows [40]:

$$C = 3 \times \left[\frac{U_1 \times U_2 \times U_3}{(U_1 + U_2 + U_3)^3} \right]^3 \quad (11)$$

$$T = \alpha \cdot U_1 + \beta \cdot U_2 + \gamma \cdot U_3 \quad (12)$$

$$D = \sqrt{C \times T} \quad (13)$$

where U_1, U_2, and U_3 represent the productive index, living index, and ecological index, respectively; C represents the coupling degree between the productive–living–ecological functions; T represents the comprehensive evaluation index; α, β, and γ are undetermined coefficients, satisfying $\alpha + \beta + \gamma = 1$. In this article, combining the results of related research and the characteristics of Jilin Province [38], $\alpha = \beta = 0.35$, $\gamma = 0.30$. D represents the coupling degree between the productive–living–ecological functions.

3. Results

3.1. Calculation of the Cultivated Land Recessive Transition Comprehensive Index

3.1.1. Cultivated Land Recessive Transition Comprehensive Index

According to the evaluation indicators and weights of the recessive morphology of cultivated land use, the cultivated land recessive transition comprehensive index of each county in Jilin Province (47 units), from 1990 to 2020, was obtained.

In order to characterize the change characteristics of the recessive morphology of cultivated land use in Jilin Province over the past 31 years (the term "Jilin Province" represents the average level of Jilin Province) and the differences in the intensity of the recessive transition of cultivated land use between counties, we first ranked the comprehensive indices of all counties, from largest to smallest, for each year from 1990 to 2020. Then, we assigned scores to each county based on the ranking. The county with the largest comprehensive index was assigned the highest score of 47, and the county with the smallest comprehensive index was assigned the lowest score of 1. The total score for each county is obtained by adding up the scores assigned to each county for each year from 1990 to 2020. The numerical magnitude of the total score determined the comprehensive ranking (Table 4).

Table 4. Cultivated land recessive transition comprehensive indices and rankings in Jilin Province.

Unit	1990		2020		Comprehensive Ranking	Unit	1990		2020		Comprehensive Ranking
	Index	Ranking	Index	Ranking			Index	Ranking	Index	Ranking	
Yushu	0.3033	1	0.3509	15	7	Meihekou	0.2241	25	0.2832	32	35
Fuyu	0.2998	2	0.3882	5	2	Ji'an	0.2139	26	0.2886	28	28
Dehui	0.2891	3	0.3049	23	9	Longjing	0.2068	27	0.249	44	36
Gongzhuling	0.2826	4	0.3762	10	1	Huinan	0.2059	28	0.2966	26	23
Nong'an	0.272	5	0.3325	17	4	Liuhe	0.2052	29	0.269	38	32
Lishu	0.2689	6	0.3707	11	8	Shulan	0.2036	30	0.279	34	24
Changling	0.2569	7	0.426	3	5	Dunhua	0.2018	31	0.2773	35	31
Qian'an	0.2555	8	0.3787	9	11	Jingyu	0.1993	32	0.2746	37	41
Siping	0.2553	9	0.3063	22	14	Huadian	0.1957	33	0.2807	33	30
Songyuan	0.2527	10	0.3811	8	10	Yongji	0.1937	34	0.2343	45	39
Shuangliao	0.2523	11	0.362	13	13	Fusong	0.1928	35	0.3842	7	19
Dongliao	0.2505	12	0.286	31	21	Tonghua	0.189	36	0.2608	40	43
Yitong	0.2473	13	0.2978	24	17	Jiaohe	0.1877	37	0.2615	39	38
Baicheng	0.2438	14	0.4971	2	6	Panshi	0.1875	38	0.2547	43	37
Changchun	0.2415	15	0.2876	29	29	Linjiang	0.1869	39	0.2921	27	26
Dongfeng	0.2414	16	0.3258	18	18	Baishan	0.1812	40	0.3151	19	27
Zhenlai	0.2373	17	0.3921	4	12	Antu	0.1807	41	0.2968	25	44
Liaoyuan	0.2363	18	0.2039	47	40	Wangqing	0.1784	42	0.287	30	45
Da'an	0.2353	19	0.333	16	20	Helong	0.1779	43	0.3077	21	46
Qian Gorlos	0.2316	20	0.5295	1	3	Tumeny	0.1776	44	0.234	46	47
Changbai	0.2314	21	0.3853	6	16	Hunchun	0.1746	45	0.3635	12	33
Taonan	0.229	22	0.3565	14	15	Yanji	0.1727	46	0.2585	41	42
Jilin	0.2289	23	0.2548	42	25	Tonghua	0.1678	47	0.2751	36	34
Tongyu	0.2268	24	0.3117	20	23						

3.1.2. Partition of Cultivated Land Use Recessive Transition

Based on the total score mentioned above, using the natural breakpoint method in the ArcGIS 10.7 platform, Jilin Province was divided into high-value, medium-value, and low-value areas.

As can be seen from Figure 2, the high-value area of recessive cultivated land-use transition includes 15 county units, such as Gongzhuling City and Fuyu City, which are mainly distributed in the plain area in the Central and Western part of Jilin Province; the medium-value area includes Huinan County, Shulan City, etc., as well as 14 county units, which are mainly distributed in the Central and Southern parts of Jilin Province, with a small distribution in the west of Jilin Province; the low-value area includes 18 county units that are mainly distributed in the Eastern part of Jilin Province, such as Huadian City and Dunhua City.

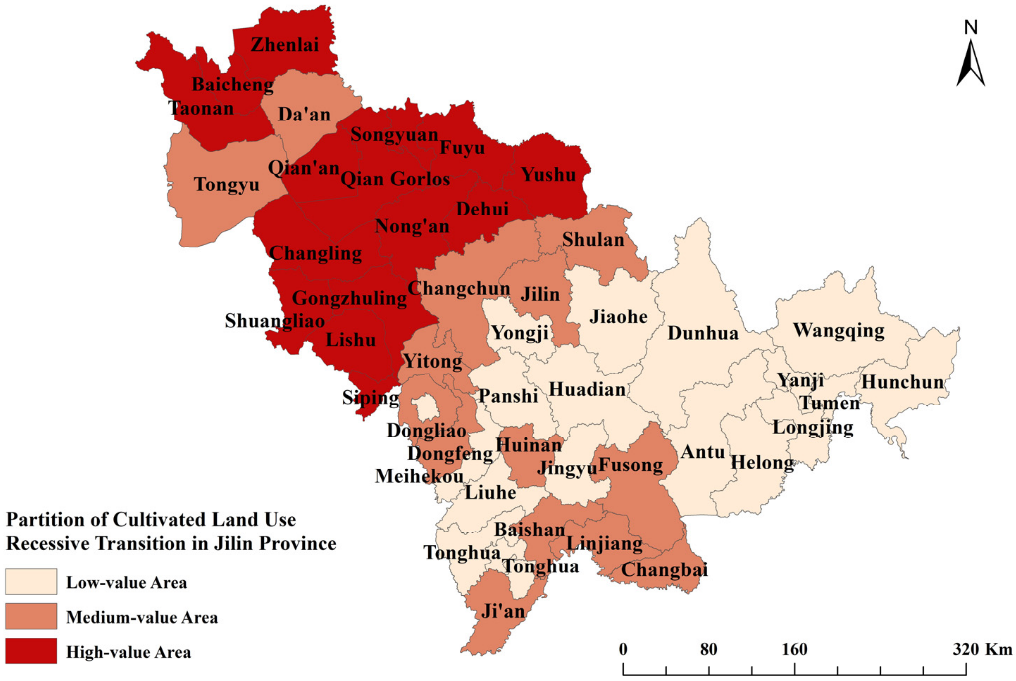

Figure 2. Partition of cultivated land use recessive transition in Jilin Province.

3.2. Temporal Changes in Recessive Cultivated Land Use Transition in Jilin Province

3.2.1. Temporal Features of Recessive Transition of Cultivated Land

We used the average of cultivated land recessive transition comprehensive indices, of all counties (districts) in an area, to represent the comprehensive index value of this area. Therefore, we obtained the cultivated land recessive transition comprehensive index of high-value, medium-value, and low-value areas from 1990 to 2020. The recessive morphology of cultivated land use in Jilin Province showed a general trend of slight fluctuations and steady increases from 1990 to 2020 (Figure 3); the cultivated land recessive transition comprehensive index in the high-value area always remained at the highest level. The fluctuation trend of the cultivated land recessive transition comprehensive index in the medium-value area was relatively close to the provincial average. The comprehensive index value in the medium-value area fluctuated slightly around the provincial average before 2000, and it has always been below the provincial average since 2001; the cultivated land recessive transition comprehensive index in the low-value area has always been at a lower level.

As shown in Table 5, the mean values of Jilin Province—high-value area, medium-value area, and low-value area—were all greater than the median, indicating that, during 1990–2020, there was a certain number of large values in these four types of regions that raised the average level of the cultivated land recessive transition comprehensive index, thus resulting in a mean value greater than the median. Looking at the year when the median appears, Jilin Province appeared in 2005, in the middle of the 31 years, indicating that the overall recessive transition of cultivated land in Jilin Province was relatively stable, and the rate of change was relatively slow. The high-value area had the largest coefficient of variation, indicating that the degree of fluctuation and change in the recessive morphology of cultivated land use, in the high-value area, was relatively large during the 1990–2020 period. In addition, the difference between the maximum and minimum values of the cultivated land recessive transition comprehensive index in the high-value area was the largest, indicating that the recessive transition of cultivated land use in the high-value area was the most significant. Although there are fluctuations, the cultivated land recessive transition comprehensive index in the high-value area always remained at the highest level of transition, indicating that the basis for the recessive transition of cultivated land use in the high-value area was relatively good, and as time goes by, the intensity of transition always remained dominant.

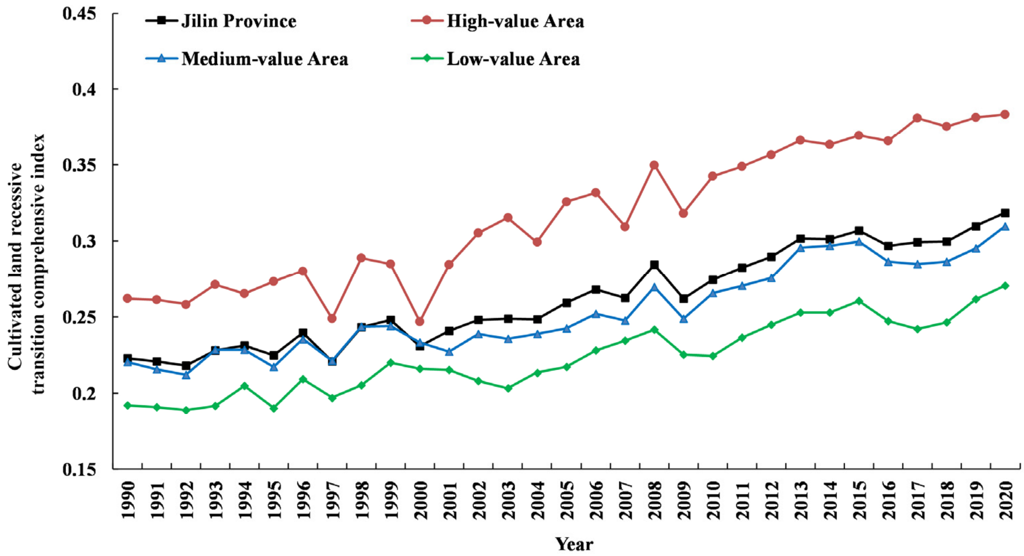

Figure 3. The change of the cultivated land recessive transition comprehensive index in Jilin Province.

Table 5. Basic statistical indicators of cultivated land recessive transition comprehensive index in Jilin Province from 1990 to 2020.

Partition	Jilin Province	High-Value Area	Medium-Value Area	Low-Value Area
Maximum	0.3183	0.3835	0.3098	0.2706
Minimum	0.2180	0.2467	0.2122	0.1889
Average	0.2623	0.3166	0.2538	0.2236
Median	0.2594	0.3154	0.2441	0.2200
Coefficient of Variation	11.84%	14.01%	11.29%	10.53%

3.2.2. Trend Shift Characteristics of Cultivated Land Use Recessive Transition

The mutation points of the recessive transition of cultivated land use in Jilin Province were obtained through multi-dimensional time series mutation point detection and segmented linear regression, as shown in the figure (Figure 4).

The recessive transition of cultivated land use in Jilin Province took two trend turns in 2003 and 2014. The positive and negative values of k represent the fluctuation of the cultivated land recessive transition comprehensive index. The larger the value of k, the greater the degree of recessive transition of cultivated land use in the corresponding period. For example, when $k_1 = 0.0021$, it indicates that the cultivated land recessive transition comprehensive index in Jilin Province increased by 0.0021, each year, from 1990 to 2003. Therefore, the transition of cultivated land use in Jilin Province was divided into the first stage of 1990–2003—the "low stage slow rise period", the second stage of 2004–2013—the "middle stage significant increase period", and the third stage of 2014–2020—the "high stage steady growth period".

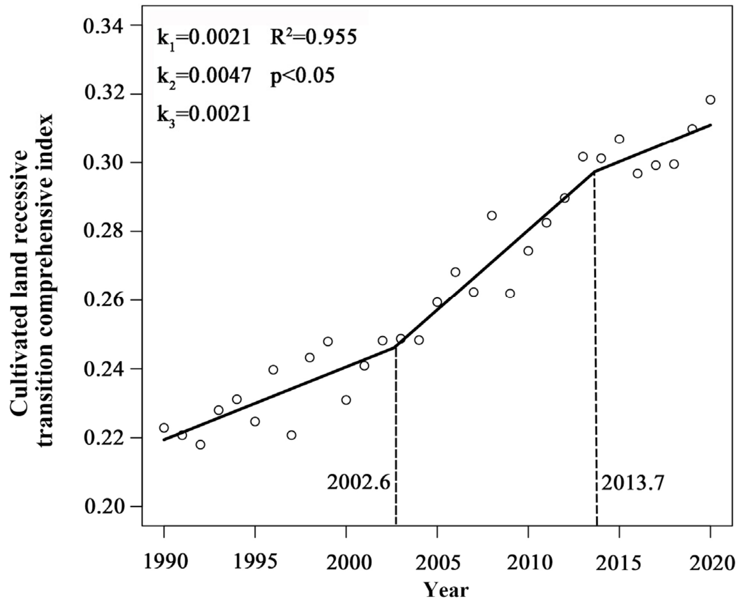

Figure 4. The change of cultivated land recessive transition comprehensive index in Jilin Province.

3.2.3. Three-Function Synergy Evolution of Cultivated Land Use Recessive Transition

From the time-series characteristics in the "three-function synergy" index scores of the recessive morphology of cultivated land use in Jilin Province from 1990 to 2020, the ranking of the index scores of the productive–living–ecological functions is: ecological index > productive index > living index. As can be seen from Figure 5, the productive and living functions of the recessive morphology of cultivated land in Jilin Province showed a fluctuating upward trend, while the ecological function was slowly declining. This suggested that the positive development of the recessive morphology of cultivated land in Jilin Province was likely achieved, at the expense of the ecological environment, to improve the levels of living and productive functions. The continuous improvement of the economic and social benefits in Jilin Province was very likely to be conditioned on the sacrifice of some ecological benefits.

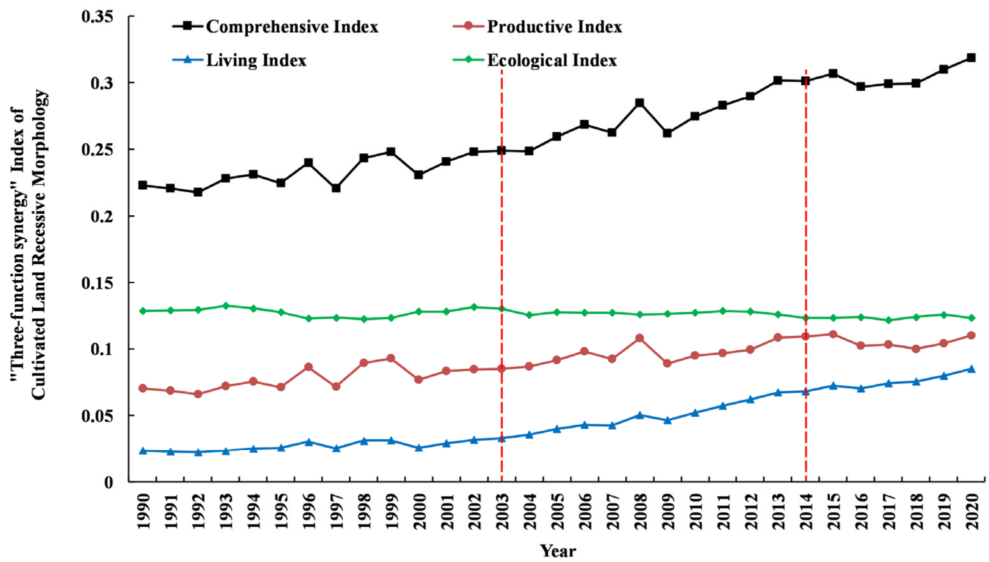

Figure 5. The "three-function synergy" index of cultivated land recessive morphology in Jilin Province.

We use the coupling coordination model to analyze what kind of relationship exists among the productive, living, and ecological functions of the recessive morphology of cultivated land in Jilin Province and whether they are closely related to each other or not. From

1990 to 2020, the coupling degree and coordination degree of productive–living–ecological functions overall showed a fluctuating upward trend, and they basically fluctuated between 1996–2000 and 2007–2009. This may suggest that certain policy, economic, or environmental events during these periods had significant impacts on the transition and coordination of the "three-function synergy" of cultivated land in Jilin Province.

The coupling degree of productive–living–ecological functions' recessive morphology of cultivated land use in Jilin Province consistently escalated, indicating an increasingly intimate "three-function synergy" and reaching the high-level coupling stage (Figure 6). The coordination degree of productive–living–ecological functions showed a fluctuating upward trend, but overall coordination remained low. During the period of 1990–2020, the recessive morphology of cultivated land use in Jilin Province, the "three-function synergy", was at a level of moderate incoordination.

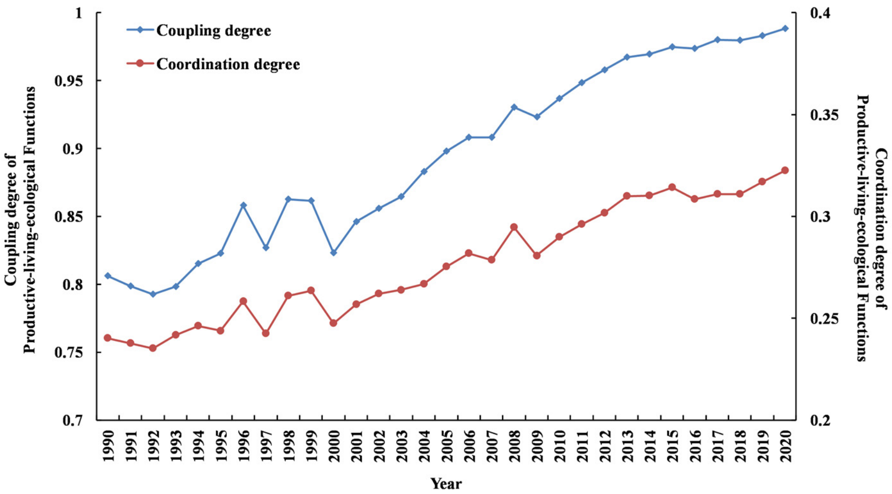

Figure 6. Coupling degree and coordination degree change of productive–living–ecological functions.

It has been shown that the income of rural residents in Jilin Province is significantly dependent on agricultural production [41]. When the productive function of cultivated land is hindered to improve, the income of rural residents will be restricted. Recent increased fertilizer use, while improving productive function, has escalated ecological pressures, impacting the regional environment [42]. Over three decades, Jilin Province's cultivated land area rose significantly, sourced primarily from forests, grasslands, and unused land development. Expansion improved food security and employment, enhancing the living function of cultivated land. Conversely, it led to reduced ecological space, expedited land desertification and soil degradation, disrupted ecosystem services, and weakened ecological function.

Additionally, the prevalent use of dry land has transitioned to paddy fields due to market and policy influences, causing an internal structure change in cultivated land [28]. Limited water resources and spatial mismatch between cultivated land and water resources resulted in the localized overloading of production capacity, adversely affecting ecological function [43,44].

The intensity of the interactions between the productive, living, and ecological functions of the recessive morphology of cultivated land was constantly changing, and the functions played by the cultivated land were also changed, resulting in the recessive morphology of cultivated land and presenting a temporal evolutionary feature, so there was a time lag in the changes in the recessive transition of cultivated land use compared to changes in the functions of cultivated land.

The challenge lies in improving the productive function of cultivated land, without weakening its ecological function, while also enhancing its living function. Jilin Province must adopt sustainable farming practices that reduce over-reliance on chemical fertilizers, protect water sources, restore ecology, maintain biodiversity, and diversify rural incomes to ensure that agricultural landscapes continue to thrive and benefit human livelihoods and regional ecological well-being.

3.3. Spatial Evolution of Recessive Transition of Cultivated Land Use in Jilin Province

3.3.1. Characteristics of the Trend Surface of Cultivated Land Use Recessive Transition

Trend surface analysis involves projecting the sampling point Z as a scatterplot onto the XZ and YZ planes and, then, making a spatial trend fitting line, simulating Z by polynomial fitting, based on the scatterplot on the projected plane [45]. In our study, the X-axis denotes the east–west direction, the Y-axis denotes the north–south direction, and the Z-axis denotes the cultivated land recessive transition comprehensive index.

Using the results of the trend surface analysis, we could three-dimensionally display the change rules of the cultivated land recessive transition comprehensive index in Jilin Province in the east–west and north–south directions (Figure 7). The green line on the figure indicates the distribution characteristics of the cultivated land recessive transition comprehensive index of Jilin Province in the east–west direction, and the blue line indicates the index in the north–south direction. It could be seen that, from 1990 to 2020, the recessive morphology of cultivated land use in Jilin Province generally presented a spatial pattern of "high in the west and low in the east", "high in the north and low in the south", and "depression in the middle". The change trend in the east–west direction was relatively gentle, while the north–south direction showed a significant trend of middle depression.

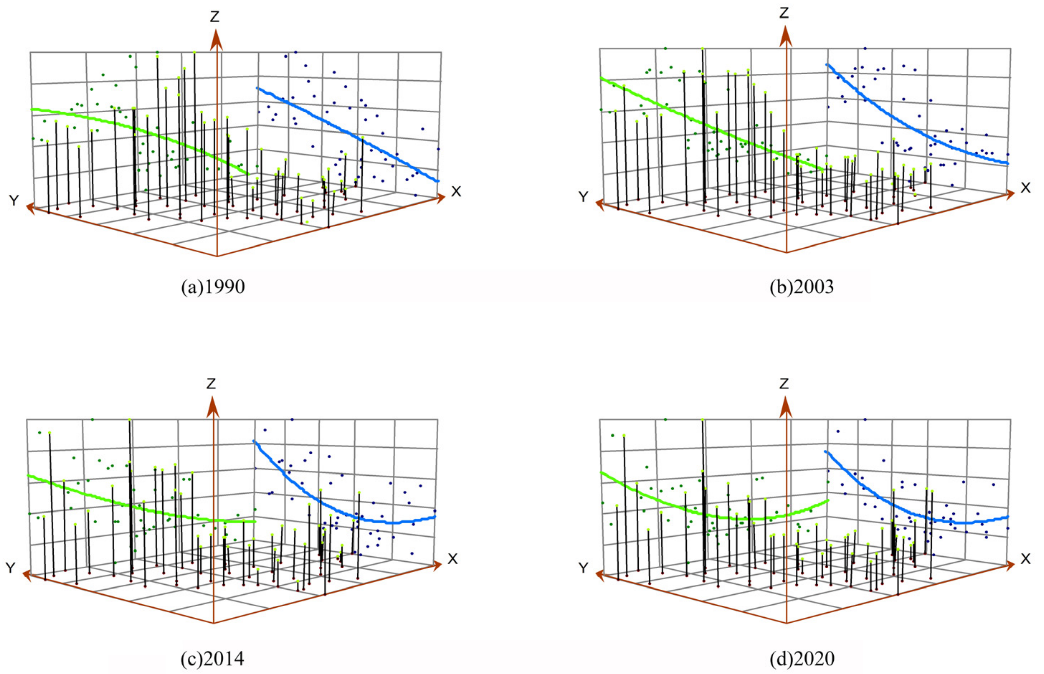

Figure 7. Trend analysis chart of the cultivated land recessive transition comprehensive index in Jilin Province.

3.3.2. Changes in the Spatial Pattern of Recessive Transition of Cultivated Land Use

As can be seen from Figure 8, the cultivated land recessive transition comprehensive index in the study area showed the spatial characteristics of high in the west and low in the east. All 47 county units in Jilin Province experienced a recessive transition of cultivated land from 1990 to 2020, and the spatial distribution characteristics of the cultivated land recessive transition comprehensive indices in Jilin Province, for each cross-sectional year, were basically consistent with the high, medium, and low-value areas defined earlier.

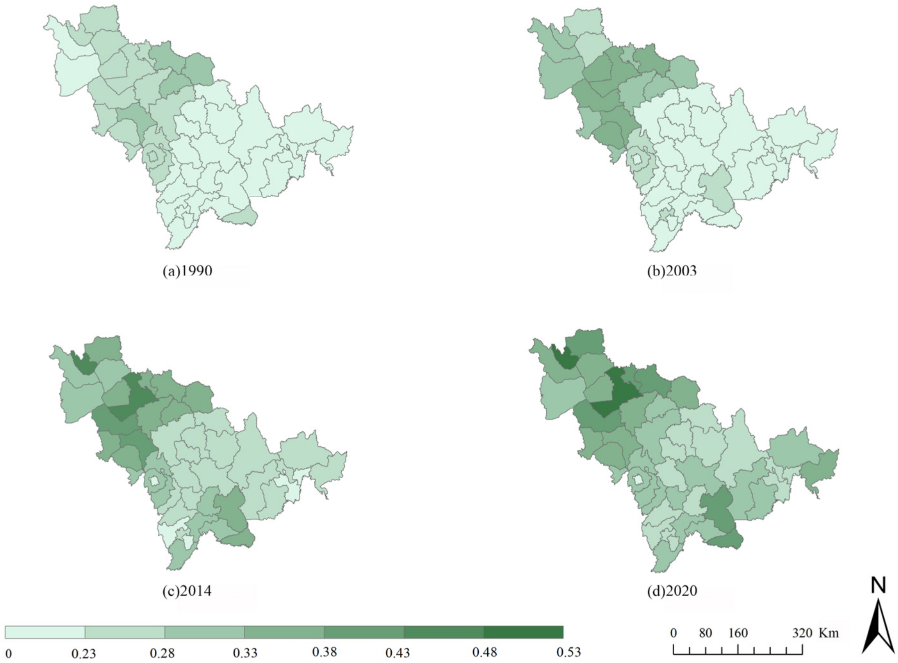

Figure 8. Spatial variation of the cultivated land recessive transition comprehensive index in Jilin Province.

Regions with a larger transition magnitude were mainly distributed in the Central and Western parts of Jilin Province, which roughly correspond to the high-value area of recessive transition of cultivated land use. The counties in the high-value area had flat terrain, strong cultivated land power, abundant water resources, high grain yield, and agricultural output value; they also had a significant advantage in economic development. Therefore, the recessive transition of cultivated land in the high-value area was more significant (see Supporting Information S1).

The county areas with moderate transition magnitudes were mainly distributed around the high-value area, and a small number were distributed in the Southern part of Jilin Province, basically corresponding to the distribution of the medium-value area. Among them, counties and cities, such as Shulan City, also contained high-grade cultivated land power and relatively abundant hydrological conditions that were conducive to agricultural production [46]; Tongyu County and Da'an City had stronger labor force carrying capacities of cultivated land and lower fragmentations of the cultivated land landscape, which were conducive to scale benefits [28,47]. Counties such as Huinan County and Fusong County had higher average agricultural output values of cultivated land, higher agricultural contributions of cultivated land, the higher ability of agricultural machinery to replace labor, and higher diversity indices of the cultivated land ecosystem [42,48]. Therefore, a relatively significant recessive transition of cultivated land use has also occurred in the medium-value area.

The county areas with smaller transition magnitudes roughly corresponded to the low-value area defined earlier. These areas had relatively less cultivated land, poor quality of cultivated land, and more severe fragmentation of the cultivated land landscape, which severely restricted the productive function of cultivated land. Although the overall level of recessive morphology of cultivated land use was relatively low and the degree of recessive transition of cultivated land use was relatively weak, the Eastern part of Jilin, where the low-value area of cultivated land use transition was located, had superior ecological conditions, rich biodiversity, and strong recovery capacity of the cultivated land ecosystem [49].

From the spatial distribution of the "three-function synergy" coupling degree and coordination degree, in 1990, the coupling of recessive morphology of cultivated land in most counties and districts of Jilin Province was in the running-in stage (Figure 9). With the continuous improvement of agriculture-related policies and agricultural production conditions [43], by 2020, the whole area of Jilin Province had basically entered the high-level coupling stage. The spatial distribution of the coupling degree is generally characterized by being high in the west and low in the east. Despite the high degree of coupling of productive–living–ecological functions, the degree of coordination between them was consistently low. The "three-function synergy" evolved from severe incoordination to basic coordination in some counties, following a similar spatial distribution and expansion pattern from central-west to northwest and southeast.

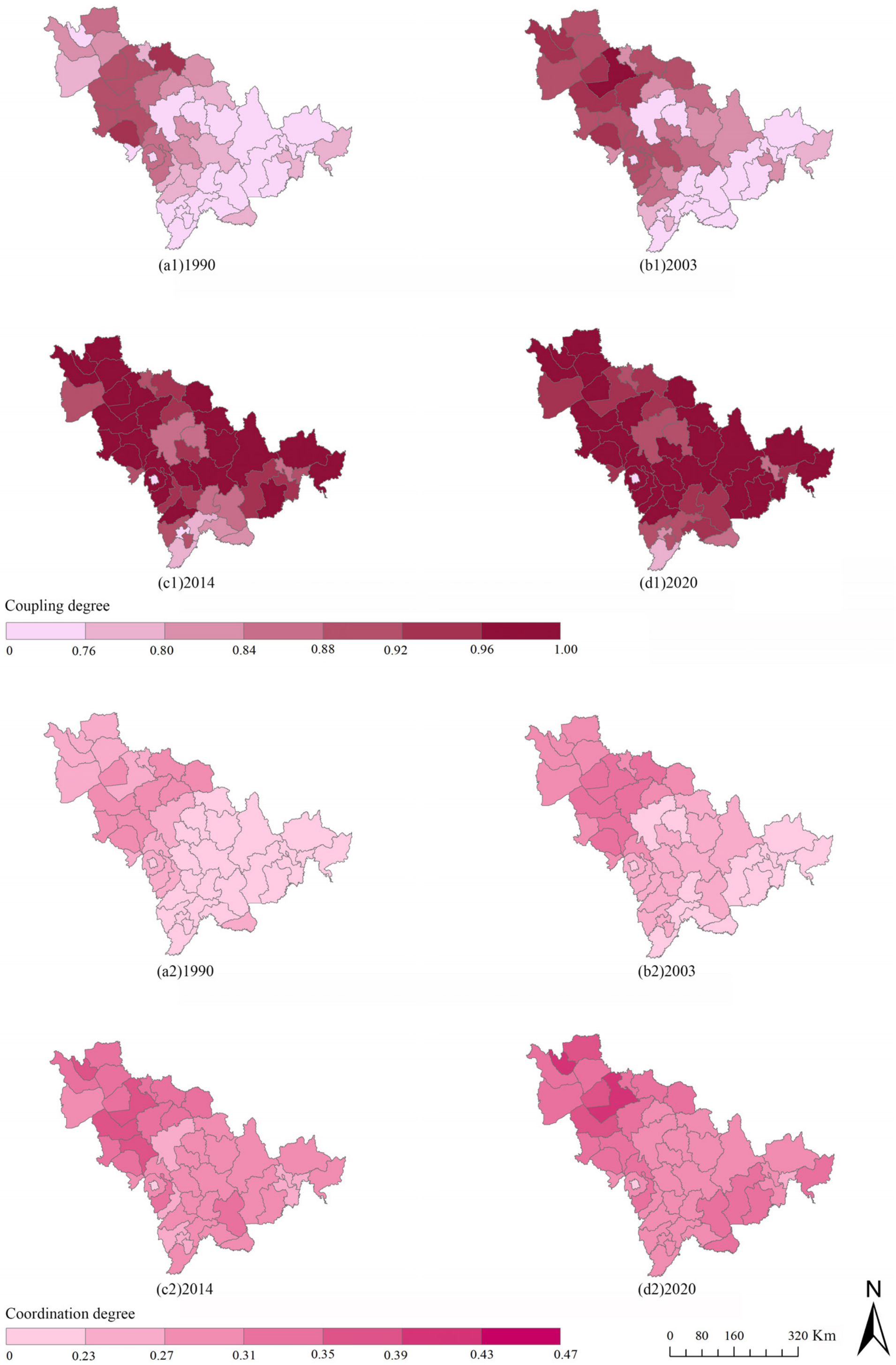

Figure 9. Spatial distribution of the "three-function synergy" coupling degree and coordination degree.

Comparing the degree of coupling and coordination in these 4 years, the interactions of the "three-function synergy" in the Western part of Jilin Province are closely related and more coordinated, while in the Eastern part of the province, the interactions of the "three-function synergy" are less relevant and less coordinated. This suggests that the Eastern part of Jilin Province is in greater need of strategies to balance the relationship between the three functions of production, living, and ecology.

3.3.3. Spatial Aggregation Analysis of Cultivated Land Use Recessive Transition

The results of the global and local spatial autocorrelation of the cultivated land recessive transition comprehensive index and the LISA clustering diagram in 1990, 2003, 2014, and 2020 are shown in Table 6 and Figure 10, respectively. The Moran's I of the cultivated land recessive transition comprehensive index for each year was greater than 0, indicating a significant positive correlation in the spatial distribution of the cultivated land recessive transition comprehensive index in each year.

Table 6. Global autocorrelation results of the cultivated land recessive transition comprehensive index in Jilin Province.

Year	Moran's I	Standard Deviation	Z Value	*p* Value
1990	0.7416	0.1007	7.6042	0.0010
2003	0.8283	0.0977	8.7087	0.0010
2014	0.6042	0.1022	6.0909	0.0010
2020	0.4972	0.0996	5.1923	0.0010

When $p < 0.05$ and the absolute value of $Z > 1.96$, there is a 95% probability that the global space is correlated.

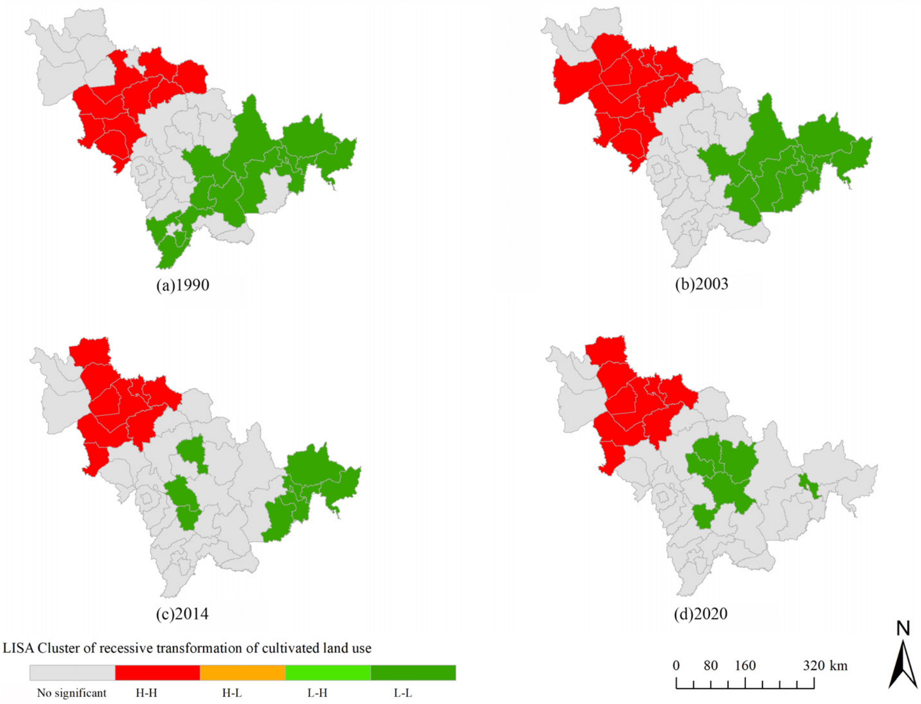

Figure 10. LISA cluster of recessive transition of cultivated land use in Jilin Province.

In the 4 cross-sectional years selected for this study, only high–high (H-H) cluster areas and low–low (L-L) cluster areas existed in Jilin Province, and no high–low (H-L) anomaly areas and low–high (L-H) anomaly areas were observed. This suggested that there were significant regional radiating and driving effects within Jilin Province. Overall, there were clear clustering differences between the eastern and western parts of Jilin Province. The H-H cluster areas basically coincided with the geographical locations of the high-value area, which is mainly distributed in the flat areas of the Western part of Jilin Province. On the other hand, the L-L cluster areas basically coincided with the geographical locations of low-value areas, which are primarily distributed in the areas with steeper terrains in Jilin

Province. It indicates that some areas in Western Jilin Province always play a positive role in the recessive transition of cultivated land, and some areas in the Eastern and Central parts of Jilin province play a negative role.

3.4. Path Selection of Recessive Transition Model of Cultivated Land Use in Jilin Province

The process of the cultivated land-use transition in Jilin Province had distinct regional characteristics. According to the previously divided high-value, medium-value, and low-value areas, for the recessive transition of cultivated land use in Jilin Province, the transition paths of cultivated land use in different transition regions of Jilin Province were explored, respectively. This will clarify the main direction of cultivated land use in the region, providing a basis and reference for the formulation and implementation of differentiated cultivated land-use policies.

3.4.1. High-Value Area of Recessive Transition of Cultivated Land

The high-value area for the cultivated land recessive transition comprehensive index mainly includes the counties and cities in the plain area in the Central and Western part of Jilin Province, corresponding to the spatial planning of Jilin Province's designation of the Central region as the "core area for grain and agricultural product production". The high-value area is located on the grain security industrial belt in the Central and Western parts of Jilin Province. The foundation of cultivated land productive function is good, and in recent years, the capacity for material and capital investment in cultivated land has significantly improved, and the level of agricultural mechanization and cultivated land production capacity has significantly improved.

In the future use of cultivated land, attention should be paid to the optimization and coordination of the "three-function synergy", and the further transition and development of the recessive morphology of cultivated land in the high-value area should be continuously and stably promoted: firstly, continue to strictly protect cultivated land and permanent basic farmland, while strengthening black land conservation tillage and improving the comprehensive grain production capacity. In counties and cities with superior cultivated land productive function conditions, such as Yushu City, Dehui City, Gongzhuling City, and Lishu City, optimize the cultivated land operation mode, make use of agricultural high-tech crop breeding, modern agricultural machinery equipment matching, and other agricultural scientific and technological forces, continue to strengthen the scale and modernization of corn, rice, and other advantageous agricultural products, give full play to the productive function of high-value cultivated land, and build diversified corn planting patterns, such as grain corn and fresh corn in Taobei District, Taonan City, and other counties and cities. At the same time, combine with the deep processing of agricultural products to increase farmers' income, taking into account the improvement of agricultural production capacity and cultivated land employment guarantee capacity. In addition, in combination with the "Three Zones and Three Lines" delineation in the national spatial planning, strictly control the invasion of cultivated land use on ecological space, make use of agricultural scientific and technological forces, such as controlled fertilizer application and intermediate tests, to enhance the ecological function of cultivated land, combine with the protection and restoration of farmland ecosystems, strengthen the compound function of farmland, play the role of concentrated contiguous cultivated land in soil and water conservation, environmental purification, water source conservation, etc., and enhance the ecological value of cultivated land.

3.4.2. Medium-Value Area of Recessive Transition of Cultivated Land

The medium-value area spatially intermingles with the high-value and low-value areas, and it is primarily located in the Central and Southern counties and cities of Jilin Province, with a small amount distributed in the Western part of Jilin. Some of the cities and counties in the medium-value area are located in the grain security industrial belt in the Central and Western parts of the province, while others are situated within the "Western

Ecological Agriculture and Animal Husbandry Development Zone" outlined in the spatial planning. As such, the direction of cultivated land use in the medium-value area is more comprehensive, making the protection and development of cultivated land more complex.

In future land use, on one hand, the focus should be on strengthening the management of cultivated land quantity and quality, thereby intensifying the protection of permanent basic farmland. On the other hand, efforts should be made to enhance soil fertility in the black soil area by combining quality and fertility enhancement in the Central part of the province with soil improvement and fertility promotion in the west, thereby improving the comprehensive ability of grain production. Additionally, in coordination with the comprehensive utilization project of saline–alkali land in Western Jilin, the orderly development of backup land resources in the Western region should be carried out, along with the promotion of farmland shelterbelt renovation, the improvement of the agricultural shelterbelt network system, and the enhancement of cultivated land protection against wind erosion, water erosion, salinization, and desertification. In areas like Da'an City and Tongyu County in Western Jilin, the planting of high-quality mixed grains and legumes should be encouraged. For regions in Central and Southern Jilin, such as Fusong County and Ji'an City, the focus can be on developing leading industries, such as green premium rice and golden corn, around gully cultivated land, while actively cultivating specialty industries such as organic fruits and vegetables, mountain grapes, traditional Chinese medicinal herbs, and tobacco. Furthermore, the deep integration of multiple business forms, such as green ecological agriculture, facility agriculture, and the leisure tourism industry, can be fostered through the implementation of the rural revitalization strategy, guiding farmers to develop green, sustainable agriculture, promoting deep processing and special processing of green agricultural products, facilitating the dual improvement of agricultural product yield and quality in Jilin Province's cultivated land use, and realizing the agricultural industry upgrade in the medium-value area of cultivated land transition.

3.4.3. Low-Value Area of Recessive Transition of Cultivated Land

The low-value area primarily comprises various counties and cities in the Eastern part of Jilin Province, corresponding to the spatial planning of the eastern region as the "Eastern Mountainous Specialty Agriculture and Forestry Development Zone" by the Jilin provincial government. As a significant ecological function zone at the national level (Changbai Mountain Forest Ecological Function Zone) and the Eastern Mountainous Specialty Agriculture and Forestry Development Zone, Eastern Jilin plays a crucial role in water conservation and biodiversity protection, making it a region with a high level of ecological function of cultivated land in Jilin Province.

In future land use, the protection of cultivated land and permanent basic farmland should be intensified, implementing a "three-in-one" protection for the quantity, quality, and ecology of cultivated land. Combined with the stabilization of the spatial distribution of cultivated land, high-grade cultivated land, such as typical black soil areas and high-standard farmland, should be prioritized to be included in the permanent basic farmland. In areas with suitable water and soil resources, moderately develop backup cultivated land resources in valleys and basins. The cultivated land resources in Eastern Jilin are relatively limited compared to the Central and Western regions, but they can fully utilize the advantages of the superior ecological function of cultivated land, and in combination with the "mountainous features" of Eastern Jilin, they can develop specialty agriculture in the Changbai Mountain region, tap into the production potential of cultivated land, promote characteristic and green agricultural production, increase farmers' income, and enhance the living function of cultivated land. For instance, areas with advantages in corn planting, such as Dunhua City, Antu County, and Wangqing County, can focus on developing corn production. In the Pinggang Plain of Huanlong City and other valley flatlands, the high-quality rice industry should be vigorously developed, and the Yanbian rice brand should be created. In places such as Dunhua City and Wangqing County, promote the grain-legume rotation model, stabilize the soybean planting area, and optimize the adjustment of grain production structure.

In the future management and policy-making of cultivated land use in Jilin Province, in addition to strengthening the investment, management, technology, and talents in agricultural production, the regional differentiated characteristics of recessive cultivated land-use transition should also be fully considered. Based on the stage of socio-economic development and the characteristics of recessive transition of cultivated land, implement differentiated and diversified management of cultivated land use. Gradually promote the transition of cultivated land resource management, achieve a comprehensive management model focusing on quantity, quality, and ecology, and build a "green-friendly" pattern to ensure the optimized allocation and efficient use of cultivated land resources.

4. Discussion

By combining the long-term trend and spatiotemporal evolution characteristics of the recessive morphology of cultivated land use in Jilin Province, it was found that the transition of cultivated land use in the study area exhibited characteristics of nonlinear evolution. The trend of the recessive morphology of cultivated land use presented a near "S" curve and "stepwise" stage characteristics. According to the change rule of the cultivated land recessive transition comprehensive index in Jilin Province and the position of the trend change of the index trend point on the long-term sequence, this study divided the recessive transition of cultivated land use in Jilin Province into three stages: the "low stage slow rise period", the "middle stage significant increase period", and the "high stage steady growth period" (Figure 11).

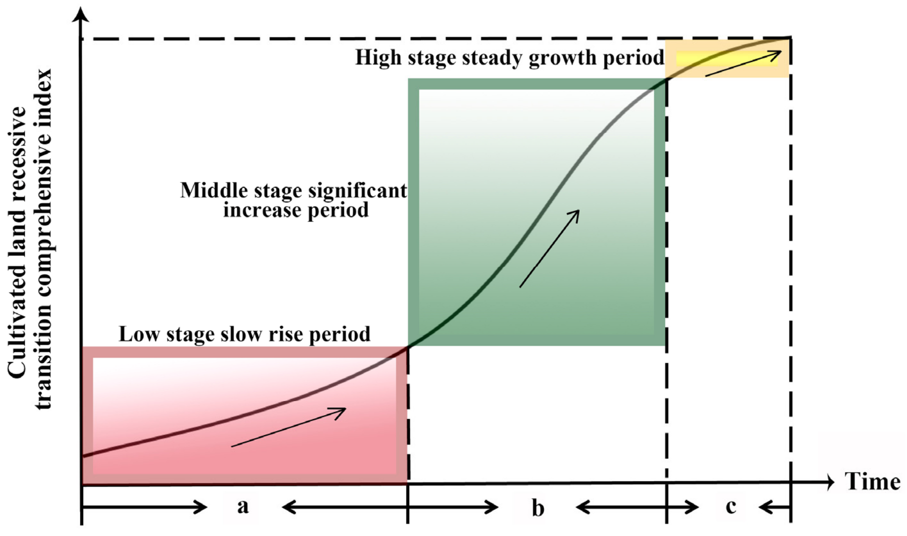

Figure 11. The model of cultivated land use recessive transition in Jilin Province.

Since 1990, agricultural development in Jilin Province has been damaged by the severe droughts in 1997 and 2000 (Figure 12). Constrained by the level of social–economic development and technological development in Jilin Province, the initial progress of the recessive transition of cultivated land use was slow. The "low stage slow rise period" in the curve of the recessive transition model of cultivated land use in Jilin Province lasted for a relatively long time (from 1990 to 2003, a total of 13 years). Since 2004, accompanied by the transition development of social economy and the improvement of technological level, the recessive transition of cultivated land use in Jilin Province entered a growth period and exhibited significant rapid growth (from 2004 to 2014, a total of 11 years). During this period, Jilin Province suffered from climate disasters that were more unfavorable to agriculture in 2007 and 2009. However, with the progress of agricultural technology and the support of the government, the development of agricultural production has improved, and the cultivated land recessive transition has entered a relatively stable stage (from 2015 to 2020, a total of 6 years).

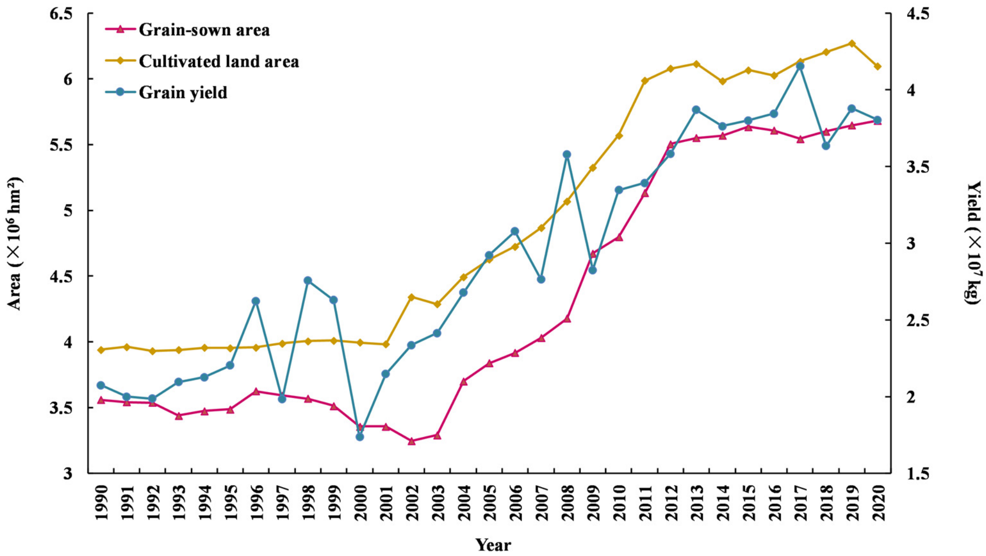

Figure 12. Changes in cultivated land area and grain production indicators in Jilin Province.

The essence of the recessive transition of cultivated land use was a dynamic process in which, under the premise of limited cultivated land resources and with the advancement of technology and socio-economic development, in conjunction with regional phase development goals, the productive, living, and ecological functions carried by cultivated land continually conflict, gradually harmonize, conflict again, and ultimately move towards coordination. However, the recessive transition model of cultivated land use proposed in this study is not immutable, but it is a conceptual transition model refined based on the recessive transition process of cultivated land use in Jilin Province. The transition models of each stage adapt to the regional economic, social, and agricultural development stages. Economic and social development, policy interventions, and external interferences are factors that lead to corresponding changes in the stages and speed of cultivated land transition. The influence of natural resources, industrial structure, as well as planning and management methods of cultivated land use on transition dynamics is also an important factor, causing the gradually increasing differences in transition between counties. More importantly, although the research area, the high-value area, the medium-value area, and the low-value area all conformed to the "S" type three-stage transition model, the periods when the sample areas entered the high stage were not consistent, and within the same transition stage, the length of the transition experienced by each county also differed. For example, the Baicheng City jurisdiction went through a 17 year period of significant increase in the mid-term, and it entered the "high stage steady growth period" in 2017. Changling County's "middle stage significant increase period" lasted for 10 years, and it entered the "high stage steady growth period" in 2011. Furthermore, not all study units followed this model to experience the transition of the recessive morphology of cultivated land use. Some areas did not experience the first stage during the research period (Qian Gorlos County) and did not enter the third stage (Hunchun City). Therefore, the transition of cultivated land use cannot be considered as a given model [50].

Based on the discussion of the spatio-temporal evolution of the recessive transition of cultivated land use in Jilin Province, this study revealed the internal mechanism of the recessive transition of cultivated land in Jilin Province from the perspective of "three-function synergy", and it constructed a model of the recessive transition of cultivated land use in Jilin Province. Due to different dominant factors (social and economic development, policy intervention) at different stages, the recessive transition process presented similar "ladder-type" stage characteristics. The results of this study are similar to and different from the results of other scholars assessing other regions. On the one hand, the model of recessive cultivated land shift in Jilin Province that we obtained is similar to other scholars' models, which is an abstract S-shaped curve. However, the model was influenced by natural conditions, such as topography and fertility, and it was adapted to regional economic, social, and agricultural development stages. Different regions have different lengths of time for each stage. For example, the results of the study by Niu, S. et al. showed that the comprehensive transition index of cultivated land utilization in the Huaihai Economic Zone of China increased, overall, from 2002 to 2017 [25]. Li, X., etc., found that the recessive transition of cultivated land, in the Huaibei region of the Jiangsu Province, declined slightly from 1995 and, then, showed a staged increase from 2004 [35]. Lyu, L. et al. found that the crop production, living security, and eco-environmental function of farmland in Sihong County showed a trend of first decreasing and then increasing [51].

From the perspective of Jilin Province, due to the influence of the economic development level, drought, and flood disasters, the level of cultivated land use was low; therefore, the first stage of the recessive transition of cultivated land use in Jilin Province lasted longer (11 years) and remained in a slow rise. After 2003, the transition model entered the second stage. Economic growth and agricultural development were regulated by policies and systems, effectively promoted the process and trend of recessive transition, and the recessive transition of cultivated land use turned to a significant increase. Due to the limitation of resource and environmental carrying capacity, the degree of transition could not increase indefinitely. After entering the high stage of stable growth, the speed of the recessive transition of cultivated land use in Jilin Province slowed down.

As the basic unit of cultivated land resource use, villages and farmers can more accurately present the micro characteristics of recessive cultivated land-use shift. Therefore, it is the direction of future research to seek to depict the characteristics and internal mechanisms of the recessive transition of cultivated land use at the micro scale. In addition, the recessive morphology of cultivated land use has multiple attributes such as quality, property rights, operation mode, input, output, and function. Limited by data availability, this study did not quantitatively research the property rights and operation mode of cultivated land, nor did it research the impact of policies. Therefore, subsequent research should pay attention to the changes in ownership and policies related to cultivated land, and it should construct a more scientific and perfect indicator system of recessive transition of cultivated land, to reveal the characteristics of recessive transition of cultivated land use in a more systematic way, in order to better achieve scientific management and the sustainable use of land resources.

5. Conclusions

Based on the productive–life–ecological functions perspective, this study analyzed the process characteristics of the cultivated land recessive transition in Jilin Province, based on the cultivated land recessive transition comprehensive index, calculated by the multi-scale indicators system. We constructed a transition model of cultivated land use recessive transition in Jilin Province, and we put forward management suggestions for areas with different transition characteristics to provide support for optimizing the utilization and management of cultivated land in Jilin Province, as well as constructing a "green and friendly" safe food production pattern.

1. Based on the cultivated land recessive transition comprehensive index, Jilin Province was divided into high-value, medium-value, and low-value areas. The cultivated land recessive transition in Jilin Province underwent two trend turning points in 2003 and 2014. In addition to this, the cultivated land recessive transition has a certain time lag compared to the change of cultivated land functions.
2. The recessive transition of cultivated land in the Central and Western regions of Jilin Province was greater. The changes in the spatial distribution characteristics of the coupling degree and coordination degree between the "three-function synergy" showed a pattern of high in the west and low in the east.

3. Combined with the long-term spatial and temporal evolution law of the recessive morphology of cultivated land in Jilin Province, the cultivated land recessive transition in Jilin Province was divided into three stages: the "low stage slow rise period", the "middle stage significant increase period", and the "high stage steady growth period".
4. In the future management and policy formulation of cultivated land use in Jilin Province, differentiated and diversified management of cultivated land use should be implemented. In the high-value and medium-value areas of the cultivated land recessive transition, natural advantages should be utilized to fully utilize the productive function of cultivated land in order to drive the living function of cultivated land and help improve its ecological value. Low-value areas with significant ecological advantages in cultivated land can rely on the "mountainous characteristics" of Eastern Jilin to create distinctive brands and achieve increased production and income through brand effects.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12091758/s1, Supporting Information S1: Distribution map of grain production, employment security and ecosystem resilience of cultivated land in Jilin Province. The western part of Jilin had flat terrain, strong cultivated land power, abundant water resources, high grain yield and agricultural output value. And the eastern part of Jilin had superior ecological conditions, rich biodiversity and strong recovery capacity of the cultivated land ecosystem.

Author Contributions: Conceptualization, L.W. and A.L.; methodology, L.W., A.L. and X.L.; software, L.W. and A.L.; validation, L.W., A.L. and C.J.; formal analysis, L.W. and H.O.; investigation, L.W. and A.L.; resources, L.W., A.L. and C.J.; data curation, A.L.; writing—original draft preparation, L.W.; writing—review and editing, A.L. and X.L.; visualization, L.W., A.L., C.J. and J.W.; supervision, L.W. and A.L.; project administration, L.W. and A.L.; funding acquisition, L.W. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data available in a publicly accessible repository that does not issue DOIs. Publicly available datasets were analyzed in this study. This data can be found here: http://www.stats.gov.cn (accessed on 7 October 2022).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Shi, P.; Wang, J.; Feng, W.; Ye, T.; Ge, Y.; Chen, J.; Liu, J. Responst of Eco-Environmental Security to Land Use/Cover Changes and Adjustment of Land Use Policy and Pattern in China. *Adv. Earth Sci.* **2006**, *21*, 111–119.
2. Long, H.; Ge, D.; Wang, J. Progress and prospects of the coupling research on land use transitions and rural transformation development. *Acta Geogr. Sin.* **2019**, *74*, 2547–2559.
3. Liu, Y. Modern Human-Earth Relationship and Human-Earth System Science. *Sci. Geogr. Sin.* **2020**, *40*, 1221–1234. [CrossRef]
4. Song, X. Discussion on land use transition research framework. *Acta Geogr. Sin.* **2017**, *72*, 471–487.
5. Wang, C. Impacts of Major Events on Host Cities' Urban Spatial Structure: Literature Review and Strategic Management Model. *Hum. Geogr.* **2012**, *27*, 13–19. [CrossRef]
6. Long, H. Land Rehabilitation and Regional Land Use Transition. *Prog. Geogr.* **2003**, *22*, 133–140.
7. Long, H.; Qu, Y. Land Use Transitions and Land Management: A Mutual Feedback Perspective. *Land Use Policy* **2018**, *74*, 111–120. [CrossRef]
8. Long, H.; Qu, Y.; Tu, S.; Zhang, Y.; Jiang, Y. Development of Land Use Transitions Research in China. *J. Geogr. Sci.* **2020**, *30*, 1195–1214. [CrossRef]
9. Long, H.; Zhang, Y.; Ma, L.; Tu, S. Land Use Transitions: Progress, Challenges and Prospects. *Land* **2021**, *10*, 903. [CrossRef]
10. Long, H. Land use transition and land management. *Geogr. Res.* **2015**, *34*, 1607–1618.
11. Ma, L.; Long, H.; Tu, S.; Zhang, Y.; Zheng, Y. Farmland Transition in China and Its Policy Implications. *Land Use Policy* **2020**, *92*, 104470. [CrossRef]
12. Song, X.; Wu, Z.; Ou, Y. Route of cultivated land transition research. *Geogr. Res.* **2014**, *33*, 403–413.
13. Zhao, Y.; Tan, Y. Spatial-temporal Changes of Cultivated Land Use at Provincial Level Since Second National Land Survey in China. *Bull. Soil Water Conserv.* **2020**, *40*, 204–212. [CrossRef]

14. Hou, Q.; Chen, Y.; Pei, T.; Ji, Z.; Xie, B. Analysis of cultivated land's spatio-temporal changes and influencing factors in Gansu Province in recent 25 years. *Arid. Zone Res.* **2022**, *39*, 955–967. [CrossRef]
15. Liu, Y.; Long, H. Land Use Transitions and Their Dynamic Mechanism: The Case of the Huang-Huai-Hai Plain. *J. Geogr. Sci.* **2016**, *26*, 515–530. [CrossRef]
16. Si, H.; Yuan, C.; Cao, Y.; Zhou, W.; Cai, C. Research on Regional Differences of Cultivated Land Changes and Countermeasures in Qinghai Province. *Res. Soil Water Conserv.* **2013**, *20*, 321–325.
17. Li, Q.; Hu, S.; Qu, S. Spatiotemporal characteristics of cultivated land use transition in the Middle Yangtze River from 1990 to 2015. *Geogr. Res.* **2017**, *36*, 1489–1502.
18. Fan, D.; Wang, P.; Lv, X.; Zhai, T. Analysis on the Spatio-Temporal Characteristics and Influencing Factors of the Explicit Transformation of Cultivated Land In Shandong. *J. Shandong Norm. Univ. (Nat. Sci.)* **2021**, *36*, 176–187.
19. Fu, H.; Liu, Y.; Sun, H.; Zhou, G. Spatiotemporal characteristics and dynamic mechanism of cultivated land use transition in the Beijing-Tianjin-Hebei region. *Prog. Geogr.* **2020**, *39*, 1985–1998. [CrossRef]
20. Song, X.; Li, X. Theoretical explanation and case study of regional cultivated land use function transition. *Acta Geogr. Sin.* **2019**, *74*, 992–1010.
21. Huan, H.; Tan, Q.; Zhu, P. Driving factors of cultivated land use change in city and countryside integration process and region comparisons. *Trans. Chin. Soc. Agric. Eng.* **2013**, *29*, 201–213.
22. Ke, S.; Cui, H.; Lu, X.; Hou, J.; Wu, Y. Research on the Spatial-Temporal Pattern and Mechanisms of Green Transition of Farmland Use: A Case of Hubei Province. *China Land Sci.* **2021**, *35*, 64–74.
23. Li, Y.; Li, Y.; Westlund, H.; Liu, Y. Urban–Rural Transformation in Relation to Cultivated Land Conversion in China: Implications for Optimizing Land Use and Balanced Regional Development. *Land Use Policy* **2015**, *47*, 218–224. [CrossRef]
24. Jiang, M.; Li, Z.; Li, J.; Liu, X. Mutation Point Detection of Cultivated Land Use Transition and Its Spatial-Temporal Characteristics: Taking Dongchuan District of Kunming City as an Example. *China Land Sci.* **2022**, *36*, 86–95.
25. Niu, S.; Fang, B.; Cui, C.; Huang, S. The spatial-temporal pattern and path of cultivated land use transition from the perspective of rural revitalization: Taking Huaihai Economic Zone as an example. *J. Nat. Resour.* **2020**, *35*, 1908–1925.
26. The State Council Information Office of the People's Republic of China Food Security in China. Available online: http://www.scio.gov.cn/zfbps/ndhf/39911/Document/1666230/1666230.htm (accessed on 15 May 2023).
27. Chen, Y.; Wang, J. China's food security situation and strategy under the background of opening-up. *J. Nat. Resour.* **2021**, *36*, 1616–1630. [CrossRef]
28. Ren, Y.; Li, X.; Wang, Z.; Yang, L. Changes of Croplands and Conversions from Dry Farmland to Paddy Field in Western Jilin Province during 1990~2015. *Remote Sens. Technol. Appl.* **2019**, *34*, 1064–1072.
29. Song, X.; Huang, Y.; Wu, Z.; Ouyang, Z. Does Cultivated Land Function Transition Occur in China? *J. Geogr. Sci.* **2015**, *25*, 817–835. [CrossRef]
30. Wang, P.; Wang, P. Spatio-Temporal Evolution of Land Use Transition in the Background of Carbon Emission Trading Scheme Implementation: An Economic–Environmental Perspective. *Land* **2022**, *11*, 440. [CrossRef]
31. Zhang, Q.; Li, F. Correlation between Land Use Spatial and Functional Transition: A Case Study of Shaanxi Province, China. *Land Use Policy* **2022**, *119*, 106194. [CrossRef]
32. Gao, J.; Zhu, Y.; Zhao, R.; Sui, H. The Use of Cultivated Land for Multiple Functions in Major Grain-Producing Areas in Northeast China: Spatial-Temporal Pattern and Driving Forces. *Land* **2022**, *11*, 1476. [CrossRef]
33. Liu, S.; Wei, X. Measurement of New Urbanization Level in Western China Based on Improved CRITIC Method. *Ecol. Econ.* **2019**, *35*, 98–102.
34. Ying, L.; Shen, Z.; Piao, S. The Recent Hiatus in Global Warming of the Land Surface: Scale-Dependent Breakpoint Occurrences in Space and Time: SCALE-DEPENDENT HIATUS IN SPACE AND TIME. *Geophys. Res. Lett.* **2015**, *42*, 6471–6478. [CrossRef]
35. Li, X.; Wang, L.; Pijanowski, B.; Pan, L.; Omrani, H.; Liang, A.; Qu, Y. The Spatio-Temporal Pattern and Transition Mode of Recessive Cultivated Land Use Morphology in the Huaibei Region of the Jiangsu Province. *Land* **2022**, *11*, 1978. [CrossRef]
36. Li, Y.; Qiao, L.; Wang, Q.; Dávid, K. Towards the Evaluation of Rural Livability in China: Theoretical Framework and Empirical Case Study. *Habitat Int.* **2020**, *105*, 102241. [CrossRef]
37. Luo, J.; Cui, J.; Liu, Y. Coupling Coordination Measurement of Land Use and Air Quality in Heilongjiang Province. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *531*, 012035. [CrossRef]
38. Ni, W.; Xia, Y.; Zhao, N. Functional Evolution and Coupling Coordination Measurement of Production-Living-Ecological Space in Rural Areas: Taking Heilongjiang Province as an Example. *China Land Sci.* **2022**, *36*, 111–119.
39. Li, W.; Wang, Y.; Xie, S.; Cheng, X. Spatiotemporal Evolution Scenarios and the Coupling Analysis of Ecosystem Health with Land Use Change in Southwest China. *Ecol. Eng.* **2022**, *179*, 106607. [CrossRef]
40. Wang, C.; Tang, N. Spatio-temporal characteristics and evolution of rural production-living-ecological space function coupling coordination in Chongqing Municipality. *Geogr. Res.* **2018**, *37*, 1100–1114.
41. Tian, J.; Wang, B.; Zhang, C.; Li, W.; Wang, S. Mechanism of Regional Land Use Transition in Underdeveloped Areas of China: A Case Study of Northeast China. *Land Use Policy* **2020**, *94*, 104538. [CrossRef]
42. Gong, H.; Zhao, Z.; Chang, L.; Li, G.; Li, Y.; Li, Y. Spatiotemporal Patterns in and Key Influences on Cultivated-Land Multi-Functionality in Northeast China's Black-Soil Region. *Land* **2022**, *11*, 1101. [CrossRef]

43. Liu, Y.; Li, J.; Yang, Y. Strategic Adjustment of Land Use Policy under the Economic Transformation. *Land Use Policy* **2018**, *74*, 5–14. [CrossRef]
44. Chen, Y.; Wang, J.; Zhang, F.; Liu, Y.; Cheng, S.; Zhu, J.; Si, W.; Fan, S.; Gu, S.; Hu, B.; et al. New Patterns of Globalization and Food Security. *J. Nat. Resour.* **2021**, *36*, 1362. [CrossRef]
45. Fan, Y.; Luo, T.; Li, K. Quality Evaluation of Rural Human Settlements and Its Spatio-Temporal Distribution Characteristics at County Level in Guangxi. *Chin. J. Agric. Resour. Reg. Plan.* 2023, pp. 1–12. Available online: http://kns.cnki.net/kcms/detail/11.3513.S.20230608.1100.002.html (accessed on 25 August 2023).
46. Gu, C.; Yu, Z. Discussion on the Current Situation of Land Resource Utilization and Related Issues in Shulan City. *Jilin Agric.* **2013**, *11*, 7.
47. Lyu, Y.; Yun, W.; Zhang, C.; Zhu, D.; Yang, J.; Chen, Y. Multi-characteristic Comprehensive Recognition of Well-facilitied Farmland Based on TOPSIS and BP Neural Network. *Trans. Chin. Soc. Agric. Mach.* **2018**, *49*, 196–204.
48. Zou, T.; Chang, Y.; Chen, P.; Liu, J. Spatial-Temporal Variations of Ecological Vulnerability in Jilin Province (China), 2000 to 2018. *Ecol. Indic.* **2021**, *133*, 108429. [CrossRef]
49. Liu, Y.; Liu, Y.; Chen, Y. Territorial Multi-functionality Evaluation and Decision-making Mechanism at County Scale in China. *Acta Geogr. Sin.* **2011**, *66*, 1379–1389.
50. Long, H. Theorizing Land Use Transitions: A Human Geography Perspective. *Habitat Int.* **2022**, *128*, 102669. [CrossRef]
51. Lyu, L.; Gao, Z.; Long, H.; Wang, X.; Fan, Y. Farmland Use Transition in a Typical Farming Area: The Case of Sihong County in the Huang-Huai-Hai Plain of China. *Land* **2021**, *10*, 347. [CrossRef]