Postprint: Evolutionary Characteristics of Spatiotemporal Patterns of Crop Planting Structure in the Fenwei Plain

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Date: 2025-06-20T00:00:00+00:00

Abstract

Food security is the foundation of national development and social stability. Investigating the spatio-temporal evolution of crop planting structure can provide a theoretical basis for ensuring regional food security and promoting sustainable agricultural development in the region. Selecting 117 counties (cities/districts) in the Fen-Wei Plain as the study area, using agricultural statistical data from 2000-2022 as the data source, and employing methods such as the standard deviational ellipse model and spatial autocorrelation, this study explores the spatio-temporal evolution patterns of major crop planting structures at the county level in the Fen-Wei Plain from 2000 to 2022. The results show: (1) From 2000 to 2022, a total of 88 types of crop planting structures emerged in the Fen-Wei Plain, among which wheat and maize and their combination types are the main crop planting structure types in the Fen-Wei Plain. From a spatio-temporal distribution perspective, the number of wheat-type counties gradually decreased, the number of maize-type counties increased year by year, wheat-maize type counties gradually diffused from the southwestern region to the northeastern region of the Fen-Wei Plain; while maize-wheat type counties showed a scattered distribution pattern throughout the Fen-Wei Plain. In terms of type richness, crop planting structure types were most abundant in 2005, while the richness index was smallest in 2015. (2) From 2000 to 2022, the planting patterns of wheat, maize, and vegetables in the Fen-Wei Plain all exhibited a distribution pattern along the northeast-southwest direction. The centroid of wheat remained basically stable, the centroid of maize continuously shifted toward the northeast, and the centroid of vegetables shifted from Heyang County southwestward to Chengcheng County. In summary, the spatial distribution of major crops in the Fen-Wei Plain shows a differentiated development trend. Wheat planting area shows a contraction trend, while maize and vegetables show an expansion trend. In the future, it is advisable to strengthen macro-level regulation of crop planting structure in the Fen-Wei Plain from the perspective of ensuring food

security, based on analyzing the spatio-temporal development trends of crop planting structure.

Full Text

Spatio-temporal Pattern Evolution Characteristics of Crop Planting Structure on Fenwei Plain

ARID LAND GEOGRAPHY Vol. 48 No. 6 Jun. 2025

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Abstract

Food security is fundamental to national development and social stability. Investigating the spatio-temporal evolution of crop planting structures provides a theoretical basis for ensuring regional food security and promoting sustainable agricultural development. This study examines 117 counties (cities/districts) in the Fenwei Plain using agricultural statistical data from 2000–2022. Employing methods such as the standard deviation ellipse model and spatial autocorrelation analysis, we explore the spatio-temporal evolution patterns of major crop planting structures at the county level. The results indicate: (1) During 2000–2022, 88 distinct crop planting structure types emerged, with wheat, corn, and their combinations being the dominant types. Spatially and temporally, the number of wheat-type counties gradually declined, corn-type counties increased annually, wheat-corn-type counties expanded from southwestern to northeastern regions, while corn-wheat-type counties remained scattered throughout the plain. Crop planting structure diversity peaked in 2005, while the richness index reached its minimum in 2015. (2) From 2000–2022, wheat, corn, and vegetable planting patterns exhibited a northeast-southwest distribution. The wheat production center remained stable, corn' s center shifted northeastward, and vegetables' center moved southwest from Heyang County to Chengcheng County. Overall, major crops show differentiated development trends: wheat planting area is shrinking while corn and vegetable areas are expanding. Future policy should strengthen macro-regulation of the Fenwei Plain' s crop planting structure based on these spatio-temporal trends and from a food security perspective.

Keywords: crop planting structure; temporal and spatial evolution; spatial autocorrelation; Fenwei Plain

1 Introduction

Crop planting structure refers to the proportional composition and spatial arrangement of different crops in regional agricultural production, which significantly influences farm household economics, regional agricultural sustainability, and food security [?]. In recent years, rapid urbanization, industrialization, and rising living standards have substantially altered dietary patterns in China, with demand for agricultural products becoming increasingly diversified and complex beyond traditional food crops [?]. Additionally, climate change and water resource constraints have placed continuous pressure on specific grain crop production in certain regions, while economic benefit disparities between grain and cash crops further drive structural transformations [?]. Therefore, accurately identifying spatio-temporal evolution patterns of regional crop planting structures is crucial for guiding structural adjustments.

Scholars have investigated crop planting structure issues at national [?], provincial [?], and city/county levels [?] using satellite remote sensing [?], agricultural statistics [?], spatial analysis [?], and time series analysis [?]. For instance, Wang et al. [?] systematically analyzed spatial distribution characteristics and dynamic changes in wheat planting area across 31 provinces, concluding that stability in central and eastern regions is key to national wheat security, while northern and southern regions require intervention to reverse declining trends. Liu et al. [?] employed center-of-gravity models and location quotient indices to examine crop pattern evolution in Shaanxi Province, finding a gradual northeastward shift in the province' s planting center. Wang et al. [?] used mathematical statistics and GIS to study spatio-temporal changes in Heilongjiang Province, revealing annual increases in total sown area, particularly for rice and corn. These multi-method, multi-level studies provide valuable references.

Plain regions serve as major grain production areas and play vital roles in regional food security. However, research on spatio-temporal evolution of crop planting structures from a large plain perspective remains limited, particularly for traditional agricultural regions in central China. In 2019, President Xi Jinping emphasized at the Yellow River Basin Ecological Protection and High-Quality Development Symposium that major grain-producing areas like the Fenwei Plain should develop modern agriculture, improve product quality, and contribute to national food security. The Fenwei Plain, one of China's seven major agricultural production regions, features suitable climate conditions, predominantly double-cropping or triple-cropping-every-two-years systems, fertile soil, and flat terrain—representing the best-matched region for light, temperature, water, and soil conditions in the middle Yellow River reaches and serving as a crucial wheat and corn production area [?]. Investigating evolution patterns of crop planting structures in the Fenwei Plain can provide theoretical support for agricultural restructuring, sustainable development, and food security, while offering policy references for other northern China regions. This study employs spatial autocorrelation and standard deviation ellipse methods to reveal spatio-temporal evolution patterns of major crop planting structures from 2000–2022,

aiming to provide a theoretical basis for optimizing agricultural structure and maintaining regional food security.

1.1 Study Area Overview

The Fenwei Plain, located in North China, comprises the Fen River Plain, Wei River Plain, and surrounding terraces. It includes 117 counties (cities/districts) across Shanxi Province (Jinzhong, Lüliang, Linfen, Yuncheng), Shaanxi Province (Xi' an, Baoji, Xianyang, Weinan, Tongchuan), and Henan Province (Luoyang, Sanmenxia), covering a total area of 76,000 km^2. As the largest alluvial plain in the middle Yellow River reaches and China' s fourth largest plain, it features concentrated, contiguous cultivated land with fertile soil, making it a vital wheat and corn production region.

1.2 Data Sources

Agricultural statistical data—including total crop sown area and individual crop areas and yields for wheat, corn, millet, soybean, potato, cotton, oil crops, and vegetables—were obtained from provincial and municipal statistical yearbooks of Shanxi, Shaanxi, and Henan, as well as the *China County Statistical Yearbook*. Geographic vector data were sourced from the Standard Map Service of the Ministry of Natural Resources (http://bzdt.ch.mnr.gov.cn). Given the limited agricultural land in Xi' an' s Xincheng, Beilin, Lianhu, Weiyang, and Yanta districts, this study selected the remaining 112 counties as research objects.

1.3 Methods

1.3.1 Classification and Naming of Crop Planting Structure Types Crop planting structure types were classified based on the proportion of individual crops in total sown area [**?**]. Crops accounting for $ $30% of total sown area were designated as primary crops, while those accounting for 15–30% were secondary crops; crops below 15% were excluded from type classification. Primary and secondary crops were connected with a hyphen in type names, using a maximum of three crops. When only primary crops existed, the type was named after the primary crop alone (e.g., "wheat type" for areas with wheat $ $30% and no secondary crops). When both existed, they were combined (e.g., "wheat-cotton-vegetable type" for areas with wheat $ $30% and cotton/vegetables at 15–30%). To visualize spatio-temporal evolution patterns from 2000–2022, this study extracted crop types with planting proportions $ $15% and mapped them using ArcGIS 10.8.

1.3.2 Crop Planting Structure Richness Index The richness index measures crop planting diversity by calculating the ratio of crop structure types in a given year to the total types across the study period [**?**]:

$$R_i = \frac{n_i}{N}$$

where R_i is the richness index for year i (values closer to 1 indicate greater diversity), n_i is the number of crop structure types in year i, and N is the total number of types across all years.

1.3.3 Standard Deviation Ellipse The standard deviation ellipse method characterizes spatial distribution features of geographic elements, providing information on central tendency, distribution range, dispersion, and primary orientation through three parameters: rotation angle, and standard deviations of long and short axes [**?**]. This study applied the method to identify concentrated planting regions, distribution directions, and range changes for crops in the Fenwei Plain.

1.3.4 Spatial Autocorrelation Spatial autocorrelation analysis, based on Tobler' s First Law of Geography, assesses spatial clustering and correlation [**?**]. Global Moran' s I measures overall spatial clustering, while local Moran' s I identifies specific patterns (high-high, high-low, low-high, low-low clusters). This study used ArcGIS 10.8 to calculate global Moran' s I for wheat, corn, and vegetable areas and yields, and mapped local spatial autocorrelation types at $P < 0.05$ significance.

2 Results and Analysis

2.1 Interannual Variations in Crop Planting Structure Types

The richness index exhibited a trend of initial increase, subsequent decrease, and final increase from 2000–2022 [Figure 2: see original paper]. The index rose from 7.69% in 2000 to 15.38% in 2005, then fell to 4.27% in 2015 before rising again after 2015. This reflects a transformation from single grain crop planting to diversified, value-added crop planting in the Fenwei Plain.

2.2 Spatial Patterns of Crop Planting Structure

2.2.1 Spatial Distribution Changes A total of 88 crop planting structure types emerged during 2000–2022, dominated by wheat-corn combinations . The four main types (wheat type, corn type, wheat-corn type, corn-wheat type) covered an average of 94 counties (80.3% of all counties).

Wheat-type counties decreased from 59 (50.4%) in 2000 to 8 (6.8%) in 2022, mainly distributed in Linfen and Yuncheng (Shanxi), Sanmenxia and Luoyang (Henan), and Weinan (Shaanxi) in 2000, but only scattered in Weinan and Baoji by 2022. Corn-type counties increased from 6 (5.1%) in 2000 to 33 (28.2%) in 2022, expanding from central Jinzhong and Lüliang to broader distributions. Wheat-corn-type counties diffused from southwestern Baoji and Xi' an toward the northeast. Corn-wheat-type counties remained scattered throughout the plain. Vegetable-type and vegetable-wheat-type counties increased steadily, primarily in Feng County, Taibai County, and Yanliang District (vegetable type),

and in Sanyuan County, Jingyang County, and Huazhou District (vegetable-wheat type). Millet, soybean, oil crops, and cotton had limited planting areas with high interannual variability [Figure 4: see original paper].

2.2.2 Spatial Distribution of Planting Area and Yield From 2000–2022, wheat planting area decreased in 71.8% of counties (38.5% significantly, $P < 0.05$), with high reduction rates (800–1260 $hm^2 \cdot a^{-1}$) in Xi' an, Weinan, and western Yuncheng [Figure 5: see original paper]. Wheat yield showed a southeast-to-northwest decreasing trend, with 55.6% of counties experiencing yield reductions (26.5% significant) and 16.2% showing increases, particularly in Yuncheng, Weinan, and Luoyang.

Corn planting area increased in 66.7% of counties (38.5% significantly), mainly in the eastern plain with growth rates >100 $hm^2 \cdot a^{-1}$. Corn yield increased in 69.2% of counties (42.7% significantly), concentrated in Shanxi, Henan, and Weinan, while decreasing in Xi' an, Baoji, and Xianyang. Vegetable area increased in 59.0% of counties (24.8% significantly), particularly in the southern plain with growth rates of 0–400 $hm^2 \cdot a^{-1}$, while decreasing areas were concentrated in Shanxi. Vegetable yield patterns mirrored area patterns.

2.2.3 Spatial Clustering Patterns Global Moran' s I indices for wheat, corn, and vegetable areas and yields were all positive and significant ($P < 0.05$) , indicating significant spatial clustering. Wheat' s I index decreased from 0.44 to 0.40, corn' s from 0.27 to 0.21, while vegetables' increased from 0.19 to 0.27, suggesting weakening spatial correlation for wheat and corn but strengthening for vegetables.

Local spatial autocorrelation patterns in 2022 [Figure 6: see original paper] revealed: - **Wheat**: Low-low clusters in northern Lüliang, Jinzhong, and Linfen; high-high clusters in south-central and southeastern Luoyang. - **Corn**: Low-low clusters in Baoji' s Feng County, Jin Tai District, Xi' an urban area, and Lüliang-Jinzhong-Linfen border; high-high clusters centered in Weinan with some in Jinzhong. - **Vegetables**: Low-low clusters in most of Lüliang and Linfen; high-high clusters at the junction of Weinan, Xianyang, and Xi' an.

2.2.4 Evolution of Production Centers Standard deviation ellipse analysis [Figure 7: see original paper] showed: - **Wheat**: Center remained stable in Dali County, Shaanxi, maintaining a northeast-southwest distribution. - **Corn**: Center shifted northeastward from Heyang County (2000) to between Hancheng (Shaanxi) and Wanrong County (Shanxi) (2022), following a northeast-southwest axis. - **Vegetables**: Center moved southwest from Heyang County to Chengcheng County (2010–2022), then southeast to Dali County after 2020, also along a northeast-southwest axis.

3 Discussion

Existing research has focused on national [?] and provincial [?] scales, with limited studies from large plain perspectives, particularly for traditional agricultural regions in central China. This study addresses this gap by analyzing spatio-temporal evolution of crop planting structures in the Fenwei Plain from 2000–2022.

Our findings align with previous research showing rising corn and declining wheat proportions [?], and increasing importance of economic crops like vegetables [?]. Crop planting structure changes are constrained by natural factors (precipitation, accumulated temperature) and socioeconomic factors (economics, technology) [?, ?]. As rational economic actors, farmers weigh economic benefits and government subsidies when selecting crops. In recent years, corn and vegetables in the Fenwei Plain have shown significantly higher economic benefits than wheat, driving structural changes alongside agricultural technology innovations and subsidy policies.

While grain crops (wheat, corn, rice) remain the cornerstone of national food security, market fluctuations and price volatility may adversely affect planting structures. Policy interventions are needed to stabilize staple food structures and prevent oversimplification, ensuring food security while allowing market mechanisms to operate.

4 Conclusion

From 2000–2022, the Fenwei Plain exhibited 88 crop planting structure types, with wheat-corn combinations dominating. The richness index showed a fluctuating trend (increase-decrease-increase). Wheat-type counties decreased, corn-type counties increased, and wheat-corn-type counties diffused northeastward, while corn-wheat-type counties remained scattered.

The planting patterns of wheat, corn, and vegetables distributed along a northeast-southwest axis. Wheat' s production center remained stable, corn' s shifted northeastward, and vegetables' moved southwestward from Heyang to Chengcheng.

Significant spatial differentiation exists in wheat, corn, and vegetable planting. Future policy should strengthen macro-regulation of the Fenwei Plain' s crop planting structure based on these spatio-temporal trends and from a food security perspective.

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Note: Figure translations are in progress. See original paper for figures.