Grain Security in the Agro-Pastoral Transitional Zone of Northern China: A Postprint Study from the Perspective of Grain Yield per Unit Area

Authors: Kong Deming, Hao Lisha, Xia Siyou, Li Hongbo, Hao Lisha

Date: 2023-06-28T00:00:00+00:00

Abstract

Drawing upon the significance of food security and grain yield per unit area in the northern agro-pastoral ecotone of China, this study employs spatial autocorrelation analysis to reveal the spatial differentiation and evolution characteristics of grain yield within the zone, as a basis for delineating regional agricultural and pastoral development zones. It further utilizes the Geodetector model to uncover the dominant factors controlling yield differentiation and their interaction effects, thereby exploring countermeasures to enhance grain yield per unit area and ensure food security within the zone. The results indicate that: (1) During 2000–2020, grain yield per unit area within the zone exhibited a relatively stable agglomeration distribution pattern, with the overarching natural environmental differentiation serving as the fundamental controlling factor, while social production conditions and their coupling level reinforced the spatial differentiation characteristics of grain yield. (2) Yield hotspot areas are primarily concentrated in the northeastern plain regions and the southwestern Hehuang Valley within the zone, coldspot areas are distributed in the central soil erosion zones and hilly regions, and sub-hotspot and sub-coldspot areas form a ring structure around the hotspots and coldspots. Based on this pattern, hotspot areas can be designated as agriculture-suitable zones, sub-hotspot and sub-coldspot areas as agro-pastoral coupling zones, and coldspot areas as ecological restoration zones, to promote coordinated agricultural and pastoral development within the zone according to local conditions. (3) During 2000–2020, the growth pattern of grain yield per unit area within the zone shifted from labor-force-dominated to modern-agricultural-technology-dominated; however, issues have emerged, including excessive decoupling of labor force from both cultivated land and modern agricultural technology, as well as insufficient coupling among various modern agricultural technologies. Therefore, it is recommended to promote the healthy growth of grain yield and enhance food security capacity through the coupled development of "human-land-technology".

Full Text

Food Security in the Argo-Pastoral Ecotone of Northern China from the Perspective of Grain Yield

KONG Deming[1,2], HAO Lisha[1,2], XIA Siyou[3,4], LI Hongbo[1,2]

[1]School of Geographical Science, Nanjing Normal University, Nanjing 210023, Jiangsu, China
[2]Jiangsu Center for Collaborative Innovation in Geographical Information Resource Development and Application, Nanjing 210023, Jiangsu, China
[3]Institute of Geographic Sciences and Natural Resources Research, Beijing 100101, China
[4]College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China

Abstract: The argo-pastoral ecotone of northern China represents a critical region for implementing national food security strategies, where sustainable increases in grain yield per unit area constitute the primary approach to ensuring food security. This study employs spatial autocorrelation analysis to reveal the spatial differentiation and evolutionary characteristics of grain yield, which serve as the basis for demarcating agricultural and pastoral development zones. Subsequently, the Geodetector model is utilized to identify the dominant factors controlling yield differentiation and their interactive effects, thereby exploring strategies to enhance grain yield and safeguard food security within the region. The main findings are as follows: (1) From 2000 to 2020, grain yield exhibited a relatively stable agglomerative distribution pattern, with macro-scale natural environmental differentiation serving as the fundamental controlling factor, while social production conditions and their coupling levels reinforced spatial variation characteristics. (2) Hotspot areas of high yield were concentrated in the northeastern plains and the southwestern Hehuang Valley, whereas coldspot areas were located in central regions with severe soil erosion and hilly terrain. Sub-hot and sub-cold areas formed concentric ring structures around these cores. Based on this stable pattern, hotspot areas can be designated as agriculture-suitable zones, sub-hot and sub-cold areas as agro-pastoral coupling zones, and coldspot areas as ecological restoration zones, enabling tailored development of agriculture and animal husbandry. (3) The growth pattern of grain yield shifted from labor-intensive to modern agricultural technology-driven approaches. However, excessive decoupling emerged between labor, arable land, and modern technologies, coupled with insufficient integration among various agricultural technologies. Therefore, promoting "labor-land-technology" coupling development is recommended to foster healthy grain yield growth and enhance food security.

Keywords: food security; spatial variation of grain yield; influencing factors; Geodetector; argo-pastoral ecotone of northern China

1. Study Area Overview

Scholarly consensus regarding the precise boundaries of the northern argo-pastoral ecotone remains unsettled. This study focuses on county-level grain yield per unit area while maintaining administrative integrity, adopting the regional delineation from Ren et al. The ecotone is bounded between 100°–125°E and 34°–49°N, encompassing 173 counties (banners, county-level cities, and districts) with a total area of approximately 73$\times10^{4}$ km^2. The region transitions from the Inner Mongolian Plateau to the North China and Northeast Plains in the east, comprises primarily the Loess Plateau in the central portion, and transitions from the Loess Plateau to the Qinghai-Tibet Plateau in the west. Elevation increases from northeast to southwest, ranging from below 200 m to over 4,500 m. Mean annual precipitation varies between 200–500 mm, while mean annual temperature ranges from 2–8°C.

2. Data and Methods

2.1 Data Sources

Grain yield per unit area is represented by the ratio of total grain output to sown area. Data on total grain output, sown area, and social production indicators were obtained from the *China County-Level Statistical Yearbooks* (2000–2020) and provincial statistical yearbooks. Elevation and slope data were derived from 30 m$\times$30 m Digital Elevation Model (DEM) data, with raster statistics and slope analysis performed using ArcGIS 10.2. Soil fertility baseline data came from the China Soil Database, employing the comprehensive soil fertility index. Due to administrative adjustments during the study period, the 2020 administrative divisions served as the baseline, yielding 173 valid county-level units.

2.2 Methods

2.2.1 Spatial Autocorrelation Analysis Global Moran's I was employed to reflect the overall spatial clustering characteristics of grain yield, while hotspot analysis (Getis-Ord Gi*) examined local spatial agglomeration to identify "high-high" clustering hotspots and "low-low" clustering coldspots. The Global Moran's I and Getis-Ord Gi* statistics were calculated using ArcGIS 10.2.*

2.2.2 Geodetector Analysis Geodetector is a statistical method for detecting driving factors behind spatial differentiation of geographic phenomena. Its fundamental principle assumes that if a region is divided into sub-regions where the sum of variances is less than the total variance, spatial heterogeneity exists. When the spatial distributions of two variables converge, statistical association is indicated. The model comprises four modules: risk detection, factor detection, ecological detection, and interaction detection.

Factor detection assesses whether a factor significantly determines spatial variation by comparing spatial consistency between the factor and the geographic phenomenon. The q-statistic quantifies the explanatory power:

$$q = 1 - \frac{1}{N\sigma^2}\sum_{h=1}^{L} N_h \sigma_h^2$$

where q represents the explanatory power of factor X on the spatial pattern of phenomenon Y (range [0,1]), with larger values indicating stronger influence. L denotes the number of strata of factor X; N and N are the numbers of units in stratum h and the entire region, respectively; and $\sigma\ ^2$ and σ^2 represent the variances of Y in stratum h and the entire region.

Interaction detection identifies combined effects of factor pairs. Interaction types include: (1) Weakening (linear or double-linear), (2) Enhancement (linear or non-linear), and (3) Independence, determined by comparing the interaction q-value with individual factor q-values. Calculations were performed using the Geodetector software.

3. Results

3.1 Spatial-Temporal Differentiation Characteristics of Grain Yield

From 2000 to 2020, Global Moran's I values for grain yield in the northern argo-pastoral ecotone were all positive and statistically significant, indicating that high-yield and low-yield counties exhibited clear spatial clustering. Moreover, Global Moran's I remained relatively stable (0.4–0.5), demonstrating that spatial differentiation patterns possessed considerable stability.

Local spatial autocorrelation revealed a nested concentric structure centered on dispersed hotspots and coldspots (Figure 4). Hotspots were distributed in the northeast, south, and southwest, covering small but expanding areas—northeastern hotspots initially expanded and coalesced before fragmenting. Coldspots were concentrated in central regions with shrinking coverage and increasing concentration. Sub-coldspot areas diminished significantly, persisting only around coldspot peripheries, while sub-hotspot areas expanded correspondingly. Overall, grain yield improved, yet spatial differentiation remained pronounced, with few high-yield and low-yield counties locked into stable locational patterns.

3.2 Analysis of Influencing Factors

Drawing on existing research, 11 indicators were selected from social production conditions and natural conditions (Table 1). Geodetector analysis quantified their effects on spatial-temporal yield differentiation (Table 2).

In 2000, the dominant factor was grain-farming population size (q = 0.534), with all factor interactions significantly enhancing explanatory power. This indicates that counties with larger farming populations invested more labor in intensive cultivation, realizing yield potential, while industrialization and urbanization-driven population decline led to farmland abandonment and reduced productivity, exacerbating spatial differentiation.

In 2010, fertilizer application became dominant (q = 0.654), with all interactions enhancing explanatory power. Given generally low soil fertility in the ecotone, fertilizer emerged as the primary means to enhance soil productivity, with usage level differences substantially influencing yield variation.

In 2020, fertilizer application remained dominant (q = 0.760), but its interaction with other social production factors declined, particularly with grain-farming population size, indicating agricultural machinery substitution for labor and decoupling of "labor-land-technology." Modern agricultural technologies became key differentiation drivers, yet weak interactions among technology factors—especially between fertilizer and other technologies—suggested insufficient synergy, risking diminishing marginal returns and soil degradation.

Natural conditions showed varied trends: slope and soil fertility constraints weakened due to land consolidation and high-quality farmland construction, while climate factors (precipitation, temperature, sunshine) gained prominence. All natural factor interactions with fertilizer exceeded q = 0.5, particularly precipitation-fertilizer interaction (q = 0.816), demonstrating that favorable natural conditions amplified fertilizer effects, reinforcing spatial differentiation.

4. Discussion

4.1 Significant and Relatively Stable Spatial Differentiation

From 2000 to 2020, grain yield exhibited significant spatial clustering. Hotspots were located in the northeastern plains (e.g., Kezuozhong Banner, Kailu County) and southwestern Hehuang Valley (e.g., Minhe County, Xunhua County), characterized by flat terrain, fertile soil, and high mechanization. Coldspots were concentrated in central Inner Mongolia (Shangdu County, Taipusi Banner) and Shanxi (Loufan County, Gujiao County), where severe land degradation, poor soil quality, and low modernization prevailed, leading to abandonment and conversion to grassland. Some naturally favorable areas like Huan County (Gansu) and Tongxin County (Ningxia) improved yields through water-saving irrigation, becoming sub-hotspots. These patterns align with previous land-use studies and agricultural zoning schemes, confirming that stable grain yield differentiation comprehensively reflects farmland productivity potential, providing a scientific basis for regional agricultural planning.

4.2 Natural-Social Condition Interactions Control Differentiation

Geodetector analysis not only corroborates existing findings—modern technology replacing labor as the dominant factor, and favorable water-heat conditions promoting yield—but also reveals new trends: constraints from slope, soil fertility, and sown area have weakened. More importantly, by analyzing factor interactions, this study demonstrates that macro-scale natural environmental differentiation forms the fundamental control, while social production conditions and their coupling levels reinforce spatial variation. This mechanistic understanding scientifically grounds the zoning approach. Additionally, excessive decoupling between labor, land, and technology, plus weak coupling among technologies, were identified as emerging issues.

4.3 Food Security Recommendations

Zoning-based Coordinated Development: Based on yield differentiation patterns, the ecotone can be divided into: (1) Agriculture-suitable zones (hotspots) in the southwest and northeast, (2) Agro-pastoral coupling zones (sub-hot/sub-cold spots) in the north and south, and (3) Ecological restoration zones (coldspots) in the central region (Table 4). In agriculture-suitable zones, land consolidation and high-standard farmland construction should enhance water/fertilizer retention. Coupling zones should integrate crop-livestock systems, adjust planting structures based on water availability, and develop drought-resistant varieties. Restoration zones should prioritize ecological barriers, promoting conversion of farmland to grassland and conservation tillage.

"Labor-Land-Technology" Coupling Development: To address decoupling issues, measures should include: (1) Establishing grain production subsidy systems to stabilize farmer income and labor scale, (2) Developing farmer cooperatives and agribusinesses to enhance land consolidation and mechanization services, (3) Improving farmers' technical skills for multi-stage machinery operation, and (4) Promoting synergistic technology application for precise water-fertilizer control, ensuring sustainable yield growth.

5. Conclusions

This study integrated spatial autocorrelation and Geodetector analyses to examine county-level grain yield patterns and drivers in the northern argo-pastoral ecotone from 2000–2020. Key conclusions are:

1) Under macro-scale natural environmental controls, social production conditions and their coupling levels reinforced spatial differentiation, creating stable, spatially dependent patterns. Hotspots concentrated in favorable northeastern plains and southwestern valleys, while coldspots occupied central degraded/hilly areas. Sub-hot and sub-cold areas formed concentric rings, enabling zoning into agriculture-suitable, agro-pastoral coupling, and ecological restoration zones for tailored development.

2) The yield growth model shifted from labor- to technology-driven, but excessive decoupling between labor-land-technology and weak inter-technology coupling emerged. Promoting "labor-land-technology"

coupling through subsidies, organizational development, and synergistic technology application is essential for sustainable yield growth and enhanced food security.

References

[1] Ji Long, Xu Chunchun, Chen Zhongdu, et al. The fluctuation of grain production in China: Characteristics, causes and implications[J]. Chinese Journal of Agricultural Resources and Regional Planning, 2020, 41(3): 46-52.

[2] Li Xiande, Sun Zhilu, Zhao Yuhan. Global food security and its governance: Development process, practical challenges and transformation strategies[J]. Chinese Rural Economy, 2022(6): 2-22.

[3] Ding Cunzhen, Xu Xuanguo. Research on security risks of international food supply chain and countermeasures[J]. Economist, 2022(6): 109-118.

[4] Zhao Lei. Global food security and food security governance with Chinese characteristics[J]. Contemporary China and World, 2022(2): 59-67, 127-128.

[5] Cheng Shengkui, Li Yunyun, Liu Xiaojie, et al. Thoughts on food security in China in the new period[J]. Journal of Natural Resources, 2018, 33(6): 911-926.

[6] Gao Shuqin, Duan Rui, Wang Hongsheng, et al. Farming pastoral ecotone of northern China plays important role in ensuring national food security[J]. Bulletin of Chinese Academy of Sciences, 2021, 36(6): 643-651.

[7] Zhang Zhixin, Wang Di, Tang Haiyun. China's grain security guarantee: An analysis based on the change of grain consumption structure[J]. Consumer Economics, 2022, 38(5): 38-49.

[8] Tao Zefu, Wang Shiqing, Sun Piling, et al. Spatio-temporal differentiation and driving factors of cropland in the agro-pastoral ecotone of northern China[J]. Arid Land Geography, 2022, 45(1): 153-163.

[9] Chen Hai, Kang Muyi, Cao Mingming. Spatial differentiation pattern of production structure in the farming-pastoral crisscross zone of north China[J]. Bulletin of Soil and Water Conservation, 2007, 27(2): 46-49.

[10] Hu Binghui, Liao Yuncheng, Wang Keqin, et al. The comparison and evolvement of agroecosystem structure in representative counties of the farming-pastoral ecotones in north China[J]. Research of Soil and Water Conservation, 2011, 18(2): 35-39, 43.

[11] Zhou Lihua, Ma Yonghuan, Ma Shaoxiu. Food supply and grain for green project in the water-wind erosion compound areas of farming and grazing interlaced zone in northern China[J]. Journal of Desert Research, 2007, 27(4): 552-557.

[12] Li Yuhong. On grain production and ecological security barrier construction in Inner Mongolia[J]. Ecological Economy, 2017, 33(3): 115-119.

[13] An Pingli, Pan Zhihua, Zheng Dawei. Reconstruction land use structure in northern ecotone: The case of Wuchuan County[J]. Resources Science, 2002, 24(1): 35-39.

[14] Yang Qian, Si Xianghui, Wang Jue. The measurement and its distribution dynamic evolution of grain production efficiency in China under the goal of reducing pollution emissions and increasing carbon sink[J]. Journal of Natural Resources, 2022, 37(3): 600-615.

[15] Yin Peihong, Fang Xiuqi, Zhang Xuezhen, et al. Identification of the susceptible regions to climate change impact on grain yield per unit area in China[J]. Acta Geographica Sinica, 2010, 65(5): 515-524.

[16] Li Menghua, Han Yingjuan, Zhao Hui, et al. Analysis on spatial-temporal variation characteristics and driving factors of fractional vegetation cover in Ningxia based on geographical detector[J]. Ecology and Environmental Sciences, 2022, 31(7): 1317-1325.

[17] Li Yuntao, Tao Li. An analysis of spatial differentiation of tourism development level in border cities of Yunnan Province and influencing factors based on geo-detector[J]. World Regional Studies, 2022, 31(3): 624-636.

[18] Liu Tongshan. Connotations, challenges, and policy recommendations for ensuring national grain security in the new era[J]. Academic Journal of Zhongzhou, 2022(2): 20-27.

[19] Zhang Liguo, Bao Bingfei, Dong Liang. Spatial and temporal pattern evolution of grain yield and spatial heterogeneity of driving factors in Poyang Lake eco-economic zone[J]. Economic Geography, 2018, 38(2): 154-161.

[20] Qiu Menglong, Cao Xiaoshu, Zhou Jian, et al. Spatial differentiation and impact factors of grain yield per hectare in Weibei Plateau based on GWR model: A case study of Binxian County, Shannxi[J]. Scientia Agricultura Sinica, 2019, 52(2): 273-284.

[21] Cheng Yeqing. Spatial pattern change and its driving factors of grain per unit area yield in northeast China[J]. Journal of Natural Resources, 2009, 24(9): 1541-1549.

[22] Liu Yu, Tang Xiumei, Pan Yuchun, et al. Analysis on spatial spillover effect and influence factors of grain yield per hectare at county level in Huang-Huai-Hai region[J]. Transactions of the Chinese Society of Agricultural Engineering, 2016, 32(9): 299-307.

[23] Shi Wenjiao, Liu Yiting, Shi Xiaoli. Quantitative methods for detecting the impacts of climate change on the fluctuation of farming-pastoral ecotone boundaries in northern China[J]. Acta Geographica Sinica, 2017, 72(3): 407-419.

[24] Ren Qiang, He Chunyang, Huang Qingxu, et al. The poverty dynamics in the agro-pastoral transitional zone in northern China: A multi-scale perspective based on the poverty gap index[J]. Resources Science, 2018, 40(2): 404-416.

[25] Deng Xiaoqian, Ma Sujuan, Cao Xiaoping, et al. Evaluation of the cultivated land fertility and trend of soil nutrient status of Huzhu County in Qinghai Province in the past 10 years[J]. Research of Soil and Water Conservation, 2022, 29(6): 112-120.

[26] Li Jie, Zheng Buyun, Wang Jinfeng. Spatial and temporal heterogeneity of hand, foot and mouth disease in China from 2008 to 2018[J]. Journal of Geo-information Science, 2021, 23(3): 419-430.

[27] Wang Jinfeng, Xu Chengdong. Geodetector: Principle and prospective[J]. Acta Geographica Sinica, 2017, 72(1): 116-134.

[28] Xia Siyou, Zhao Yuan, Xu Xin, et al. Spatiotemporal pattern and driving factors of grain production in Jiangsu Province[J]. Economic Geography, 2018, 38(12): 166-175.

[29] Wang Jundi, Liu Zhiqiang, Liu Liyin, et al. Study on the influencing mechanism of spatial differentiation of green rate of built district of typical transects in China based on geodetector[J]. Ecological Economy, 2020, 36(10): 104-111.

[30] Yan Xudong, Wu Xiaoguang, Zhang Hongfei, et al. Regional food production layout based on food security and ecological: The Inner Mongolia Autonomous Region[J]. Journal of Arid Land Resources and Environment, 2017, 31(9): 156-162.

[31] Tang Yingfang, Li Hongxia, Liu Jinhui, et al. Situation of grain production in Gansu Province and countermeasures for grain security in new period[J]. Gansu Agricultural Science and Technology, 2021, 52(8): 63-71.

[32] Wen Jing, Zhang Chao, Zhang Lijun, et al. Spatiotemporal evolution and influencing factors of Chinese grain production under climate change[J]. Journal of Henan University (Natural Science Edition), 2020, 50(6): 652-665.

[33] Wen Qi, Liu Yansui. The response of water, land and food security towards the aridification and the adaptive measures: Case study of northern Shaanxi Province[J]. Journal of Arid Land Resources and Environment, 2008, 22(7): 7-11.

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