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Spatial-temporal Characteristics of Eco-efficiency of Cultivated Land Use in Shannxi Plain, North-west China

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Abstract: Cultivated land plays a crucial role in guaranteeing food security, but the production factor inputs in the cultivated land use can also cause environmental pollution. Assessing the eco-efficiency of cultivated land use (ECLU) has an essential effect on achieving sustainable agricultural development. However, studies of the ECLU have focused on the assessment of large regions and differences due to environmental factors but have lacked the assessment of single production areas. This study utilizes the SBM to measure the ECLU in Shannxi Plain, based on 2011 to 2021 statistics. The results of the study provide a factual basis for the realization of sustainable agricultural development and recommendations for the formulation of policies for sustainable agricultural development.

Keywords: Cultivated land use; Ecological efficiency; SBM model; Carbon emission.

1. Introduction

Cultivated land is the foundation for ensuring food security contributes significantly to the ecosystem and is an essential resource for human survival and social development (Heyl et al., 2021). In the process of rapid urbanization and population growth, the excessive use of chemical fertilizers by farmers to increase food production has led to the large-scale accumulation of phosphorus in arable soils, threatening lakes and rivers with eutrophication, causing ecosystem imbalances and restricting agricultural production (Liu et al., 2017). Therefore, how to enhance the eco-efficiency of cultivated land use (ECLU) and realize the sustainable development of agricultural systems has become the focus of attention of scholars all over the world (Heidenreich et al., 2022). As a populous country with limited cultivated land resources, China has a per capita cultivated land area that is far below the world average standard, while at the same time safeguarding food security, which aggravates the excessive input of agricultural production factors. This high-input, high-output, low-efficiency agricultural production model overdraws soil fertility and generates a large amount of carbon emissions, thus China has placed greater emphasis on agro-ecosystems. In recent years, successive policies have been put forward to promote agricultural modernization and achieve sustainable agricultural development. Therefore, measuring ECLU is necessary to improve the sustainability of cropland ecosystems and to build sustainable agricultural production systems.

The Shannxi Plain is an important grain producing area in China, with about 80% of the main grain-producing counties in Shaanxi Province located in the area, and about 70% of the cultivated land in the region, which makes for excellent conditions for agricultural production. However, in recent years, the Shannxi Plain has been facing the problem of water shortage, and the irrigation water exceeds the supply rate, which directly affects agricultural production. Moreover, large amounts of chemical fertilizer and pesticide inputs over a long period have resulted in low soil organic matter and serious pollution. Therefore, there is an urgent need to measure the ECLU in Shannxi Plain and explore the impact mechanism of ECLU to guide the scientific and orderly development of sustainable agriculture.

2. Eco-efficiency of Cultivated Land Use

2.1. Definition of eco-efficiency of cultivated land use

Eco-efficiency is defined as the efficiency with which ecological resources are utilized to meet the needs of human survival and represents the degree of coordinated development of a complex ecosystem, which emphasizes the reduction of environmental pollution while maximizing economic output (Beltrán-Esteve et al., 2017). Cultivated land use efficiency is the use of labor, fertilizers, pesticides, and land as inputs, and agricultural output and food production as desired outputs, emphasizing the reduction of unnecessary factors of production and the enhancement of technological efficiency to increase the desired outputs (Guth and Smędzik-Ambroży, 2020). ECLU is interpreted as adjusting the allocation of factors of production to maximize food production and agricultural output, and to reduce environmental pollution caused by over-inputs of factors of production, that is, to reduce undesirable outputs, and therefore, carbon emissions are added to the model as undesirable outputs to represent environmental costs (Toma et al., 2017).

2.2. Measuring the eco-efficiency of cultivated land use

The focus of this study is to measure the ECLU that takes into account the environmental costs, therefore, the super-efficient SBM model proposed by (Tone, 2002) is used and carbon emissions are included in the model as a non-desired output. Reference to previous studies, we chose five input variables, two desired outputs, and one non-desired output. The five input variables were agricultural labor, fertilizers, pesticides, diesel fuel, and irrigation, the output variables were gross agricultural product and food production, and the non-desired output was carbon emissions. Carbon emissions and agricultural production factors are inseparable in the process of cultivated land use, so it is important to pay attention to the impact of cultivated land use on the environment. All variables were divided by crop sown area considering that the area of cultivated land varies between counties.

In calculating carbon emissions, based on the studies of, we chose fertilizers, pesticides, diesel fuel, agricultural films, tillage, and irrigation as the carbon sources in the process of cultivated land use. Carbon emissions are calculated as equation (1), and the carbon emission coefficients are selected as shown in table (1).

$$E = \sum_{i=1}^{6} E_i = \sum_{i=1}^{6} T_i \times \alpha_i \quad (1)$$

Table 1. Carbon emission Coefficients for different carbon sources

Carbon source	Fertilizer	Pesticide	Diesel fuel	Agricultural film	Tillage	Irrigation
Unit	kg/kg	kg/kg	kg/kg	kg/kg	kg/hm2	kg/hm2
Coefficient	0.8956	4.9341	0.5927	5.18	312.6	266.48

2.3. Spatial analysis of eco-efficiency of cultivated land use

Spatial autocorrelation identifies the spatial correlation of the ECLU ensuring the accuracy of the spatial measurement model using the global MoranI index to identify the level of spatial correlation between regions.

3. Results

3.1. Value of eco-efficiency of cultivated land use

Overall, the average ECLU in Shannxi Plain grew from 0.452 in 2011 to 0.721 in 2021 with significant efficiency improvements, as shown in Table (3). Except for Xingping, Huyi, and Zhouzhi, the ECLU of all districts improved, with the fastest growth rates in Weibin, Mei, and Lintong, which increased by 0.770, 0.721 and 0.713, respectively, which indicated that the ecosystems of cropland in these districts have been significantly improved. Dali, Tongguan, Fuping, and Pucheng had different levels of increase, but the average values were only 0.188, 0.225, 0.227, and 0.233, indicating that factor inputs in these districts still need to be improved. We found a slow growth from 2011 to 2018 and a rapid growth of ECLUs in Shannxi Plain from 2019 to 2021, a trend attributed to cultivation-related policies, socio-economic growth, and advances in agricultural technology. During the study year, the government successively launched policies on the cultivated land use, such as strengthening the quality of cultivated land, controlling the quality of land reclamation, promoting the construction of agricultural high-tech industries.

All regions of the Shannxi Plain showed an increasing trend during 2011-2021. The overall ECLU shows a fluctuating upward trend as it grows from 0.452 in 2011 to 0.514 in 2012, followed by a brief decline to 0.469 in 2014, then remains essentially stable from 2014 to 2018, and finally shows a rapid increase starting in 2019, rising for three consecutive years to 0.721 in 2021. The Western Region shows two declines in 2013 and 2016, then a steady increase from 2016, and a rapid increase starting in 2019 to 0.909 in 2021. The ECLU in the North Central region is closest to the mean, with only small increases and decreases between 2011 and 2018, and a noticeable upward trend beginning in 2019. The Central Region follows a similar trend to the overall change, but with a greater increase or decrease, reaching an ECLU of 0.815 in 2021 second only to the Western Region. The ECLU in the East has improved, but with an ECLU of only 0.467 in 2021, there is still a lot of space for improvement.

3.2. Spatial characteristics of the eco-efficiency of cultivated land use

3.2.1. Spatial distribution of eco-efficiency of cultivated land use

To ensure the comparability of ECLUs in different time periods, ECLUs were classified into five grades: low efficiency (0-0.3], Medium-low efficiency (0.3-0.5], medium efficiency (0.5-7], Medium- high efficiency (07-1), and high efficiency [1-∞], and the efficiency grade change trends and spatial distributions of ECLU in Shannxi Plain was obtained. Overall, in 2011, there were only four high efficiency districts, and 24 low and medium-low efficiency districts occupying more than two-thirds of the districts, indicating a low overall efficiency. In 2014, the overall efficiency improved slightly, with the number of low efficiency districts decreasing and the number of medium efficiency districts increasing. The efficiency of districts gradually improved in 2017, with the number of medium efficiency districts decreasing and the number of high efficiency districts increasing. By 2021, the overall efficiency has improved significantly, with the number of low and medium-low efficiency districts reduced to 9, with only two low efficiency districts in Dali and Zhouzhi counties, 7 medium efficiency districts, and the number of high and medium efficiency districts increased to 16, mainly in the western and central clusters.

3.2.2. Spatial autocorrelation analysis of eco-efficiency of cultivated land use

The Moran's I was positive and passed the significance test of 1%, 5%, and 10% respectively during the study years. The Moran's I show an overall trend of "increasing, then decreasing, then increasing", gradually increasing from 0.09 in 2011 to 0.202 in 2015, then decreasing to 0.105 in 2019, and finally increasing to 0.184 in 2021, which indicates that ECLUs at the county level in Shannxi Plain have a stable positive spatial correlation, so the spatial econometric model is further used to investigate their spatial effects. spatial correlation, so further spatial econometric modeling was used to investigate its spatial effects.

ECLU of Shannxi Plain has significant regional differences, in 2011, the western and north central regions were mostly medium and low efficiency regions, the central region has no obvious clustering characteristics, and in the eastern region, only Huayin City is high efficiency the rest are all low efficiency regions. The four high-efficiency regions of Qishan, Xingping, Gaoling, and Huayin experienced a decline in ECLU between 2011 and 2014, while the remaining districts in the north-central and eastern regions remained low and medium-low efficiency, with the western and central regions beginning to show a clustering of medium efficiency districts, and the overall trend is still upward. The ECLU continued to grow in all regions between 2014 and 2017, with high efficiency districts clustering in the Central region, no significant change in the North Central and Eastern regions, and an overall decline in the Western region. There is significant growth in efficiency across regions between 2017- and 2021, with the Central and Western regions dominated by high and medium-high efficiency districts, the North Central region mostly medium efficiency districts, and medium-low efficiency districts predominantly located in the East region.

4. Conclusion

This study measured the ECLU in the Shannxi Plain and explored the Spatial characteristics of ECLU. We find that:(1) from 2011 to 2021, the overall ECLU of Shannxi Plain grows significantly, and the ECLU of the remaining regions except Xingping, Shuangyi and Zhouzhi are improved; (2) spatially, there is a positive spatial correlation of ECLUs, and there are regional differences, with the western and central regions being mostly high-efficiency and medium-efficiency districts followed by the central region being mostly medium-efficiency districts, while the low efficiency and medium-low efficiency districts are mostly located in the west region. The results show that even though natural conditions are similar within the one production area, ECLUs are still subject to differences in socioeconomic influences. Therefore, exploring internal differences provides a basis for implementing precision policies and reducing pollution of cultivated land to achieve sustainable development of agricultural systems.

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