Study on the Measurement of Agricultural Eco-Efficiency and the Influencing Factors in the Yellow River Basin

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Abstract. Based on the background of getting the “Double Carbon” target and the high-quality advancement of the Yellow River basin, the agricultural carbon emissions and agricultural eco-efficiency of the nine provinces in the Yellow River basin from 2011 to 2021 were quantified using a carbon emissions computation model and an Super-SBM Model. ArcGIS was utilized to clarify the spatiotemporal evolution features of both variables, and a panel Tobit model was utilized to conduct empirical assessment of the contributing factors of agricultural eco-efficiency. The results demonstrated that since 2016, the carbon emissions of the Yellow River basin have shown the "high output-low emissions" of characteristics. The agricultural eco-efficiency is overall at a medium to high level and has constantly improved environmentally, but there are significant inter-provincial differences. Empirical examination analysis indicated that the economic development level of the Yellow River basin is positively U-shaped with regard to agricultural eco-efficiency, and rural per capita disposable income, machine tool density, industrialization level, and the regard of field planting of food crops have a substantial effect on agricultural ecological efficiency. Among them, machine tool density shows a negative effect, while other factors show a positive effect. Based on this, a proposal is designed to improve the structure of agricultural input determinants] by pooling determinant endowments, promote the reasonable assignment of agricultural factor resources among provinces, and enhance agricultural ecological efficiency to support the high-quality promote of the Yellow River basin.

1 Introduction

In September 2020, General Secretary Xi Jinping announced at the 75th session of the UN General Assembly that "China strives to reach the peak of carbon dioxide in 2030 and attain carbon neutrality before 2060". In October 2021, the State Council issued the "Working Guidance For Carbon Dioxide Peaking And Carbon Neutrality In Full And Faithful Implementation Of The New Development Philosophy", which is a systematic overall approach for achieving peak carbon emissions and carbon neutrality (referred to as "Double Carbon"). As an important ecological shelter in China, the low-carbon evolution of the Yellow River Basin is of great significance to the realization of China's "double carbon" goal. General Secretary Xi Jinping clarified the important perspective of the Yellow River basin in China's economic advancement and ecological protection. Enhancing agricultural eco-efficiency is a realistic selection to attain low-carbon development and "Double Carbon" goals in the Yellow River Basin. In 2021, the State Council's "China to fully advance rural vitalization, enable modernization of agriculture, rural areas" pointed out that demonstration counties for in-depth management of agricultural surface source pollution should be built in the Yellow River Basin to advance the green development of agriculture.

As the main production area of agricultural products in China, the Yellow River Basin accounts for about one-third of the country's food production, and the bottlenecks of agricultural surface source pollution and greenhouse gas emissions produced by its effective agricultural construction have become key barriers to its low-carbon development. Therefore, breaking the bind on the development of agro-ecological and economic systems, balancing the association between ecological protection and economic advancement in the Yellow River Basin is the primary task to promote the high-quality progress of the Yellow River Basin in an integrated manner. Hence, we constructed an agricultural eco-efficiency evaluation method from the opinion of carbon emission reduction and sequestration, quantifies the agricultural eco-efficiency of nine provinces in the Yellow River Basin from 2011 to 2021 using the Super-SBM model with undesired output, clarified the spatial and temporal evolution characteristics of agricultural carbon emission and agricultural eco-efficiency in the Yellow River Basin based on ArcGIS, and explored the influencing factors of agricultural eco-efficiency using the panel Tobit model to provide a reference basis for promoting high-quality agricultural development in the Yellow River Basin and attaining the alignment with China's "double carbon" goal.
2 Index system and Methods

2.1 Index system

The concept of eco-efficiency was defined as the ratio of economic value created in production activities to environmental impact [1]. The essence of Agricultural Eco-efficiency (AEE) is to obtain as much economic output as possible with as little investment in agricultural resources and environmental costs as possible, and comprehensively weigh the harmonious and win-win relationship among economy, ecology and resources [3]. We construct the evaluation index system of AFF in the Yellow River Basin is constructed (Table 1). The calculation of agricultural carbon emission refers to the model and calculation coefficient of carbon emission of Li Bo et al. [3], and selects six types of direct or indirect carbon emission coefficients, including 312.6 (kg/hm²) of agricultural tillage, 25 (kg/hm²) of agricultural irrigation, 4.9341 (kg/kg) of pesticide, 0.8956 (kg/kg) of chemical fertilizer, 5.15 (kg/kg) of agricultural film and 0.5927 (kg/kg) of diesel oil. Agricultural non-point source pollution emissions are mainly based on the emission (loss) coefficient of the farming and sowing process given by the 'Agricultural Pollution Source Emission Coefficient Manual', and considering regional differences to calculate the total pollution quantity of pesticides, fertilizers and agricultural film pollution.

Table 1. Index system of agricultural eco-efficiency

<table>
<thead>
<tr>
<th>First grade indexes</th>
<th>Second index</th>
<th>Variable declaration</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production inputs</td>
<td>Land input</td>
<td>Total sown area of crops</td>
<td>Thousand hectares</td>
</tr>
<tr>
<td></td>
<td>Water use input</td>
<td>Effective irrigation area</td>
<td>Thousand hectares</td>
</tr>
<tr>
<td></td>
<td>Pesticide input</td>
<td>Pesticide usage</td>
<td>10000 tons</td>
</tr>
<tr>
<td></td>
<td>Fertilizer input</td>
<td>Fertilizer application amount</td>
<td>10000 tons</td>
</tr>
<tr>
<td></td>
<td>Agricultural film input</td>
<td>Agricultural plastic film usage</td>
<td>10000 tons</td>
</tr>
<tr>
<td></td>
<td>Mechanical input</td>
<td>Total power of agricultural machinery</td>
<td>10000 kilowatts</td>
</tr>
<tr>
<td></td>
<td>Labor input</td>
<td>Number of agricultural labourers</td>
<td>10000 people</td>
</tr>
<tr>
<td></td>
<td>Asset input</td>
<td>Total value of agricultural fixed assets investment</td>
<td>RMB 100 million</td>
</tr>
<tr>
<td>Desirable outputs</td>
<td>Economic output</td>
<td>Total agricultural output value</td>
<td>RMB 100 million</td>
</tr>
<tr>
<td></td>
<td>Social output</td>
<td>Total agricultural output</td>
<td>10000 tons</td>
</tr>
<tr>
<td></td>
<td>Ecological output</td>
<td>Agricultural carbon sinks</td>
<td>10000 tons</td>
</tr>
<tr>
<td>Undesirable outputs</td>
<td>Agricultural carbon emissions</td>
<td>The sum of carbon emissions from farming, irrigation, pesticides, fertilizers, agricultural films, etc.</td>
<td>10000 tons</td>
</tr>
<tr>
<td></td>
<td>Agricultural non-point</td>
<td>Pesticide, fertilizer, agricultural film</td>
<td>tons</td>
</tr>
</tbody>
</table>

2.2 Research methods

2.2.1 Calculation of agricultural carbon emission

Based on the IPCC carbon emission coefficient method, the calculating equation is as follows:

\[ C = \sum C_j = \sum E_j \times F_j \]  

(1)

C is the total carbon emissions, \( C_j \), \( E_j \) and \( F_j \) are the carbon emissions, activity level and carbon emission coefficients of the carbon source respectively of \( j \).

2.2.2 Calculation of agricultural non-point source pollution emissions

According to the accounting methods and of agricultural source production and pollution discharge in the 'Manual of Accounting Methods and Coefficients for Emission Source Statistical Survey', the calculating equation is as follows:

\[ P = \sum P_j = \sum E_j \times Q_j \]  

(2)

\( P \) is agricultural non-point source pollution, \( P_j \), \( E_j \), \( Q_j \) is respectively the pollution amount, activity, level emission coefficient of agricultural non-point source of \( j \).

2.2.3 Calculation of agricultural carbon emission intensity

The agricultural carbon emission intensity test refers to the carbon consumed per unit of agricultural economic benefit [4], so the agricultural carbon emission intensity can be expressed as:

\[ T = \frac{C}{GDP_p} \]  

(3)

\( T \) is the agricultural carbon emission intensity, \( C \) is the total agricultural carbon emission, and GDP\(_p\) is the total agricultural output value.

2.2.4 Super-efficient SBM model of undesirable output

Because the traditional DEA model is difficult to distinguish the efficiency differences of multiple decision-making units with the same maximum efficiency value of 1, and there are limitations in the selection of regression models for analyzing influencing factors, this paper chooses the super-efficient SBM model proposed by Andersen et al. [5], which can further distinguish its effectiveness. The model can effectively overcome the above problems, that is, the obtained optimal solution is dimensionless and the SBM efficiency value is allowed to be greater than 1.
Suppose that there are n decision-making units in the agricultural production ecosystem of the Yellow River basin. Each decision-making unit contains m production input factors, S₁ desirable output factors and S₂ undesirable output factors. This paper uses the super-efficiency SBM model with undesirable output to measure the agricultural ecological efficiency. The formula is as follows:

$$\min \theta = \frac{1 + \frac{1}{m} \sum_{i=1}^{m} w_i^\prime x_{ij}}{1 - \frac{1}{S_1 + S_2} \left( \sum_{i=1}^{m} w_i^\prime y_{ij}^d + \sum_{i=1}^{m} w_i^\prime y_{ij}^u \right)}$$

s.t. \( \sum_{i=1}^{m} y_{ij}^d = w_j^\prime y_{ij} - w_j^\prime y_{ij}^* \), \( i = 1, 2, \cdots, m \)

\( y_{ij}^d \geq \sum_{j=2}^{S_2} y_{ij}^d + w_j^\prime, r = 1, 2, \cdots, s_2 \)

\( y_{ij}^u \geq \sum_{j=1}^{S_1} y_{ij}^u + w_j^\prime, z = 1, 2, \cdots, s_1 \)

\( \lambda_i > 0, j = 1, 2, \cdots, n, j \neq k; w_j^\prime \geq 0, i = 1, 2, \cdots, m \)

\( w_j^\prime \geq 0, w_j^\prime \leq y_{ij}^d, r = 1, 2, \cdots, s_1; w_j^\prime \geq 0, z = 1, 2, \cdots, s_2 \)  (4)

Among them, n is the number of decision-making units; \( x_{ij} \) represents the i input of the k unit. Similarly, \( y_{ij}^d \) and \( y_{ij}^u \) are the r desired output and z undesired output of the k unit respectively; m, S₁ and S₂ are the numbers of input, desired output and undesired output respectively; \( w_j^\prime \), \( w_j^\prime \) and \( w_j^\prime \) are the slack of input, desired output and undesired output respectively; \( \lambda \) is the weight vector of each decision-making unit; \( \theta \) is the value of agricultural ecological efficiency.

2.2.5 Tobit model

Because the efficiency values are mostly limited dependent variables between 0 and 1, the ordinary least squares estimation cannot meet the unbiasedness. Therefore, this paper uses the panel Tobit model to test the influence of various influencing factors on the agricultural eco-efficiency in the Yellow River Basin. The maximum likelihood estimation method ensures the unbiasedness and effectiveness of parameter estimation. The specific form of the model is as follows:

$$\left\{ \begin{array}{l}
Y_{i, t}^* = \beta_0 + \sum_j \beta_j X_{i, t, j} + u, \quad u \sim N(0, \sigma^2) \\
Y_{i, t} = \max(0, Y_{i, t}^*)
\end{array} \right.$$  (5)

Among them, \( Y_{i, t} \) is the agricultural eco-efficiency value of the i province in the t year, \( Y_{i, t}^* \) is the latent variable, \( X_{i, t, j} \) is the j influencing factor of the i province in the t year, \( \beta_0 \) is the intercept term, \( \beta_j \) is the parameter to be estimated of the j influencing factor, and \( u \) is the random error term subject to normal distribution.

3 Results and Analysis

3.1 Time-series characteristics of agricultural carbon emissions in the Yellow River Basin

From Figure 1, it can be seen that the agricultural carbon emissions in the Yellow River Basin showed a generally gradual increase followed by a gradual decrease in the overall trend. During the period from 2011 to 2015, the carbon emissions continued to increase, reaching a maximum value of 309.914 in 2015, with a 6% increase compared to 2011. Annual carbon emissions increased by 1.18% during this period. From 2015 to 2021, the downward trend was more significant, and the lowest emissions value was recorded in 2021, with a reduction of 1.68% per year during 2011-2021.

Fertilizers are the most important source of agricultural carbon emissions, with an average contribution rate of 62.15% to carbon emissions, followed by plastic films, diesel fuel, and pesticides, with average contribution rates of 17.32%, 11.57%, and 6.22% respectively. From an inter-year change vision, the carbon emissions from the use of fertilizers are consistent with the overall trend of agricultural carbon emissions, which shows a gradual increase followed by a gradual decrease. The carbon emissions peak in 2015 reached 19.32 million tons, accounting for 62.04%.

The emissions of carbon dioxide due to the use of plastic films in agriculture have been on a rising trend before 2016 and reached a maximum of 514.8 million tons in 2016. However, it has since decreased gradually, but its proportion in agricultural total emissions has been gradually increasing, reaching a maximum of 17.32% in 2021. Although the emissions of carbon dioxide due to agricultural land occupation and agricultural irrigation have shown a trend of annual fluctuations, it accounts for a very small proportion of agricultural total emissions, and the carbon sinks brought by crops can offset their generated carbon dioxide, making them insignificant. The carbon emissions due to pesticides and agricultural diesel have been decreasing, but the overall reduction is not significant, and their proportion in agricultural total carbon dioxide emissions is the same.

![Fig 1. The timeline characteristics of agricultural carbon dioxide emissions structure from 2011 to 2021.](image-url)
3.2 Spatial-characteristics of agricultural carbon dioxide emissions in the Yellow River Basin.

We explored the spatial characteristics of agricultural carbon dioxide emissions in the Yellow River Basin using ArcGIS 10.8, focusing on both the total amount of agricultural carbon dioxide emissions and their intensity. The study shows that the color blue indicates higher carbon dioxide emissions, while the color red indicates higher carbon dioxide intensity. According to Figure 2, the two provinces of Henan and Shandong are the high-emitting areas for agricultural carbon dioxide emissions in the Yellow River Basin, followed by Sichuan, which is located in the middle-to-high emitting area. Shaanxi and Inner Mongolia are classified as medium-emitting areas, while Shanxi, Gansu, Ningxia, and Qinghai are classified as low-to-middle emitting areas. From the perspective of agricultural carbon dioxide intensity, all provinces in the Yellow River Basin had higher average carbon dioxide intensity in 2011, with an average of 0.207. Ningxia, Gansu, Inner Mongolia, and Henan are located in the high-intensity emitting areas, followed by Shanxi, Shandong, Shaanxi, and Sichuan, which are located in the middle-to-high emitting areas.

During the period from 2011 to 2016, carbon emissions in the Yellow River Basin increased except for Shandong Province. However, the intensity of carbon emissions decreased gradually. The agricultural carbon emissions changed greatly in Inner Mongolia and Gansu, where Gansu shifted from a low-emissions area to a medium-emissions area, and Inner Mongolia shifted from a medium-emissions area to a high-emissions area. The low-value areas remained in Qinghai and Ningxia. Although the agricultural carbon emissions of Shandong decreased, they remained in a high-emissions area. In contrast, the carbon emissions of Henan increased from 2011, and they greatly increased the agricultural carbon emissions of the entire Yellow River Basin. From the perspective of carbon emissions intensity, Gansu, Ningxia, and Henan Provinces entered the medium-to-high intensity area, while Shaanxi and Shandong decreased to the medium intensity area. Qinghai and Sichuan entered the medium-to-low intensity area.

From 2016 to 2021, the agricultural carbon emissions and carbon emissions intensity in the Yellow River Basin showed a positive trend. Combining Figure 2 and Figure 3, the total carbon emissions in the Yellow River Basin decreased from 3102 in 2016 to 2700 in 2021. The optimization of agricultural carbon emissions in Gansu was the most significant, shifting from a medium-to-high emissions area to a medium emissions area. Although the agricultural carbon emissions of other several provinces decreased, there was no improvement in the emissions level. A more optimistic conclusion can be drawn by comparing the carbon emissions intensity of the Yellow River Basin in 2016 and 2021. The carbon emissions intensity of nine provinces in the Yellow River Basin decreased by one or two levels. The carbon emissions intensity of Qinghai, Sichuan, and Shaanxi has decreased to the lowest level. Shanxi and Ningxia Provinces shifted from a high-to-medium emissions area to a medium-to-high emissions area. Gansu, Henan, Shandong, and Inner Mongolia Provinces shifted from a medium-to-high emissions area to a medium-to-low emissions area. The average carbon emissions intensity of the Yellow River Basin decreased from 0.167 in 2016 to 0.111 in 2021, crossing from a high-to-medium emissions area to a medium-to-low emissions area.
Through comparative analysis, we found that during the century from 2011 to 2021, the agricultural carbon emissions in the Yellow River Basin showed an inverted "U"-shaped trend. The agricultural carbon emissions intensity illustrated a gradually declining trend. It showed that the development of agriculture in the Yellow River Basin shifted from "low output-low emissions" to "high output-high emissions" and then to "high output-low emissions". Under the goal of "Double Carbon", the development of agriculture in the Yellow River Basin is constantly optimized and improved. From the side, it demonstrates that since 2016, the agricultural ecology of the Yellow River Basin has continued to improve.

3.3 Spatiotemporal characteristics of AEE in the Yellow River basin

3.3.1 Overall efficiency analysis

Matlab R2022a was utilized to calculate the agricultural ecological efficiency of nine provinces in the Yellow River Basin from 2011 to 2021. As shown in Fig 4, the agricultural ecological efficiency values in the Yellow River Basin fluctuated between 0.80 and 1.03 during the investigation period, with an average efficiency of 0.88. From the perspective of temporal evolution, the amplitude of AEE in the entire region fluctuated relatively small, showing a two-stage trend of "fluctuation decline followed by fluctuation increase". The value of mean decreased from 0.89 in 2011 to 0.81 in 2016, and then increased to the highest value of 1.03 in 2021. Referring to the standards [6-7], the AEE in the Yellow River Basin is broadly at a moderately high level, achieving relative effectiveness according to DEA. It means that the input allocation in agricultural construction activities within the basin is relatively reasonable.

3.3.2 Provincial efficiency analysis

Analysis from the perspective of province, Qinghai has rather high AEE. As a demonstration province for green organic agriculture and livestock products in China, it has attained a green govern coverage rate of over 47%. Agricultural non-point source pollution has been effectively controlled, and actions to reduce the use of chemical fertilizers and pesticides have been highly successful. Inner Mongolia and Sichuan have an average annual efficiency value of 0.98, possibly due to the abundant agricultural resources in Inner Mongolia. During the 13th Five-Year Plan period, Inner Mongolia implemented the “control of fertilizer and pesticide” action, resulting in significant achievements in agricultural planting structure, favorable trends in economic crop production, and a significant increase in agricultural productivity. Sichuan has applied the agricultural construction policy of “control, reduction, and basic requirements,” adhering to an ecological priority policy and investing special funds for ecological poverty alleviation, effectively keeping AEE within the province. Shaanxi has an annual average agricultural ecological efficiency value of 0.97, with small fluctuation amplitude, essentially achieving relative effectiveness according to DEA. With its advantages in modern agricultural technology and openness to the outside world, Shaanxi leads the innovation-driven frontier of agricultural technology in China’s arid and semi-arid regions in terms of agricultural ecological protection.

Agricultural ecological efficiency in Shanxi, Gansu, and Shandong is lower than the total average in the river basin. Shanxi has long relied on coal resources for economic development, and many areas suffer from insufficient agricultural infrastructure and perennial resource constraints. Located in the Loess Plateau, excessive development has triggered severe soil erosion, rapid decline of soil fertility, increasing desertification, and the excessive utilization of fertilizers and pesticides, which hinders the refinement of AEE. Gansu is located at the intersection of the Loess Plateau, the Qinghai-Tibet Plateau, and the Inner Mongolia Plateau, characterized by intricate terrain, diverse landforms, and climate types. It has an annual average precipitation that is less than half of the national average. It belongs to normal dryland agriculture, leading to inevitable excessive utilization of pesticides, fertilizers, and plastic film, exacerbating the inconsistencies between advancement and ecosystem. In Shandong, the agricultural production capacity is mainly based on high consumption and high input. It suffers from severe agricultural non-point source pollution, with issues such as plastic film pollution and inefficient utilization of straw lacking effective management. The carrying capacity of agricultural ecological resources frequently shows warning signs. In summary, there is significant room for improvement in AEE in these three provinces.

3.4 Analysis on influencing factors of AEE

Identifying the factors that impact AEE is crucial for realizing the “Double-Carbon” goal in the Yellow River Basin. This study selects eight variables from five
dimensions, comprising economic level, natural conditions, agricultural inputs, industrialization level, and agricultural structure, to analyze their impact on AEE in the Yellow River Basin[8], as shown in Table 2.

Table 2. Indicators of Affecting AEE

<table>
<thead>
<tr>
<th>Category</th>
<th>Variable</th>
<th>Description</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economic Level</td>
<td>Rural Per Capita Disposable Income</td>
<td>Rural residents' per capita disposable income</td>
<td>10,000 ¥/person</td>
</tr>
<tr>
<td></td>
<td>Per Capita Agricultural Value Added</td>
<td>Agricultural, forestry, animal husbandry, and fishery value added per capita</td>
<td>10,000 ¥/person</td>
</tr>
<tr>
<td>Natural Conditions</td>
<td>Agricultural Disaster Rate</td>
<td>Area of crop disaster/Total area of crop cultivation</td>
<td>%</td>
</tr>
<tr>
<td>Agricultural Input</td>
<td>Agricultural Machinery Density</td>
<td>Agro-machinery power/Crop planting area</td>
<td>KW/hectare</td>
</tr>
<tr>
<td></td>
<td>Fertilizer Use Intensity</td>
<td>Fertilizer application amount/Arable land area</td>
<td>tons/hectare</td>
</tr>
<tr>
<td>Industrialization Level</td>
<td>Proportion of Industrial Added Value</td>
<td>Industrial value added/Regional GDP</td>
<td>%</td>
</tr>
<tr>
<td>Agricultural Structure</td>
<td>Planting Structure</td>
<td>Proportion of grain crop planting area/Total crop planting area</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Output Structure</td>
<td>Agricultural Value Added/Regional GDP</td>
<td>%</td>
</tr>
</tbody>
</table>

Considering that this study focuses on the nine provinces that are located in the Yellow River Basin, inter-provincial heterogeneity may lead to individual effects in the model. Therefore, a panel Tobit model with arbitrary effects is adopted for regression analysis. The results are listed in Table 3. Model 1 mainly examines the non-linear implication between agricultural ecological efficiency in the Yellow River Basin and the economic level. Model 2 investigates the specific impact of all factors on agricultural ecological efficiency. Based on the results of the LR test for Model 1 and Model 2, both reject the null hypothesis of no individual effects, thus confirming the efficacy of the model selection.

The results of Model 1 show that the linear terms of the two variables to economic level, are negative, while the quadratic terms are positive. This indicates a positive U-shaped connection between the economic level and agricultural ecological efficiency in the Yellow River Basin. This result is highly consistent with the findings of earlier studies such as Wang Baoyi (2018)[9] and the core viewpoint of the Environmental Kuznets Curve theory. The previous analysis revealed a inverted U-shaped pattern in carbon emissions in the Yellow River Basin. Combined with the findings of Model 1, it can be understood that when the economic development level in the Yellow River Basin is relatively low, there is a more urgent pursuit of output, which result in an extensive agricultural development mode. As the economic level improves, carbon emissions gradually increase while agricultural ecological efficiency continues to decline. However, when the economy reaches a certain level, aided by strong material conditions, people's demand for a good environment becomes stronger. Agricultural development begins to shift towards an intensive model, and agricultural ecological efficiency continuously improves with the growth in economic level, forming a positive U-shaped relationship.

The results of Model 2 indicate that per capita disposable income in the economic level has a positive effect on agricultural ecological efficiency, while per capita agricultural value-added shows a non-significant negative impact. The agricultural disaster rate exhibits a non-significant negative effect on agricultural ecological efficiency[10]. The occurrence of natural disasters reduces expected output and damages agricultural ecological efficiency. The non-significant effect may be due to continuous improvement in agricultural infrastructure and upgrading of disaster warning systems, which gradually reduce the marginal effects of disasters. Both factors of agricultural inputs have an inhibitory effect on agricultural ecological efficiency. The significance test of agricultural machinery density suggests that although mechanical inputs can effectively improve productivity, the use of energy sources such as petroleum and chemicals impose a heavy burden on the ecological environment. Using environmentally friendly machinery is the future direction for the development of green agricultural machinery in the Yellow River Basin. The improvement in industrialization level has a significant promoting effect on agricultural ecological efficiency. The increase in technological level and factor utilization brought about by industrial development provide a favorable foundation for the intensive and modernization of agriculture. Within the agricultural structure, an increase in the proportion of sown area for grain crops has a positive effect on agricultural ecological efficiency, indicating that grain crop production in the Yellow River Basin has demonstrated significant economies of scale. However, an increase in the proportion of agricultural output value has a negative impact on agricultural ecological efficiency. This may be attributed to the fact that the increase in agricultural output value in the Yellow River Basin is primarily reliant on high carbon-emitting inputs such as energy machinery, fertilizers, and pesticides. How to achieve increased expected output while simultaneously considering the environment and ecological efficiency remains a concern in the future.

Table 3. Regression Results

<table>
<thead>
<tr>
<th>Exploratory Variables</th>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Per Capita Disposable Income (Squared)</td>
<td>-0.1168(0.2161)</td>
<td></td>
</tr>
<tr>
<td>Per Capita Agricultural Value Added (Squared)</td>
<td>-0.9722*(0.4216)</td>
<td></td>
</tr>
<tr>
<td>Rural Per Capita Disposable Income</td>
<td>0.2153***(0.0739)</td>
<td>0.2463***(0.0581)</td>
</tr>
<tr>
<td>Per Capita Agricultural Value Added</td>
<td>0.1673***(0.0729)</td>
<td>-0.0276(0.0231)</td>
</tr>
<tr>
<td>Agricultural Disaster Rate</td>
<td>--</td>
<td>-0.0471(0.1444)</td>
</tr>
<tr>
<td>Agricultural Machinery Density</td>
<td>--</td>
<td>0.0431***(0.0108)</td>
</tr>
<tr>
<td>Intensity of Fertilizer Use</td>
<td>--</td>
<td>-0.2788(0.2575)</td>
</tr>
<tr>
<td>Proportion of Industrial Added Value</td>
<td>--</td>
<td>0.6754*(0.2817)</td>
</tr>
<tr>
<td>Planting Structure</td>
<td>--</td>
<td>0.7153***(0.2208)</td>
</tr>
</tbody>
</table>
endowment conditions of each province in the basin, improve the AEE of the Yellow River Basin, and promote agricultural carbon emissions in the Yellow River Basin, and promote the rational allocation of agricultural factor resources among different provinces and regions. Qinghai and Sichuan as the upper reaches of the Yellow River Basin region should play a leading role in green prevention and control demonstration areas, adhere to the ecological priority policy, take advantage of the location, to create green and organic products and well-known brand base. Shaanxi has good economic development, so it can sustain the advantages of modern agricultural science and the opening to the outside world, focusing on the development of modern agriculture and leading agricultural ecological protection with innovation in science and technology. Henan and Ningxia should vigorously develop refined agricultural industries, increase the added value of agricultural products, improve ecological protection compensation mechanisms, and improve AEE by optimizing planting patterns on the basis of existing arable land protection. Shanxi, Gansu and Shandong should speed up the improvement of agricultural infrastructure, overcome the problem of resource constraints, increase policy and financial support, and encourage local governments and farmers to develop green and low-carbon agricultural production, actively promote the evaluation system of green and low-carbon development of agriculture, and explore the establishment of a market-based mechanism for the price of agricultural ecological resources.

### 4 Conclusion and Discussion

#### 4.1 Conclusion

Based on the background of getting the "Double Carbon" goal and the high quality development of the Yellow River Basin, this study uses agricultural production and environmental impact data at nine provincial scales in the Yellow River Basin from 2011 to 2020 to evaluate agricultural carbon emissions and AEE by using a carbon emission calculation model and a super-SBM model. A panel Tobit model is also used to analyze the driving forces of the evolution of AEE in the watershed, and the outcomes are as follows:

During 2011-2021, agricultural carbon emissions in the Yellow River Basin show an inverted "U" curve, but the intensity of agricultural carbon emissions shows a progressively decreasing trend, indicating that the agricultural development in the Yellow River Basin has changed from "low output-low emission" to "high yield-high emission" and then to "high yield-low emission". The AEE of the Yellow River basin is at a medium to high level. The AEE values in the Yellow River Basin fluctuated between 0.80 and 1.03, with an annual average value of 0.88. In terms of temporal evolution, the amplitude of AEE in the whole region fluctuated less, showing a two-stage trend of "fluctuating down and then fluctuating up". In terms of spatial evolution, there are differences in efficiency levels among different provinces, with a fluctuating trend from upstream to downstream from high to low and then up again. The overall efficiency is high in Qinghai, Sichuan, Ningxia, Inner Mongolia, Shaanxi and Henan, while the efficiency in Gansu, Shanxi and Shandong is low.

As for the influencing factors, the results of the empirical analysis show that the level of economic development and agro-ecological efficiency in the Yellow River Basin exhibit a positive U-shaped relationship among the influencing factors, the per capita disposable income of rural residents, density of agricultural machinery, industrialization level, and the proportion of food crop sown area have significant effects on agroecological efficiency, with the density of agricultural machinery showing an inhibitory effect and other factors showing a facilitating effect.

#### 4.2 Discussion

In response to the findings of the study, in order to reduce agricultural carbon emissions in the Yellow River Basin, improve the AEE of the Yellow River Basin, and promote the high-quality development of the Yellow River Basin, the following suggestions are proposed: Integrate the endowment conditions of each province in the basin, improve the structure of agricultural input factors, and promote the rational allocation of agricultural factor resources among different provinces and regions. Qinghai and Sichuan as the upper reaches of the Yellow River Basin region should play a leading role in green prevention and control demonstration areas, adhere to the ecological priority policy, take advantage of the location, to create green and organic products and well-known brand base. Shaanxi has good economic development, so it can sustain the advantages of modern agricultural science and the opening to the outside world, focusing on the development of modern agriculture and leading agricultural ecological protection with innovation in science and technology. Henan and Ningxia should vigorously develop refined agricultural industries, increase the added value of agricultural products, improve ecological protection compensation mechanisms, and improve AEE by optimizing planting patterns on the basis of existing arable land protection. Shanxi, Gansu and Shandong should speed up the improvement of agricultural infrastructure, overcome the problem of resource constraints, increase policy and financial support, and encourage local governments and farmers to develop green and low-carbon agricultural production, actively promote the evaluation system of green and low-carbon development of agriculture, and explore the establishment of a market-based mechanism for the price of agricultural ecological resources.

### References

