Analysis of characteristics and influencing factors of agricultural carbon emission in Jiangxi Province, southeast China

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Abstract: With the continuous economic development and population growth, carbon emissions from farmland utilization cannot be underestimated. In this study, the life cycle assessment method was employed to determine the accounting boundaries and sources of carbon emissions from cultivated land use. A STIRPAT model and a carbon emissions accounting system from cultivated land utilization were developed to explore the characteristics and influencing factors of carbon emissions in Jiangxi Province. Additionally, targeted countermeasures were proposed to promote low-carbon utilization of cultivated land in the region. The results show that the total carbon emission underwent four distinct stages: "steady growth, fluctuating growth, rapid decline, and leveling off". Specifically, carbon emissions decreased from 220.2 t in 1990 to 17.8 t in 2019. In terms of carbon emission intensity, the overall trend is downward, with the intensity dropping below 7 t/hm^2 after 2009. The number of agricultural population, total agricultural machinery power, and rural investment were identified as significant driving factors for carbon emissions from cultivated land utilization in Jiangxi Province. Conversely, land productivity and investment in science and technology exhibited inhibitory effects on carbon emission growth. Enhancing technological investment and improving land productivity were found to be conducive to promoting low-carbon utilization of cultivated land in Jiangxi.

Keywords: cultivated land utilization, STIRPAT model, carbon emission accounting, driving factors
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1 Introduction

The development and utilization of arable land serve as the foundation of ensuring food production, yet they also contribute to increased carbon emissions. With the 75th United Nations General Assembly's proposal of the "dual carbon" goal and its integration into China's overall ecological civilization construction framework, global attention to carbon emissions from land use has grown significantly[1]. Carbon emissions from arable land use originate from multiple sources, directly or indirectly from agricultural inputs (e.g., fertilizers, pesticides, and agricultural machinery operations) in human activities[2], and inherently from soil itself through changes in material circulation and physicochemical properties. Internationally, carbon emissions calculations primarily rely on the Intergovernmental Panel on Climate Change (IPCC) emission factor method, which quantifies emissions from both carbon sources and sinks. For instance, Samuel and Phebe[3] accurately calculated the agricultural carbon emissions in the Ghana region using the emission factor method. Norse[4] applied it to calculate carbon emissions changes from input materials and crop growth processes. Bessou et al.[5] identified fertilizer use and straw open burning as significant drivers of arable land carbon emissions through this approach. Similarly, Peterson utilized the carbon emission factor method for land use carbon emissions accounting in their research area[6]. In China, Zhang et al.[7] quantified the total carbon emissions from land use in Henan Province (1993-2015), identifying agricultural inputs as the main source of carbon emissions, including fertilizers, pesticides, plastic films, agricultural machinery, tillage, and irrigation. Hu et al.[8] calculated the total carbon emissions from land use for 30 provinces and cities in China from 2001 to 2006 using the emission factor method, expanding the boundaries of carbon emission sources from an energy consumption perspective. Zhou et al.[9] constructed a carbon emission accounting framework system using the life cycle method to estimate carbon emissions in the Northeast region from 1979 to 2015. It is evident that the IPCC method and the life cycle method (LCA) can accurately express carbon emissions from arable land use.

Carbon emissions from arable land use are influenced by farming practices, agricultural production modes, and technological development. Transitioning from fallowing to no-tillage practices can significantly reduce carbon emissions from arable land use[10]. Li et al.[11] proposed that the differences in carbon emissions are caused

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by different agricultural production methods based on survey results of carbon emission driving factors in various countries worldwide. Gomiero et al.[12] found that the development of organic agriculture helps alleviate the high carbonization of arable land use. Awais et al.[13] pointed out the correlation between economic development and arable land use carbon emissions when studying the bidirectional relationship of carbon emissions. Through research, Ben[14] found that a continuous increase in economic output promotes an increase in carbon emissions from land use. Ismael et al.[15] using Jordanian data, linked technological progress to reduced agricultural carbon emissions, a finding supported by Khalid's research on technology-advanced regions[16]. In China, Gao et al.[17] using Baicheng City as an example, analyzed the influencing factors of regional agricultural carbon emissions using the STIRPAT model, identifying population, GDP per capita at comparable prices, total power of agricultural machinery, ratio of agricultural productivity, rural investment, and urbanization rate as the main influencing factors of Baicheng City's agricultural carbon emissions. Based on the modified Kaya Identity, Liu et al.[18] used an expanded STIRPAT model to analyze the factors affecting the intensity of agricultural carbon emissions in Guangdong, showing a significant positive correlation between urbanization level, agricultural population size, and carbon emissions in Guangdong. Li et al.[19] calculated the agricultural carbon emissions and carbon source contribution of each province from the perspective of eight major economic regions, studying the regional characteristics and spatial clustering of carbon emissions using spatial autocorrelation, while Zhou et al.[9] used the Logarithmic Mean Divisia Index (LMDI) model to assess driving factors. Notably, land productivity and technological investment increase emissions, whereas input-output ratio, per capita arable land, and technology intensity decrease them. Wen et al. further revealed spatiotemporal patterns of farmland carbon emissions and ecological efficiency in the Dongting Lake area using the SBM-Undesirable model[20]. In summary, the driving factors of carbon emissions can be systematically analyzed through multiple modeling approaches. Representative models include the STIRPAT model, Geographically Weighted Regression (GWR), Logarithmic Mean Divisia Index (LMDI) model, and SBM-Undesirable model. Among these, key influencing factors primarily revolve around three dimensions: economic development scale, population structure, and technological advancement level[9,18,20-24].

As a major grain-producing province in China, Jiangxi Province has intensified high-standard farmland since 2011, boosting food production. However, excessive land use has degraded soil health and exacerbated carbon emissions, necessitating urgent low-carbon transition strategies. This study employs a life cycle approach to quantify total carbon emissions from Jiangxi's farmland use, covering fuel combustion, livestock management, soil maintenance, agricultural inputs, and straw management. By analyzing emission characteristics and using an improved STIRPAT model to identify drivers of emission intensity, this research provides targeted recommendations for Jiangxi's agricultural sustainability and ecological civilization goals.

2 Data sources and methods

2.1 Data sources

Data on crop yield, cultivated land area, paddy field area, nitrogen fertilizer application rate, among others, mainly came from the *Jiangxi Statistical Yearbook* (1990-2019). Livestock quantities for livestock management carbon emissions were sourced from the same yearbook. Diesel consumption data for carbon emissions from fuel combustion were sourced from the *China Rural Statistical Yearbook* (1990-2019). Data on agricultural material inputs, including nitrogen fertilizer, phosphorus fertilizer, potassium fertilizer, pesticide, and plastic film application rates, were obtained from the "China Rural Statistical Yearbook" from 1990 to 2019. The area of mechanized irrigation in agricultural material input carbon emissions was sourced from the "China Agricultural Yearbook" from 1990 to 2019. Data on cultivated land area, agricultural contribution to GDP, and urbanization rate came from the Jiangxi Statistical Yearbook (1990-2019); the number of agricultural science and technology personnel came from the "National Agricultural Science and Technology Statistical Data Compilation"; sown area and crop yield data were obtained from the "Jiangxi Statistical Yearbook" and "China Rural Statistical Yearbook" (1990-2019); agricultural population and total agricultural machinery power came from the annual provincial data from the National Bureau of Statistics from 1990 to 2019. Missing data for some years were interpolated using the trend function in Excel. Data preprocessing was performed using Excel 2021 for missing value interpolation (trend function method). Statistical analyses, including correlation analysis (Pearson coefficient), principal component analysis (extracting common factors with eigenvalues >1), and multiple linear regression (least squares method), were conducted using SPSS 26.0 software to ensure scientific rigor and reproducibility of data processing.

2.2 Research methods

2.2.1 Life cycle assessment method

The life cycle assessment method divides the entire process of land use into three stages: agricultural product production, crop planting, and crop harvesting. It categorizes and summarizes the carbon emissions into five categories: soil maintenance, livestock management, fuel combustion, agricultural input materials, and straw disposal[20-22].

1) Soil maintenance carbon emission calculation method

The carbon emissions induced by soil maintenance are calculated based on soil carbon flux, methane emissions from paddy fields, soil N_2O emissions, and carbon emissions from urea application[23-26]:

$$\mathrm{GHG}_1 = -F_C/100 + E_r \times 6.8182/1000 + \frac{E_N}{28} \times 44 \times 81.2727 + E_u/100 \tag{1}$$

where, GHG_1 is the total carbon emissions caused by soil maintenance, t; F_c is soil carbon flux, mg/m²·s¹; E_r is the methane emissions from rice fields, t; E_N is the soil N_2O emissions, t; E_u is carbon emissions from urea application, t; 6.8182 and 81.2727 are conversion factors for methane and N_2O to CO_2 equivalent.

2) Livestock management carbon emission calculation method

The carbon emissions induced by livestock management are calculated based on methane release from livestock intestinal fermentation, N_2O release from manure treatment, and methane release from manure treatment[15]:

$$\mathrm{GHG}_2 = E_{ef} \times 6.8182 + E_{mn} \times 81.2727 + E_{mc} \times 6.8181 \tag{2}$$

where, GHG_2 is the total carbon emissions caused by livestock management, t; E_{ef} is the methane emitted from livestock enteric fermentation, t; E_{mn} is N_2O emissions from livestock manure handling, t; E_{mc} is the methane emissions from livestock manure handling, t.

3) Fuel combustion carbon emission calculation method

This part mainly calculates the carbon emissions caused by the consumption of agricultural diesel during land use:

$$\mathrm{GHG}_3 = E_{\mathrm{fu}} = \mathrm{AM}_{\mathrm{fu}} \times f_{\mathrm{fu}} \quad (3)$$

where, GHG_3 is the total carbon emissions caused by fuel combustion, t; E_{fu} is the carbon emissions from diesel combustion, t; $\mathrm{AM}_{\mathrm{fu}}$ is the diesel consumption, 10^4 t; f_{fu} is the diesel emission coefficient. Diesel consumption data is from the China Rural Statistical Yearbook, and diesel emission coefficient data is from research by Chen Shun[15].

4) Agricultural input materials carbon emission calculation method

The carbon emissions caused by agricultural input materials, including fertilizers, pesticides, agricultural films, and irrigation, are calculated[27]:

$$\mathrm{GHG}_4 = E_{\mathrm{fer}} + E_p + E_{\mathrm{fi}}/10 + E_{\mathrm{ir}}/10000 \quad (4)$$

where, GHG_4 is total carbon emissions caused by agricultural inputs, t; E_{fer} is carbon emissions from all fertilizers applied in cultivation, t; E_{p} is the carbon emissions from all pesticides applied in cultivation, t; E_{fi} is the carbon emissions from plastic film used in cultivation, t; E_{ir} is the carbon emissions during irrigation processes.

5) Straw disposal carbon emission calculation method

The carbon emissions caused by straw disposal, including methane emissions from open burning of straw and N_2O emissions, are calculated[28,29]:

$$\mathrm{GHG}_5 = E_{\mathrm{crC}}/10 + E_{\mathrm{crN}}/10 \quad (5)$$

where, GHG_5 is the total carbon emissions caused by straw management, t; E_{crC} is the methane emissions from open burning of straw, t; E_{crN} is the N_2O emissions from open burning of straw, t.

2.2.2 STIRPAT model

The Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model is widely used for predicting carbon emissions. It incorporates factors influencing energy consumption and carbon emissions based on the IPAT equation, allowing in-depth analysis of the disproportionate impact of different factors on the dependent variable. This study combined various researchers' findings and the natural economic conditions of Jiangxi Province, selecting factors such as agricultural population, land productivity, total agricultural machinery power, agricultural output ratio, rural investment, urbanization rate, and technological fund investment as the main influencing factors of carbon emissions[30-32]. A multivariate non-linear model was constructed to represent the relationship between carbon emissions from land use in Jiangxi and these factors[33-36]:

$$E = k \times A^{a1} \times P^{a2} \times M^{a3} \times G^{a4} \times I^{a5} \times U^{a6} \times T^{a7} \times \varepsilon \quad (6)$$

where, E is total carbon emissions of cultivated land use in each year, 10^4 t; K: constant; A is regional demographic factors, expressed in terms of agricultural population (10,000); P is planting development level, expressed by land productivity (%); M is regional agricultural development level, expressed by the total power of agricultural machinery, 10^4 kW; G is regional industrial structure, expressed by the contribution rate of agriculture to GDP (%); C is capital factor, calculated in rural investment, 100 million CNY; U is urbanization status, expressed as urbanization rate (%); T is the development degree of agricultural technology, represented by scientific and technological capital investment, CNY; ai (i=1, 2, ... , 7) is the influence index of each driving factor, indicating that each 1% change of A, P, M, G, I, U, and T will cause a change in ai% of E; ε is random perturbation term of the model, indicating other influencing factors.

3 Result and analysis

3.1 Carbon emission characteristics of arable land use in Jiangxi Province

Using the aforementioned method, carbon emissions from arable land use in Jiangxi during 1990-2019 were calculated, with results shown in Figure 1. Over this period, the total carbon emissions decreased from 22.0278 million t in 1990 to 17.8 million t in 2019, with an average annual emission of 22.1 million t. The peak value occurred in 2006 at 26.1 million t, while the lowest emission was recorded in 2019 at 17.8 million t.

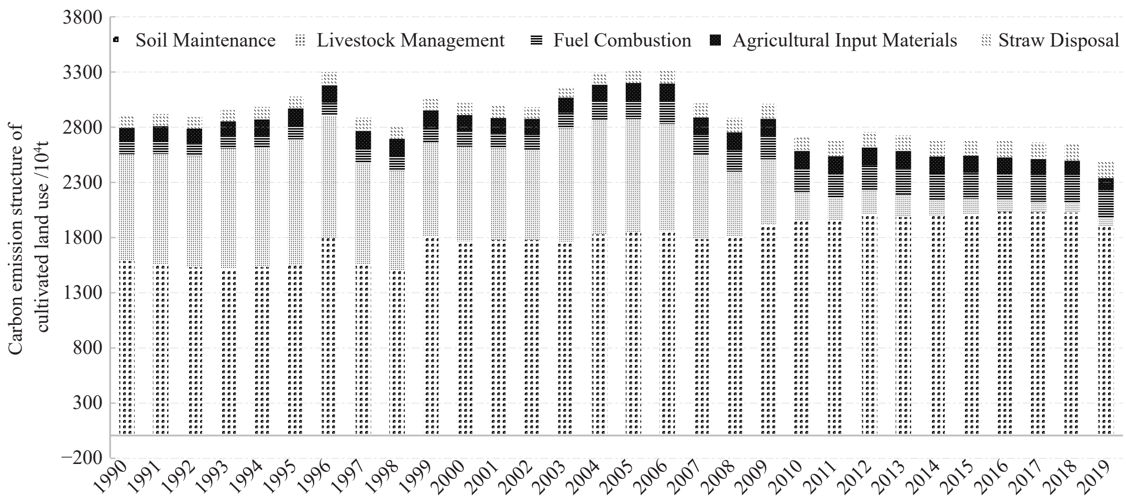

Figure 1 Carbon emission structure of cultivated land use in Jiangxi (1990-2019)

Over the past 30 years, soil maintenance has remained the primary source of carbon emissions from arable land use in Jiangxi, exhibiting a continuous upward trend. Since 2007, its proportion has even exceeded 50%, likely attributed to advancements in agricultural technology, adjustments in the national economic industry structure, and increased adoption of agricultural machinery. The most notable shift in carbon emission structure over these three decades was observed in residual storage management, which decreased from 9.7019 million t in 1990 to 0.7574 million t in 2019, a 93.3% reduction potentially associated with the rise of modern agriculture. Carbon emissions from agricultural material inputs showed a slow but steady increase over the 30 years, indicating a gradual annual growth in agricultural investments in Jiangxi. By contrast, carbon emissions from straw handling and fuel combustion remained relatively stable with minimal fluctuations.

The total carbon emissions exhibited four distinct temporal stages: stable growth, growth with fluctuations, rapid decline, and stabilization. Emissions decreased from 22.0278 million t in 1990 to 17.8 million t in 2019. In terms of carbon emission intensity, Jiangxi has shown an overall downward trend, peaking at 10.30 t/hm^2 in 1995 and dropping to below 7 t/hm^2 after 2009, reflecting initial success in low-carbon land utilization. The level of agricultural economic development is a key driver of agricultural carbon emissions changes, while policies ensuring food self-sufficiency and security also contributed to modern agriculture's high carbon intensity.

Figure 2 illustrates changes in carbon emissions and intensity from arable land use in Jiangxi during 1990-2019, spanning four stages:

Stable growth (1990-1996): Emissions rose from 22.0 to 26.0 million t (18.05% increase).

Fluctuating decline (1996-1998): A sharp drop occurred, falling from 26.0 million t in 1996 to 21.8 million t in 1997 and 20.98 million t in 1998.

Rebound growth (1998-2006): Emissions increased by 19.77% to 26.17 million t, driven by agricultural expansion.

Sustained decline and stabilization (2006-2019): Emissions decreased to 19.7 million t by 2011 (14.48% reduction, attributed to irrigation carbon abatement measures) and stabilized at 17.82 million t in 2019.

Carbon intensity followed a similar trajectory: peaking at 10.30 t/hm^2 in 1995 after rising from 9.38 t/hm^2 in 1990, fluctuating between 8.69 t/hm^2 (1996) and 7.48 t/hm^2 (2009), then dropping to 6.55 t/hm^2 in 2019—below the 7 t/hm^2 threshold since 2009.

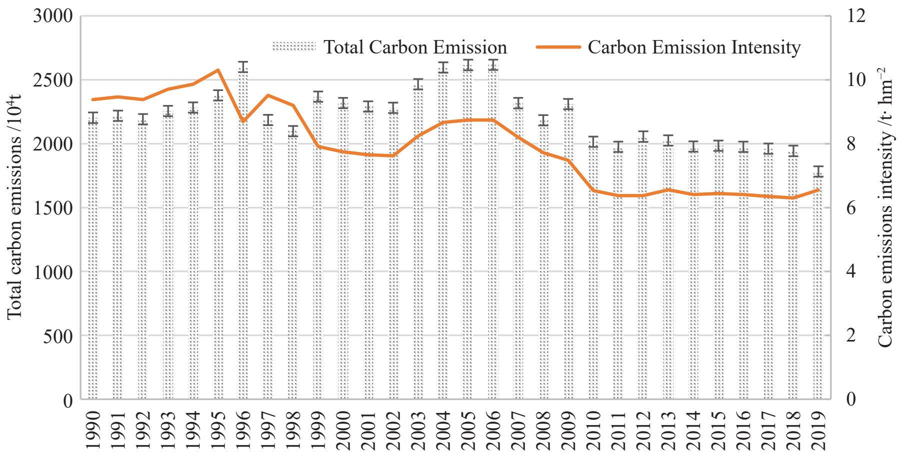

Figure 2 Total carbon emissions and intensity from cultivated land use in Jiangxi Province (1990-2019)

Jiangxi Province's agricultural economy remains relatively underdeveloped. As the research of Yao et al.[37] indicates, factors tied to agricultural economic development and policies ensuring food security are primary drivers of changes in agricultural carbon emissions. For instance, less-developed agricultural regions may rely on inefficient farming practices, leading to higher carbon emissions, whereas economically advanced areas can adopt modern production methods—such as mechanization, clean energy application, and improved agricultural input efficiency—thereby reducing carbon intensity. The elevated carbon emissions in 2004 and 2005 may be attributed to the agricultural tax reduction policy, which stimulated increased farming activity and relative investments. From 2011 onwards, carbon emissions have remained stable or slightly decreased, primarily due to the high-standard farmland construction project. As Chen Yubin's policy evaluation shows, this initiative has further mitigated carbon emissions from land use by enhancing agricultural operational efficiency[38].

3.2 Analysis of carbon emission influencing factors of farmland in Jiangxi Province

Using SPSS statistical software to analyze, the correlation between various driving factors of carbon emissions from farmland in Jiangxi was conducted, and the results are shown in Table 1. A correlation coefficient greater than 0 indicates a positive correlation between two variables. For example, agricultural population is positively correlated with the contribution of agriculture to GDP, rural investment, and urbanization rate. A correlation coefficient less than 0 indicates a negative correlation between two variables; for instance, agricultural population is negatively correlated with land productivity, total power of agricultural machinery, and investment in scientific and technological funds.

Table 1 Correlation coefficient of driving factors

Driving factors	*A*	*P*	*M*	*G*	*I*	*U*	*T*
A	1	-	-	-	-	-	-
P	–0.979	1	-	-	-	-	-
M	–0.697	0.620	1	-	-	-	-
G	0.896	–0.838	–0.784	1	-	-	-
I	0.418	–0.501	–0.326	0.259	1	-	-
U	–0.986	0.951**	0.752	–0.956	–0.364	1	-
T	–0.973	0.0998	0.591	–0.834	–0.485	0.946	1

Note: Agricultural population (*A*), total power of agricultural machinery (*M*), contribution rate of agriculture to GDP (*G*), rural investment (*I*), urbanization rate (*U*), land productivity (*P*), technology funding input (*T*), **denotes significance with p<0.01

After processing the seven influencing factors of carbon emissions from land use in Jiangxi Province in the natural logarithmic transformation table, using them as original variables, and applying the SPSS statistical software, two composite variables $F1$ and $F2$ were extracted. From the cumulative column of initial eigenvalues in Table 2, it can be seen that $F1$ and $F2$ can explain 95.546% of the original variables.

Thus, two composite factors $F1$ and $F2$ are obtained:

$$F1 = -0.955\ln A + 0.991\ln P + 0.896\ln M - 0.995\ln G - 0.438\ln I + 0.99\ln U + 0.983\ln T \quad (7)$$

$$F2 = 0.073\ln A + 0.088\ln P + 0.161\ln M - 0.054\ln G - 0.895\ln I + 0.118\ln U + 0.062\ln T \quad (8)$$

Table 2 Total variance of principal component analysis

Factor	Initial eigenvalues extract			Sum of squares of loads		
	Total	Variance percentage	Cumulative/%	Total	Variance percentage	Cumulative/%
1	5.827	83.243	83.243	5.827	83.243	83.243
2	0.861	12.302	95.546	0.861	12.302	95.546
3	0.233	3.326	98.871	-	-	-
4	0.064	0.913	99.785	-	-	-
5	0.012	0.171	99.956	-	-	-
6	0.003	0.041	99.997	-	-	-
7	0.000	0.003	100.000	-	-	-

This is the relationship between original variables and composite variables. The purpose is to use $F1$ and $F2$ as intermediary variables to conduct a least squares regression analysis with the processed carbon emissions. From Table 3, it is known that $F1$ mainly explains agricultural population, land productivity, total power of agricultural machinery, contribution rate of agriculture to GDP, rural investment, urbanization rate, and technology funding input, with coefficients of these original variables all exceeding 0.8, where $\ln P$, $\ln M$, $\ln U$, $\ln T$ have positive effects, and $\ln A$, $\ln G$ have negative effects. $F2$ mainly explains agricultural investment, i.e., lnI.

Table 3 Component score coefficient matrix of principal component analysis

Original variable	Component	
	$F1$	$F2$
$\ln A$	–0.955	0.073
$\ln P$	0.991	0.088
$\ln M$	0.896	0.161
$\ln G$	–0.995	–0.054
$\ln I$	–0.438	0.895
$\ln U$	0.99	0.118
$\ln T$	0.983	0.062

By transforming the natural logarithm of carbon emissions from land use in Jiangxi Province, selecting the processed 30-year carbon emissions from land use in Jiangxi Province as the dependent variable, and the two extracted composite variables $F1$ and $F2$ as the explanatory variables, a multiple regression analysis is conducted using SPSS software:

$$\ln E = 2.980 - 0.192F1 + 0.744F2$$
$$R^2 = 0.816, F = 59.706, P(sig) = 0.000 \quad (9)$$

From the above equation, it is evident that the linear model fits well. By simplifying the equation and removing natural logarithms, the model for the impact factors of land use emissions in Jiangxi from 1990 to 2018 is obtained:

$$\ln E = 2.980 + 0.1345\ln P - 0.0082\ln A + 0.0579\ln M + 0.0358\ln V + 0.7528\ln C + 0.0159\ln U - 0.0284\ln T$$

Further transformation yields:

$$E = 19.5878P^{0.1345}A^{-0.0082}M^{0.0579}V^{0.0358}C^{0.7528}U^{0.0159}T^{-0.0284} \quad (10)$$

The above equation represents a multivariable nonlinear STIRPAT impact factor analysis model for carbon emissions from land use in Jiangxi from 1990 to 2019, with results as shown in Table 4.

Table 4 Influence index of each factor

Influencing factors	Influence index
Agricultural population (A)	0.135
Land productivity (P)	–0.008
Total power of agricultural machinery (M)	0.058
The contribution rate of agriculture to GDP (G)	0.036
Rural investment (I)	0.753
Urbanization rate (U)	0.016
Investment in science and technology (T)	–0.029

Among them, the number of agricultural population (A), total power of agricultural machinery (M), contribution rate of agriculture to GDP (G), rural investment (I), and urbanization rate (U) have a positive effect on the increase of carbon emissions from cultivated land. Rural investment has the most significant impact, followed by agricultural population, total power of agricultural machinery, contribution rate of agriculture to GDP, and urbanization rate. Specifically, for carbon emissions, an increase of 1% in rural investment will lead to a corresponding increase of 0.7528% in carbon emissions from cultivated land; an increase of 1% in agricultural population will lead to a corresponding increase of 0.135% in carbon emissions from cultivated land; a 1% increase in the total power of agricultural machinery will lead to a corresponding increase of 0.058% in carbon emissions from cultivated land; a 1% increase in the contribution rate of agriculture to GDP will result in a 0.036% increase in carbon emissions from cultivated land; and a 1% increase in the urbanization rate will lead to a corresponding increase of 0.016% in carbon emissions from cultivated land. Additionally, land productivity (P) and technological investment (T) have a negative effect on the increase of carbon emissions from cultivated land. Specifically, for carbon emissions, an increase of 1% in land productivity will result in a decrease of 0.008% in carbon emissions from cultivated land; and an increase of 1% in technological investment will lead to a decrease of 0.028% in carbon emissions from cultivated land.

In summary, among all driving factors, agricultural population, total agricultural machinery power, and rural investment are the primary positive influencers. Specifically, a 1% increase in agricultural population, total agricultural machinery power, and rural investment correlates with 0.135%, 0.058%, and 0.753% increases in carbon emissions, respectively. By contrast, land productivity and technological investment exert restraining effects, with each 1% increase leading to 0.008% and 0.028% reductions in carbon emissions.

4 Discussion

As the fundamental resource and carrier of agricultural production, farmland plays a pivotal role in human survival and development by providing essential functions such as food production and ecosystem services. However, rapid urbanization and the extensive use of agricultural inputs like pesticides and fertilizers have caused a dual decline in China's farmland quantity and quality. This has not only led to variations in carbon emissions but also exacerbated pressure on food security.

Through an analysis of the changes in the carbon emission structure in Jiangxi farmland utilization from 1990 to 2019, and an identification of driving factors, this study found that agricultural population, total agricultural machinery power, and rural investment exhibit positive impacts on carbon emissions, while land productivity and technological input demonstrate negative effects. Integrating these findings with Jiangxi's natural economic conditions, effective control of farmland carbon emissions can be achieved by appropriately enhancing negatively correlated factors and adjusting positively correlated factors in the influencing elements. These are specifically manifested as: growth in agricultural population inherently drives production and consumption, leading to increased carbon emissions; improvement in total agricultural machinery power exacerbates agricultural production, raises energy consumption, and alters land use patterns, thereby escalating carbon emissions; increase in rural investment promotes agricultural development, enhances rural trade and consumption, and transforms planting management models - all contributing to higher carbon emissions.

Therefore, rational control of rural population, scientific management of total agricultural machinery power, and efficient allocation of rural investment represent viable strategies to adjust farmland carbon emissions. Notably, the intensity of technological input is inversely proportional to the total carbon emissions, indicating that technological input exerts a restraining effect on carbon emissions from farmland utilization in Jiangxi. Increasing the number of agricultural technology personnel and technological investment can therefore reduce emissions and promote low-carbon farmland utilization.

Compared with Henan[39], Jiangxi has a higher proportion of carbon emissions from soil maintenance (>50% vs. 35%), attributed to faster decomposition of soil organic matter in Jiangxi's red soil regions[40]. Compared with Guangdong[18], Jiangxi has a lower level of agricultural mechanization (annual growth rate of total agricultural machinery power is 1.2% slower), resulting in a smaller contribution of machinery to carbon emissions. Jiangxi's annual precipitation (>1600 mm) prolongs paddy field flooding, significantly affecting methane emissions (Er)[41]. The 2011 high-standard farmland construction policy promoted large-scale farming, reducing carbon emission intensity by 12.3% during 2011-2019[42]. Aligning with the 2023 Central Document's call for "agricultural green and low-carbon transition," the urgency of popularizing straw return technology in Jiangxi (current return rate: 65%) is discussed to reduce emissions from straw burning (accounting for ~8% of total emissions).

Boosting land productivity is another key pathway to reducing farmland carbon emissions, with the core approach being to expand cultivated crop areas for scale utilization.

Firstly, preventing farmland abandonment and promoting intensive use: Conducting surveys and registrations of farmland to implement real-time dynamic monitoring; Statistically summarizing idle farmland area and quality data, reporting to local land authorities for professional evaluation, and formulating differentiated management strategies (e.g., improving poor-quality land through multi-channel funding for cultivation).

Furthermore, advancing intensive and large-scale farmland management: Promoting the "separation of three rights" in contracted land, encouraging land circulation, and incentivizing professional households and enterprises to contract land through subsidies.

Finally, strengthening dynamic monitoring of farmland use: Addressing severe issues of non-grain and non-agricultural farmland use through techniques like land surveys and remote sensing; Imposing fines and mandatory corrections for non-agriculturalization and inefficient, extensive farmland practices, given that purpose changes even for agricultural reinvestment lead to significant fertility decline and require substantial resources for restoration.

5 Conclusions

From 1990 to 2019, the total carbon emissions from farmland utilization in Jiangxi underwent four distinct stages: "stable growth - fluctuating growth - rapid decline - stabilization". The carbon emissions decreased from 22.0278 million t in 1990 to 17.8247 million t in 2019. In terms of carbon emission intensity, there was an overall downward trend, steadily increasing from 1990 to 1995, peaking at 10.30 t/hm^2 in 1995, fluctuating and decreasing from 1996 to 2009, and dropping below 7 t/hm^2 after 2009, indicating initial success in the low-carbon utilization of farmland. Regarding the composition of carbon emission sources, soil maintenance accounted for nearly 50% of the total emissions in Jiangxi from 1990 to 2019, making it the primary contributor. This was followed by agricultural material input, livestock management, fuel combustion, and straw processing, indicating that promoting low-carbon farmland utilization could prioritize soil maintenance practices. In terms of influencing factors on farmland carbon emissions, agricultural population, total power of agricultural machinery, urbanization rate, agricultural contribution to GDP, and rural investment all contributed to carbon emissions in Jiangxi, with agricultural population, total power of agricultural machinery, and rural investment being the main drivers. By contrast, land productivity and technological investment exhibited restraining effects on carbon emissions from farmland utilization. Enhancing technological investment and improving land productivity can effectively promote low-carbon utilization of farmland in Jiangxi, which is of great significance for ecological civilization.

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