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The impact of green and low carbon agricultural production on farmers' income in minority areas: a case study of Y Town, Zhijin County, Guizhou Province

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Developing green and low-carbon agriculture is an important and effective way to promote farmers' income growth. Given the country's "dual carbon" goal, the study of the impact of green and low-carbon agriculture on the income of farmers in ethnic minority areas is crucial for China to achieve the goals of socialist modernization and common prosperity. Taking Y Town, Zhijin County, Guizhou Province as an example, this paper uses the OLS regression method to empirically study the impact of green and low-carbon agricultural production methods on the income of farmers in ethnic minority mountainous agricultural areas based on the field survey data of 881 farmers. The regression results indicate that there is a positive correlation between green and low-carbon agricultural production and the household income levels of farmers; adopting green and low-carbon agricultural production technologies can effectively promote the growth of farmers' household income. In addition, education level, health status, and the new rural social pension insurance have all had a significant effect on the income of rural households, however, due to the difficulty in establishing trust relationships, agricultural service outsourcing has reduced the household income level of farmers. As an example, the land transfer behavior in Y Town has no significant effect on increasing farmers' incomes. Finally, it is recommended to increase fiscal and financial support as well as effectively enhancing farmers' policy awareness and perception of green and low-carbon agricultural production technologies by improving farmers' general trust and institutional trust by strengthening farmers' agricultural education and skills training while cultivating technology-based farming. At the same time, it is necessary to break the geographical restrictions on land transfer scale and achieve moderate-scale land management while promoting the use and adoption of green and low-carbon agricultural production technologies, thereby improving agricultural production efficiency and product quality, and increasing the sustainable growth of farmers' income. The main contribution of this study is to expand the research scope of green and low-carbon agriculture to ethnic minorities and mountainous agricultural areas.

KEYWORDS

low carbon, agriculture, farmers' income, agricultural production technology, land transfer

1 Introduction

Agriculture is the foundation of a country or region's development and the guarantee for the continuous development and progress of the entire national economy. On the one hand, agriculture is the most basic sector of material production, providing humanity with a material foundation for survival, and is the source of a society's clothing, food, and survival. On the other hand, agriculture provides raw materials for other sectors, such as industry, and is a necessary condition for the existence and development of other material and all non-material sectors of production. The economic and social development of a country or region cannot be separated from agriculture and its development of agriculture is the primary condition for all production. At the same time, agricultural development is closely related to climate change. On the one hand, agriculture is the fundamental industry most affected by climate change (Wang et al., 2023). Climate changes such as drought and high temperatures have actually led to a 3–8% decrease in global grain production of rice, wheat, corn, and other crops (Zou, 2021). China's meteorological disasters caused by climate change events have reduced the production of major grain crops by about 10% while climate change has led to a decrease of about 5% in food protein and trace elements (Zou, 2021). On the other hand, agriculture has dual attributes, namely as carbon source and carbon sink. Agricultural production activities are not only an important source of greenhouse gas emissions, but also have a strong carbon sink effect. According to the fourth assessment report released by the IPCC in 2007, agricultural emissions of CH_4 and NO_2 account for 50 and 60% of total human activities respectively, while their greenhouse gas emissions account for 14% of the global total, making them the second largest source of greenhouse gas emissions in the world between electric heating production and exhaust emissions (Intergovernmental Panel on Climate Change, 2007). At the same time, agricultural production also has a strong carbon sequestration effect. It can achieve biological carbon sequestration through its own multiple channels and methods, including the photosynthesis of plants in various ecosystems such as farmland, forests, and grasslands. Through these methods, about 30% of global annual anthropogenic carbon emissions can be absorbed (Wang et al., 2023). In view of this, the green, low-carbon, sustainable, and high-quality development of agriculture has become a focus and concern for countries around the world.

China is a major agricultural country and issues related to agriculture, rural areas, and farmers are a global concern that affects the development of our party and people's cause, as well as a fundamental dilemma that affects the national economy and people's livelihoods. Currently, 500 million out of China's 1.4 billion people still reside in rural areas. Farmers are the fundamental force behind China's economic and social development as well as the main force driving the country's modernization. Solving the problems of agriculture, rural areas, and farmers is a requirement for achieving China's industrialization, urbanization, and socialist modernization, as well as an effective way to guarantee achieving the goal of the people's common prosperity. Among the issues related to agriculture, rural areas, and farmers, increasing the income of farmers is the central task of rural work (State Council Office, 2016) and the key to solving rural issues.

At the same time, China has entered a new era of ecological civilization construction. Adhering to the concept of a community with a shared future for mankind and the belief that "green mountains and clear waters are invaluable assets," China has actively participated in international carbon neutrality and climate change actions, and pledged to the world to achieve carbon peak by 2030 and carbon neutrality by 2060 (Zou, 2021). Guided by the "dual carbon" goal, green and low-carbon agriculture that continuously increases yield, reduces input, reduces pollution, and improves efficiency (Zhang, 2019) has become the development direction of China's agriculture, hence the country's agricultural development has begun a new stage.

At present, China has become a moderately prosperous society and is moving toward the second centenary goal. If China wants to be strong, agriculture must be strong; if China wants to be beautiful, rural areas must be beautiful; if China wants to be rich, farmers must be rich (Zhang and Cui, 2023). Therefore, in the new stage of development, the issue of "agriculture, rural areas and farmers" is of primary importance for China to enter the new era of building a socialist and modernized strong country, while the core issue of China's agriculture and rural development is the growth of farmers' income (Xiao, 2021). Thus, promoting the continuous growth of farmers' income has become the core and key to solving the problems of agriculture, rural areas, and farmers. Family farming is the most important and stable basis of farmers' income in China. In view of this, under the "dual carbon" goal, studying the impact of the green and low carbon agricultural production mode on farmers' income has guiding significance for China in terms of solving the "three rural issues| while realizing the high-quality development and modernization of agriculture.

China is a united multi-ethnic country, therefore in order to achieve socialist modernization and common prosperity, "No one nation can be left behind" (Xi, 2021). Guizhou Province has a large number of ethnic minorities and is also an economically and socially underdeveloped province. It is a region that requires special attention to consolidate achievements concerning poverty alleviation while achieving the goal of common prosperity. Y Town is a remote township under the jurisdiction of Zhijin County, Guizhou Province. According to field research results, of the 41,055.43 mu of arable land in the town, about 80 per cent is mountainous, making it a mountain economy and agricultural town. By the end of 2021, the town had a total registered residence of 44,103, of which 28,924 are ethnic minorities such as Chuanqing, Miao, Bai, accounting for 65.58% of the town's total population. It is a typical township where ethnic minorities gather and live. Hence, it is of great practical significance to study the influence of green and low-carbon agricultural development on farmers' income in economically underdeveloped ethnic minority mountainous agricultural areas of China in order to solve the problems of agriculture, rural areas, and farmers, thereby comprehensively realizing agriculture's modernization and a common prosperity.

2 Literature review

At present, there is a wealth of research in domestic and foreign academic circles on the development of green and low-carbon agriculture and its impact on farmers' income. These studies focus mainly on the concepts, influencing factors, low-carbon agriculture or agricultural green production policies, and the impact of low-carbon agriculture on farmers' income.

2.1 Overview of green and low-carbon agriculture

2.1.1 Concept of low-carbon agriculture

Research on low-carbon agriculture began in the 1990s, and Maston's "ecological intensive agriculture" has included the meaning of low emissions (Matson et al., 1997), which is the prototype of low-carbon agriculture. In 2003, the UK government issued the Energy White Paper "Our Energy Future Creating a Low Carbon Economy," which for the first time explicitly proposed a low-carbon economic development concept characterized by "low resource consumption" and "low environmental pollution." As an important field for the low-carbon economy, the concept of a low-carbon agriculture subsequently emerged and became the mainstream value of the international community. Wang (2008) was the first scholar in China to propose the concept of a "low-carbon agricultural economy" (Jiang, 2020). He believed that the low-carbon agricultural economy is an economy that releases the least amount of greenhouse gasses during agricultural production and operations, while also achieving the maximum social benefits (Wang, 2008). Zhao and Qian (2009) viewpoint is similar, believing that low-carbon agriculture aims to achieve maximum benefits while minimizing greenhouse gas emissions in agricultural production and operations. Mellon (2010), on the other hand, believes that low-carbon agriculture should be a concept that aims to reduce atmospheric greenhouse gas emissions while increase carbon sinks as a means to transform agricultural production and farmers' lifestyles in order to achieve high efficiency, low energy consumption, low emissions, high carbon sink agriculture. Gao et al. (2011) have a more comprehensive definition of low-carbon agriculture, suggesting that it is a new modern agricultural system that, while ensuring social demand and food security, saves resources, reduces inputs and emissions, improves efficiency, increases benefits, and captures carbon storage through measures such as technology, policies and management, all in order to minimize direct and indirect greenhouse gas emissions in the atmosphere during the entire process of pre-production, production, and post-production.

In summary, although scholars have different interpretations of the meaning of low-carbon agriculture, its essence and core are consistent, namely low input, consumption, pollution and emissions respectively, while also achieving high efficiency. From 2020 onwards, the meaning of "low-carbon agriculture" has become more diverse, including "carbon peaking" and "carbon neutrality" (Wang et al., 2023), referring to reducing greenhouse gas emissions, achieving peak carbon emissions, and ultimately zero net emissions.

2.1.2 Factors influencing the development of low-carbon agriculture

The key link in the development of low-carbon agriculture is the use and adoption of low-carbon agricultural production technology. Therefore, the research of domestic and foreign scholars on the factors affecting the development of low-carbon agriculture is mainly carried out from the perspective of factors affecting farmers' adoption of green low-carbon agricultural technology. These influencing factors mainly include:

(1) Personal characteristics of producers (Thangata and Alavalapati, 2003; GuangYin and Xin, 2021; Wang et al., 2022): age of the farmer, extension contact and the number of people who contribute to farm work, education level, and farmers' cognition and perception levels. Among these characteristics, a given farmer's policy cognition has a significant positive impact on their low-carbon agricultural technology adoption behavior and adoption intensity (GuangYin and Xin, 2021). The awareness, perceived benefits, and willingness of farmers to engage in green agriculture are directly proportional to their green production behaviors, while perceived costs have a negative impact on their willingness and behavior to engage in green production (Wang et al., 2022).

(2) Resource endowment, such as information, household capital endowment, etc. Information transmission plays an active role in promoting agricultural technology adoption and diffusion through extension services and social learning. Both extension services and social learning are strong determinants of technology adoption and diffusion (Genius et al., 2014). The low capital level and unreasonable structures to some extent inhibit the willingness of farmers to invest in green production methods such as returning straw to the field (Zhang et al., 2017).

(3) Government regulations, such as social interaction and conversion subsidies, informal institutions and environmental regulations, the number of peer adopters and conversion subsidies have a positive but diminishing impact on the adoption rate of organic agriculture (Chatzimichael et al., 2014). Both informal institutions and environmental regulations have a promoting effect on the green production behavior of farmers. The value orientation, disciplinary supervision, and internalization of transmission in informal institutions can promote the green production behavior of farmers, while the guiding and incentivizing elements in environmental regulations also have a positive effect on the green production behavior of farmers (Li F. et al., 2019). Ecological agriculture needs to be supported by advanced technology and sufficient financial support has become the core factor affecting the adoption of ecological agriculture technology (Zheng and Su, 2023).

In addition, farmers' trust, agricultural insurance, risk avoidance and loss avoidance, land dispersion, dietary structure, etc., also have a significant impact on farmers' adoption of green and low-carbon technologies. Farmers' trust significantly enhances their low-carbon agricultural technology (LCAT) adoption behavior, while the magnitude of the effect is characterized by specific trust > general trust > institutional trust chain (Zhou et al., 2023). Agricultural insurance could suppress agricultural carbon emissions directly and indirectly through low-carbon technology innovation, thus preventing the acceleration of the greenhouse effect. It has been discovered that the suppression effect of agricultural insurance on agricultural carbon emissions is more significant in the eastern regions and non-main grain-producing areas of China (Shijie et al., 2023). Both risk aversion and loss aversion significantly inhibit farmers' LCAT adoption: more risk-averse or more loss-averse farmers are less likely to adopt LCAT (Hui et al., 2023). The degree of land dispersion and cultivation methods are significantly negatively correlated with the adoption behavior of green agricultural technologies by farmers. The experience of village

cadres, agricultural income, degree of organization, business scale, and knowledge of fertilization technology are positively and significantly correlated with farmers adoption behaviors (Hou et al., 2019). The reduction in demand for meat and the cultivation of feed crops will reduce greenhouse gas emissions and release land for carbon sequestration through afforestation (Heikki and Janne, 2022).

2.1.3 Policy suggestions for developing low-carbon agriculture

Regarding the factors that affect the development of green and low-carbon agriculture, domestic and foreign scholars have proposed policy recommendations to promote the development of green and low-carbon agriculture from aspects of development models, trust enhancement, conceptual, and cognitive enhancement, and land management scale.

Hutchinson et al. (2007) research suggests that low-carbon agriculture should prioritize the development model of agricultural carbon sinks. Managing animal diets and livestock manure management systems can also reduce the emissions of CH4 and N2O in livestock production processes (Johnson et al., 2007). Implementing intensive crop management methods and utilizing intensification principles to improve agricultural ecological efficiency is also considered the main path to achieve greenhouse gas emissions reduction in agriculture while meeting production needs (Snyder et al., 2009).

Developing villages through agricultural education and low-carbon animal husbandry is a strategy to harness the potential of nature. At the same time, it is possible to encourage the application of agriculture and low-carbon farms, as well as the adoption of technology for the resource utilization of livestock and poultry manure, in order to, respectively, reduce household exhaust emissions in the production process, increase production output, increase community economic level, improve the welfare of farmers, and benefit the environment (Syafrudin et al., 2023).

In addition, by strengthening the general and institutional trust of farmers (Zhou et al., 2023), the government can vigorously promote the benefits of LCAT (Hui et al., 2023), encourage them to play a promotional and exemplary role, improve their policy awareness, promote the use and adoption of green and low-carbon agricultural technologies, improve the quality of agricultural products, and thus enhance the spillover effects of green agricultural technologies (Hou et al., 2019). Alternatively, by accelerating land transfer and achieving moderate scale management of land, farmers can adopt LCAT (Hou et al., 2019; Hui et al., 2023).

In addition, relevant policy measures are also crucial for the development of low-carbon agriculture, such as building an interactive mechanism that supports and integrates informal and formal institutions, enhancing farmers' conceptualization of low-carbon agriculture, strengthening agricultural technology innovation and promotion, improving the quality of agricultural production personnel, providing financial and financial support (Qin, 2014), and increasing subsidy standards for low-carbon agricultural technology, etc. (GuangYin and Xin, 2021). Promoting the development of agricultural insurance in order to encourage low-carbon technology innovation is crucial to accelerating the process of "carbon peak and neutrality," especially for the eastern regions and non-main grain-producing areas of China (Shijie et al., 2023).

2.2 The impact of green and low-carbon agriculture on the income of farmers

The development of green and low-carbon agriculture has multiple impacts on agriculture or household income. On the one hand, the green production behavior of farmers may increase the planting cost of crops, thereby reducing their agricultural income (Ma et al., 2019).

On the other hand, adopting green and low-carbon agricultural technologies and developing green agriculture can increase the commodity rate of agricultural products, promoting deep processing of agricultural products, increasing the added value of agricultural products, and encouraging agricultural efficiency and income growth for farmers (Zhu, 2020). Alternatively, the absolute and relative income of farmers can be increased by providing high-quality and high-priced agricultural products and enhancing the position of farmers in the agricultural supply chain (Li and Zhao, 2009). Developing green agriculture is an important way to promote farmers' income growth (Zhu, 2020). The study by Chen et al. (2021) shows that adopting green production technologies can significantly improve the income level of tea farmers. The latter who adopt green production technologies can increase their household annual income by 32.6%. If the number of technologies adopted increases by one unit, the farm income increases by 20.6%. This is significant at the 1% level (Poudel et al., 2023). The study by Abrham et al. (2023) suggests that climate-smart agriculture (CSA) can help smallholder farmers adapt to climate change and increase agricultural productivity, thereby enhancing household income and food security. Furthermore, the average annual agricultural income per hectare of land for farmers who adopt collective management is 20.30% higher than that of those who do not adopt it (Abrham et al., 2023).

In addition, the impact of green production behavior by farmers on their agricultural income varies greatly in different market stages. In the early stages of implementing green production behavior, due to incomplete market mechanisms such as unclear quality agricultural product qualification inspection standards and asymmetric market information, high-quality products cannot be priced well, which can easily lead to the phenomenon of inferior coins driving out good coins (Wang, 2015). Therefore, in the short term, the green production behavior of farmers may not have a significant impact on increasing agricultural income. However, in the long run, with the continuous improvement of the market mechanism for high-quality agricultural products and the formation of a positive feedback mechanism, the impact of green production behavior of farmers on their agricultural income will become increasingly significant (Xiao, 2021).

In summary, although the academic research on green and low-carbon agriculture has not been long, the research results are very rich, especially in terms of the connotation, influencing factors, policy measures, and their impact on farmers' income and the development of green and low-carbon agriculture. However, up until now, there is a lack of research on the impact of green and low-carbon agriculture on the income of farmers in ethnic minority areas. China is a united multi-ethnic country, and achieving socialist modernization and common prosperity requires "no one nation can be left behind" (Xi, 2021). Therefore, it is very important for China to study the impact of green and low-carbon agriculture on the income of farmers in ethnic minority mountainous agricultural areas. Taking Y Town of Guizhou Province as an example, this paper empirically analyzes the impact of

green and low-carbon agricultural production on the incomes of farmers in this ethnic minority mountainous agricultural area. The aim is to provide useful references and suggestions for the realization of agricultural modernization and common prosperity goals in China's ethnic minority areas.

3 Model construction and data description

3.1 Model construction

The model constructed in this section is the income determination model of farmers, which in turn is based on the Mincer income equation. The Mincer income equation is a function of income determination and income difference derived by the economist Mincer based on human capital theory. The original basic form of this model is as follows (Mincer, 1974).

$$\log y = \log y_0 + rs + b_1 x + b_2 x^2 + u \quad (1)$$

In Equation 1, y represents the income of the worker, s represents the length of education of the worker, x represents the length of work experience (years) of the worker, and u is the random error term. This function is actually a model for studying income determination and has been widely applied in empirical research on factors affecting household income. In empirical research, researchers usually add various income-related variables, such as age, gender, political identity, etc., to the income determination model based on their research objectives.

Based on Mincer's income equation and the research purpose, the income equation of the household level in this study is set as follows (*the relationship between the* variables *included in this study and income will be explained in Section 3.2*).

$$\ln(income) = \beta_0 + \beta_1 lowcorbon + \beta_2 X_i + \beta_3 Y_i + \upsilon \quad (2)$$

The income level of the farmer is determined by Equation (2). X in the equation stands for the personal feature vector of the head of household i that may affect the disposable income of the household. In this article, the head of household refers to the member who plays a leading role in household management and decision-making, and may not necessarily be the "head of household" registered in the household registration book. In the equation, Y is the characteristic vector of agricultural production that may affect the disposable income of farmers' households, and subscript i is the *ith* sample farmer. The explained variable in Equation (2) is the average monthly disposable income of farmers. In order to reduce the heteroscedasticity in the sample data and linearize its trend (Li X. et al., 2019), the natural logarithm of the average monthly disposable income of rural households is taken for the explained variable, and the mean after de-logarithm is 7.64 and the standard deviation is 1.046. Of the explanatory variables, the core explanatory variable is green and low-carbon agricultural production mode, and we use the negative indicator "farmers using agricultural plastic films in agricultural production" as the proxy for this variable. On the one hand, agricultural plastic films can resist adverse environments, provide superior growth and development conditions for crops, improve agricultural yield and income, and have been widely used worldwide, especially the "ground cover film," which is regarded as one of the greatest inventions in planting or agricultural production in the past century (Wang, 2021). On the other hand, the production of agricultural plastic films requires a large amount of energy consumption and generates ECR-GHG emissions (Chi et al., 2021). In addition, most agricultural plastic films are difficult to degrade and are likely to cause serious adverse effects on the ecological environment. The use of agricultural plastic films is not a green and low-carbon agricultural production method.

As for the personal feature vector X of the core members farmer i, which may affect the disposable income of peasant households, the main variables included in this study are: gender (gen), age (age), nation (nat), marital status (mar), party membership (mem), educational level (edu), state of health (heal), social minimum living allowance (allo) and new rural social endowment insurance (endo).

In addition to the core explanatory variables, among the agricultural production feature vector Y that may affect the disposable income of rural households, the variables included in this study are agricultural service outsourcing and lease-out area.

3.2 Data and descriptions of variables

The data used in this study are all from the field survey of the research team. The rural household samples were collected from the rural household registration database of Y Town, Zhijin County, Guizhou Province by the research team using the systematic sampling method. A total of 881 valid sample data were obtained. Due to the fact that the survey data covers a large amount of individual-level social and demographic information, it is helpful to identify the impact of green and low-carbon agricultural production methods on the disposable income of rural households on the basis of controlling individual characteristics.

The definitions of the variables included in income determination Equation (2) in this study are as follows:

The explained variable is the average monthly disposable income of rural households, and is measured by the natural logarithm of the average monthly disposable income of the sample rural households in 2021. From the explanatory variables, the core explanatory variable is the green and low-carbon agricultural production mode (low-carbon), which is measured by the negative indicator, namely the use of agricultural plastic film by farmers in agricultural production. If farmers use agricultural plastic films in agricultural production, the value is 1, otherwise the value is 0.

In the personal feature vector X of the core members farmer i, which may affect the disposable income of farmers' families, the main variables included in this study are:

(1) Gender (gen), a dummy variable with the value of 1 for males and 0 for females. Theoretically speaking, due to the different innate characteristics of physiology and the body as well as the influence of traditional Chinese ideas and family division of labor, male farmers have advantages over women in traditional agricultural production and migrant work.

(2) Age, the real age of the head of household of the surveyed farmers. Generally speaking, with the increase of age, farmers have more experience in traditional agricultural production, so that the household income of farmers will increase correspondingly.
(3) Nation (nat), the ethnic identity of the head of the household of the surveyed farmer, is a dummy variable with a value of 1 for Han nationality and 0 for minority nationality. Due to the unique traditions and customs in minority areas, the agricultural production habits and methods of farmers in such areas may be different from those in Han areas, which may lead to differences in household income of farmers.
(4) Marital status (mar), a dummy variable, is assigned as 1 if the respondent is married/has a spouse, otherwise it is assigned as 0. In China's social system, having spouses for farmers means more social and economic resources, leading to higher levels of household income.
(5) Party membership (mem) is a dummy variable. If the head of the surveyed farmer household is a member of the Communist Party of China, the value is 1, otherwise it is 0. Political identity is an important element of social capital (Kung and Lee, 2001; Knight and Yueh, 2008). In China, the masses of party members, let alone the cadres who are party members, have a substantial right to participate in rural governance and business decision-making. They can quickly and accurately obtain valuable political and economic information through meetings, documents, etc., and convert this into economic benefits (Kung and Lee, 2001; Knight and Yueh, 2008). Therefore, the *per capita* income of "party member households" (i.e., households with family members who are members of the Communist Party of China) is higher than that of "non-party member households," in other words, party membership can brings with an income effect (Cheng et al., 2016). In addition, in China, party membership is also an important factor that affects an individual's status and labor participation (Li, 2023), which in turn affects the income level of his family.
(6) Educational level (edu) refers to the years of education for those residents who have received education. In China, receiving education is currently the main way for farmers to accumulate capital. Generally speaking, the higher the education level of farmers, the more conducive it is to the optimal allocation of agricultural production resources in rural production, improving the ability of farmers to learn advanced production technologies, thereby promoting their income growth (Xiang et al., 2022).
(7) Health status (health) is a dummy variable that is evaluated by the head of household as a reference to their peers. It is assigned an integer of 1–5 and corresponds to residents' health status as either "very bad," "bad," "fair," "good," and "very good"; Health status is an important factor determining labor productivity and it is directly proportional to labor productivity. That is, the better the physical health of farmers, the higher their labor productivity (Liang, 2019). In this way, whether in agricultural production or working outside, farmers with better physical health will have higher income levels.
(8) Social minimum living allowance (allo). This is a method of income redistribution, which is based on the government's transfer payment and is a direct monetary assistance method for low-income groups. Under the same economic state, farmers who receive the minimum living guarantee have a higher income level than those who do not. This variable is a dummy variable. If a member of the surveyed household has received the government's minimum living security allowance, it is assigned a value of 1, otherwise it is assigned a value of 0.
(9) New rural social endowment insurance (endo). The implementation of the new rural social security system can promote the transfer of labor between urban and rural areas (Bertrand et al., 2003; Cally et al., 2009), thereby having a positive impact on the income of rural households (Zhang, 2021). This variable is a dummy variable. If the surveyed farmers have family members who have participated in the new rural social pension insurance, the value is 1, otherwise, the value is 0.

Among the characteristic vector Y of agricultural production that may affect the disposable income of rural households, the main variables included in this study are:

(1) Green and low-carbon agricultural production mode (low-carbon) is a dummy variable. If the surveyed farmer uses agricultural plastic film in agricultural production, the value is 1, otherwise the value is 0.
(2) Agricultural service outsourcing is a virtual variable that examines whether the farmers surveyed have outsourced agricultural services such as farming, harvesting, and technology during the agricultural production process. If the farmers surveyed outsource agricultural services in agricultural production, the value is 1, otherwise the value is 0. Theoretically speaking, the outsourcing of agricultural services can improve agricultural production efficiency through specialized division of labor, thereby increasing the income level of farmers.
(3) Leased-out area. Rental land is also an important source of income for semi-medium farm households (Singh et al., 2017). Theoretically speaking, the larger the land area transferred by the surveyed farmers in the land circulation, the higher the income level. The variables included in this study and their definitions are shown in Table 1 while descriptive statistics for each variable in Table 2.

4 Result analysis and discussion

Result Analysis and Discussion. In this section, the least square method (OLS) regression is used to estimate Equation (2) of household income determination and the results are shown in Table 3.

The regression results in Table 3 show that the "low-carbon" variable passes the significance test at the level of 1% and the coefficient is negative. It shows that the household income level of farmers who use plastic film is lower than that of farmers who do not use plastic film. There is a positive correlation between green and low-carbon agricultural production methods farmers' and household income levels. The household income level of farmers who use low-carbon production methods for agricultural production is higher than that of farmers who use non low-carbon production methods for agricultural production. Low carbon agricultural production

TABLE 1 List of variables.

List of variables	
Variables	Definitions
income	ln (Average disposable monthly income of rural households (Yuan))
gen	1 means male and 0 means female
age	the actual age of the household head
nat	1 means Han and 0 means Minority
mar	1 means Having a spouse and 0 means other
mem	1means the household head being a member of the Communist Party of China and 0 means other
edu	The number of years of formal schooling that the surveyed household head received
heal	5 means very good; 4 means Good; 3 means fair; 2 means Bad; 1 means Very bad
allo	1means the surveyed farmers having received the minimum living security allowance, 0 means other
endo	1means family members of the surveyed farmer participating in the new rural endowment insurance, 0 means other
lowcarbon	1 means the surveyed farmer using agricultural plastic film in agricultural production, 0 means other
outs	1 means the surveyed farmer outsourcing agricultural services in agricultural production, 0 means other
leased-out	The land area leased out by the surveyed farmers during land transfer (mu)

methods can promote the growth of household income for farmers. The research results of Ma et al. (2022) also prove this: the adoption of green agricultural production technologies by agricultural producers can reduce agricultural pollution emissions, increase agricultural output value, and thus improve farmers' income and well-being. This is basically consistent with the research findings of Chi et al. (2021), which showed a clear "U" relationship between green and low-carbon agricultural production technologies and household agricultural income. The research conclusion of this article is also consistent with the actual production of farmers. Due to the need to save production costs, the plastic film used by the sample farmers is non-degradable. Due to the time-consuming and laborious removal of plastic films as well as the insufficient awareness of environmental hazards among farmers, most of the sample farmers choose to dispose of plastic residues in farmland, causing soil pollution (Koskei et al., 2021), which has adverse effects on the environment and human health (Rodrigues et al., 2019). Non low-carbon agricultural production methods will have negative externalities on society, thereby reducing the welfare and income levels of farmers. From the perspective of farmers, in the short term sample farmers improve agricultural yield and income by adopting a non-low carbon production method relying on agricultural plastic film for agricultural production, which can resist adverse environments and provide superior growth and development conditions for crops. However, in the long run, adopting non-low carbon agricultural production methods is irrational, as soil pollution can reduce agricultural yield and product quality, leading to a decrease in household income for farmers.

The age variable passes the significance test at the 5% level, and the coefficient is negative. It shows that the average disposable monthly income of rural households will decrease with an increase in age. This was also confirmed by the studies of Wang et al. (2021) and Xiang et al. (2022). This is because, compared to older farmers, young farmers have more energy, are more receptive to new things, can obtain modern agricultural production and management information more efficiently, and can learn and master modern agricultural knowledge and technology more quickly.

The marital status variable passed the significance test at the level of 1%, and the coefficient was positive, indicating that the income level of married farmer families was significantly higher than that of unmarried farmer families. This is consistent with the research conclusions of Agwu and Orji (2013), Fan (2020), Zhang (2021), and Wonder et al. (2022).

The variable of educational attainment passes the significance test at the level of 1% while the coefficient is positive. This indicates that education level plays a significant role in promoting the household income of farmers, that is, the longer the duration of education, the higher the education level, the higher the household income level of farmers. This was also confirmed by the studies of Liu and Zhao (2020), Wang et al. (2021), Xiang et al. (2022), and Mina et al. (2022).

The health status variable passed the significance test at the 1% level and had a positive coefficient. It shows that this variable has a positive promoting effect on the income of rural households, that is, the healthier the body, the higher the income level of rural households. Consistent conclusions have been drawn by Fan (2020), Zhang (2021), Xiang et al. (2022), and Mina et al. (2022).

The variable of "new rural social endowment insurance" also passed the significance test at the level of 1%, and the coefficient was positive. This shows that the new rural social endowment insurance has a significant role in promoting the household income of rural households, and the household income level of insured households is significantly higher than the total household income of non-insured households. This is consistent with the findings of Zhang et al. (2015) and Zhang (2021).

The gender variable did not pass the significance test, indicating that the gender of the household head of the surveyed rural households had no significant impact on the household income of rural households, which was consistent with the research results of Zhang (2021) and Xiang et al. (2022). This is because family decisions are collective, and although the head of the household plays a major role in family decision-making, it is not necessarily decisive. Ethnic variables did not pass the significance test, indicating that ethnic identity has no significant impact on rural household income, which is contrary to the research results of Tang and Huang (2017) and Fan (2020). The reasons are as follows: First, regional differences. The sample region involved in this study – Guizhou Province – is an area where ethnic minorities gather and has a high degree of ethnic integration. There is no difference between different ethnic identities in education, employment and other aspects. Second, China's long-standing policy of ethnic equality has produced practical results. Political status variables did not pass the significance test, indicating that party membership has no significant impact on household income, which is contrary to Kung and Lee (2001), Knight and Yueh (2008), Cheng et al. (2016), and Li (2023). The reason is that, given the continuous improvement of the socialist market economy system with Chinese characteristics, the process of rural governance and

TABLE 2 Descriptive statistics for each variable.

Variable	Obs	Mean	Std. Dev.	Min	Max
income	881	3019.103	1827.027	200	5,000
lincome	881	7.640	1.046	5.298	8.517
gen	881	0.848	0.359	0	1
age	881	55.528	13.219	17	94
nat	881	0.603	0.490	0	1
mar	881	0.988	0.111	0	1
mem	881	0.034	0.181	0	1
edu	881	6.350	3.068	0	16
heal	881	3.814	1.365	1	5
allo	881	0.044	0.206	0	1
endo	881	0.691	0.462	0	1
lowcarbon	881	0.393	0.489	0	1
outs	881	0.260	0.439	0	1
leased-out	881	0.498	0.841	0	5.470

TABLE 3 The impact of green and low-carbon agricultural production on household income of farmers.

The explained variable is the natural logarithm of the average monthly disposable income of rural households			
gen	−0.058 (−0.035)	heal	0.651*** (0.033)
age	−0.009** (0.003)	allo	−0.022 (0.088)
nat	0.007 (0.021)	endo	0.407*** (0.023)
mar	0.554*** (0.123)	Low-carbon	−0.239*** (0.036)
mem	−0.109 (0.079)	outs	−0.283*** (0.051)
edu	0.030*** (−0.004)	leased-out	−0.016 (0.019)
group	control		
R^2	0.899		
F	2837.78		
Obs	881		

***Means significant at 1% significance level; **indicates significant at a significance level of 5%; The values in parentheses are the robust standard deviations corrected for village-level clustering.

TABLE 4 Distribution of land transfer scale of sample farmers.

Transfer scale (mu)	<1	[1,2)	[2,3)	[3,4)	[4,5)	>5
Number of farmers (hu)	704	124	35	9	8	1
Proportion (%)	79.91	14.07	3.97	1.02	0.91	0.11

Data source: field survey and collation.

decision-making in China is becoming more and more open and transparent, while the economic benefits of party membership are gradually disappearing. The "minimum living security" variable did not pass the significance test, indicating that the enjoyment of minimum living security did not significantly affect the household income of rural households. This is inconsistent with the views of Chen et al. (2020). The reasons are as follows: (1) The number of farmers in Y Town who enjoy the minimum living guarantee is very small, accounting for only 4.4% of the total sample, so it cannot significantly affect the total household income level of farmers; (2) The minimum living guarantee amount is relatively small, with an average of about 205 yuan per person per month (data obtained from field investigations), and this amount does not have a significant effect on increasing the total income of households. The above factors lead to the insight that enjoying the minimum living guarantee cannot have a significant impact on the total income of rural households.

The statistical regression results in Table 3 also show that in the agricultural production feature vector Y, which may affect the disposable income of farmers and households, the agricultural service outsourcing variable passes the significance test at the 1% level and the coefficient is negative. This indicates that in the process of agricultural production, agricultural service outsourcing reduces the household income level of farmers. This is contrary to the research conclusions of Machila (2015), Lyne et al. (2018), and Xiang and Xiaoqin (2023). The reason may be that it is difficult to establish trust between farmers and agricultural outsourcing service providers in the regions where the sample farmers are located. The distrust of such service providers by farmers leads to an increase in production costs and a waste of economic resources. For example, farmers may conduct real-time supervision when agricultural outsourcing service providers deliver services.

In the process of land circulation, land transfer (or land rental) has no significant impact on the income of rural households, which is inconsistent with the theoretical analysis and findings of Ying and Sihong (2022) and Congjia and Lingming (2021). Through in-depth investigation, it is found that the reasons why the conclusions drawn in this study are inconsistent with the theoretical analysis may mainly stem from the following three aspects:

(1) The scale of land transfer is generally small, resulting in an insignificant impact on the income of farmers.

Y Town, located in the Yunnan Guizhou Plateau with more mountains than flat dams, is a typical mountainous terrain. As a result, a large part of the cultivated land in the town is located in the mountains, with a large slope where production and operational costs are much higher than that of flat land. Thus, land demanders were more inclined to transfer land from the dam area with flat terrain, especially in the early stages of land transfer implementation. Indeed, by the end of 2021, the land transfer of Y Town was limited to the land in the dam area, and farmers whose land is not in the dam area could not participate in the transfer. The geographical conditions of Y town determined that the proportion of land in the dam area in the cultivated land of most farmers is relatively low, at an average of about 15%. This resulted in a relatively small scale of land transferred by most farmers even if they participated in land transfer. As shown in Table 4, of the 881 sample farmers, the number of farmers with land transfer area less than 1 mu is the highest, with a total of 704 households, accounting for about 80% of the sample farmers. There are 124 households with a land transfer area greater than 1 mu but less than 2 mu, accounting for approximately 14% of the total sample households. The number of farmers with land transfer areas between 3 and 5 mu is less than 2% of the total sample size. However, there is only one household with a land transfer area greater than 5 mu

The small scale of land transfer leads to the small amount of property income from land transfer behavior. As shown in Table 5,

among the sample farmers, the maximum income from land transfer is 3,282 yuan a year while the minimum is 0 yuan. The average annual property income of each household from land transfer is about 299 yuan.

To sum up, the geographical conditions of Y Town restrict the scale of land transfer, leading to farmers in Y Town being unable transfer land or that the land area transferred is generally small at the present stage, so farmers derive less income from land transfer. As a result, the impact of land transfer on household income is not significant.

(2) The transfer scale restricts the release of the agricultural labor force.

Due to geographical conditions and natural endowments, farmers in Y Town are currently unable to participate in land transfer or the scale of land transfer is generally small. As shown in Table 5, of the sample farmers, the smallest land area involved in land transfer is 0 mu, the largest is 5.47 mu, and the average land area of each household involved in land transfer is about 0.5 mu. By the end of 2021, the *per capita* cultivated land area of Y Town was about 1.27 mu, and the average total cultivated land area of each household was about 5 mu. As a result, even if they participated in land transfer, the proportion of the land area transferred by farmers is small, and the vast majority of farmers cannot transfer all the cultivated land owned by them. In fact, of the cultivated land transferred by the sample farmers, only the flat and high-quality land in the dam area was transferred by the land demand side, while the mountainous cultivated land was classified as "inferior goods" and still remained in the hands of farmers. This leads to the observation that even after participating in land transfer, sample farmers still needed to invest labor in the production and operation of mountainous farmland. As a result, this part of the labor force cannot be liberated from agricultural production, cannot be transferred to the non-agricultural sector for employment, and cannot obtain higher wage income compared to agricultural production (Fei and Weijuan, 2015; Zhonghao and Xingwen, 2016).

To sum up, the geographical conditions and natural endowments of Y Town limit the scale of land transfer, so that farmers are still tied to agricultural production after the transfer of some of the high-quality land, and the agricultural labor force cannot be fully released (Ruifen and Anlu, 2015; Zhang et al., 2018), resulting in an insignificant income increase effect of land transfer for farmers.

(3) Land transfer leads to "unemployment."

The unemployment of farmers caused by the transfer of land management rights is also one of the reasons why the impact of land transfer on the income growth of Y Town farmers is not significant. After in-depth investigation, it was found that about 41.57% of farmers whose main source of income is agricultural production and operations have lost their land management rights after transferring them, while their household labor force is basically in a state of "unemployment." The reasons include: ① insufficient employment opportunities in surrounding towns. The transfer of land management rights has released some rural labor from agricultural production. However, due to the backward development of the local secondary and tertiary industries and the impact of the COVID-19 epidemic, the surrounding cities and towns have not been able to provide sufficient jobs for this surplus labor, resulting in "unemployment" and accompanying "land loss" for some rural surplus labor. ② Insufficient human capital accumulation. School education is the main way to achieve human capital accumulation. However, as can be seen from Table 2, the average education span of sample farmers is 6.35 years. This means that most of the peasants in Y Town do not receive school education after primary school. Most of the surplus rural labor force become low-skilled workers due to a lack of human capital accumulation and are at a disadvantage when they are transferred to non-agricultural sectors, especially when they are exported or transferred to such sectors in the developed eastern regions. The shortage of human capital accumulation leads to the lack of conditions and capital for rural surplus labor to transfer to non-agricultural sectors, which results in "unemployment" accompanying "land loss" for some rural surplus labor. ③ Local complex. Local complex is a unique cultural phenomenon of the Chinese nation. The influence of this culture on peasant household behavior is mainly reflected in the excessive dependence of rural surplus labor on the local geographical environment, living customs, etc. and an inadaptability to the natural and cultural environment of foreign villages. The results of field research show that most of the sample farmers have different degrees of local complex, and some of the rural surplus labor force cannot leave their hometown and follow to the non-agricultural sector as the result.

To sum up, the land transfer behavior in Y Town has no significant effect on increasing the income of farmers due to three reasons: the limitations of geographical conditions and natural endowments on the scale of land transfer, insufficient release of the agricultural labor force, and "unemployment" caused by land transfer.

TABLE 5 Descriptive statistics of land transfer of sample farmers.

	Maximum	Minimum	Average value
Land transfer area (mu)	5.47	0	0.5
Land transfer income (yuan)	3,282	0	299

Data source: field survey and collation.

5 Conclusion and policy implications

Under the guidance of the "dual carbon" goals, the Chinese government has further increased its efforts to develop green and low-carbon agriculture, with the goal of continuously increasing production, reducing input, reducing pollution, and improving efficiency (Zhang, 2019), thereby effectively promoting the growth of farmers' income, achieving the modernization of agriculture, while realizing the goal of common prosperity. This paper takes Y Town, Zhijin county as an example. Using the OLS regression method and based on field survey data of 881 farmers, the paper has empirically studied the impact of green and low-carbon agricultural production methods on the income of farmers in ethnic minority mountainous agricultural areas. The main contribution of this study is to expand the research scope of green and low-carbon agriculture to ethnic minorities and mountainous agricultural areas. The final results are as follows: (1) There is a positive correlation between green and low-carbon agricultural production methods and household income levels while adopting green and low-carbon agricultural production technologies can effectively promote the growth of household income for farmers; (2) Education level, health status, and new rural social

pension insurance all have a significant promoting effect on the income of rural households; (3) Due to the difficulty in establishing trust relationships, agricultural service outsourcing has reduced the household income level of farmers; (4) The insignificant effect of land transfer behavior in Y Town on farmers' income is due to three reasons: the limitations of geographical conditions and natural endowments on the scale of land transfer; insufficient release of agricultural labor; and "unemployment" caused by land transfer.

Based on the above research results, this study makes the following policy recommendations:

(1) Increase fiscal and financial support, such as raising low-carbon agricultural technology subsidy standards while developing agricultural insurance, etc., to encourage agricultural technology innovation and promotion. Deepen publicity efforts, enhance the policy awareness of farmers, as well as their awareness and perception of low-carbon agriculture, and increase the intensity of farmers adopting low-carbon agricultural technologies. Encourage large and professional farmers to play a demonstrative role, promote the use and adoption of green and low-carbon agricultural technologies, improve agricultural production efficiency and product quality, thereby promoting the sustainable growth of farmers' income.

(2) Attach importance to school and agricultural education in rural areas, strengthen skills training for farmers, and cultivate technology farmers. Education and training are the main ways to accumulate human capital. Improving the human capital accumulation and skill level of rural residents requires the intervention of government departments: strengthening publicity efforts to guide rural residents in ethnic minority areas to deeply understand the importance of school education will help to achieve this. Assist villagers in solving difficulties and provide conditions for children and adolescents in rural areas to receive as much school education as possible. Provide free opportunities for training in green and low-carbon agricultural production technologies and skills, organize regular and irregular technical and skill training for farmers, and enhance their awareness of green and low-carbon agricultural production technologies. Integrate production, learning and research, cultivating technology-based farmers, while making the fields a classroom for promoting low-carbon agricultural production technologies. Through learning by doing and doing by learning, we can effectively enhance farmers' perception of green and low-carbon agricultural production technologies and low-carbon agricultural concepts.

(3) Further improve and perfect the social security system and institutions in rural areas. On the one hand, there is a need to realize full coverage of rural residents' endowment and medical insurance. On the other hand, it is necessary to increase the range of benefits from endowment insurance and medical insurance for rural residents, comprehensively achieving "medical care for illness and care for the elderly," while providing guarantees for the continuous improvement of farmers' income and living standards.

(4) Strengthen the construction of social integrity system while continuously improving the awareness and level of integrity of the whole society. In addition, deepen the general and institutional trust of farmers, and have the government certify the qualifications and credit of agricultural outsourcing service providers, so as to improve the trust of farmers in agricultural service providers and agricultural production efficiency.

(5) Make full use of the resource endowment of minority areas, develop characteristic agriculture, and abolish the restrictions imposed by geographical conditions on the scale of land transfers. There is also a need to achieve large-scale land management and create conditions for the use and adoption of green and low-carbon agricultural technologies, thereby improving the quality of agricultural products and increasing farmers' incomes. For example, relying on leading agricultural enterprises, the development of mountainous economy can be achieved by planting crops or economic crops suitable for mountainous areas, such as chili peppers, tobacco, traditional Chinese medicine, oil tea, etc., thus increasing the economic value of mountainous output. With the improvement of the output value of mountainous areas, the latter will no longer be "inferior commodities," thereby breaking restrictions on land transfer scale caused by land demanders' "discrimination" against mountainous areas, hence increasing the property income of land transfer out of households.

(6) Extend and broaden the agricultural industry chain, while promoting the integration of three industries in ethnic minority rural areas. The crucial factor determining the impact of land transfer behavior in Y Town on farmers' income growth is that the surplus rural labor force cannot be smoothly transferred to the non-agricultural sector. The key to the smooth transfer of surplus rural labor to the non-agricultural sector lies in providing sufficient employment opportunities. To create a sufficient number of such opportunities, it is necessary to extend and widen the agricultural industry chain, thereby achieving, respectively, the deep processing of characteristic agricultural products, relying on the resource endowment of ethnic minority areas to realize the deep integration of primary, secondary and tertiary industries, and the construction of a green and low-carbon agricultural industrial system. On the one hand, this will create employment opportunities for the agricultural labor force released from land transfers, so that they can work on their doorstep. On the other hand, it provides conditions for the high-quality development of green and low-carbon agriculture.

6 Limitations and future research directions

The limitations of our study are presented and also the directions for future research here. The present study is limited to ethnic minority areas and mountainous agricultural areas in China, therefore its research results and development suggestions may not be applicable to non-ethnic minority areas and non-mountainous agricultural areas. To that end, it is recommended to extend research frameworks to non-ethnic minority areas and non-mountainous agricultural areas.

The selected index for green and low-carbon agricultural production in this study is a single index, which does not provide a comprehensive measurement of the green and low-carbon agricultural production modes. Hence, it is suggested that future studies should adopt a more comprehensive index to measure various aspects of green and low-carbon agricultural production methods.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

YL: Conceptualization, Formal analysis, Funding acquisition, Methodology, Software, Writing – original draft. TP: Data curation, Investigation, Writing – review & editing. YC: Supervision, Writing – review & editing. JY: Supervision, Writing – review & editing. CL: Investigation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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