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Drivers and mechanisms of cropland abandonment in typical mountainous areas of Southwestern China

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Cropland abandonment has become a common phenomenon globally, which not only causes waste of land resources, but also affects agricultural development and food security. As the largest developing country, China has witnessed particularly severe cropland abandonment under the combined effects of socioeconomic transformations and policy adjustments, especially in its southwestern mountainous regions. To systematically investigate the status and determinants of cropland abandonment in typical mountainous areas of China, this study employed multilevel regression analysis based on household surveys to construct a three-level "plot-household-village" Logit model. The research systematically examined influencing factors and driving mechanisms of cropland abandonment, providing scientific evidence for regional land management. The results reveal an abandonment rate of approximately 10.4% in typical mountainous areas of Southwestern China. Spatially, the abandonment rate demonstrates an inverse correlation with elevation, a parabolic relationship with cultivation distance (initially increasing then decreasing), and positive correlations with declining land quality and increasing slope gradient. Regarding determinants, plot-level land quality emerged as the most critical explanatory factor (coefficient = 0.623). At household level, degree of part-time farming and agricultural labor density per unit area showed significant impacts (coefficients = 0.350 and −1.011 respectively). Village-level analysis identified per capita cultivated land area as the primary determinant, exhibiting a significant negative correlation (coefficient = −1.166). These multi-scale factors interact synergistically, forming a complex hierarchical driving mechanism for cropland abandonment. The findings highlight the necessity for differentiated land management strategies that account for scale-specific characteristics in mountainous regions.

KEYWORDS

cropland abandonment, land use change, influencing factors, typical mountainous areas, China

1 Introduction

Land use and land cover change (LUCC), as a visual representation of the impacts of human activities on the Earth's surface, is both influenced by human behavior and counteracted by human societies (Saxena et al., 2018; Yin et al., 2018; Montràs-Janer et al., 2024). Among the various land use types, cropland, with its unique function, plays an irreplaceable role in providing food resources for human survival, yet this supply capacity is also under pressure

from population scale growth (Alexander et al., 2015; Li et al., 2024). According to the global demographic trend forecast (Gerland et al., 2014), the future demand for food is expected to double by 2050 (Tilman et al., 2011; Tilman and Clark, 2014; Kehoe et al., 2017), while the resource and environmental carrying capacity of cropland is close to its limit (Valin et al., 2014). At the same time, environmental issues such as climate change, land degradation and ecological deterioration are becoming increasingly serious, and coupled with the impacts of new crown epidemics and geopolitical conflicts in recent years, food security has become a topic of global concern (Prosekov and Ivanova, 2018; Lee et al., 2024). Sustainable Development Goal 2, adopted by the United Nations in 2015 (United Nations, 2015), emphasizes the importance of achieving the eradication of hunger, guaranteeing food security and promoting sustainable agricultural development by 2030. As the carrier of food production, cropland is a strategic resource for maintaining national food security and social stability (Su et al., 2023). The increasingly serious problem of cropland abandonment not only leads to the continuous shrinkage of cropland resources, exacerbating the conflict between people and land (Yin et al., 2020; Zhang et al., 2023), but also leads to the decline of effective sown area, and then causes degradation of the quality of cropland, which threatens the foundation of food security directly. Although specific data on abandoned cropland are not yet available globally, studies have shown that this phenomenon is not only common in developed countries, but also shows a high prevalence in developing countries (Kuemmerle et al., 2009; Alcantara et al., 2012; Herrando et al., 2014), especially in China.

As the world's largest developing country, China only uses 7% of the world's arable land resources to provide food security for 22% of the world's population, which makes the per capita possession of cropland extremely limited, and arable land resources are particularly precious (Bai et al., 2015). Influenced by multiple factors such as changes in socio-economic factors and policy adjustments, the phenomenon of cropland abandonment has appeared to varying degrees in many parts of China since the 1980s, especially in hilly and mountainous areas (Yuan et al., 2024). According to statistics, mountainous counties (districts) in China account for about 43% of the total land area (Zhou and Wang, 2023). These areas generally have problems such as scattered and fragmented land parcels, high proportion of cropland with high and steep slopes, etc. (Yang et al., 2022). Restrictive factors such as difficulty in farming, inconvenient transportation, and continuous loss of rural labor force have led to particularly serious cropland abandonment in mountainous areas (Xiang et al., 2022; Lu et al., 2024). Some research results show that the abandonment rate of mountainous counties in China (areas with more than 80% of mountainous area within the county) reached 14.32%, with the abandonment rate even exceeding 30% in some areas of Jiangxi Province and Chongqing Municipality (Shengfa et al., 2017). These data indicate that cropland abandonment has not only become a remarkable phenomenon and norm in China's current land use, but also a rapidly developing form of land use change (Yu et al., 2017).

Cropland abandonment is a complex and multidimensional phenomenon, and its occurrence and development are affected by the interaction of natural conditions, social structure, economic environment, and policy system (Blair et al., 2018). Exploring the intrinsic mechanism of cropland abandonment is an important basis for making decisions on cropland abandonment management and evaluating the effects of related policy interventions. Some scholars have shown that the process of cropland abandonment and its driving mechanism differ significantly in different countries and regions (Wang J. et al., 2024). Generally speaking, the drivers of abandonment can be summarized in the following aspects: economic, institutional, policy and climate dimensions. Among them, the level of economic development is the main driver of cropland abandonment in most countries and regions around the world, and this phenomenon is especially prominent in developed countries and regions such as Europe and Australia (Müller et al., 2013; Lieskovsky and Lieskovská, 2021). In China, the country is currently at a critical stage of transition from traditional smallholder economy to agricultural modernization. The implementation of the reform and opening-up policy has greatly promoted economic development, especially the development of the coastal areas has attracted a large number of rural laborers from the central and western regions, which has led to the increasingly prominent problem of cropland abandonment in the central and western regions of China (Xu et al., 2019; Su et al., 2020). Moreover, the phenomenon of cropland abandonment in China shows significant regional heterogeneity: mountainous areas are the high incidence of abandonment, while the degree of abandonment in plain areas is relatively mild. The problem of cropland abandonment in mountainous areas is particularly serious due to the fragmentation of land parcels, the difficulty of cultivation, and the inconvenient transportation in mountainous areas, as well as multiple constraints such as the continuous loss of rural labor force. In addition, the core drivers of cropland abandonment are often different in different regions and historical stages (Li and Li, 2017).

Given China's vast size, diverse topography and climate, the causes of cropland abandonment are often intertwined with the impacts of multiple social, economic, and natural factors, and the identification of the factors affecting cropland abandonment must be based on the specific study area, and in-depth analyses of the unique driving mechanisms must be carried out in order to formulate a more targeted conservation response. Youyang County, Chongqing Municipality, is a typical mountainous area in Southwest China, and is also the largest county in Chongqing Municipality, making it one of the best study areas for research on cropland abandonment in China. In this study, we will combine the data from the questionnaire survey of field farmers in the study area, and use methods such as the multilevel analysis model to develop a systematic analysis of influencing factors from multiple dimensions. By comprehensively examining key variables such as natural environmental features (e.g., topography, climatic conditions), socio-economic conditions (e.g., demographic changes, level of economic development), and farmers' behavioral decision-making, this study will identify and quantify the main drivers of cropland abandonment in mountainous are-as, and further reveal their mechanisms, so as to target the implementation of reclamation of abandoned land as a short-term effective way to increase food production, which has a significant effect on the protection of food security and the response to the global food crisis. The main objectives of this study are as follows: (1) To conduct a questionnaire survey of farmers in mountainous areas to systematically grasp the distribution characteristics of abandoned cropland in typical mountainous areas in Southwest China. (2) To investigate the influencing factors and mechanisms affecting the abandonment of cropland in mountainous areas by using multilevel analysis models and other methods. (3) Combining the results of the questionnaire survey and quantitative analyses, we propose countermeasures to mitigate cropland abandonment in typical mountainous areas in Southwest China, which will serve as a reference for policy makers and managers.

2 Data sources and methods

2.1 Overview of the study area

This study takes cropland in mountainous areas as the object of research, and the case area is chosen to be Youyang County, Chongqing Municipality, China (Figure 1). Youyang County is located in the hinterland of the Wuling Mountains in the south-eastern border of Chongqing Municipality, China, and its topography is controlled by geological structure and lithology, with low mountains and hills dominating, and the topography of the whole county has a lot of ups and downs. The topography of the county is divided into middle mountainous areas (800–1895 m above sea level), low mountainous areas (600–800 m above sea level), troughs and flat dams (263–600 m above sea level). Its topography is mainly mountainous, with limited water and cropland resources, making it a suitable area for conducting

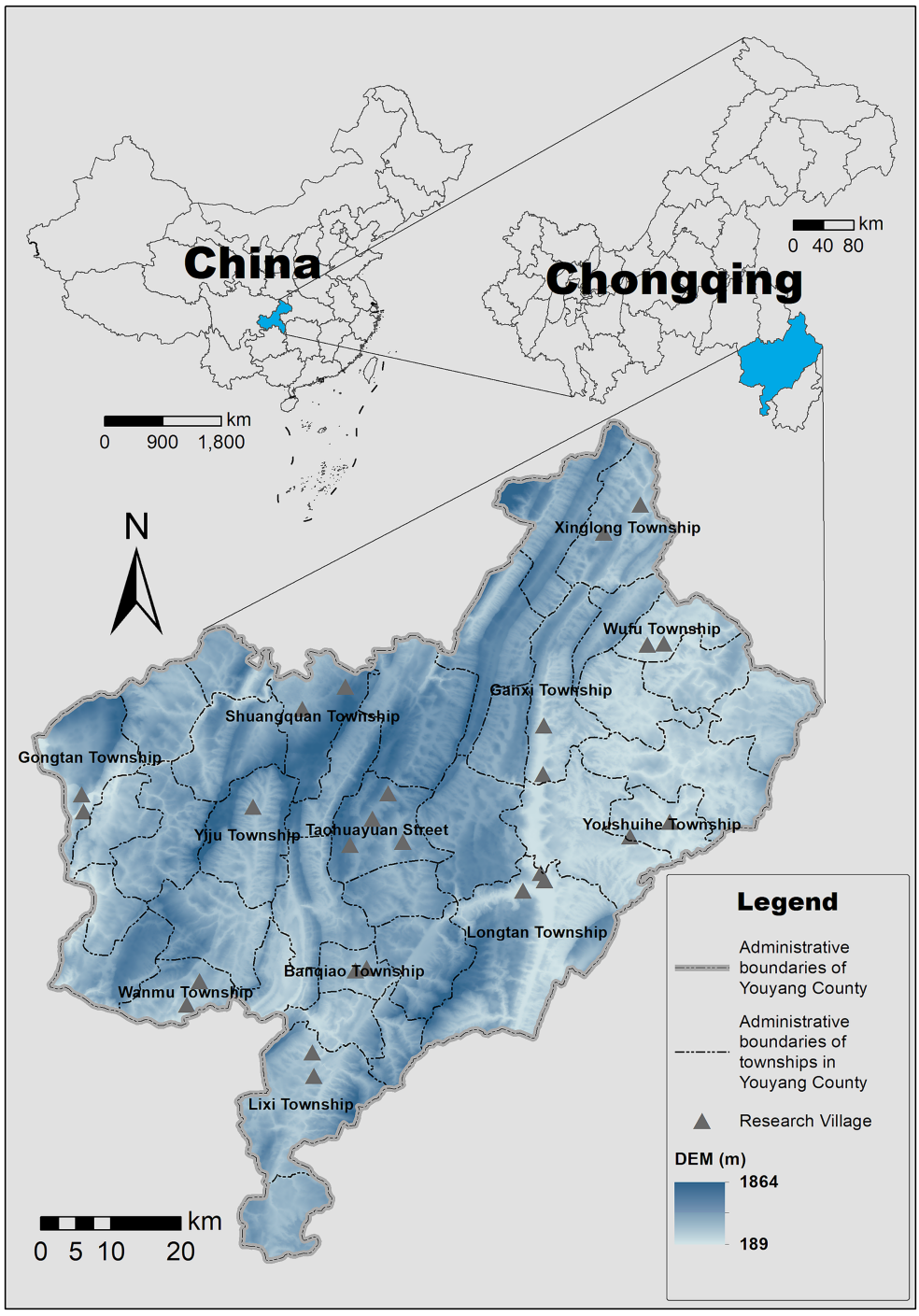

FIGURE 1
Geographic location of the study area and distribution of villages in the field study.

research on cropland abandonment in typical mountainous areas in southwest China.

Combined with the village boundary map of Youyang County, 24 typical administrative villages were selected for household questionnaire surveys in 12 townships, namely, Taohuayuan Street, Shuangquan Township, Yijiu Township, Banqiao Township, Gongtan Township, Wanmu Township, Lixi Township, Longtan Township, Xinglong Township, Wufu Township, Sluoxi Township, and Youshuihe Township, based on the locational conditions and economic status of each county and township by means of stratified sampling (Figure 1). About 9 farming households were randomly selected within each natural village for the survey. In this study, questionnaire surveys were completed for more than 130 farm households, and 110 valid questionnaires were collected, involving a total cropland area of 88.52 ha.

2.2 Questionnaire survey of farmers

During the field research, this study scientifically classified cropland into five basic categories based on its actual utilization status: one category is cropland that is currently under cultivation; the second category is cropland that is already in a state of abandonment; the third category is cropland areas where the policy of returning cropland to forests has been implemented; the fourth category is cropland that has been transferred to the operation of other farmers; and the fifth category is cropland that is fallow.

The questionnaire survey used the Participatory Rural Appraisal (PRA) method to collect data covering three dimensions: village, farm household and plot (Table 1). First, each village was interviewed by the village head or village secretary to understand the basic village situation, which mainly included information on the collective size of the village, population size, cropland area, abandonment and replanting, labor force going out to work, and planting structure. Then, on this basis, a random sampling survey was conducted on farm households in the village, with the survey object mainly being the head of the household, and each household survey took about 0.5–1 h. The survey covers core data such as the composition of household members, labor force employment status, agricultural and non-agricultural income, and household expenditure. The data at the plot level are also based on questionnaires, focusing on key data such as the natural conditions of the cropland (including cultivation area, quality of cropland, slope, distance, availability of water sources, and whether it is leveled or not), changes in ownership, and inputs and outputs of agricultural factors of production, as well as the mode of transferring cropland, the number of years, and the rent, for the transferred cropland, for the retired cropland, and the amount of subsidies, and for the abandoned cropland. For fallow plots, record the number of years and amount of subsidy; for abandoned plots, record the number of years and reasons.

2.3 Research methods

2.3.1 Multilevel analysis of factors affecting cropland abandonment

This study adopts a multilevel analysis approach to explore the influencing factors of the cropland abandonment phenomenon and its underlying mechanisms. First, cropland abandonment is not the result of a single factor, but is influenced by the interaction of multidimensional factors such as the natural characteristics of the land parcel, the attributes of the farm household, and the socio-economic conditions of the village. For this reason, the survey data in this study are organized according to a hierarchical structure: specifically, plots are nested within farm households as the lowest level unit, while farm households are further nested within the village as a higher-level scale.

Faced with the limitations of traditional statistical methods in dealing with such nested data - i.e., the assumptions of sample independence and variance uniformity are often contrary to the reality - this study introduces Hierarchical Linear Modeling (HLM) as a research tool (Green et al., 2006). The use of the HLM model can solve the problem of statistical analysis of hierarchical or multilevel data, and can also overcome the shortcomings of traditional statistical analysis methods for analyzing multilevel data that lead to analytical inference errors. The method can consider the variation of data on the

TABLE 1 List of contents of the questionnaire for farmers.

Basic information		Content of the survey	Target audience
Villages	Basic information on villages	Village area, population size, distance from the county town, height of the sea wave, area of cropland, area of forest land, labor force, cultivation, industry, policy implementation, etc.	Village chiefs or village cadres
Farmer household	Basic information about the family	Number of people in the household, type of part-time work, area of cropland, source of income, agricultural machinery and equipment	Farmer household
	Labor force situation	Sex, age, level of education, type of employment, time and place of work, income from work	Farmer household
	Household expenditures	Expenditure on production, living, medical care, education, interpersonal relations, etc.	Farmer household
Land plot	Fundamental characteristic	Plot size, slope, quality class, proximity to home, basic amenities	Farmer household
	Operating land plot	Types of crops grown, production inputs, outputs and consumption	Farmer household
	Plots leased to other farmers	Transfer mode, transfer period and transfer rent	Farmer household
	plots of abandoned cropland	Years and reasons for abandonment	Farmer household
	Plots of land retired from cultivation	Number of years of fallow and subsidies	Farmer household

same level as a whole as well as the variation of data between different levels. It can not only effectively deal with the hierarchical structure of data, but also accurately capture the effects of variables at each level on cropland abandonment through the combination of fixed and random effects (Ker, 2014).

Cropland abandonment, as a dichotomous response variable, is suitable for analyses using logistic regression models. Based on this, this study starts from the basic Logistic regression model and gradually extends to construct a multilevel analysis framework in order to systematically examine the factors affecting cropland abandonment. In order to facilitate understanding and analysis, only one core explanatory variable is introduced in each level of the model, and the impact mechanism of the multilevel structure on the research problem is clearly demonstrated through step-by-step modeling. In this process, the logistic regression model is transformed into a linear form with the help of logit transformation, which enables convenient estimation of parameters and intuitive interpretation of model effects. This approach maintains the simplicity of the model while ensuring the systematic and scientific nature of the analysis.

In this study, a three-level logistic model of plot-farmer-village was introduced to investigate the influencing factors of cropland abandonment. Firstly, it was tested whether the stratified variation of cropland abandonment was significant. A basic three-level Logit model (without predictor variables) was constructed using whether or not abandonment of plots occurred (1 = abandonment occurred, 0 = no abandonment occurred) as the response variable:

$$Level-1: Y_{ijk} = \ln\left(\frac{P_{ijk}}{1-P_{ijk}}\right) = \beta_{0jk} + \varepsilon_{ijk}, \mathrm{var}\left(\varepsilon_{ijk}\right) = \sigma^2$$
$$Level-2: \beta_{0jk} = \pi_{00k} + \mu_{0jk}, \mathrm{var}\left(\mu_{0jk}\right) = \tau_\beta$$
$$Level-3: \pi_{00k} = \gamma_{000} + e_{00k}, \mathrm{var}\left(e_{00k}\right) = \tau_\pi$$

where i, j and k represent the plot, farmer and village scales, respectively, and P_{ijk} is the probability of abandonment in plot i. At the village scale, γ_{000} is the fixed intercept term of the model, and $\exp.(\gamma_{000})/(1 + \exp.(\gamma_{000}))$ denotes the overall average probability of occurrence of desertion across villages; e_{00k} is a random term representing the variation across villages, with variance $\mathrm{var}.(e_{00k})$ of τ_π. At the farm household scale, $\exp.(\pi_{00k})/(1 + \exp.(\pi_{00k}))$ denotes the overall average probability of abandonment across farmers within village k; μ_{0jk} is a random term representing the variation across farmers within the same village with variance $\mathrm{var}.(\mu_{0jk})$ of τ_β. ε is an error term with error variance $\mathrm{var}.(e_{00k})$ of σ^2. The overall variance of the model is:

$$\mathrm{var}\left(Y_{ijk}\right) = \tau_\pi + \tau_\beta + \sigma^2$$

Based on the Intra-Class Correlation (ICC), the proportion of the overall variance explained by the variance between units in each stratum (farmers and villages) in the overall variance was calculated and the significance of the stratified variance was judged:

$$\begin{cases} ICC_{Household} = \tau_\beta / \left(\tau_\pi + \tau_\beta + \sigma^2\right) \\ ICC_{Village} = \tau_\pi / \left(\tau_\pi + \tau_\beta + \sigma^2\right) \end{cases}$$

Second, the basic three-layer Logit model was extended to a three-layer nested Logit model with fixed and random slopes. On the first layer of the model, plot quality (Q), distance to tillage (D), and slope (S) characteristic variables were added. Each plot has four coefficients in the equation of the first layer, i.e., intercept (β_{0jk}), and slopes (β_{1jk}, β_{2jk}, and β_{3jk}) for different variables of plot characteristics. The equations for the first layer are as follows:

$$Level-1: Y_{ijk} = \ln\left(\frac{P_{ijk}}{1-P_{ijk}}\right) = \beta_{0jk} + \beta_{1jk}\left(Q_{1jk}\right) + \beta_{2jk}\left(D_{2jk}\right) + \beta_{3jk}\left(S_{3jk}\right) + \varepsilon_{ijk}$$

In the second layer of the model, the type of farm household (T), the number of people working in agriculture per acre of cropland (P), the average age of the family labor force (Y), and the power of farm machinery (W) characteristic variables are introduced. The equations for the second layer are as follows:

$$Level-2: \begin{cases} \beta_{0jk} = \pi_{00k} + \pi_{01k}\left(T_{jk}\right) + \pi_{02k}\left(P_{jk}\right) + \pi_{03k}\left(Y_{jk}\right) + \pi_{04k}\left(W_{jk}\right) + \mu_{0jk} \\ \beta_{1jk} = \pi_{10k} \\ \beta_{2jk} = \pi_{20k} \\ \beta_{3jk} = \pi_{30k} \end{cases}$$

On the third layer of the model, the variables altitude (H), distance from the village to the county town (J), and cropland area per capita in the village (A) are added. The equations for the third layer are as follows:

$$Level-3: \begin{cases} \pi_{00k} = \gamma_{000} + \gamma_{001}\left(H_k\right) + \gamma_{002}\left(J_k\right) + \gamma_{003}\left(A_k\right) + e_{00k} \\ \pi_{01k} = \gamma_{010} \\ \pi_{02k} = \gamma_{020} \\ \pi_{03k} = \gamma_{030} \\ \pi_{04k} = \gamma_{040} \\ \pi_{10k} = \gamma_{100} \\ \pi_{20k} = \gamma_{200} \\ \pi_{30k} = \gamma_{300} \end{cases}$$

The equations from the first, second and third levels of the above model are combined to obtain the final three-level nested Logit model, the complete model is shown below:

$$Y_{ijk} = \ln\left(\frac{P_{ijk}}{1-P_{ijk}}\right) = \gamma_{000} + \gamma_{001}\left(H_k\right) + \gamma_{002}\left(J_k\right) + \gamma_{003}\left(A_k\right) + \gamma_{010}\left(T_{jk}\right) + \gamma_{020}\left(P_{jk}\right) + \gamma_{030}\left(Y_{jk}\right) + \gamma_{040}\left(W_{jk}\right) + \gamma_{100}\left(Q_{jk}\right) + \gamma_{200}\left(D_{jk}\right) + \gamma_{300}\left(S_{jk}\right) + \mu_{0jk} + e_{00k}$$

In this study, a step-by-step modeling approach was adopted to gradually add different levels of variables from the empty model to

finally construct a complete model system containing three scales of plots, farmers and villages, and the model was run and analysed by HLM v8.0 software.

2.3.2 Selection of variables for the multilevel analysis model

Several variables from the above study were sorted out to construct explanatory variables at the plot-farmer-village scale and to make preliminary inferences about the possible directions of their roles (Tables 2). The data of the explanatory variables were all obtained from the questionnaire survey of farmers, and the explanatory variables were mean-centered before being used in the model runs and calculations.

Based on the preliminary analysis of the questionnaire research results, combined with related research results, this study selected three explanatory variables of plots' cropland distance, quality grade and slope at the plot scale to analyze the direct cropland conditions and focus on the natural endowment of cropland itself. Cropland distance shows that round-trip time-consuming and transportation cost directly affects the convenience of cropping; quality grade reflects soil fertility and output potential to determine the economic benefits; and the higher slope of cropland leads to increase the difficulty and cost of cropping.

The following four explanatory variables were selected for the farm household scale: the degree of part-time employment of farm households, the number of people working in agriculture per unit of cropland area, the average age of people working in agriculture, and the total power of agricultural machinery and equipment, to analyze the labor resource allocation of farm households. From the point of view of the degree of part-time employment of farm households, farm households with a high proportion of non-farm employment are less dependent on agriculture, which may lead to the neglect of cropland; the number of people working in agriculture per unit of cropland area reflects the degree of labor scarcity; the age of people working in agriculture responds to the limited physical strength of aging farm households, which is difficult to take on heavy farm work and tends to leave the land in the ground; mechanization can substitute for the shortage of manpower, and the lack of power of agricultural machinery and equipment, the labor constraints cannot be alleviated, which may exacerbate the abandonment of the land. This may exacerbate abandonment.

Three explanatory variables, village elevation, village distance to county town, and village per capita cropland area, were selected for the village scale to portray the macro constraints of village geographic location and development conditions on cropland utilization. The village altitude may lead to different farming convenience; the distance from the village to the county town may affect the labor force's choice of non-farm employment; the per capita cultivated area reflects the relationship between people and land, and too small (fragmentation) or too large (labor shortage) per capita area may induce abandonment.

TABLE 2 Selection of explanatory variables for cropland abandonment.

Variable names	Descriptions	Mean	Intended direction
Explained variables (plot scale, *n* = 687)			
Whether or not cropland is abandoned	1 = yes, 0 = no	0.15	
Explanatory variables			
Level 1 - parcel scale (*n* = 687)			
Distance of farming	actual distance from the plot to the farmer's residence (km)	1.92	+
Cropland quality rating	1 = superior, 2 = higher, 3 = medium, 4 = lower	2.43	+
Slope of cropland	1 = 0–6°, 2 = 6°–15°, 3 = 15°–25°, 4 = 25° or more	2.23	+
Level 2 - farm household scale (*n* = 110)			
Types of part-time work by farmers	1 = purely agricultural, 2 = part-time agricultural, 3 = part-time non-agricultural, 4 = non-agricultural	3.31	+
The number of people working in agriculture per unit of cropland area	number of farmers per unit of cropland area (persons/ha)	9.00	–
Average age of agricultural labor force	average age of the agricultural labor force (years)	61.67	–
Power of agricultural machinery	total power of household agricultural machinery (kw)	1.98	–
Level 3 - village scale (*n* = 26)			
Elevation of villages	average altitude of villages (m)	577.42	–
Distance from village to county town	distance from village to county centre (km)	56.99	?
Area of cropland per capita in villages	per capita cropland area of villagers (ha/person)	0.12	?

The data come from a questionnaire survey of farmers; the '+' sign in the ex-pected direction indicates a positive impact, the '–' sign indicates a negative impact, and the '?' The '+' sign indicates a positive impact, the '–' sign indicates a negative im-pact, and the '?' sign indicates that the direction of impact is uncertain.

3 Results

3.1 Characteristics of cropland resources

3.1.1 Overall situation of cropland resources

Based on the data from the questionnaire survey of the farmers, this study conducted statistics on the cultivated land resources in Youyang County. The questionnaire survey involved a total of 88.47 ha of arable land of all farm households, and the distribution of the area of each type of arable land is shown in Figure 2. Among them, the area of cropland operated by family contract is 35.37 ha accounting for 40.0% of the total cropland area surveyed; the area of rented-in cropland is 39.9 ha accounting for 45.1%; the area of rented-out cropland is 0.93 ha accounting for 1.1%; the area of abandoned cropland is 9.24 ha accounting for 10.4%; the area of cropland returned to the farmland and forests is 3.03 ha, accounting for 3.4%. In this study, we use cropland abandonment rate to indicate the degree of abandonment of cropland, i.e., the area of abandoned cropland as a percentage of the total area of cropland. The statistics show that the abandonment rate of cropland in Youyang County is about 10.4%.

3.1.2 Characteristics of the distribution of abandoned cropland

In order to solve the problem of uneven spatial distribution of cropland, this study adopted the indicator of cropland abandonment rate to analyze the distribution characteristics and influencing factors of abandoned cropland. We selected key factors such as altitude of cropland, farming distance, quality grade of cropland, terrain slope, and the number and time allocation of family laborers, and explored the correlation between single variables and the abandonment rate of cropland. The results of this analysis not only help to reveal the spatial distribution pattern, but also lay the basic data support for the comprehensive analysis of multiple factors.

3.1.2.1 Elevation distribution of abandoned cropland

In this study, we analyzed the influence of the altitude distribution of abandoned cropland on the abandonment rate, and classified the landform types into flat site area (299–556 m), low mountainous area (613–768 m), and middle mountainous area (921–1145 m) according to the different altitudes of the surveyed villages. The statistical results of the farmers' questionnaire survey (Table 3) show that the sample villages with an elevation of 299–566 m, including Banqiao, Honghua, and Wanmu villages, surveyed the area of abandoned cultivated land of 3.93 ha, with an average abandonment rate of 16.5%; and the sample villages with an elevation of 613–768 m, including Liangfeng, Yongxiang, and Damu villages, surveyed the area of abandoned cultivated land of 4.35 ha, with an average abandonment rate of 11.6%. The average rate of abandonment was 11.7%; the sample villages with an elevation of 921–1145 m, including Shuangfu Village, Longchi Village, Tianshanbao Village and Tianma Village, surveyed abandoned cultivated land area of 0.95 ha, with an average rate of abandonment of 3.5%.

3.1.2.2 Distribution of abandoned cropland with distance from cropland, cropland quality and slope

Based on the results of the questionnaire survey of farmers, the distribution of abandoned cropland with farming distance, quality of the cropland and slope was counted in this study (Figure 3).

The first is the distance of cultivation. In this study, the cultivation distance was divided into equidistant sections according to the interval of 0.5 km, and the abandoned rate of cropland in each section was shown in Figure 3a. With the increase of tillage distance, the rate of abandoned land increased first and then decreased, which could be divided into several sections: when the tillage distance was in the range of 0.5–1 km, the phenomenon of abandoned land rarely occurred; when the tillage distance was in the range of 1–3 km, the rate of abandoned land was generally stable, and the rate of abandoned land varied from 8.5 to 12.5%; when the tillage distance was in the range of 3–3.5 km, the rate of abandoned land increased significantly, reaching 31.9%. When the tillage distance is more than 3.5 km, the abandoned rate drops to 13.5%. Through analysis, this phenomenon is related to cultivated land circulation.

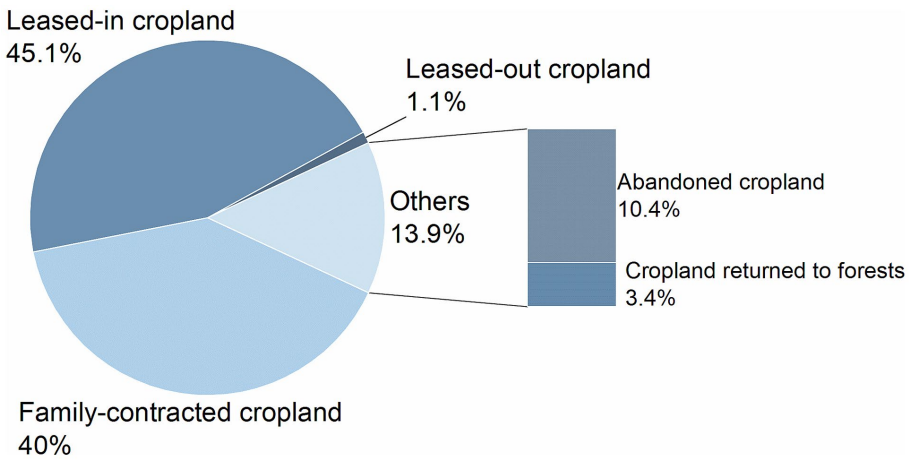

FIGURE 2
Distribution of cropland categories in the case area.

TABLE 3 Cropland abandonment statistics for the village sample.

Geomorphologic type	Elevation range (m)	Villages	Cropland area (ha)	Area of abandoned cropland (ha)	Rate of abandonment (%)
Flat site	299–556	Banqiao Village, Honghua Village, Wanmu Village, Guanba Village, Zhaiba Village, Shiying Village, Baojia Village, Baxiang Village, Tuping Village, Wufu Village, Gaoqiao Village, Quankong Village, Taiping Village, Dadi Village and Houxi Village.	23.83	3.93	16.5
Low mountain	613–768	Liangfeng Village, Yongxiang Village, Dagi Village, Shuicheba Village, Ma'ancheng Village, Muping Village, Shixiang Village	37.09	4.35	11.7
Middle mountain	921–1,145	Shuangfu Village, Longchi Village, Tianshanbao Village, Tianma Village	27.55	0.95	3.5

The quality of cropland is categorized into superior land, high land, medium land and low land, mainly based on the registration information on the land contract management right certificates held by farmers. According to the results of the cropland questionnaire survey, the quality of cropland in Youyang County is dominated by high and medium land, and in general, the rate of abandonment increases with the decline of cropland quality (Figure 3b). Farmers left fewer excellent and high-quality land abandoned, with abandonment rates of only 6.0 and 6.6%. Medium land was next with a rate of 12.3%. The poorest quality low land had the highest cropland abandonment rate of 43.6%.

During the cropland questionnaire survey, the slope grading of cropland was categorized into four categories: below 6°, 6–15°, 15–25° and above 25°, according to the slope grading grades commonly used in topography. The results of the questionnaire survey show (Figure 3c) that the slope of cropland in Youyang County is mainly dominated by sloping cropland, and the greater the slope, the higher the rate of cropland abandonment. The abandonment rate of plots with gentle slopes (below 6° and 6–15°) is less than 6%; the abandonment rate of plots with steeper slopes (15–25°) is 12.8%. For plots with slopes of 25° or more, the rate was 42.6%.

3.2 Causes and timing of abandonment of cropland

In this study, the causes of cropland abandonment were classified into labor shortage, distance, inferior land and other reasons. The results of the questionnaire survey showed that labor shortage and long distance were the main reasons for cropland abandonment (Table 4), which led to abandonment of cropland with an area of more than 4.67 ha in each case. In addition, by visiting the farmers, wild boar activities gnawing crops and making it impossible to cultivate close to them is also one of the important reasons for the abandonment of cropland.

In addition, in terms of duration of abandonment (Table 5), 6 years and above was the main duration of abandonment, resulting in more than 6.67 ha of abandonment involving 35 farm households. This was followed by 3, 5 and 4 years with 0.95, 0.73 and 0.67 ha respectively, involving 4, 3 and 5 households, respectively.

3.3 Impact of household labor on cropland abandonment

3.3.1 Degree of part-time farming

Based on the degree of non-agriculturalization and the differences in the types of livelihoods of agricultural households, and with reference to the research results on the classification of relevant types of agricultural households in China (Kimhi and Tzur-Ilan, 2021), this study classifies the types of part-time employment of agricultural households into four categories: pure agricultural households, agricultural part-time households, non-agricultural part-time households and non-farming households. Agricultural households are divided into agricultural and non-agricultural households according to the presence or absence of agricultural activities in their livelihood activities, and then agricultural households are further divided according to the proportion of non-agricultural income: purely agricultural households are those in which non-agricultural income accounts for less than 5% of total household income; agricultural part-time households are those in which non-agricultural income accounts for between 5 and 50% of total household income; and non-agricultural part-time households are those in which non-agricultural income accounts for more than 50% of total household income.

According to the results of the survey data analysis, the degree of part-time employment of different types of farm households showed a correlation with the rate of abandonment of cropland. A total of 110 sample households were selected for this study, including 7 pure farming households, 5 agricultural part-time house-holds, 45 non-agricultural part-time households and 53 non-farming households. From the specific data of the abandonment situation (Figure 4), the area of abandoned cropland of pure farming households was 0.47 ha, with an abandonment rate of 1.74%. The abandonment rate of cropland here is expressed as the ratio of the sum of the abandoned cropland area in all pure farm households to the sum of all

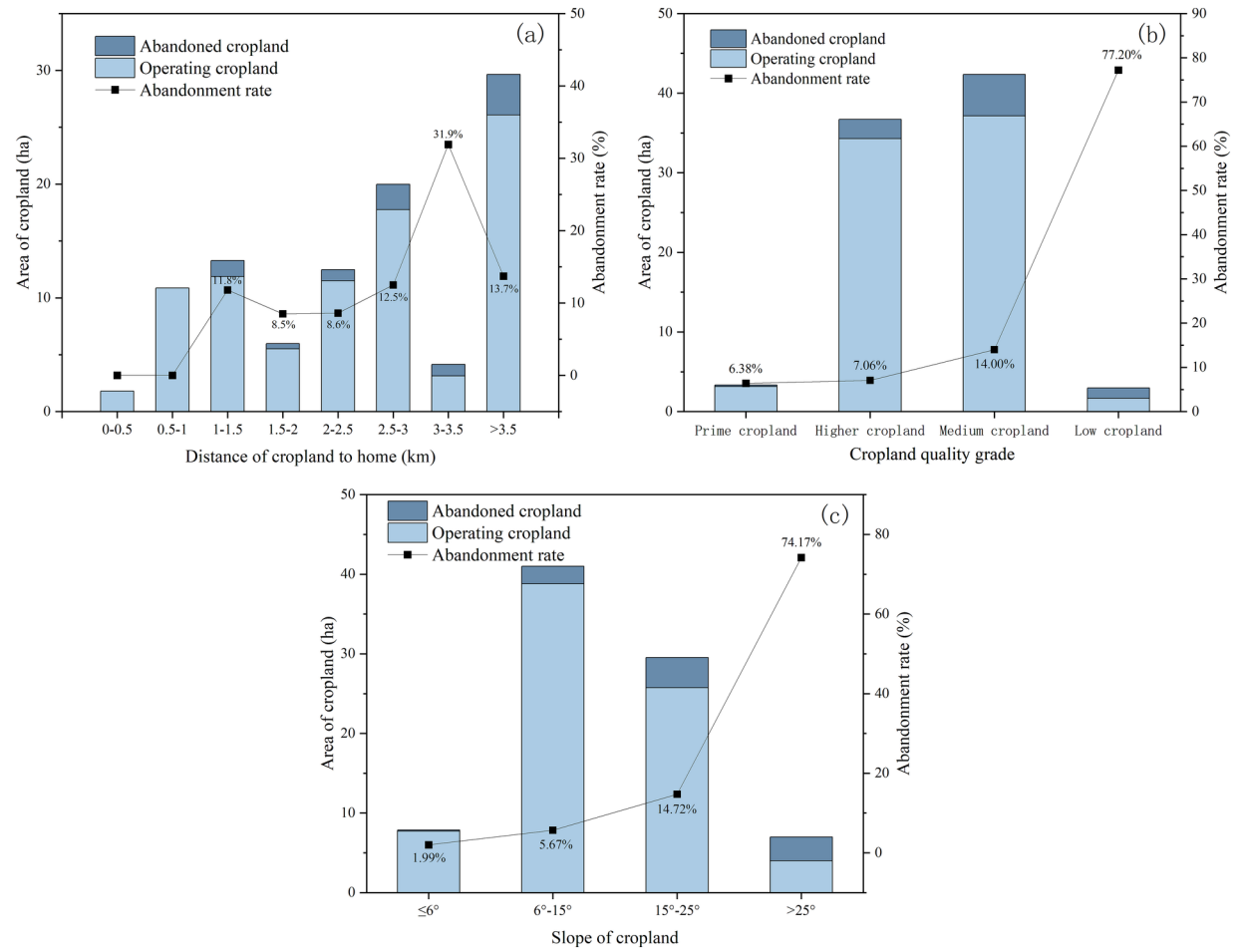

FIGURE 3
Distribution of abandoned cropland with farming distance **(a)**, cropland quality **(b)** and slope **(c)**.

TABLE 4 Statistics on the causes of cropland abandonment in the sample of villages.

Reasons for abandonment	Area of abandoned cropland (ha)	Note
Labor shortages	5.04	—
Long-distance	4.7	—
Low quality	1.4	—
Other reasons	2.63	This was mainly due to the fact that wild boars and others had eaten the crops, rendering the plots uncultivated.

TABLE 5 Statistics on the number of years of cropland abandonment in the sample of villages.

Age at abandonment	3 years	4 years	5 years	6 years	More than 6 years
Area (ha)	0.95	0.67	0.73	4.05	2.83
Number of households (household)	4	5	3	19	16

cropland area in all pure farm households. The area of abandoned cropland of part-time agricultural households was 0.33 ha, with an abandonment rate of 2.21%; and the abandonment situation of non-agricultural part-time and non-farming households was significantly intensified, which was 4.74 ha (21.71%) and 3.7 ha acres (29.68%), respectively. These data visualize a significant

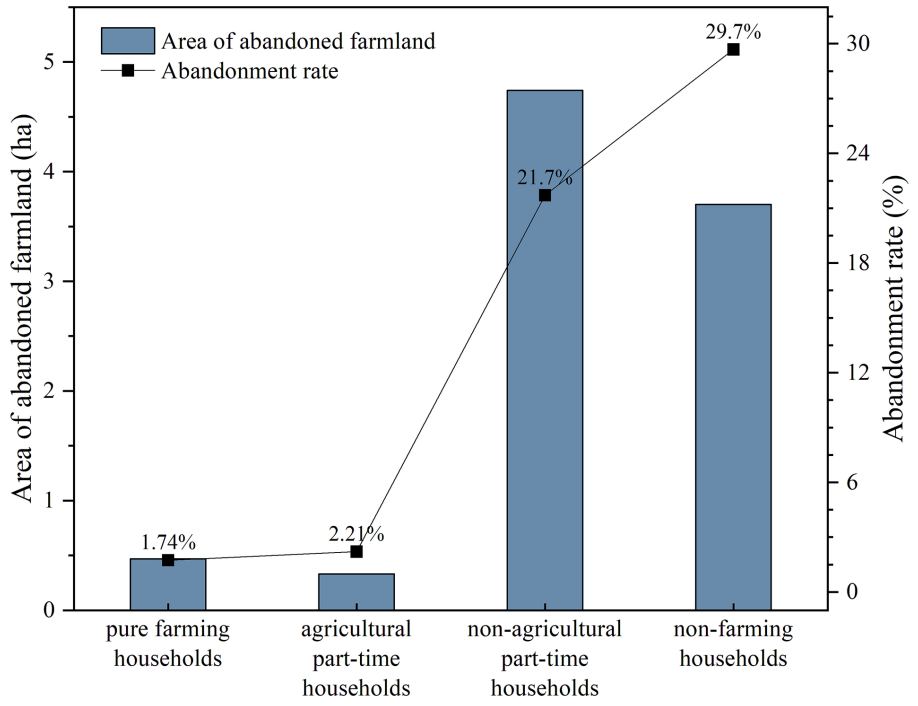

FIGURE 4
Area of abandoned cropland and abandonment rate of each type of farm household.

upward trend in cropland abandonment as the degree of part-time farming increases. This suggests that in mountainous areas, part-time farming may exacerbate cropland abandonment in mountainous areas.

3.3.2 Characteristics of the labor resource endowment of abandoned households

In addition to the constraints of natural conditions of cropland, household labor resource endowment is also an important factor affecting cropland abandonment (Liang et al., 2013). For this reason, this study measures the household labor input of farm households through two indicators: the number of people working in agriculture and the number of days working in agriculture per unit of cropland area. The number of people working in agriculture per unit of cropland area refers to the number of people working in agriculture per unit of cropland area in a given household, while the number of days working in agriculture per unit of cropland area refers to the cumulative number of hours of agricultural labor per unit of cropland area in the same household throughout the year. Based on the existence of abandonment behavior of farm households, this study divides the sample households into two categories: households without abandonment and households with abandonment. Based on the analysis of the questionnaire data (Figure 5), the input of the number of people working in agriculture per unit of cropland area is significantly higher in households without abandonment than in households with abandonment, at 5.17 and 3.8 people/ha, respectively; at the same time, in terms of the number of days of working in agriculture per unit of cropland area, the inputs of the labor of households without abandonment are more adequate than those of households with abandonment, at 159.99 and 133.04 days/ha, respectively.

3.4 Multilevel analysis of factors affecting cropland abandonment

The degree of covariance between variables can be detected by the variance expansion factor (VIF) (Wu et al., 2021). It is usually considered that when the value of VIF is greater than 10, it indicates the existence of severe multicollinearity; if $5 < VIF < 10$, it indicates the existence of a certain degree of multicollinearity; and when VIF is less than 5, it indicates that the problem of multicollinearity in the regression model is acceptable. After the covariance test, it was found that the variance inflation factors of the selected variables were significantly lower than 5, which indicates that there is no significant multicollinearity problem in the study data. The results of multilevel logistic regression are shown in Table 6.

In Table 6, Model 1 is the most basic null model, which only tests whether there is a significant difference in the mean cropland abandonment rate between villages without introducing any explanatory variables. The results show that there is a significant difference in cropland abandonment rates between villages, while no significant effect is shown at the farm household level. In terms of cross-level correlation coefficients, 5.3 and 15.5% of the equations were explained by the characteristic variables at the farm household scale and village scale, respectively.

Model 2 introduced key explanatory variables on the basis of the null model, and the results showed that all three explanatory variables at the plot scale (cropping distance, cropland quality, and slope) had a significant effect on the rate of cropland abandonment ($p < 0.05$), and all of them were positive, and the direction of the effect was in line with the expected direction. From the values of regression coefficients, cropland quality grade was the most critical factor explaining whether

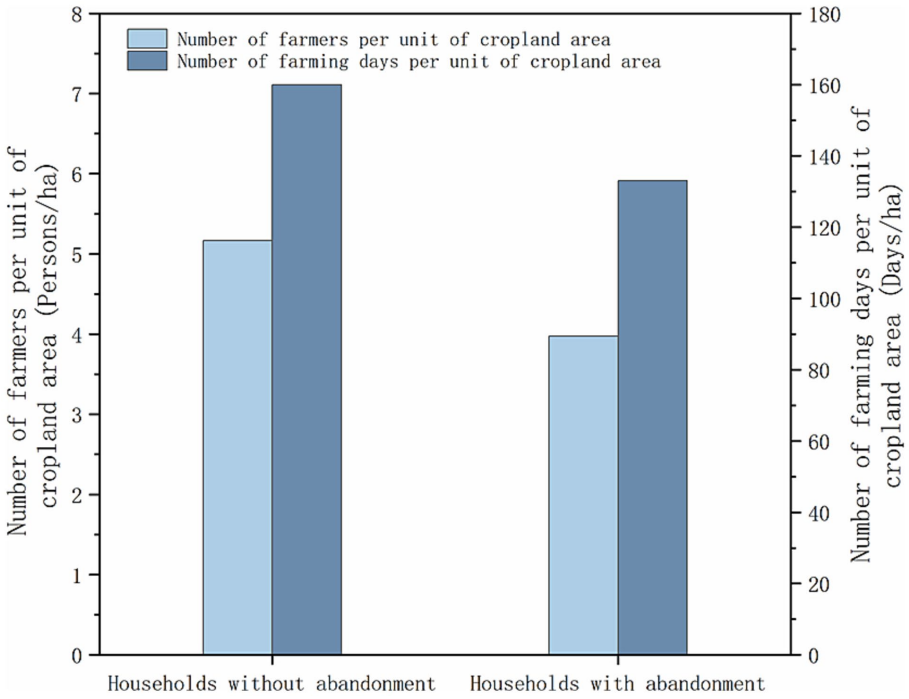

FIGURE 5
Comparison of agricultural labor resources of households with and without cropland abandonment.

TABLE 6 Multilevel logistic regression results of cropland abandonment.

Variable names	Model 1	Model 2	Model 3	Model 4
Fixed effects				
Level 1 — Parcel Scale				
Intercept	−1.868*	−2.104*	−2.125*	−5.989*
Distance of farming		0.573*	1.272*	1.629*
Cropland Quality Rating		0.623*	1.156*	1.450*
Slope of cropland		0.399*	1.175*	1.484*
Level 2 — Farm household scale				
Types of part-time work by farmers			0.350*	0.581*
The number of people working in agriculture per unit of cropland area			−1.011*	−1.663*
Average age of agricultural labor force			−0.011	−0.032
Power of agricultural machinery			−0.073	−0.056
Level 3 — Village Scale				
Elevation of villages				0.704
Distance from village to county town				0.063
Area of cropland per capita in villages				−1.166*
Random effect				
Level 2 — Farm household scale				
$Var(\mu_{0jk})$	0.231	0.567	0.432	0.630
$ICC_{Household}$	0.053	0.123	0.109	0.143
Level 3 — Village Scale				
$Var(e_{00k})$	0.437*	0.635*	0.789*	0.424*
$ICC_{Village}$	0.155	0.113	0.244	0.235
Model goodness of fit				
ROC	0.565	0.879	0.855	0.892

*Represents coefficients significant at the 5% level.

cropland was abandoned or not, followed by cropping distance and slope, with correlation coefficients of 0.623, 0.573 and 0.399, respectively.

Model 3 further introduces explanatory variables at the farm household scale, and the results show that the explanatory variables at the plot level act in the same direction as in Model 2. At the same time, the type of farm household part-time business and the number of people working in agriculture per unit of cropland area at the farm household scale all have a significant effect on the rate of cropland abandonment, with correlation coefficients of 0.350 and −1.011, respectively, of which the number of people working in agriculture per unit of cropland area is the most critical factor at the farm household scale, with a negative effect, i.e., the greater the number of people working in agriculture per unit of cropland area, the more adequate the household's agricultural labor force is, and the less abandoned cropland the household has. The type of farm household part-time business is a positive effect, i.e., the smaller the share of non-farm income of a farm household, the more the family has the same share of non-farm income. The less; the type of farm household part-time work is a positive influence, i.e., the smaller the proportion of non-farm income of the farm household, the higher the rate of cropland abandonment. The other two explanatory variables at the farm household scale, including the age of farm labor force evaluation and the power of farm machinery, all show negative effects on cropland abandonment rate, with correlation coefficients of −0.032 and −0.056, respectively, but the effects are not significant.

Model 4 is then the final complete model, containing explanatory variables at the plot, farm household and village scales. The results of the model show that the direction of the influence of explanatory variables on cropland abandonment at each scale is consistent with the previous model. At the village level, village per capita cropland area is the most critical factor and has a significant negative effect on cropland abandonment rate, with a correlation coefficient of −1.166. Larger per capita cropland area usually means that each villager owns more land resources, which may motivate farmers to make more active use of this land for farming to meet their own food needs or to increase their incomes. Thus, larger per capita cropland area may be associated with lower abandonment rates. Second, both village elevation and distance to the county centre had a positive, but not significant, effect on cropland abandonment, with correlation coefficients of 0.704 and 0.063, respectively.

Receiver Operating Characteristic (ROC) is a curve that responds to the rate of true positives versus false positives of a model's results, and is often used as an important metric for assessing the accuracy of a model's simulation results. It can comprehensively consider the performance of the model under different thresholds, and performs well in assessing the overall classification ability of the model, which is not affected by the distribution of sample categories. AUC (Area Under Curve) is defined as the area under the ROC curve enclosed with the coordinate axis, and the closer the value is to 1, the better the model performance is. It is generally believed that when the AUC is 0.5–0.7, the model has practical effect; when the AUC is greater than 0.7, the model performs better. In this study, the ROC of the initial model (Model 1) was 0.565, which increased to 0.879 when the plot-scale variable was introduced, indicating the significant improvement effect of the plot-scale variable on the model fit and predictive ability. However, the ROC of the model did not show any significant improvement when the variables at the household and village scales were added to the model, and even decreased, with the ROCs of 0.855 and 0.892, respectively. These variables at the household and village scales can explain part of the variance and have a significant effect on cropland abandonment, but they have a relatively limited role in improving the overall predictive effect of the model. This result suggests that we need to weigh the actual contribution of each variable to the model performance during the model construction process.

4 Discussion

4.1 Influence of natural characteristics of plots on farmers' cultivation

Most of the current studies use natural geographic data such as DEM and slope, combined with socioeconomic data such as population and GDP (Guo et al., 2023; Hong et al., 2024), and use modeling methods such as Geodetector to explore the drivers of cropland abandonment. However, this cannot systematically analyze the drivers and mechanisms of cropland abandonment for a small-scale study area (city, county, or village). In this study, we systematically analyzed the drivers of cropland abandonment through a questionnaire survey of farmers, and provided a systematic explanation for understanding the abandonment phenomenon. At the plot scale, how to measure the convenience of cropland plots for growing crops are mainly based on the difficulty of cultivation, the convenience of plots, etc. The results of this study indicate that cropland distance, cropland quality, and slope are the key factors affecting the abandonment rate, which is also consistent with the findings of related studies (Hong et al., 2024).

The convenience of cropland plots depends mainly on the distance from the plot to the farmer's house and the length of commuting time. Due to the complexity and variability of mountainous terrain, plots are usually located far away from each other, and the farther the distance to cropland, the higher the farmers' production cost and time investment, which may reduce farmers' willingness to cultivate, and thus result in cropland that is more likely to be left fallow. The results of this study showed that within the range of 0.5–1 km, farmers were able to easily manage their daily farming practices, and thus had a lower rate of abandonment. However, when the farming distance is too far, the time and physical cost required to travel to and from the cropland increases significantly, exceeding the affordability of some farmers, who are more inclined to abandon the more distant land under limited conditions. At the same time, in more distant areas, land owners or contractors tend to transfer land to other farmers or business entities, which on the one hand can obtain corresponding rent, and on the other hand, under the encouragement of the policy of reclamation, can also avoid the abandonment of cropland due to the distance. Through the survey, this part of cropland is often also rented by large planting households, and through the way of large-scale and mechanized operation, the more distant land can continue to be cultivated by reducing the dependence on their own labor input.

The accessibility of cropland plots is also affected by the elevation of the cropland. The results of this study show an overall decreasing trend in abandonment rates with increasing elevation, a phenomenon

that is diametrically opposed to conventional thinking. This anomaly was explored qualitatively in this study based on fieldwork. Through investigation and analysis, this study found that cropland at high altitudes is well suited for growing baked tobacco, and profits tend to be higher. In Tianshanbao Village, Youyang County, the village is at an altitude of 1,104 m, and the landscape belongs to the middle mountainous area, and the climate and environment are very suitable for the cultivation of roasted tobacco. These phenomena can explain the lower rate of cropland abandonment in high-altitude villages, where cropland is often transferred to large households growing roasted cigarettes, thus effectively avoiding or reducing cropland abandonment. The results of this study are basically consistent with the findings of other scholars.

For planting difficulty, it is mainly reflected in cropland quality and slope (Wang F.et al., 2024). Cropland quality is an important factor affecting agricultural productivity. High-quality cropland usually has high soil fertility, good water conditions and infrastructure to support efficient agricultural production activities. Farmers are more likely to achieve stable yields and returns on superior and high-quality land, and are therefore less likely to leave it fallow, which is their preferred option for sustaining agricultural production. As the quality of cropland declines (from medium to low grade land), the fertility, irrigation conditions and infrastructure of the land gradually deteriorate, the efficiency of agricultural production significantly decreases, and the input–output ratio is low, making it difficult to maintain normal agricultural production activities. In terms of slope, the greater the slope of the cropland, the more difficult it is to use the land, the lower the efficiency of farming, and the inability to carry out cattle power or mechanical operations, and can only rely on the input of manual labor, labor time and energy is limited, in order to maximize the return, which also makes the probability of abandonment of the cropland greatly increased. In response to this, policy makers and managers should prioritize improving the production conditions of low-quality cropland (e.g., water conservancy facilities, road construction, etc.) to increase its agricultural production potential, thereby reducing the abandonment rate. In addition, low-quality cropland can also be focused on production and management or ecological restoration through land transfer to achieve optimal allocation of resources.

In addition, the difficulty of cultivation is also reflected in the size of the plots. During the field questionnaire survey, many narrow and small plots of abandoned cropland were also found, and most of these plots were cultivated at high elevation differences and over long distances. Some studies have shown that the size of cropland plots is an important driver of cropland abandonment, and it has the same important explanatory power as the slope of cultivated land. In economically underdeveloped mountainous areas, small, fragmented croplands with complex terrain tend to face a higher risk of abandonment (Wang et al., 2022; Wu et al., 2022; Huang et al., 2025). As the total cropland area is limited, under these conditions, the distribution of small plots of cropland is more dispersed, making it difficult to form a large-scale piece of land, and requiring farmers to invest more cost and effort (Chen et al., 2022). Moreover, such topographic features make it possible that the abandonment of a single plot may have a significant effect on neighboring plots, i.e., agricultural land abandonment behavior is geographically clustered (Zhuang and Luo, 2024). This effect stems from the existence of significant production correlations among neighboring farmers (Wang et al., 2011; Zhuang and Luo, 2025). Specifically, farmers often collaborate and share information collectively, and when one unit experiences abandonment, its neighboring plots tend to be at higher risk of abandonment because they are not supported by positive external conditions.

4.2 Mechanisms of farm household behavior on cropland abandonment

4.2.1 Consideration of farmers' economic returns from cropland cultivation

The economic income status of farmers is a key factor in determining whether they leave their cropland fallow. According to economic theory, net farm income is the result of total income minus total inputs (Tan et al., 2021). Among them, the total income depends on crop yield and market price, while inputs include all costs in the production process. In terms of crop yields, the research among mountain farmers found that although the unit area yield of food crops has increased in recent years, the overall increase in yield is more limited due to the limited total area of cropland. Most households mainly grow staple crops such as corn, sweet potatoes, potatoes and rice, and their per capita cropland resources are extremely limited, resulting in each household being able to achieve only basic self-sufficiency, and not even enough to purchase, making it difficult to obtain additional agricultural income through the sale of agricultural products. In terms of food prices, there is less room for the market price of food crops to rise, so some farmers have begun to consider adjusting their planting structure in favor of crops with higher economic value. The research found that those farmers who are able to maintain a certain level of agricultural income tend to engage in the cultivation of cash crops such as roasted tobacco, tea or oil tea. The net returns per unit area of these crops are significantly higher than those of traditional food crops, about 8 to 20 times higher (Wang and Wang, 2022). In summary, the economic returns of farmers and their choice of cropland use constitute an important driving force behind the phenomenon of cropland abandonment in mountainous areas.

4.2.2 Driving mechanisms of labor inputs and cropland abandonment

Agricultural production, as an economic activity that requires long-term investment, is highly dependent on the stability of labor (Jiang et al., 2019). However, in the production practices of mountain farming households, agricultural returns are generally low and difficult to meet basic household livelihood needs. The results of this study also show that among the 110 households in the sample, the proportion of purely agricultural households is only 6.36%, while the vast majority of the remaining households (93.64%) have laborers going out to work or engaging in non-agricultural activities. The research found that the younger generation of farmers generally choose to go out to work in order to pursue higher sources of income. At the same time, the time span of agricultural production is long, and there are large time differences between various production segments (Zheng, 2024). Within a limited time, the income that farmers can generate by working outside the farm is much higher than the net income

from engaging in agricultural production. This makes young laborers more inclined to choose non-farm employment paths, thus further exacerbating the labor resource constraints in rural areas. The limited nature of household labor resources and the constraints on time allocation make leaving cropland fallow a choice of last resort.

As China's urbanization process advances, the trend of rural–urban migration is becoming increasingly evident. This process not only provides more employment opportunities for migrant workers, but also makes some rural households think of settling in towns. This change in the pattern of population movement directly increases the possibility of cropland abandonment (Qiu et al., 2020). For farmers who stay in the countryside, the structure of the family labor force shows obvious aging characteristics. After the younger generation has gone out to work, the only people left in the village are often the elderly and children. Older laborers face greater limitations in engaging in high-intensity agricultural labor due to physical limitations. Some studies have shown that the ratio of agricultural labor force and the number of people going out to work are important social factors affecting the abandonment of cropland. There is a significant negative correlation between these two variables: the larger the population of migrant workers, the lower the proportion of agricultural labor force (Haiguang et al., 2013).

In addition, the composition of the family members of a farming household has a significant impact on their off-farm employment choices. For young families, the eco-nomic and time investment in raising children and supporting the elderly is large, which makes some young laborers prefer to engage in non-agricultural occupations nearby. This approach not only makes it possible to combine agricultural production activities, but also reduces the risk of cropland abandonment to some extent. It is worth noting that the dual role of women in agricultural production and family care has a significant impact on cropland abandonment, and the proportion of female labor force, and the proportion of the population supported and nurtured in a farm household all have an indirect effect on cropland abandonment.

In summary, diminishing returns from agriculture, decreasing labor inputs and diversifying off-farm employment options are important drivers of cropland abandonment. This phenomenon is not only influenced by individual economic rational decision-making, but also closely related to socio-economic variables such as family life cycle and population migration (Bai et al., 2015; Yuan et al., 2024). Against the backdrop of accelerated urbanization, the continued loss of labor resources in rural areas and changes in family structure will continue to have a profound impact on agricultural production patterns. And some studies have shown that the degree of cropland abandonment increases with the expansion of urban scale (Jiang et al., 2019), which is caught in a circular logic. By deeply analyzing the driving mechanism behind the non-farm employment choices of farm households, it can provide a theoretical basis for the formulation of targeted agricultural policies. For example, the risk of cropland abandonment can be reduced by optimizing the structure of the agricultural industry, upgrading the level of agricultural mechanization, and improving the social security system for the left-behind population to effectively alleviate the problem of labor shortage (Geng et al., 2024).

4.3 Impact of village conditions on cropland abandonment

At the village scale, villages, as the basic unit of land use, have an important influence on cropland abandonment due to their external environmental conditions. In this study, three key variables were selected as influencing factors at the village scale, namely village altitude, distance from the village to the county town, and per capita cropland area in the village. The results showed that village altitude was negatively correlated with the abandonment rate, i.e., the abandonment rate was lower in high altitude areas, which might be related to climatic conditions and agricultural suitability. Through the questionnaire survey, it was also found that in high-altitude villages, the climate and environment are very suitable for planting baking tobacco, and the profit of planting baking tobacco is often much higher than that of maize and rice and other food crops. In addition, through the survey, we also learnt that the government of Youyang County has introduced the policy of 'reclaiming abandoned cropland' since 2023, and some large farmers have reclaimed more than 667 ha of abandoned cropland with the help of the village collectives, which have been used to plant cash crops such as roasted tobacco. These circumstances can explain the lower rate of cropland abandonment in high-altitude villages. In these areas, cropland is often transferred to large households that grow roasted tobacco, which effectively avoids or reduces the abandonment of cropland, which is also basically consistent with the findings of other scholars (Yan et al., 2016; Zhang et al., 2023).

The results of the analyses at the three scales of plots, farmers and villages can be seen that cropland abandonment is a multifactorial and multilevel problem involving the natural environment, agricultural production conditions, farmers' behavioral choices and the external socio-economic environment, and so on. Factors at different scales interact with each other to form a complex mechanism driving abandonment.

4.4 Policy implications

The phenomenon of cropland abandonment in hilly and mountainous areas has become more pronounced as a result of multiple factors such as changes in socio-economic factors and policy adjustments. Based on the natural differences of different regions, for different regions of abandoned cropland, should be based on the natural differences, according to the local policy. First of all, the administrator should strengthen the support for the management of abandoned cropland, and can set up special funds for cropland protection, which can be used to support the reclamation and restoration of abandoned land and the improvement of agricultural production conditions. For the poor natural conditions of abandoned cropland, improve the agricultural infrastructure, improve farming conditions, and enhance the level of mechanical operations. In addition, administrators should work to improve the comprehensive efficiency of farmers' grain cultivation and strengthen agricultural support and protection subsidies. Especially in townships where the problem of abandonment is more serious, but also to strengthen the targeting of subsidies, to ensure that the subsidies can really be paid to the hands of grain farmers. In addition, the government and other departments can improve the cropland transfer market, increase the

rate of cropland transfer, so as to achieve the purpose of reducing the abandonment of cropland.

5 Conclusion

Cropland abandonment is a complex natural-social compound system problem, and its formation is not only affected by external factors such as natural conditions, but also closely related to the behavior of farm households and the level of economic development and other internal drivers. This study takes Youyang County, a typical mountainous area in Southwest China, as an example. Based on the questionnaire survey of farmers, we constructed a three-layer logit model of "plot-farmer-village" using multilevel regression and other methods to systematically analyze the influencing factors and driving mechanisms of cropland abandonment, which also provides a theoretical basis for targeted policy formulation and regional land management. It also provides a theoretical basis for targeted policy making and regional land management.

Based on field survey data, the abandonment rate of cropland in typical mountainous areas in southwest China is about 10.4%. The overall distribution of abandoned cropland is characterized by the following: the abandonment rate shows a decreasing trend with the increase of elevation; the abandonment rate shows an increasing and then decreasing trend with the increase of farming distance; the abandonment rate increases with the decrease of the quality of cropland, and increases with the increase of the slope of cropland and so on. In terms of influencing factors, cropland quality, the number of farm laborers per unit area, and village per capita cropland area were the key explanatory variables at the plot, farm household, and village scales, respectively, with correlation coefficients of 0.623, −1.011, and −1.166, respectively, which showed a significant effect on the abandonment rate. Cultivated land abandonment is a multifactorial and multilevel problem involving natural environment, agricultural production conditions, farmers' behavioral choices and external socioeconomic environment. In the future, the relevant management departments can take measures to improve farming conditions, increase farmers' income from grain cultivation, and improve the market for the transfer of arable land, with a view to alleviating the problem of cropland abandonment.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

HY: Data curation, Methodology, Software, Writing – original draft. ZZ: Conceptualization, Writing – review & editing. QY: Writing – original draft, Data curation.

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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. Author Contributions.

Generative AI statement

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References

Alcantara, C., Kuemmerle, T., Prishchepov, A. V., and Radeloff, V. C. (2012). Mapping abandoned agriculture with multi-temporal MODIS satellite data. *Remote Sens. Environ.* 124, 334–347. doi: 10.1016/j.rse.2012.05.019

Alexander, P., Rounsevell, M. D. A., Dislich, C., Dodson, J. R., Engstrom, K., and Moran, D. (2015). Drivers for global agricultural land use change: the nexus of diet, population, yield and bioenergy. *Global Environ. Change-Human Policy Dimen.* 35, 138–147. doi: 10.1016/j.gloenvcha.2015.08.011

Bai, X., Wen, Z., An, S., and Li, B. (2015). Evaluating sustainability of cropland use in Yuanzhou County of the loess plateau, China using an Emergy-based ecological footprint. *PLoS One* 10:e0118282. doi: 10.1371/journal.pone.0118282

Blair, D., Shackleton, C. M., and Mograbi, P. J. (2018). Cropland abandonment in south African smallholder communal lands: land cover change (1950-2010) and farmer perceptions of contributing factors. *Land* 7:121. doi: 10.3390/land7040121

Chen, H., Meng, F., Yu, Z. N., and Tan, Y. Z. (2022). Spatial-temporal characteristics and influencing factors of cropland expansion in different agricultural regions of Heilongjiang Province, China. *Land Use Policy* 115:106007. doi: 10.1016/j.landusepol.2022.106007

Geng, Y. Q., Yang, X. L., Zhang, N. G., Li, J. Y., and Yan, Y. (2024). Sustainable rural development: differentiated paths to achieve rural revitalization with case of Western China. *Sci. Rep.* 14:31507. doi: 10.1038/s41598-024-83339-x

Gerland, P., Raftery, A. E., Ševčíková, H., Li, N., Gu, D. A., Spoorenberg, T., et al. (2014). World population stabilization unlikely this century. *Science* 346, 234–237. doi: 10.1126/science.1257469

Green, J. L., Green, J., Camilli, G., Camilli, G., Elmore, P. B., and Elmore, P. (2006). Handbook of complementary methods in education research. *3rd* Edn. New York: Routledge.

Guo, A., Yue, W., Yang, J., Xue, B., Xiao, W., Li, M., et al. (2023). Cropland abandonment in China: patterns, drivers, and implications for food security. *J. Clean. Prod.* 418:138154. doi: 10.1016/j.jclepro.2023.138154

Haiguang, H., Xiubin, L., and Jiping, Z. (2013). Impacts of part-time farming on agricultural land use in ecologically-vulnerable areas in North China. *J. Res. Ecol.* 4, 70–79. doi: 10.5814/j.issn.1674-764x.2013.01.010

Herrando, S., Anton, M., Sarda-Palomera, F., Bota, G., Gregory, R. D., and Brotons, L. (2014). Indicators of the impact of land use changes using large-scale bird surveys: land abandonment in a Mediterranean region. *Ecol. Indic.* 45, 235–244. doi: 10.1016/j.ecolind.2014.04.011

Hong, C., Prishchepov, A. V., and Bavorova, M. (2024). Cropland abandonment in mountainous China: patterns and determinants at multiple scales and policy implications. *Land Use Policy* 145:107292. doi: 10.1016/j.landusepol.2024.107292

Huang, X., Zhou, Z., Zhao, X., Wu, G., Long, Y., and Chen, J. (2025). Information extraction and characteristic analysis of cultivated land abandonment in karst rocky desertification mountainous areas based on time-series vegetation index. *Sci. Rep.* 15:12554. doi: 10.1038/s41598-025-97304-9

Jiang, J. Q., Huang, W. Z., Wang, Z. H., and Zhang, G. S. (2019). The effect of health on labour supply of rural elderly people in Chinaan empirical analysis using CHARLS data. *Int. J. Environ. Res. Public Health* 16:1195. doi: 10.3390/ijerph16071195

Kehoe, L., Romero-Munoz, A., Polaina, E., Estes, L., Kreft, H., and Kuemmerle, T. (2017). Biodiversity at risk under future cropland expansion and intensification. *Nature Ecol. Evol.* 1, 1129–1135. doi: 10.1038/s41559-017-0234-3

Ker, H. (2014). Application of hierarchical linear models/linear mixed-effects models in school effectiveness research. *Univer. J. Educ. Res.* 2, 173–180. doi: 10.13189/ujer.2014.020209

Kimhi, A., and Tzur-Ilan, N. (2021). Structural changes in Israeli family farms: long-run trends in the farm size distribution and the role of part-time farming. *Agriculture* 11:518. doi: 10.3390/agriculture11060518

Kuemmerle, T., Muller, D., Griffiths, P., and Rusu, M. (2009). Land use change in southern Romania after the collapse of socialism. *Reg. Environ. Chang.* 9, 1–12. doi: 10.1007/s10113-008-0050-z

Lee, C. C., Zeng, M. L., and Luo, K. (2024). How does climate change affect food security? Evidence from China. *Environ. Impact Assess. Rev.* 104:107324. doi: 10.1016/j.eiar.2023.107324

Li, S. F., and Li, X. B. (2017). Global understanding of farmland abandonment: a review and prospects. *J. Geogr. Sci.* 27, 1123–1150. doi: 10.1007/s11442-017-1426-0

Li, W. B., Liang, Y. J., Liu, L. J., He, Q. Q., Huang, J. J., and Yin, Z. C. (2024). Spatio-temporal impacts of land use change on water-energy-food nexus carbon emissions in China, 2011-2020. *Environ. Impact Assess. Rev.* 105:107436. doi: 10.1016/j.eiar.2024.107436

Liang, Y., Feldman, M. W., Li, S., and Daily, G. C. (2013). Asset endowments, non-farm participation and local separability in remote rural China. *China Agric. Econ. Rev.* 5, 66–88. doi: 10.1108/17561371311294766

Lieskovsky, J., and Lieskovská, D. (2021). Cropland abandonment in Slovakia: analysis and comparison of different data sources. *Land* 10:334. doi: 10.3390/land10040334

Lu, D., Wang, Z., Li, X., and Zhou, Y. (2024). Evaluation of the efficiency and drivers of complemented cropland in Southwest China over the past 30 years from the perspective of cropland abandonment. *J. Environ. Manag.* 351:119909. doi: 10.1016/j.jenvman.2023.119909

Montràs-Janer, T., Suggitt, A. J., Fox, R., Jönsson, M., Martay, B., Roy, D. B., et al. (2024). Anthropogenic climate and land-use change drive short- and long-term biodiversity shifts across taxa. *Nature Ecology & Evolution* 8, 739–831. doi: 10.1038/s41559-024-02326-7

Müller, D., Leitao, P. J., and Sikor, T. (2013). Comparing the determinants of cropland abandonment in Albania and Romania using boosted regression trees. *Agric. Syst.* 117, 66–77. doi: 10.1016/j.agsy.2012.12.010

Prosekov, A. Y., and Ivanova, S. A. (2018). Food security: the challenge of the present. *Geoforum* 91, 73–77. doi: 10.1016/j.geoforum.2018.02.030

Qiu, B., Yang, X., Tang, Z., Chen, C., Li, H., and Berry, J. (2020). Urban expansion or poor productivity: explaining regional differences in cropland abandonment in China during the early 21st century. *Land Degrad. Dev.* 31, 2540–2551. doi: 10.1002/ldr.3617

Saxena, R., Watson, L. T., Wynne, R. H., Brooks, E. B., Thomas, V. A., Zhiqiang, Y., et al. (2018). Towards a polyalgorithm for land use change detection. *ISPRS J. Photogramm. Remote Sens.* 144, 217–234. doi: 10.1016/j.isprsjprs.2018.07.002

Shengfa, L. I., Xiubin, L. I., Liangjie, X. I. N., Minghong, T. A. N., Xue, W., Renjing, W., et al. (2017). Extent and distribution of cropland abandonment in Chinese mountainous areas. *Resour. Sci.* 39, 1801–1811. doi: 10.18402/resci.2017.10.01

Su, Y., Qian, K., Lin, L., Wang, K., Guan, T., and Gan, M. Y. (2020). Identifying the driving forces of non-grain production expansion in rural China and its implications for policies on cultivated land protection. *Land Use Policy* 92:104435. doi: 10.1016/j.landusepol.2019.104435

Su, Y. Y., Wu, S. K., Kang, S. G., Xu, H., Liu, G. S., Qiao, Z., et al. (2023). Monitoring cropland abandonment in southern China from 1992 to 2020 based on the combination of phenological and time-series algorithm using Landsat imagery and Google earth engine. *Remote Sens.* 15:669. doi: 10.3390/rs15030669

Tan, Y. Z., Chen, H., Xiao, W., Meng, F., and He, T. (2021). Influence of farmland marginalization in mountainous and hilly areas on land use changes at the county level. *Sci. Total Environ.* 794:149576. doi: 10.1016/j.scitotenv.2021.149576

Tilman, D., Balzer, C., Hill, J., and Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. USA* 108, 20260–20264. doi: 10.1073/pnas.1116437108

Tilman, D., and Clark, M. (2014). Global diets link environmental sustainability and human health. *Nature* 515, 518–522. doi: 10.1038/nature13959

United Nations. (2015). *Transforming our world: the 2030 agenda for sustainable development* [online]. United Nations. Available online at:https://sdgs.un.org/2030agenda [Accessed 2015-09-25].

Valin, H., Sands, R. D., van der Mensbrugghe, D., Nelson, G. C., Ahammad, H., Blanc, E., et al. (2014). The future of food demand: understanding differences in global economic models. *Agric. Econ.* 45, 51–67. doi: 10.1111/agec.12089

Wang, Y. M., Li, J. X., and Kong, X. Z. (2022). What drives land abandonment in core grain-producing areas? Evidence from China. *Int. J. Environ. Res. Public Health* 19:5090. doi: 10.3390/ijerph19095090

Wang, P., and Wang, F. Z. (2022). A study of the impact of land transfer decisions on household income in rural China. *PLoS One* 17:e0276559. doi: 10.1371/journal.pone.0276559

Wang, L., Wang, C., and Li, X. (2011). Spatial correlation diagnosis of different farmers' land use behaviors--the case of Bailin Village, Shapingba District, Chongqing municipality, in: Utilizing the advantages of resource science and technology to guarantee the innovative development of Western China--Chinese Society of Natural Resources 2011 annual academic conference

Wang, J., Wang, J., Xiong, J., Sun, M., and Ma, Y. (2024). Spatial-temporal characterization of cropland abandonment and its driving mechanisms in the karst plateau in eastern Yunnan, China, 2001–2020. *PLoS One* 19:e0307148. doi: 10.1371/journal.pone.0307148

Wang, F., Xue, D., and Yang, Z. Y. (2024). Can agricultural technological progress promote China's interprovincial rural revitalization? An analytical perspective based on agricultural-scale operations. *PLoS One* 19:e0309339. doi: 10.1371/journal.pone.0309339

Wu, R., Li, Z., and Wang, S. (2021). The varying driving forces of urban land expansion in China: insights from a spatial-temporal analysis. *Sci. Total Environ.* 766:142591. doi: 10.1016/j.scitotenv.2020.142591

Wu, M., Liu, G., She, S., and Zhao, L. (2022). Factors influencing abandoned farmland in hilly and mountainous areas, and the governance paths: a case study of Xingning City. *PLoS One* 17:e0271498. doi: 10.1371/journal.pone.0271498

Xiang, J., Chen, W., and Wu, J. (2022). Dynamic response relationship between cultivated land marginalisation and rural labour out-migration in mountainous areas in China: evidence from a vector autoregressive model. *Environ. Sci. Pollut. Res.* 29, 44207–44219. doi: 10.1007/s11356-022-18807-w

Xu, D. D., Deng, X., Huang, K., Liu, Y., Yong, Z. L., and Liu, S. Q. (2019). Relationships between labor migration and cropland abandonment in rural China from the perspective of village types. *Land Use Policy* 88:104164. doi: 10.1016/j.landusepol.2019.104164

Yan, J. Z., Yang, Z. Y., Li, Z. H., Li, X. B., Xing, L. J., and Sun, L. X. (2016). Drivers of cropland abandonment in mountainous areas: a household decision model on farming scale in Southwest China. *Land Use Policy* 57, 459–469. doi: 10.1016/j.landusepol.2016.06.014

Yang, L., Zhao, C., Jiao, S., Li, S., Wang, L., and Li, Y. (2022). Reconstructing spatial pattern of historical cropland in karst areas of Guizhou, Southwest China. *Sci. Rep.* 12:22391. doi: 10.1038/s41598-022-26793-9

Yin, H., Brandao, A., Buchner, J., Helmers, D., Iuliano, B. G., Kimambo, N. E., et al. (2020). Monitoring cropland abandonment with Landsat time series. *Remote Sens. Environ.* 246:111873. doi: 10.1016/j.rse.2020.111873

Yin, H., Pflugmacher, D., Li, A., Li, Z. G., and Hostert, P. (2018). Land use and land cover change in Inner Mongolia - understanding the effects of China's re-vegetation programs. *Remote Sens. Environ.* 204, 918–930. doi: 10.1016/j.rse.2017.08.030

Yu, Z. L., Liu, L., Zhang, H., and Liang, J. S. (2017). Exploring the factors driving seasonal farmland abandonment: a case study at the regional level in Hunan Province, Central China. *Sustainability* 9:187. doi: 10.3390/su9020187

Yuan, H., Chen, Y., Lin, J., Zhang, Y., and Zhu, C. (2024). Analysis of the spatial differentiation and driving force of arable land abandonment and non-grain in the hilly mountainous areas of Gannan. *Heliyon* 10:e33481. doi: 10.1016/j.heliyon.2024.e33481

Zhang, M. X., Li, G. Y., He, T. T., Zhai, G., Guo, A. D., Chen, H., et al. (2023). Reveal the severe spatial and temporal patterns of abandoned cropland in China over the past 30 years. *Sci. Total Environ.* 857:159591. doi: 10.1016/j.scitotenv.2022.159591

Zheng, L. Y. (2024). Big hands holding small hands: the role of new agricultural operating entities in farmland abandonment. *Food Policy* 123:102605. doi: 10.1016/j.foodpol.2024.102605

Zhou, C., and Wang, Q. (2023). Effect of the characteristic town policy on sewage treatment in mountainous areas: evidence from Chongqing. *Heliyon* 9:e22830. doi: 10.1016/j.heliyon.2023.e22830

Zhuang, J., and Luo, B. (2024). Farmland abandonment and food production — An investigation of a nonlinear relationship. *J. Huazhong Agri. Univ.* 2, 58–68. doi: 10.13300/j.cnki.hnwkxb.2024.02.006

Zhuang, J., and Luo, B. (2025). The effect of contiguous planting on farmers' abandonment behavior — based on the analytical clues of "contiguous planting—vertical division of labor—farmland abandonment". *J. Huazhong Agric. Univ.* 1, 8–18. doi: 10.13300/j.cnki.hnwkxb.2025.01.002