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# Ecological compensation of agricultural heritage conservation: case of the mountainous *Juglans hopeiensis* planting system in Beijing

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**Introduction:** Agricultural heritage, consisting of farmers' livelihood activities, experiential knowledge systems, and rural landscapes, is an integrated regional system with significant historical, cultural, and biodiversity value based on the natural environment and land use. Agricultural heritage is rich in traditional wisdom on the use of natural resources and is of great value in achieving the goals of sustainable agriculture and food security. The protection of agricultural heritage provides a favorable environment for farmers to engage in agricultural production, and provides a wide variety of potential agricultural production processes, thus adopting possibilities for the transformation of sustainable food systems. Ecological compensation can be an effective method for narrowing the development gap caused by heritage conservation. It can improve farmers' livelihoods in heritage sites and stimulate the enthusiasm of farmers to protect the agricultural heritage.

**Methods:** Taking the mountainous *Juglans hopeiensis* planting system in Beijing as a case study, we evaluate the amount of ecological compensation using the contingent valuation method based on statistical data and interviews with farmers by combining with their willingness to accept compensation and income gap with other farmers. In addition, we analyze the factors affecting farmers' willingness to accept compensation.

**Results:** The results show that ecological compensation at a standard of RMB 9823.13 yuan/($hm^2 \cdot a$) can meet the livelihood needs of farmers in heritage sites, thus bridging the income gap between farmers in and around the heritage sites. Whether farmers accept compensation is mainly influenced by five variables: gender, education level, per capita income, household members, and the proportion of therapy walnut income in household income.

**Discussion:** We suggest that a concrete ecological compensation mechanism should be further constructed to ensure the effective implementation of ecological compensation and the longtime existence and development of agricultural heritage. This study can not only provide a reference for calculation of the ecological compensation amount and the establishment of ecological compensation mechanism for agricultural heritage in Beijing, but it is also crucial for the development of policies to ensure long-lasting conservation of agricultural heritage and continuous enhancement of farmers' livelihoods, and to improve the adaptation of global agricultural systems.

KEYWORDS

**agricultural heritage, ecological compensation, CVM, evaluate, WTA, Beijing**

## 1 Introduction

The contemporary global emphasis on the intricate interconnections among sustainable agriculture, food security, and livelihoods underscores their interplay grounded in economic principles (Tansuchat and Plaiphum, 2023). The sustainability of agriculture depends on the availability and richness of natural resources in the ecosystem. Adequate availability of food depends on natural resources. Ensuring food security is one of the greatest challenges facing the international community (Dela Cruz and Koohafkan, 2009). Sustainable agriculture contributes to ensure food and nutrition security, which is in line with Sustainable Development Goal 2 (The 17 Goals, 2015; Farooq et al., 2019; Liu et al., 2024). As typical agricultural ecosystem, agricultural heritage is abundant in natural resources and has significant ecological value. The protection of agricultural heritage is very important for the sustainable development of agriculture and food security. Agricultural heritage is created, shaped and maintained by generations of farmers and herders based on different species and their interactions, using a combination of locally adapted, unique and often ingenious management practices and technologies (Koohafkan and Dela Cruz, 2011). Agricultural heritage systems, based on sustainable practices, can still provide food and livelihood security, resources and services to local communities, while also serving as examples of adaptation and mitigation to adverse impacts by climate change and other harsh conditions, as well as models of resilience and sustainability (Agnoletti and Santoro, 2022). Altieri (2004) proposed that agricultural heritage can provide cultural and ecological services for everyone and guarantee food security and agricultural biodiversity. Along with industrialization and progress in agro-technology, many traditional agricultural systems have been replaced by modern ones or abandoned by farmers owing to low profits and tiring work processes (Douglas et al., 1994; Sluis et al., 2014). Although modern agricultural technology can increase the output and efficiency of agriculture, it can also engender negative effects on both human and animal life, such as land-use changes, habitat loss, inefficient water use, soil erosion and degradation, pollution, and genetic erosion (Bindi and Olesen, 2011). These pose enormous challenges for the sustainable development of agriculture.

The Globally Important Agricultural Heritage System (GIAHS) initiated by the UN's Food and Agriculture Organization (FAO) in 2002 was designed as an initiative to respond to agricultural environmental issues, food security, and the crisis of sustainable agricultural development. GIAHS aims to identify, support, safeguard, and conserve agricultural heritage systems and the livelihoods connected with them, agricultural and associated biodiversity, landscapes, and knowledge systems and cultures (Food and Agriculture Organization of the United Nations, 2012). In 2005, the Rice Fish Culture System of Zhejiang was identified as the first GIAHS protection pilot in China and part of the first batch in the world. Since then, research has emerged on the protection and use of systematic agricultural heritage in China (Min and Zhang, 2018).

There are many practical approaches to the protection, inheritance, and development of agricultural heritage, with studies focusing on various perspectives. Su et al. (2020) studied the relationship between agricultural heritage protection, tourism, and community livelihood and concluded that the multilayer integration of tourism and agricultural heritage systems could sustain traditional agriculture and enhance community livelihoods. Analyzing cases in the United Kingdom, Korea, and China, Park et al. (2016) found that public–private partnerships, local regulation systems, land control, and land use planning are crucial for the protection of agricultural heritage sites. Sun et al. (2014) suggested that several GIAHS sites in China should make full use of the spontaneity of natural systems, provide guarantees for the sustainable development of agriculture, and adopt specific models to reduce environmental risks to ensure the stability of farmers' income and of agricultural systems.

Balancing the protection and development of agricultural heritage remains challenging. Such protections are focused on agroecosystems, biodiversity, landscapes and farmer knowledge, culture, and social organization. Farmers as the main body to protect agricultural heritage might receive less benefit, and their economic development can be restricted when they bear a large part of protection costs. Farmers in heritage sites should therefore be reasonably compensated. In 2007, the FAO observed that in order to provide different combinations or higher levels of environmental services for agricultural heritage, it is necessary to compensate producers for losses caused by production methods and market systems that do not recognize nor differentiate the value of heritage products or production methods.

As a means of protecting agricultural heritage, ecological compensation not only encourages farmers to adopt environmentally friendly production methods to fully utilize the ecological service function of agricultural heritage, but also compensates them for the increased costs and reduced outputs resulting from traditional production methods, thus internalizing their external contribution (Liu et al., 2014). Determining ecological compensation standard is also challenging and has been investigated by many researchers. For the evaluation of ecological compensation amount, scholars use different methods. Using methods based on the economic value of resources and the environment, Wang et al. (2015) built a model to evaluate an ecological compensation standard of RMB $60.99 \times 108$ yuan/a, intended to make up for the loss brought about by the construction of reservoir dams. They accomplished this through the application of different methods for evaluating the economic value of resources and the environment. Taking Hani Terrace as an example, Liu et al. (2017) considered the improvement of ecological functions, farmers' willingness to be compensated, and opportunity costs and formulated a compensation standard of RMB 9,000 yuan/($hm^2$·a). Using the double-boundary dichotomous conditional value assessment method, Lv et al. (2019) estimated the ecological compensation standard for chemical fertilizer application control in Lishui District, Nanjing, and arrived at RMB 882.49 yuan/($hm^2$·a). Lu et al. (2021) brought ecological benefit into the compensation standard for farmland non-point source pollution control using the selective experiment method. Based on utility theory, Luan et al. (2021) determined that the ecological compensation standard for agricultural non-point source pollution control in the Dongting Lake Basin was RMB 1640.20 yuan/($hm^2$·a). Using the contingent valuation method (CVM), He et al. (2023) concluded that the payment standard for rice farmers in Guanxi is RMB 2,689.5 yuan/($hm^2$·a), based on their willingness to pay for paddy fields. Studying the Yangtze River Delta, Mao and Niu (2024) quantitatively analyzed various ecosystems in the region in three dimensions: ecosystem service value, ecological carrying capacity, and ecological footprint; they calculated ecological compensation as RMB 6,825.596 billion yuan for Shanghai, RMB

6,412.264 billion yuan for Jiangsu, RMB 12,088.852 billion yuan for Zhejiang, and RMB 3,675.637 billion yuan for Anhui.

Most existing studies focus on the construction of a compensation mechanism and the calculation of compensation standards for a certain region. However, few have focused on the combination of agricultural heritage protection and ecological compensation. This study, therefore, selects the mountainous *Juglans hopeiensis* planting system in Beijing as the research object, introduces CVM into the calculation of ecological compensation standards, and evaluates specific systems. This can provide a reference for ecological compensation in agricultural heritage sites.

Next, we describe the research area. Then, section 3 presents the methods used to calculate the ecological compensation standard. Section 4 discusses the results, and section 5 concludes with the practical application of the method and the scope for future research. Figure 1 depicts our research framework.

## 2 Study area

*Juglans hopeiensis* is a natural hybrid walnut of *J. regia* L. and *J. mandshurica* Maxim, distributed in some mountainous areas of Hebei, Tianjin, Shanxi, and Beijing. *Juglans hopeiensis* has a hard texture and diverse patterns. It is used for massage acupoints in the hand and is also referred to as wenwan walnuts or hand therapy walnuts. Therapy walnuts offer health benefits by stimulating acupuncture points on the hands, which can promote blood circulation, relieve fatigue, and improve sleep. They are also carved as artistic works and have high collector value (Zhang et al., 2024). According to historical records, therapy walnuts originated in the Han (202–220 BC) and Sui (581–618 BC) dynasties, prevailing in the Tang (618–907 BC) and Song (960–1279 BC) dynasties and flourishing in the Ming (1368–1644 BC) and Qing (1644–1911 BC) dynasties. They have a history of more than 2,000 years and are rich in heritage resources. The mountainous *J. hopeiensis* planting system in Beijing, recognized as a "China Important Agricultural Heritage" by the Ministry of Agriculture in 2015, mainly includes therapy walnut trees, therapy walnut products, and traditional walnut tree planting technologies, land-use patterns, and interconnected humans-to-nature landscapes. This planting system not only produces fine walnuts with health benefits and artistic value but is also significant for biodiversity and sustainable agricultural development. In order to prolong the life of therapy walnut tree and improve the yield and quality of therapy walnuts, the local government has strict control over the application of pesticides and fertilizers. This can not only ensure the safety of products, but also promote the recovery and sustainability of the ecological environment. In addition, local farmers have introduced the concept of agricultural circular economy while taking advantage of regional advantages to develop the walnut industry, and formed a variety of compound farming models under walnut trees in a unique way, such as stocking chickens, ducks and other livestock and poultry under walnut trees. The model can realize nutrient circulation and produce products without pollution, which is conducive to maintaining biodiversity.

The core area of the mountainous *J. hopeiensis* planting system is located in Xiong'erzhai Township (abbreviated XEZ), which is part of the Sizuolou Natural Reserve in Beijing. It is distributed between 117°05′48″–117°13′32″ E and 40°14′04″–40°19′19″ N. The topography is mainly low

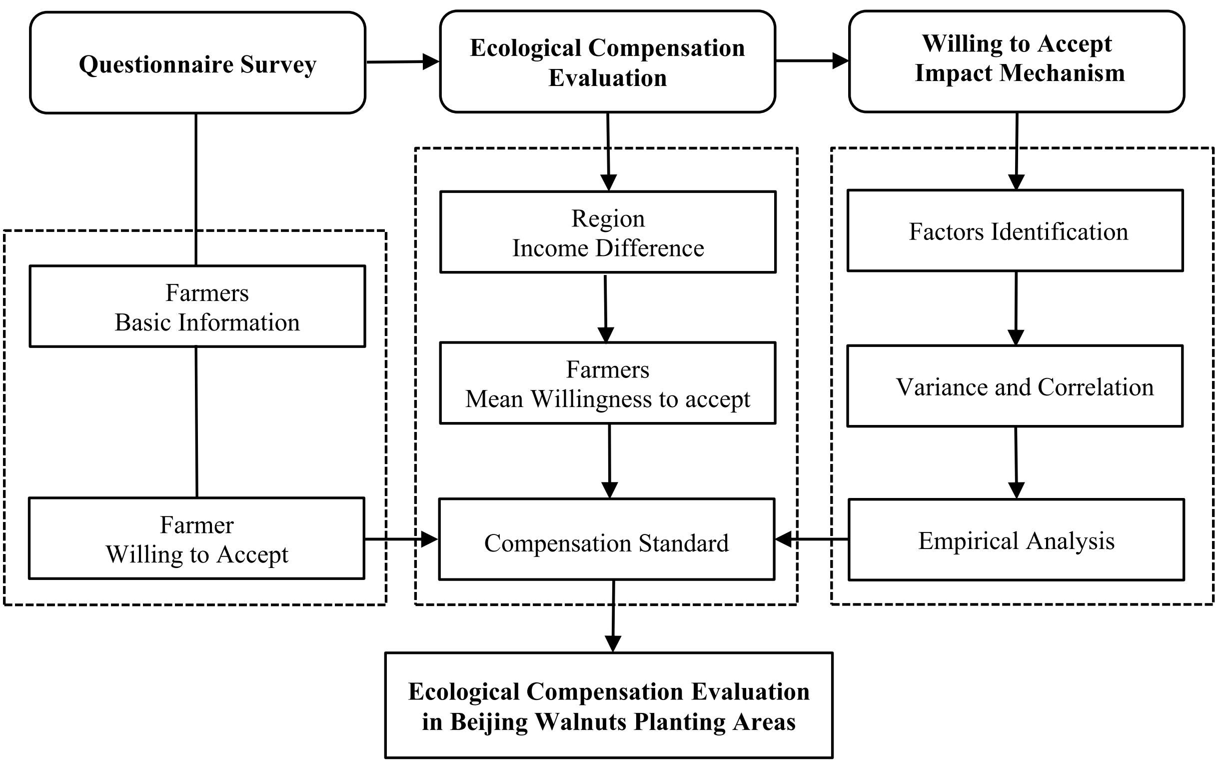


FIGURE 1
Research framework.

hills with gentle relief. XEZ has a temperate continental monsoon climate with significant seasonality, annual average temperature of 11.5°C and annual average rainfall of 681 mm. The area is rich in water resources. The walnut planting area lies in the warm temperate zone in front of the mountain, stretching more than 100 km. The environment is highly suitable for the growth of walnut trees, with sufficient sunlight and large air temperature differences between day and night. The local brown soil supports tree growth and walnut quality. The region is abundant in flora and fauna resources and lush vegetation, with more than 100 species of wild animals and more than 500 species of wild plants. It is reported that in 1989 and 2003, leopard and wild sika deer were found in the Beijing Sizuolou nature reserve, respectively. Among wild plants, the 10 families with the most species are Compositae, Gramineae, Papilionaceae, Rosaceae, Labiatae, Liliaceae, Ranunculaceae, Cyperaceae, Umbeliferae and Cruciferae (Chen et al., 2006). Figure 2 shows the main distribution range of therapy walnut in Beijing Sizuolou nature reserve.

# 3 Data source and research method

## 3.1 Questionnaire design and data acquisition

The questionnaire consists of two parts. The first part covers basic information about the interviewees, who are farmers in the heritage site. This information includes gender, age, education level (EL), household members (HM), per capita income (PCI), proportion of therapy walnut income in household income (PWIH), and walnut tree acreage (WTAC). The second part investigates farmers' willingness to accept compensation and specify the amount of such compensation. The interviewer explained the questions during the interviews to ensure the farmers freely and precisely expressed their information and willingness.

Beitumen Village and Donggou Village, the core distributed areas of walnut trees, were chosen to conduct the research. In September 2022, two five-person groups were dispatched to the two villages; they took 5 days to communicate with the villagers and finish the interviews. Most of the interviewed farmers comprised the main labor force of the household. Finally, 99 questionnaires were collected and then input into an online questionnaire system. After preliminary screening, 8 invalid questionnaires were excluded, and 91 remained for analysis (effective rate: 91.9%).

The income data for Pinggu District and XEZ are official data provided by local authorities.

## 3.2 Research method

The CVM is commonly used to measure willingness to pay (WTP) and willingness to accept (WTA). It can be used to evaluate

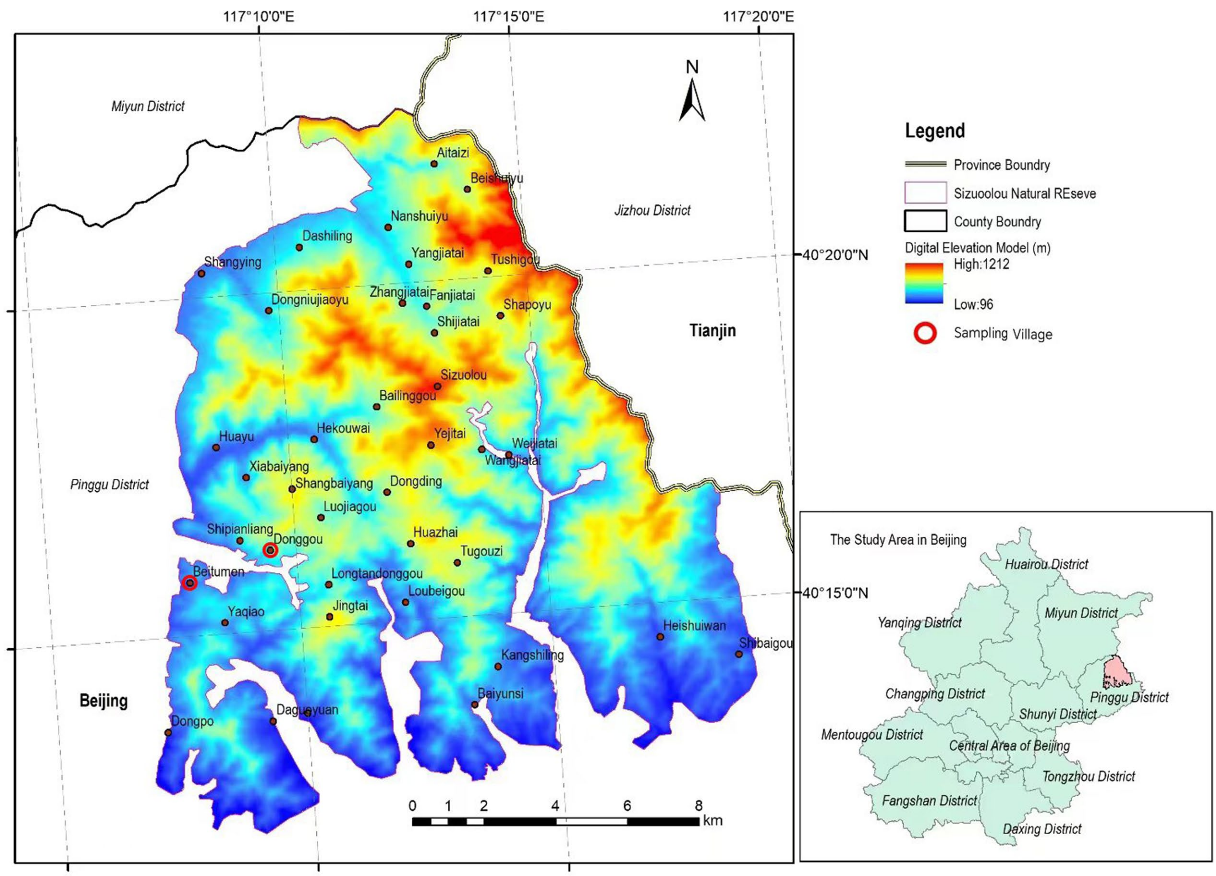


FIGURE 2
Main distribution range of therapy walnut in Sizuolou nature reserve in Beijing.

the value of public goods with intangible benefits, such as cultural heritage, environmental benefits, and ecological value. Various studies have confirmed its usefulness for studying farmers' WTP or WTA (Amigues et al., 2002; Del Saz-Salazar et al., 2009; Nimoh et al., 2024). We use CVM to evaluate residents' WTA regarding ecological compensation for agricultural heritage conservation.

### 3.2.1 Guiding mode of CVM for WTA

Payment card (PC), a crowd-centered guidance method for CVM, is selected to calculate the amount of compensation farmers are willing to accept. For the compensation amount interval, we referred to existing research and considered the long-term observation of farmers' income and local government finances. We gave the respondents four bidding intervals of [3,000–6,000], [6,000–12,000], [12,000–18,000], and [18,000–21,000], allowing them to fill in the amount they wished to be compensated.

### 3.2.2 CVM deviation and its treatment

Using PC as a guiding method requires the interviewees to choose within a given range. Therefore, the setting of the mark value affects the final result. If the mark value is improperly set, it might lead to large deviations in the results. By comparing the change degree and value of rural per capita income between the heritage site and Pinggu District, we calculate the difference and set the minimum compensation amount. Determining the starting point, range, and spacing of standard values can effectively solve the problem of standard value deviation. The mark value is acquired by dividing the difference by the average area of farmers' walnut planting, which is used as the reference for the standard value. Then, the statistical interval required for the compensation willingness value is gained by increasing or decreasing on this basis.

### 3.2.3 Valuation method

We obtain the interviewees' WTA in the form of PC. Respondents wrote down their compensation amount within the selected bidding interval. Based on these amounts, the mean willingness to accept (MWTA) of farmers is calculated as follows:

$$MWTA = \sum_{i=1}^{n} \left( WTA_i \right) / n \tag{1}$$

where $WTA_i$ refers to the willingness of the $i$-th effective interviewee to be compensated, and $n$ is the total number of effective samples.

## 3.3 Analysis method

We use analysis of variance (ANOVA) to compare whether there are significant differences between the mean values of three or more groups. This can help determine whether the differences between different groups are attributable to random variation or the influence of the treatment. Correlation analysis was employed to study the relationship between two or more variables, which can measure the intensity and direction of the correlation between variables. We take WTA as a dependent variable. Gender, age, EL, HM, PCI, PWIH, and WTAC are taken as factors for analysis and research. We mainly refer to previous studies (Zeng et al., 2018; He et al., 2023) for variable selection. The analysis of the factors affecting farmers' WTA deals with multiple variables. By using ANOVA and correlation analysis, and introducing multiple factors into the model, we can analyze each variable's influence on farmers' WTA more clearly.

# 4 Results

## 4.1 Descriptive statistical analysis of samples

Table 1 presents the demographic characteristics of the participants, showing details related to gender, age, EL, HM, PCI, PWIH, and WTAC. This demographic information sheds light on the profile of the respondents and provides valuable context of the participants. The majority of the respondents who completed

TABLE 1 Demographic characteristics of respondents.

| Item | Category | Number (persons) | Percentage (%) |
|---|---|---|---|
| Gender | Male | 65 | 71.43 |
| | Female | 26 | 28.57 |
| Age (years old) | 22–30 | 6 | 6.59 |
| | 31–50 | 63 | 69.23 |
| | 51–65 | 21 | 23.08 |
| | Over 65 | 1 | 1.10 |
| Education level | Primary school | 4 | 4.40 |
| | Secondary school | 37 | 40.66 |
| | High school | 34 | 37.36 |
| | Bachelor's degree and postgraduate | 16 | 17.58 |
| Household number | Less than 3 | 13 | 14.29 |
| | 4–5 | 57 | 62.64 |
| | 5–6 | 18 | 19.78 |
| | Over 6 | 3 | 3.3 |
| Personal per capita income (RMB yuan) | Less than 10,000 | 7 | 7.69 |
| | 10,000–30,000 | 53 | 58.24 |
| | 30,000–60,000 | 28 | 30.77 |
| | Over 60,000 | 3 | 3.30 |
| The proportion of therapy walnut income in total household income household income (%) | 0–20 | 13 | 14.29 |
| | 20–40 | 50 | 54.95 |
| | 60–80 | 24 | 26.37 |
| | 80–100 | 4 | 4.40 |
| Walnut tree acreage ($hm^2$) | Less than 0.13 | 12 | 13.19 |
| | 0.13–0.33 | 47 | 51.65 |
| | 0.33–0.67 | 29 | 31.87 |
| | Over 0.67 | 3 | 3.30 |

the questionnaire are male, accounting for 71.43%. They are aged 46 years on average, with relatively fewer younger participants. This reflects rural population aging trend in the study area. Data from the seventh national population census in China showed that in 2020, the population aged 60 and above in rural areas accounted for 23.8% of the total rural population (Shen et al., 2023). Labor is the most direct and critical factor affecting the improvement of agricultural productivity. Rural population aging gives rise to concerns about future agricultural sustainability. Most have a junior high or high school education; only 17.58% of respondents have a higher education background. Regarding HM, the household number is largely 4–5, accounting for 62.64%. Average PCI is RMB 20000 yuan. Participants with more than half of the household income coming from therapy walnut account for 20–40%; 14.29% do not rely on income from walnut planting at all. This shows that few families depend entirely on therapy walnut income. During COVID-19, the therapy walnut market took a downturn, and farmers' enthusiasm for planting therapy walnut trees decreased. For WTAC, most farmers tend to plant therapy walnut trees within 0.13–0.33 $hm^2$. The average area of walnut tree planting is 0.33 $hm^2$.

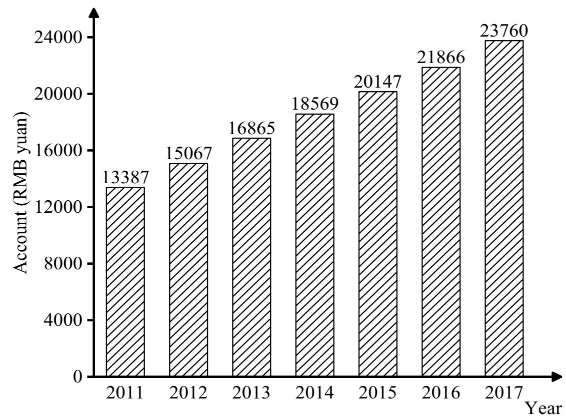


FIGURE 3
Per capita disposable income of rural residents in Pinggu District from 2011 to 2017.

## 4.2 Statistical analysis of income

In Figure 3, the horizontal axis represents time, and the vertical axis represents the per capita disposable income of rural residents in Pinggu District. Income increased from RMB 13,387 yuan in 2011 to RMB 23,760 yuan in 2017, an increase of 77.48% in 6 years. The per capita disposable income of farmers in XEZ increased from RMB 10,032.4 yuan in 2011 to RMB 16,700 yuan in 2021, an increase of 66.46%, which was lower than that in Pinggu District.

In XEZ, average local per capita income is RMB 20,000 yuan (Table 1). The per capita income growth rate is about 10% lower than that of Pinggu District. Thus, the income difference is around RMB 2,000 yuan per person per year. We divide the income difference by the per capita walnut planting area and calculate the compensation standard value as 6,060 yuan/($hm^2$·a). Based on the benchmark, the compensation amount is set to four bidding intervals: RMB 3,000–6,000, 6,000–12,000, 12,000–18,000, and 18,000–21,000 yuan/($hm^2$·a).

TABLE 2 Statistical results of WTA.

| Item | Category | Number | Percentage (%) |
|---|---|---|---|
| Willingness to accept compensation | Yes | 87 | 95.60 |
| | No | 4 | 4.40 |
| Reasons for reluctance to accept compensation | Declining production of therapy walnuts | 3 | 75 |
| | Low profitability of therapy walnuts | 2 | 50 |

TABLE 3 Statistical results of compensation amount.

| Serial number | Compensation amount [RMB yuan/($hm^2$·a)] | Number | Percentage (%) |
|---|---|---|---|
| 1 | 3,000–6,000 | 3 | 3.30 |
| 2 | 6,000–12,000 | 9 | 9.89 |
| 3 | 12,000–18,000 | 17 | 18.68 |
| 4 | 18,000–21,000 | 58 | 68.13 |

## 4.3 Analysis of farmers' WTA ecological compensation

### 4.3.1 Descriptive analysis of farmers' WTA

Regarding the respondents' WTA, the main items include whether they are willing to accept compensation and the compensation amount. Table 2 shows that only four people are unwilling to accept compensation, because of the decline in output and low profit of therapy walnut. Most prefer to accept compensation.

Regarding compensation funds, Table 3 shows that for more than half of the farmers, compensation is concentrated in the range of RMB 18,000–21,000 yuan/($hm^2$·a), which meets their demand for higher income. The WTA trend increases with increased compensation. Figure 4 shows the process of farmers' WTA.

### 4.3.2 Analysis of factors affecting farmers' WTA

We conduct the ANOVA and correlation analysis of farmers' WTA using SPSSAU v. 23.0. WTA is taken as a dependent variable, and gender, age, EL, PCI, HM, PWIH, and WTAC are the independent variables. Table 4 shows the results. EL, PCI, HM, and PWIH pass the significance test at the level of 1%, while gender passes at 5%. These are treated as factors affecting farmers' acceptance of compensation. Age and WTAC have no significant effect on WTA and are excluded from future analysis. EL negatively influences farmers' WTA. The higher the EL, the greater the awareness of heritage conservation. Farmers with higher education mostly hope that the government or other organizations can protect agricultural heritage through investment. But the role of ecological compensation in protecting agricultural heritage is not obvious, it

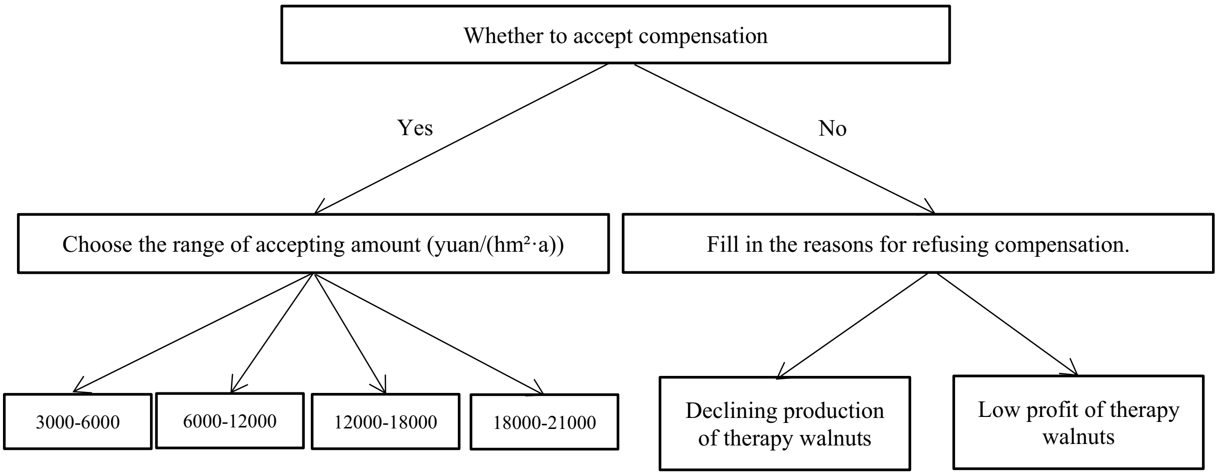


FIGURE 4
The process of WTA.

TABLE 4 Results of variance analysis and correlation analysis of WTA.

| Factors | *F* | *P* | Pearson correlation | Sig. (2-tailed) |
|---|---|---|---|---|
| Gender | 4.543 | 0.036 | 0.220* | 0.036 |
| Age | 2.397 | 0.074 | — | — |
| Educational level (EL) | 9.815 | 0.000 | −0.351** | 0.001 |
| Per capita income (PCI) | 15.242 | 0.000 | −0.400** | 0.000 |
| Household member (HM) | 5.657 | 0.001 | 0.303** | 0.004 |
| The proportion of therapy walnut income in total household income (PWIH) | 7.283 | 0.000 | −0.361** | 0.000 |
| walnut tree acreage (WTAC) | 1.574 | 0.202 | −0.204 | 0.053 |

** and * indicate the 1 and 5% significance levels, respectively.

serves more is to improve the livelihood level of farmers. PCI also has a significant negative influence on WTA. Farmers with higher PCI have broader income sources and less dependence on walnut planting. Thus, their WTA ecological compensation is generally low. Meanwhile, low-income families hope to improve their living standards through ecological compensation. HM is positively correlated with WTA. The larger the family, the easier it is to accept compensation under heavier economic pressure, and vice versa. Judging from PWIH, households with higher income from planting therapy walnuts have stronger enthusiasm for planting walnuts, and ecological compensation has no significant impact on them. The effect of gender on WTA might be associated with the gender structure of the participants.

## 4.4 Calculation of ecological compensation

According to Equation 1 (MWTA), the average compensation amount is RMB 13,586.25 yuan/(hm$^2$·a) based on farmers' WTA. By comparing the income of Pinggu District with XEZ, the difference in compensation amount is 6,060 yuan/(hm$^2$·a). The compensation standard calculated from WTA is relatively higher than that achieved from incoming regional differentiation. The former could hardly be accepted by the local government. However, the latter should not be accepted by walnut farmers. Thus, the study determines the average value of the regional income difference and farmers' MWTA as the ecological compensation standard. The ecological compensation standard is finally set to RMB 9,823.13 yuan/(hm$^2$·a).

# 5 Discussion, conclusion, and limitation

## 5.1 Discussion

Agricultural heritage encapsulates the quintessence of traditional eco-agricultural practices with abundant biodiversity and species resources. Biodiversity conservation can effectively contribute to food security by reducing the pressure of agriculture on vulnerable areas and endangered species and making food farming more resilient and sustainable (Kahane et al., 2013). Adequate species resources and traditional production methods guarantee the sustainability and security of food system. The inheritance and protection of agricultural heritage is in line with the requirements of the Sustainable Development Goals. GIAHS are diverse and locally adapted agricultural systems, which resulted from centuries of biological and cultural exchanges between humankind and the environment, delivering goods and services from ecosystems and securing the subsistence of small-scale farmers and indigenous communities (Reyes et al., 2020). As industrialization and urbanization accelerate, many traditional agricultural production methods are being gradually abandoned, leading to the reduction of the sustainability of agricultural systems (Jiao et al., 2016). It is urgent to protect the agricultural heritage to achieve the goals of sustainable agricultural development and food security. As one of the countries that actively participate in GIAHS projects, China has taken various measures to protect agricultural heritage. As an effective means to protect agricultural heritage, ecological compensation for farmers can not only narrow the developing gap between heritage sites and other areas, raising the living standards of farmers in heritage sites and enhancing farmers' enthusiasm for protecting agricultural heritage, but also help maintain agricultural biodiversity and sustainable development of agriculture (Liu et al., 2018). However, most previous studies focused on the construction of compensation mechanisms or the calculation of compensation standards in certain wetlands or basins (Liu et al., 2022; Liu et al., 2023; Lu et al., 2024) while relatively few have considered ecological compensation for agricultural heritage. Existing research on ecological compensation for agricultural heritage mainly focuses on ecological function (Liu et al., 2017; Miao and Wang, 2017), but few thoroughly investigate farmers, ignoring their key role in agricultural heritage conservation. Farmers, as the main participants and practitioners in the protection of agricultural heritage sites (Wan et al., 2023), have to pay more costs in the process of taking responsibility for protecting heritage sites, resulting in less benefits and difficulty improving their quality of life.

The mountainous *J. hopeiensis* planting system in Beijing is an eco-friendly agricultural system. While utilizing geographical advantages to develop the walnut industry, local farmers have also adopted the technologies of circular economy in agriculture production, forming kinds of integrated planting and breeding patterns under the walnut trees, such as rearing chickens, ducks and other livestock or planting vegetables or medical herbals under the walnut trees. These production patterns ensure food security, and promotes the restoration of the ecology and the maintenance of biodiversity, which guarantees for farmers to engage in diversified agricultural systems, and promotes the realization of the goals of sustainable agriculture and food security. This study takes the system as a case study and enriches existing research on the combination of agricultural heritage and ecological compensation. This is conducive to solving the problem of the sustainable development of farmers' livelihoods in the process of protecting agricultural heritage and achieve the coordinated development of heritage sites and other regions.

There are still some difficulties in determining reasonable and effective compensation amounts (Peng et al., 2021; Yang et al., 2022). This study provides a convenient and feasible scheme for the evaluation of ecological compensation. First, local farmers' understanding of agricultural heritage and ecological compensation policy has increased, which contributes to improve future decision-making. Second, most studies emphasize compensation for ecosystem services (Fu et al., 2021; Zhang et al., 2023). The estimated compensation amount is often high. However, governments who primarily implement ecological compensation policy (Liu et al., 2022) face an increased financial burden and therefore find it difficult to accept the amount. In this study, we obtain the amount of compensation by taking into account farmers' WTA and the regional income gap; it can therefore be more readily accepted by farmers and the government. Further, our method for calculating ecological compensation is relatively brief and is easily extended to other agricultural heritage sites. Finally, reasonable ecological compensation can achieve a win-win situation that enhances farmers' livelihoods which strengthen their enthusiasm for agricultural heritage conservation, and alleviates the government's financial burden. Therefore, ecological compensation for farmers in heritage sites can balance the protection and development of agricultural heritage.

There remains an enormous gap between opportunity cost, contribution, and compensation amount, resulting in the efficiency of compensation falling far short of expectations. Thus, we should guide more groups toward actual ecological compensation, except for government subsidies, and adopt various compensation methods, such as physical compensation, labor compensation, and resources, to invest in the operation of ecological compensation. In addition, we suggest constructing a complete ecological compensation mechanism for heritage sites, which includes defining the subjects and objects of heritage, payment methods, supervision and participation mechanisms. Recommendations include setting up ecological compensation funds for protected areas, accelerating the marketization of regional ecological compensation, and carrying out publicity about ecological compensation to support the long-term development of heritage sites.

## 5.2 Conclusion

By the average of regional income differences and farmers' MWTA, we calculated that the final ecological compensation standard was RMB 9823.13 yuan/($hm^2$·a) for farmers in XEZ. An ecological compensation amount of RMB 9823.13 yuan/($hm^2$·a) can make up for the income gap between the heritage site and farmers around the heritage site and promote the development of the farmers' livelihoods, which could serve as a reference for local ecological compensation standards.

Moreover, we conduct ANOVA and correlation analysis on the influencing factors of farmers' WTA in the heritage site. Whether farmers accept compensation is mainly related to five variables: gender, EL, PCI, HM, and PWIH. Farmers' WTA is positively correlated with HM, but has a negative correlation with EL, PCI, and PWIH. The lower the EL, PCI, and PWIH, the higher the WTA. Households with more members have stronger WTA. Gender is also related to WTA, which could be associated with the local gender structure.

## 5.3 Limitation

This study has good generalizability and demonstrates effectiveness in the concrete implementation process of ecological compensation, and the results can be easily approved by local farmers and government. However, there are still several limitations to this paper. The sample data in this study come first-hand from study area survey, and the coverage is small. More samples from more agricultural heritage sites could provide more reliable data support for related studies in the future. Due to the limited data acquisition, we only collected the data from 2011 to 2017 for the rural per capita disposable income in Pinggu District, which may have a slight impact on the final result. Besides, our calculation of the compensation standard does not take the opportunity cost of heritage development and the value of ecological resources as evaluation items. Compared with the value of ecological services, the calculated compensation amount is low. While compensating farmers for their losses in preserving their agricultural heritage, it has failed to bring farmers' incomes up to the income line of the Pinggu District. Comparatively speaking, it still lags behind the economic level of non-heritage areas. Hence, it is necessary to further include these factors in future research and strengthen the scientific analysis. Finally, it is very important to formulate solutions and support local communities to solve farmers' needs. We have discussed little about how to formulate solutions and address the needs of farmers in the paper. We will consider it as comprehensively as possible in the future research.

## 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

HD: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. GX: Conceptualization, Data curation, Investigation, Methodology, Project administration, Resources, Writing – original draft. YL: Data curation, Investigation, Methodology, 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.

## Publisher's note



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