Characteristics, Conservation, and Utilization of Agricultural Biodiversity in Globally Important Agricultural Heritage Systems (Postprint)

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Abstract

In 2002, the Food and Agriculture Organization of the United Nations (FAO) proposed the concept of "Globally Important Agricultural Heritage Systems (GIAHS)"and a dynamic conservation philosophy, aiming to establish a conservation system for globally important agricultural heritage systems and their associated landscapes, biodiversity, knowledge, and culture, and to secure worldwide recognition and protection as a foundation for sustainable management. Since then, particularly with support from the Global Environment Facility, the GIAHS concept and conservation philosophy have gained increasing recognition from countries and international organizations. Through proactive exploration at project pilot sites during implementation, not only has agricultural biodiversity and cultural diversity in heritage sites been effectively conserved, but the sustainable socio-economic development of these sites has also been promoted. Based on 11 GIAHS sites in China and their conservation efforts, this paper analyzes the characteristics of agricultural biodiversity in agricultural heritage sites across five dimensions: genetic diversity, species diversity, ecosystem diversity, landscape diversity, and cultural diversity. It elaborates on the ecological principles and concepts guiding the utilization of agricultural biodiversity in these sites. Finally, it proposes recommendations for conserving and utilizing agricultural biodiversity in agricultural heritage sites through four approaches: establishing monitoring and evaluation systems, strengthening research on agricultural biodiversity conservation and sustainable management, creating incentive mechanisms for agricultural biodiversity conservation, and developing self-maintenance and sustainable development mechanisms for agricultural heritage sites.

Full Text

Preamble

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Agrobiodiversity Features, Conservation and Utilization of China' s Globally Important Agricultural Heritage Systems*

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Abstract
Recent increases in agricultural productivity have largely been attributed to the availability of high-yielding varieties, farm irrigation and agrochemical inputs. However, many of the inputs and practices of intensive agriculture have remained detrimental to human health, environmental quality and biodiversity conservation. The shortage of intensive modern agriculture requires "agriculture rethinking" and learning back from traditional agricultural systems. Conservation of existing biodiversity in traditional agricultural systems and the adoption of biodiversity-based practices have been proposed as a way of improving the sustainability of agricultural production. In 2002, the Food and Agriculture Organization of the United Nations (FAO) started an initiative of Globally Important Agricultural Heritage Systems (GIAHS) that emphasized dynamic conservation ideas. FAO defined GHAHS as "remarkable land use systems and landscapes rich in globally significant biological diversity evolving from the co-adaptation of a community with its environment and its needs and aspirations for sustainable development" . The GIAHS initiative aimed to establish the basis for international recognition, dynamic conservation and sustainable development management of such systems as agricultural biodiversity and the associated biodiversity, knowledge systems, food and livelihood security, landscapes and cultures. Since then, an increasing number of countries and international organizations have accepted the concept of GIAHS with the related dynamic conservation ideology, as especially supported by Global Environment Facility (GEF). Over five years of implementation of GEF project in pilot countries have shown that not only agrobiodiversity and cultural diversity been effectively protected, but also sustainable socio-economic development has been well promoted. Based on 11 GIAHS sites in China, this paper analyzed the agrobiodiversity features from the view of genetic diversity, species diversity, ecosystem diversity, landscape diversity and cultural diversity. It then illustrated the ecological thoughts and principles, and some suggestions were put forward

for conservation and utilization of agrobiodiversity. The approaches included the establishment of monitoring and evaluation systems, intensification of agrobiodiversity conservation and sustainable management research, formulation of incentive mechanisms for agrobiodiversity, and setting up of self-supporting and sustainable development mechanisms.

Keywords
Globally Important Agricultural Heritage Systems (GIAHS); Agrobiodiversity; Conservation and utilization; Dynamic conservation; Sustainable development

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The concept of Agricultural Heritage Systems originates from the Globally Important Agricultural Heritage Systems (GIAHS) conservation initiative launched by the Food and Agriculture Organization of the United Nations (FAO) in 2002 [1]. This project, supported by the Global Environment Facility (GEF), aims to conserve globally significant agricultural biodiversity and cultural diversity that are under threat. In 2005, FAO formally prepared the "Dynamic and Adaptive Management of GIAHS" project, selecting five different types of traditional agricultural systems across six countries as the first batch of GIAHS pilot sites. The project was approved by the GEF Council in 2008 and implemented from 2009 to 2014. Over the past decade, international attention to agricultural heritage has continued to grow. By the end of 2015, 36 traditional agricultural systems in 15 countries had been inscribed on the GIAHS list, with China accounting for 11 of them—the highest number among all countries. As one of the outcomes of China' s GIAHS project implementation, the Ministry of Agriculture launched the China-Nationally Important Agricultural Heritage Systems (China-NIAHS) identification and conservation program in 2012. By the end of 2015, it had announced 62 designated sites in three batches, making China the first country in the world to establish a national-level agricultural heritage recognition and protection system.

Whether considering the background of the agricultural heritage conservation initiative or the selection criteria for GIAHS and China-NIAHS, agrobiodiversity constitutes the core element of agricultural heritage [2–4]. In agricultural heritage sites, traditional varieties are preserved within traditional agricultural ecosystems, which remain important carriers of local farmers' livelihood strategies and traditional cultural inheritance. Agrobiodiversity conservation is achieved through farmers' farming activities and management, enabling protected genetic resources to continuously adapt and evolve alongside changes in nature, society, and economy, thereby constantly renewing and enriching their diversity. Therefore, conserving agricultural heritage represents an important approach to the in-situ conservation of agrobiodiversity [5].

1. Agrobiodiversity Features of Agricultural Heritage Sites

Agricultural heritage sites exhibit extremely rich agrobiodiversity. Through continuous seed selection and preservation, farmers choose traditional varieties adapted to local environments with different resistances and characteristics for diversified planting to meet cultivation requirements under various ecological and climatic conditions. Multi-species mixed farming and breeding practices help resist meteorological and biological disasters and ensure stable harvests. This rich genetic and species diversity, along with time-honored traditional agricultural techniques such as rotation and multiple cropping, intercropping and relay cropping, terraced farming, mulberry-dyke fish-ponds, agroforestry, and rice-fish co-culture, provides crucial insights for exploring the conservation and utilization of agrobiodiversity and promoting sustainable agricultural development.

1.1. Agro-genetic Diversity

In agricultural heritage sites, farmers tend to maintain the diversity of traditional varieties based on socioeconomic and environmental change factors (Table 1). The main characteristics include: (1) Traditional varieties better meet needs compared to modern varieties. For example, in the Congjiang Dong' s Rice-Fish-Duck System in Guizhou, glutinous rice cultivation not only provides tasty, filling, and portable food but also offers medicinal roots. Glutinous rice is also essential for folk activities such as seasonal festivals, life rituals, and social celebrations [6]. (2) High yields can be obtained with low external inputs (such as pesticides and herbicides). Research in the Honghe Hani Rice Terraces System in Yunnan shows that compared with monoculture of high-quality rice, mixed intercropping of diverse rice varieties achieves 81.1%–98.6% control efficacy against rice blast and increases yield by 630–1,040 kg per hectare [7]. The region' s rich rice variety diversity also corresponds to rich genetic diversity and physiological race composition of the rice blast pathogen. Since variety diversity facilitates co-evolution between host varieties and pathogens, dominant races struggle to emerge, effectively controlling disease epidemics [8]. (3) Insensitivity to abiotic stresses. Studies show that traditional varieties of millet in the Aohan Dryland Farming System in Inner Mongolia perform well under drought stress [9]. (4) Mixed cropping of different genotypes can reduce risks. Due to the unique three-dimensional agricultural climate of the Honghe Hani Rice Terraces in Yunnan, with diverse local ecological environments and variable climate, local ethnic groups must plant multiple varieties to ensure stable production [10].

1.2. Agricultural Species Diversity

In terms of heterogeneity of biota, species diversity can promote nutrient cycling and nutrient retention in both spatial and temporal dimensions within ecosystems. Agricultural heritage sites exhibit significant characteristics of composite systems (Table 2), emphasizing the integrity and interactions among multiple

components within the system. In these sites, farmers increase farmland species diversity through mixed planting such as intercropping and relay cropping, and by introducing other species like fish and ducks into rice paddies.

Recent ecological studies have demonstrated that increasing species richness can have substantial impacts on ecosystem processes even at lower levels [11]. This effect is particularly pronounced in farmland ecosystems with relatively simple species composition. Due to niche complementarity mechanisms, different species exhibit differences in resource utilization, or positive interspecific relationships exist, thus species diversity promotes the optimization of ecosystem functions [12–14]. Five-year field experiments in the Qingtian Rice-Fish Culture System in Zhejiang showed that the rice-fish co-culture system without pesticide input achieved significantly higher rice yield and stability compared to rice monoculture without pesticides, while weed biomass decreased by 93.57%, sheath blight incidence by 54.35%, and rice planthopper density by 44.74% [15–16]. Similar results were obtained from field experiments and surveys in the Congjiang Dong' s Rice-Fish-Duck System in Guizhou: compared with rice monoculture, rice-fish-duck co-culture achieved 100% control efficacy against major paddy weeds such as Monochoria vaginalis and Rotala indica, and over 90% control against Ceratophyllum demersum, Sagittaria pygmaea, Potamogeton distinctus, and Hydrilla verticillata; sheath blight incidence decreased by 34.67%, rice planthopper density by 46.39%, and rice leaf roller density by 31.89% [17–18]. Additionally, soil physical and chemical properties improved significantly, with soil organic matter content increasing by 18.44%, and available nitrogen, phosphorus, and potassium contents increasing by 20.45%, 13.80%, and 16.20%, respectively [17].

Studies using stable carbon and nitrogen isotopes have shown that compared with rice monoculture, rice-fish and rice-fish-duck composite systems have more complex food webs and trophic levels, thereby enhancing the stability of agricultural ecosystems [19].

1.3. Agricultural Ecosystem and Landscape Diversity

In agricultural heritage sites, the construction of aquatic-terrestrial micro-ecosystems enables farmland to coexist interwoven with forests, grasslands, wetlands, and other ecosystems, increasing farmland ecosystem diversity. For example, the coexistence of rice paddies, fish ponds, and forest ecosystems is a common landscape in the Congjiang Dong' s Rice-Fish-Duck System in Guizhou. By digging ponds to store water and raise fish, aquatic environments are artificially created, leading to multiplied populations of frogs—known as "crop protectors" —which can effectively control pest outbreaks. By concentrating forest patches within rice paddies and dividing paddies along contour lines, a landscape structure with interspersed distribution of paddies and forest patches is formed, which can increase beneficial bird populations and reduce pest numbers [20]. Since rice paddies are embedded within forest ecosystems, forming a composite organism, water cycling within the system is promoted.

For instance, when temperatures rise during the day, water from paddies enters the atmosphere through transpiration and evaporation but is retained due to the blocking effect of forest ecosystems, condensing back into dew or fog at night when temperatures drop and returning to the paddies. Additionally, local residents create shallow grass belts 5–7 meters wide in transition zones between forest and paddy ecosystems, with artificial control through cutting, burning, or livestock grazing. These grasslands not only increase ventilation and light penetration around paddies and prevent wildlife from entering but also provide grazing land for cattle, horses, and sheep, reduce surface runoff, decrease sediment deposition, and mitigate debris flow and flash flood hazards. The existence of grassland ecosystems also enhances grassland biodiversity.

At the landscape scale, the process of co-evolution between local residents and nature has formed unique, living agricultural landscapes composed of forests, grasslands, farmland, rivers, lakes, and villages (Table 2). Empirical research in the Honghe Hani Rice Terraces System in Yunnan, using the Longjia small watershed as a case study, found that the main landscape types included rice terraces, dry terraces, broadleaf forests, coniferous forests, tea plantations, and villages (Figure 1). Rice terraces accounted for 44.6% of the total landscape area, followed by broadleaf forests at 29.5%, dry terraces at 19.2%, and coniferous forests, villages, and tea plantations at 4.6%, 2.0%, and 0.1%, respectively. Broadleaf forests, rice terraces, and dry terraces all featured large, continuous landscape patches: forests concentrated in higher elevations in the west, rice terraces mainly distributed below 1,500 m in the east, and dry terraces relatively dispersed between forests and rice terraces but continuously distributed within certain elevation ranges [21]. Such heterogeneous yet well-connected agricultural landscapes exhibit more significant regulation and support functions [22–23].

1.4. Agricultural Cultural Diversity

Due to the close relationship between cultural diversity and biodiversity, ethnic culture has become a non-negligible important aspect in biodiversity conservation and management today. Cultural diversity is also considered an important component of biodiversity [24]. In agricultural heritage sites, local residents have accumulated rich experience through long-term adaptation to nature, which is fully reflected in the traditional cultures of various ethnic groups and has become an important component of agricultural heritage systems.

In the Congjiang Dong' s Rice-Fish-Duck System in Guizhou, there is an extremely close relationship between Dong agrobiodiversity and traditional culture, with obvious manifestations in clothing, diet, architecture, medicine, and other traditional cultural aspects. Meanwhile, intangible cultural forms such as religion (power of belief), customary law (village regulations), and customs have all played positive roles in agrobiodiversity conservation [17,25].

In the Honghe Hani Rice Terraces in Yunnan, the Hani people protect animals,

plants, and their survival-dependent forests, mountains, and land through totem worship and nature worship; they build collective memory through ancestor worship to maintain family and clan connections and establish identity and belonging; they maintain human awe of nature through belief in ghosts and witchcraft; and they sustain the stability and sustainable development of the rice terrace system through practical and effective resource management knowledge (mainly concerning water, farmland, and organisms) [21,26]. Under such beliefs and mindsets, various Hani sacrificial activities carry ecological and cultural significance for agrobiodiversity and ecosystem conservation (Table 3).

2. Ecological Principles for Agrobiodiversity Utilization in Agricultural Heritage Sites

1) **Principle of Minimum Modification**: In agricultural heritage sites, local residents' production and lifestyle adapt as much as possible to the natural ecological environment, pursuing harmony between humans and nature. In Congjiang, Guizhou, the Dong people learn from nature by observing natural swamps to build rice-fish-duck systems, minimizing differences between paddies and the natural ecological background, thereby achieving high stability and sustainable development in agricultural production. The unique reproductive culture of Congjiang' s Zhanli people effectively controls population size, achieving balance and coordination between population growth and natural resource supply.

2) **Principle of Integrity**: The possession and use of natural resources are maintained as completely as possible, with this ecological thought integrated into traditional culture to ensure long-term preservation. The Dong people particularly emphasize the protection of village forests, famous ancient trees, and waterside vegetation, attach importance to afforestation, and incorporate these into "Dong Kuan" (Dong regulations) with legal status. For example, in 1869 (the eighth year of the Tongzhi reign), Changchun Village in Panlao Township, Liping County, Guizhou, where the Dong people live in compact communities, erected a prohibition stele: "Our village has a green dragon at the back, with lush forests remaining evergreen throughout the four seasons, a blessed land created by nature. For the fortune of our descendants, prosperity of livestock, and bountiful harvests, the whole village gathered at Daping to swear an oath by slaughtering a chicken and mixing its blood with wine: not a single blade of grass or tree on our back dragon mountain or penholder mountain may be cut arbitrarily; violators shall share the same red fate as the blood and the same end as the wine."

3) **Principle of Adapting to Local Conditions and Balanced Utilization**: Agricultural biodiversity and its products are utilized in a balanced manner according to local conditions. In the Congjiang Dong' s Rice-Fish-Duck System, local residents utilize as many as 17 plant species from 12 families, including 6 edible species (35.3% of total), 6 fodder species

(35.3%), 4 Dong medicinal species (23.5%), and 1 each for weaving materials and green manure (5.8% each) [17].

4) **Principle of Sustainable Development**: Agrobiodiversity is the foundation and condition for human survival and development, and its sustainable utilization is the primary condition for maintaining sustainable human society. In agricultural heritage sites, local residents adjust their lifestyles according to natural resource conditions, determining their consumption standards within ecological carrying capacity and developing and utilizing agro-biological resources rationally. In Congjiang, the "Dong Kuan" contains seasonal regulations: "Traditionally, in the first lunar month, we go up the mountains with knives and axes to cut firewood; in the second month, we wear bamboo hats and rain capes; in the third month, we use rakes; in the fourth month, we use plows and harrows; in the fifth month, we have eggplants and cucumbers; in the sixth month, rice ears emerge; in the seventh month, do not linger in granaries for love; in the eighth month, do not stay with companions for play. These rules must be taught to every boy and trained into every girl in every household; those who disobey shall not be tolerated in four villages or six caves." This clearly announces the Dong people' s agricultural calendar: the first to third lunar months are for forestry operations, with thinning and selective cutting arranged in the first month and forest inter-tillage in the second and third months; field farming only begins after the fourth month. Such seasonal arrangements, except for necessary forest management periods, keep forest areas completely closed for most of the year, protecting forest biodiversity.

3. Recommendations for Agrobiodiversity Conservation and Utilization in Agricultural Heritage Sites

3.1. Establish Monitoring and Evaluation Systems

Once the agrobiodiversity, traditional agricultural knowledge, techniques, and agricultural landscapes contained in agricultural heritage are lost, their unique and significant ecological, cultural, and even economic benefits will disappear accordingly. Therefore, on the one hand, comprehensive evaluation methods are needed to fully understand the agrobiodiversity features of agricultural heritage, explore their ecological values, and identify major threats. On the other hand, real-time and regular acquisition of the status of agrobiodiversity in heritage sites and the impacts and effects of conservation and development measures is necessary to establish effective monitoring systems [27] and form early warning mechanisms. Given the agrobiodiversity features of agricultural heritage sites and the large amount of spatial and attribute data involved, Geographic Information Systems (GIS) have broad application prospects in this field [28].

3.2. Strengthen Research on Agrobiodiversity Conservation and Sustainable Management

Agrobiodiversity in agricultural heritage sites is the fundamental guarantee for local residents' survival, livelihood, and living. Therefore, it is first necessary to study and deeply understand the reasons why local residents maintain and preserve agrobiodiversity, giving them full respect to promote sustainable utilization [29]. Encourage multidisciplinary and cross-sectoral comprehensive research and demonstration, with researchers, farmers, and other stakeholders participating together. Employ integrated research methods from ecology, sociology, and economics to explore the ecosystem service functions of agrobiodiversity under different management scenarios, focusing on the relationship between economic development and agrobiodiversity conservation. When exploring adaptive management of agrobiodiversity, support should also be given to agricultural production methods based on the multifunctionality of agrobiodiversity.

3.3. Establish Incentive Mechanisms for Agrobiodiversity Conservation

Incentive mechanisms should be established to promote agrobiodiversity conservation and sustainable utilization. Actively exploring market-based mechanisms to attract social capital investment in agrobiodiversity conservation is an aspect requiring attention. Since agrobiodiversity conservation belongs to the public service domain, compensation for ecosystem services provided by agrobiodiversity in agricultural heritage sites has traditionally been government-led [30–33]. The "Decision of the Central Committee of the Communist Party of China on Several Major Issues Concerning Comprehensively Deepening Reform" passed at the Third Plenary Session of the 18th CPC Central Committee affirmed the decisive role of the market and encouraged social capital investment in environmental fields. During implementation, ecological compensation mechanisms should be established based on in-depth research on the long-term value of agrobiodiversity and game-playing among various stakeholders. The government should fully recognize the significance of cooperation with social capital, broaden investment channels for social capital, promote integration of various types of capital with complementary advantages, and give full play to the market' s decisive role in resource allocation. Non-governmental organizations should play important roles in developing and protecting agrobiodiversity, coordinating relationships between farmers and ecological compensation providers, and increasing prices of products beneficial to agrobiodiversity conservation [34–35]. The role of social capital in ecological compensation is particularly important because social recognition can long-term motivate individuals to maintain public interests, thereby bringing greater economic and ecological benefits [36]. As shown in Figure 2, recognition and economic compensation from ecosystem service beneficiaries to providers can better motivate providers to continuously protect agrobiodiversity.

3.4. Establish Self-Maintaining and Sustainable Development Mechanisms in Agricultural Heritage Sites

Leveraging advantages such as good ecological environments, unique crop varieties, traditional farming methods, and profound ethnic cultures in agricultural heritage sites, develop ecological economies with regional characteristics, enhance the ecological and cultural connotations of agricultural products, and strengthen internal development vitality. Driven by the GIAHS project, the brand recognition of both Qingtian rice and field fish has greatly improved. Rice from the Qingtian Rice-Fish Culture System now commands a price (around 4 yuan per kilogram) significantly higher than ordinary rice (about 2.4 yuan per kilogram) with supply falling short of demand. Field fish prices have doubled from the project' s initial stage, increasing from 24 yuan to about 100 yuan per kilogram [37]. Other heritage sites such as Honghe Prefecture in Yunnan and Aohan Banner in Inner Mongolia have also achieved remarkable results in agricultural product development. Additionally, developing eco-tourism based on the agrobiodiversity and cultural diversity of agricultural heritage sites is an effective way to promote secondary and tertiary industries. It should be noted that whether developing organic agriculture or eco-tourism, attention must be paid to protecting traditional culture and ensuring fair distribution of benefits. Since farmers are direct participants in agrobiodiversity conservation, only by benefiting them can their enthusiasm for conservation be increased.

Conserving agrobiodiversity in agricultural heritage sites involves not only protecting agrobiodiversity itself but also protecting the concepts of rational utilization of agrobiodiversity in heritage sites, the relationship between agrobiodiversity and cultural diversity, as well as evaluating and monitoring agrobiodiversity and implementing adaptive management. Establishing self-maintaining and sustainable development mechanisms in agricultural heritage sites that adapt to socioeconomic and natural condition changes will create opportunities for future human survival and development [38].

At the management level, corresponding policies should be formulated, such as establishing incentive mechanisms for agrobiodiversity conservation, guiding agricultural heritage sites to carry out conservation from a policy perspective, and supervising the implementation of the "Management Measures for Important Agricultural Heritage" and conservation and development plans for agricultural heritage. At the community level, farmers are direct participants in agrobiodiversity conservation, and emphasis should be placed on their utilization of biodiversity resources. As urbanization changes livelihood patterns and lifestyles, which may impact agrobiodiversity, conservation should not only focus on agrobiodiversity itself but also strengthen research on influencing factors closely related to farmers' production, livelihood, knowledge, and living, and propose corresponding countermeasures.

In addressing the practical issue of agrobiodiversity conservation in agricultural heritage sites, specific analysis is required for specific problems. Given the com-

plexity of agricultural heritage types, practical effectiveness should serve as the measurement standard. Conservation methods can be flexible and diverse, with selective emphasis. In today' s challenging conservation environment, exploring and attempting multiple channels to protect agrobiodiversity should be beneficial and harmless. Agrobiodiversity conservation cannot be separated from the support of cultural diversity, and the composite characteristics of agricultural heritage mean that its conservation and utilization models integrate cultural diversity protection content, providing demonstration and reference value for agrobiodiversity conservation in traditional areas.

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Note: Figure translations are in progress. See original paper for figures.