A Review of Research on the Conservation of Rice Terrace Agricultural Heritage: Postprint

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Abstract

Terraces are mountain agricultural production systems excavated in accordance with mountain slopes and local conditions. Many terraces continue to serve productive functions today, demonstrating human wisdom in adapting to and utilizing nature. The production techniques, agricultural management experiences, and traditional agricultural knowledge they contain offer important insights and reference value for the sustainable development of agriculture. They represent both a typical mountain ecological agriculture model and an outstanding ecological and cultural landscape, as well as an extremely precious agricultural cultural heritage. Among them, rice terraces constitute an extremely representative and important type. Against the backdrop of rapid industrialization and urbanization, the disadvantages of rice terraces—such as high labor intensity and low production efficiency due to the inability to employ mechanized operations—have become increasingly prominent. In some places, the unreasonable development of tourism has also given rise to numerous problems in the ecological environment and socio-cultural aspects of terrace agricultural systems, and even led to the collapse of terraces due to conversion to dryland farming or abandonment. The issues of rice terrace conservation and sustainable development have attracted increasing attention from scholars across different disciplines. Based on a systematic collection of domestic and international research literature on rice terrace conservation, this paper analyzes from the perspectives of conservation objects, conservation measures, main problems, and their causes. The study shows that: 1) The conservation objects of rice terraces include three components: terrace landscape, terrace ecology, and terrace culture. Among them, terrace landscape includes terrace structure, water source conservation forests, farmland irrigation systems, and villages; terrace ecology includes traditional crop varieties, biodiversity, farmland environmental quality, and traditional smallholder integrated management models; terrace culture includes material culture such as residents' clothing and buildings, as well as intangible culture composed of spiritual culture like songs, dances, and festivals, and institutional

culture like water resource management and forest management. 2) The main causes of problems such as terrace landscape destruction, environmental pollution, biodiversity reduction, and traditional culture facing loss mainly lie in the impact of modern technology, market demand-driven forces, low comparative benefits of traditional agriculture, and unreasonable development of alternative industries. 3) The main conservation measures for rice terraces include: moderate industrial development, constructing and improving conservation management systems and mechanisms, and strengthening scientific research. Future research on rice terrace conservation should, while emphasizing multidisciplinary integrated research, focus on internal and external factors of terrace system degradation, long-term monitoring and dynamic assessment, suitable industrial development models and pathways, and tracking and evaluation of typical cases.

Full Text

A Review of Conservation of Rice Terraces as Agricultural Heritage Systems*

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Abstract

Terraces are ancient agricultural field systems created by ancestors according to local terrain that still perform production functions today. These land use systems clearly demonstrate human wisdom in adapting to and taking advantage of the natural environment. The cultivation and management experiences and traditional agricultural knowledge embedded in terrace systems can offer important insights and references for the sustainable development of modern agriculture. With industrialization and urbanization, however, the limitations of terrace agriculture in production efficiency have become increasingly obvious. The terrain constraints on using farm machinery, combined with overwhelming tourism development, have led to a series of natural and man-made environmental and societal problems. These negative effects have brought terrace agriculture to the brink of collapse. Consequently, numerous research projects on terrace agriculture protection have been conducted.

This paper reviews available literature on rice terrace protection across three aspects: protected objects, existing problems and causes, and protective measures. The protected objects primarily comprise landscapes, ecosystem services, and social cultures in rice terrace areas. Protected landscape elements include terrace structures, water conservation forests, farm irrigation systems, and villages. Key protected objects within ecosystems encompass traditional crop varieties,

biodiversity, environmental quality of terraces, and comprehensive agricultural patterns. Protected social culture mainly consists of material cultures (e.g., traditional costumes and old buildings), spiritual cultures (e.g., ethnic songs and dances and traditional festivals), and institutional cultures (e.g., management of water resources and forests). Challenges facing rice terrace systems include landscape destruction, environmental pollution, biodiversity loss, and disappearance of traditional cultures. These challenges are primarily caused by impacts of modern science and technology, market demands, low comparative advantages of traditional agriculture, and unscientific industrial development. In response to these challenges, protective measures need to be implemented across three categories: reasonable industrial development, building institutions and protective management mechanisms, and developing scientific research. Future studies on rice terrace conservation should focus on mechanisms of key terrace issues, case studies, comprehensive subject researches, long-term observation, and industrial development research.

Keywords: Rice terraces system; Globally Important Agricultural Heritage Systems (GIAHS); China Nationally Important Agricultural Heritage Systems (China-NIAHS); Eco-cultural landscape; Mountain eco-agriculture; Agro-biodiversity; Sustainable agricultural development

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Terraces are step-like farmlands created by mountain residents over generations to meet food needs, and can be divided into water terraces (rice terraces) and dry terraces. Built according to mountain topography, terraces continue to perform production functions today, embodying human wisdom in adapting to and utilizing nature. The production techniques, agricultural management experiences, and traditional agricultural knowledge they contain offer important insights and references for modern agricultural sustainable development [1–2]. The origin and development of terraces have undergone complex historical processes, reflecting changes in social productivity and relations [3–4]. Because terraces are mostly distributed in remote mountainous areas with poor transportation and information access, unique social and cultural characteristics have formed under closed environments [5–6], giving terrace agricultural systems multiple functions and values. Due to their long history, rich biodiversity, and embodiment of traditional knowledge and techniques, they are considered important agricultural heritage systems. By the end of 2015, seven rice terrace sites had been designated as China Nationally Important Agricultural Heritage Systems (China-NIAHS). Among them, the Hani terraces in Honghe Hani and Yi Autonomous Prefecture, Yunnan Province, were designated as a Globally Important Agricultural Heritage System (GIAHS) by the FAO in 2010 and inscribed on the UNESCO World Heritage List in 2013 due to their massive scale, beautiful landscape, and unique ethnic culture. The Ziquejie terraces in Xinhua County, Hunan Province, were recognized as one of the first World Heritage Irrigation Structures in 2013 for their ancient and ingenious irrigation system.

While rapid tourism development has brought economic benefits to local areas, it

has also triggered negative impacts such as dramatic social and cultural changes [8], economic conflicts among different stakeholder groups [9], and ecosystem destruction and environmental pollution [10]. Meanwhile, against the backdrop of rapid industrialization and urbanization, terrace agriculture has suffered major shocks due to low mechanization levels, high labor intensity, and low comparative benefits, with some areas even experiencing abandonment and terrace collapse [11–12]. These issues have attracted scholars'attention, especially since the FAO launched the GIAHS project in 2002, prompting researchers from different disciplines to explore terrace conservation from various perspectives [13–15]. Based on a comprehensive collection of domestic and international literature on rice terrace conservation, this paper reviews research progress across three aspects: conservation objects, problems and causes, and protection approaches. It also analyzes existing research gaps and future priorities to provide references for researchers and managers.

1. Conservation Objects of Rice Terraces

Rice terraces constitute a complex ecosystem encompassing social, economic, and natural factors; therefore, their conservation should be comprehensive and systematic. Current research primarily focuses on three aspects: terrace landscape, terrace ecology, and terrace culture.

1.1 Terrace Landscape

The rich, dynamic landscape characteristics of rice terraces and their associated socio-cultural systems have become valuable tourism resources [7], attracting increasing numbers of visitors. However, rapid tourism development has created challenges. Rice terraces are distributed in mountainous areas with variable climates and frequent geological disasters, making it difficult to maintain system stability. Constrained by natural conditions, water and nutrients required for production are more difficult to obtain than in plain areas. Nevertheless, rice terraces have not only maintained normal production for thousands of years but also demonstrated strong adaptability to extreme climate events [16], which is inevitably related to scientific terrace landscape structures [17–18]. The terrace landscape is a "materialized"composite system that includes not only the terraces themselves but also the forest ecosystem above them and the water system connecting forests, villages, and terraces [19–20]. Therefore, conserving the rice terrace landscape essentially means protecting farmland structure, water conservation forests, irrigation systems, and village systems (Table 1).

Regarding the terraces themselves, ridges are the most important factor for water, fertilizer, and soil conservation, maintaining both production functions and landscape stability [21], and constitute the core of rice terrace landscapes. Research shows that ridge stability is influenced by water depth, plow layer thickness, and vegetation coverage [22], and can be damaged by burrowing animals and sudden changes in soil moisture content [23].

Planting patterns are the determining factor for rice terrace landscapes. Converting paddy fields to dry land or abandoning them not only destroys aesthetic appeal but also affects terrace stability. Studies indicate that water terrace area and spacing are important elements forming visual aesthetics; converting paddy to dry land reduces terrace scale, disrupts distribution rhythm, and diminishes beauty [24]; abandonment increases the incidence of terrace collapse and landslides [25], thereby destroying terrace landscapes. Therefore, terrace ridges and planting patterns are important conservation targets.

Beyond farmland itself, villages and their upper water source forests and sacred forests, as well as irrigation systems, are integral components of terrace landscapes. The balanced structure of farmland and forest and the three-dimensional distribution pattern of forest-village-terrace represent important expressions of harmonious beauty [24]. Functionally, rational village layout ensures convenience for farmers' field work, while forest water conservation functions can effectively regulate uneven temporal distribution of precipitation. Irrigation canal networks channel water from forests to villages, then divert nutrient-rich water from villages to lower fields, ensuring year-round water and nutrient supply for terraces [26–27], overcoming the shortcomings of uneven spatiotemporal precipitation distribution and lack of reservoir storage in mountainous areas [28]. Therefore, villages, water conservation forests, and irrigation systems are also conservation objects.

Additionally, the large landscape of forest-village-terrace-water system and small landscapes of settlements, forests, and terraces have become important tourism resources due to their aesthetic value, playing a significant role in promoting the multifunctionality of terrace agriculture and local economic development.

1.2 Terrace Ecology

Constrained by topography, rice terraces have maintained traditional small-scale farming patterns, diversified crop varieties, and eco-agricultural models such as rice-fish and rice-duck systems. These practices preserve rich traditional rice variety resources, protect farmland biodiversity, ensure ecosystem stability, and guarantee safe agricultural production, maintenance of good farmland ecological environments, and supply of diverse foods [26,29–31]. Research shows that in the Honghe Hani terrace region alone, over 100 traditional rice varieties are preserved, with the genetic diversity index of red rice being three times that of modern improved varieties. These varieties are resistant to poor soil and diseases, giving them strong adaptability to plateau environments and more stable yields than introduced varieties [32], which is significant for new variety breeding.

Studies in Honghe Hani terraces, Yunnan and Congjiang, Guizhou show that food webs in rice-fish, rice-duck, and rice-fish-duck ecological agriculture models are more complex with more trophic levels than those in large-scale monoculture systems. The mutual constraints arising from these complex nutritional relation-

ships among organisms make agricultural ecosystem structures more stable [33-34]. Planting multiple different traditional rice varieties in adjacent small fields dilutes pathogenic genes due to large differences in crop genotypes, effectively reducing the probability of diseases and pests such as rice blast and planthoppers [35].

Due to transportation constraints, economic limitations, and the regulatory capacity of rice terrace composite farming systems, chemical inputs such as pesticides and fertilizers are rarely used, making farmland water and soil environments cleaner than in chemical agriculture [34]. Moreover, composite agricultural management models have higher solar energy conversion efficiency and more vibrant systems, reducing pressure on farmland environments [36] and maintaining good environmental quality in rice terraces.

The composite planting patterns, crop variety and related species diversity, and clean water and soil environmental quality provide special advantages for developing high-quality agriculture with distinctive, organic, and green characteristics.

1.3 Terrace Culture

Unique cultural characteristics constitute an internal force for rice terrace landscape and ecological conservation, forming an important foundation for their long-term stable development [37-38]. These intangible cultures, derived from terrace production activities and expressed through agricultural experience, traditional customs, festivals, beliefs, and worship, as well as cultures attached to physical objects like buildings and costumes, act as invisible forces maintaining terrace landscape and ecological stability [17]. These cultures can be summarized into three categories (Table 2): material culture, spiritual culture, and institutional culture [39].

In terms of material culture, traditional costumes and ornaments in many terrace areas feature exquisite craftsmanship, beautiful patterns, complex techniques, and rich cultural connotations [6,40]. Various traditional buildings are aesthetically pleasing, ingeniously designed, and practically constructed, harmoniously integrating with the natural environment [41-42]. Traditional village layouts demonstrate wisdom in utilizing topography, ecological environments, and land [43]. Terrace dietary culture embodies people' s adaptation to natural environments and wisdom in rational resource utilization [44]. Agricultural production experience guides people in timely farming practices [45], while agricultural tools in terrace areas demonstrate effectiveness for terrace production [46-47]. This unique material culture reflects adaptation to and stability of terrace production and life, meeting local needs for production, living, and social interaction.

Spiritual culture in rice terrace systems contributes significantly to terrace maintenance. Many festivals and customs are related to terrace production, such as eating new rice festivals during harvest [48-49]. Worship of forests, prohibitions

on cutting water source forests, and village deity worship protect normal terrace production [50]. Many songs and dances in terrace areas originate from agricultural labor behaviors [51], while myths, legends, and beliefs generally teach people how to protect terraces to obtain good results [52–53]. This spiritual culture either guides people to protect terraces, constrains destructive behaviors, or transmits labor knowledge, thereby maintaining long-term production functions.

Institutional culture ensures terrace system stability by mandatorily managing people' s behavior. Protection research mainly involves water resource management, forest management, village regulations, and traditional customs [54], which provide institutional guarantees for terrace production systems. Even today, with scientific thinking becoming increasingly popular, these remain the most effective forces for stabilizing terrace systems.

2. Problems and Causes in Rice Terrace Systems

2.1 Problems Facing Rice Terraces

Against the backdrop of rapid urbanization and industrialization, influenced by economic benefits and changes in production and lifestyle, the sustainability of both natural ecosystems and socio-cultural systems in rice terrace systems faces numerous challenges.

Regarding terrace landscapes, deforestation of water source forests has reduced water conservation capacity. Irrigation canal systems have been damaged by road construction, exacerbating soil erosion and landslides. Due to climate change and high water consumption, problems such as insufficient water supply and ridge collapse have become serious [54]. Village renovation and construction have replaced traditional dwellings with modern buildings that are sturdy, practical, and convenient to build [55]. The use of large excavators and tourism development have led to new residential construction along roads, which can no longer reflect the characteristics of adapting to mountain topography [56].

In terms of terrace ecology, introduction of high-yield crop varieties has replaced abundant local traditional varieties, reducing crop genetic and species diversity. Heavy use of pesticides and fertilizers has caused soil compaction, salinization, pesticide residue exceedance [54], and heavy metal pollution [57], leading to declining farmland environmental quality and increasing food safety risks. Due to water shortages and higher labor costs for rice cultivation compared to dryland farming, many farmers have converted rice cultivation to dryland crops, reducing terrace-related biodiversity [58].

Regarding terrace culture, transmission of intangible cultural heritage such as local dialects, traditional handicrafts, folk songs and dances, customs, and agricultural proverbs faces difficulties [18,54]. Ethnic costumes and ornaments are worn less frequently, and ethnic cultural characteristics are increasingly diluted [59]. Young people mostly work outside their hometowns, agricultural produc-

tion knowledge and experience face loss, and traditional cultural transmission mechanisms are gradually disappearing [60]. Overly commercialized tourism development models, catering solely to tourist needs, have caused distortion of traditional culture, while rising living costs or deteriorating living environments in traditional villages have prompted residents to relocate [60].

2.2 Analysis of Main Causes

The causes of these problems are multifaceted, involving both natural condition changes and, more significantly, human factors. First, improved transportation and increased scientific and cultural knowledge in terrace areas are dismantling traditional cultural systems that once sustained survival, weakening love, worship, and reverence for terrace systems and reducing the constraining power of traditional culture on behavior [61]. Second, under market-oriented conditions, increased employment opportunities combined with low comparative benefits of traditional agriculture in terrace areas have led many farmers to abandon traditional management practices or migrate for non-agricultural work [15,29]. Third, driven by market demand and economic development, water conservation forests have been cut down and replaced with economic forests, destroying the stability of the terrace natural environment [58,62]. Fourth, unscientific tourism development models have altered traditional landscape structures and impacted traditional culture [55].

3. Protection Approaches for Rice Terraces

3.1 Industrial Development Driving Terrace Conservation

The foundation for conserving terrace landscapes, ecology, and culture lies in terrace agricultural production and related industries based on terrace natural and human resources. Therefore, promoting terrace conservation through industrial development becomes the primary choice.

First is tourism development. Utilizing terrace natural resources and environmental advantages to develop ecotourism enables farmers to achieve self-development while achieving ecological and environmental protection [2]. Using folk culture and agricultural production processes in terrace areas to develop ethnic and leisure agriculture; using terrace scenery to develop sightseeing, photography, and sketching tourism; using traditional agricultural procedures to develop experiential tourism involving tea picking and processing, loach catching, fish catching, snail collecting, and rice wine brewing, as well as health tourism; using mountain environments to develop outdoor sports tourism; and using the historical, ecological, and agricultural advantages of terrace agricultural heritage to establish research, education, and publicity bases for thematic tourism. Through these diverse tourism forms, local farmers' cultural pride and consciousness can be effectively enhanced [29,63]. From a holistic conservation perspective, gradually integrating local ethnic culture as "living heritage" with terraces and villages to establish eco-museum tourism development models [64]

represents an effective industry-driven conservation approach.

Second is developing high-quality characteristic agriculture using distinctive biological resources and environmental advantages. This includes developing characteristic agricultural products such as terrace red rice, purple rice, glutinous rice, fish, ducks, and eggs; developing green or organic agricultural products using the good ecological environment of terraces; and using the traditional culture, farming methods, crop varieties, and ecological agriculture elements contained in World Heritage and agricultural heritage brands to increase product prices [2,29]. Developing compound eco-agricultural models such as rice-fish-duck, rice-snail, and rice-loach systems can improve farmland production efficiency and benefits [65].

3.2 Institutional Construction Promoting Terrace Conservation

First is improving the terrace system regulatory framework. Currently, typical rice terrace systems worldwide have been designated as GIAHS, NIAHS, or World Heritage sites, making terrace system conservation an important task for local governments. Institutionalizing and legalizing terrace heritage conservation management to prevent and constrain destructive behavior is one of the most effective approaches [66–67]. For example, local governments should promptly formulate and issue locally suitable and operable management regulations to legalize terrace heritage conservation [66–67]; develop systems limiting tourist numbers based on terrace landscape carrying capacity [62]; and protect primary forests in terrace areas and control economic tree planting ranges through local laws and regulations to ensure terrace system stability [58].

Second is establishing traditional culture inheritance mechanisms. Establishing folk organizations to supervise and guide tourism' s utilization and management of cultural resources in terrace areas can prevent cultural abuse [58]. Building a culture-industry-led inheritance model, such as government-led models through protection regulations, resource provision, and participation in folk cultural activities [68], and improving public cultural cognition through various traditional culture publicity and display activities can facilitate cultural transmission [69].

Third is establishing reasonable benefit distribution and compensation mechanisms. Terrace conservation requires multi-party participation, so compensation mechanisms for ecological and cultural protection must be established to enable community residents to share benefits from conservation and development, creating synergy among enterprises, residents, and government [2,60]. Benefit-sharing mechanisms can take various forms, such as developing ecological compensation standards for reduced pesticide and fertilizer use based on farmer willingness-to-accept surveys and government cost-benefit analysis, encouraging farmers to develop eco-agriculture and enjoy its benefits; or determining government price compensation for organic conversion period rice by comparing input-output differences between terrace and plain areas, reducing organic production risks through price compensation to encourage organic production

[15].

3.3 Scientific Support for Terrace Conservation

Rice terrace systems are sustainable agricultural production systems, and rigorous scientific research can help improve conservation and management levels. For example, Sharda et al. [70] found that maintaining a 1:4 ratio between level and sloping terraces in India' s sub-humid regions minimizes profit risks during rainy seasons. Researchers have proposed establishing multidisciplinary research teams for long-term study of rice terrace natural-social-economic systems to ensure scientific conservation and development measures. For instance, landscape ecology researchers could study forest-village-terrace structures and ratios to guide land use composition and ratio planning for terrace cultural landscapes; ethnology and anthropology researchers could deeply study Hani culture to promote fine traditions and abandon undesirable ones, enabling cultural inheritance and optimization [18].

4. Research Prospects

4.1 Problems in Existing Research

Through reviewing domestic and international research results, this paper summarizes rice terrace conservation research across three aspects: conservation objects, main problems and causes, and protection approaches (Figure 1 [Figure 1: see original paper]). Despite years of effort and significant progress providing strong support for conserving this important agricultural heritage, gaps remain compared to urgent conservation needs. Main problems include:

First, in terms of research scale, most existing studies are macro-level conservation concept discussions with few specific case studies. Although many researchers have proposed promoting conservation through tourism and high-quality characteristic agriculture, most remain at the macro conceptual level, lacking studies on implementation mechanisms and research on operable industry type selection, organizational forms, spatial layout, risks, and economic benefits.

Second, regarding research methods, there are many descriptive studies but few convincing quantitative analyses, and even fewer studies using longitudinal or horizontal comparative analysis across time and space, consequently affecting the scientific validity and operability of proposed conservation measures.

Third, from the perspective of protection mechanism construction, there is little research on multi-party participation and analysis of games and cooperation among stakeholders. Studies on how tourism income distribution mechanisms affect participants' conservation enthusiasm or on farmers' and enterprises' willingness regarding government-promoted characteristic agriculture are virtually nonexistent.

Fourth, regarding research content, studies on the mechanisms of terrace problem generation are insufficient. Most existing research provides general descriptions of terrace problems, while systematic research from social, economic, and natural perspectives remains inadequate.

4.2 Future Research Priorities

Based on conservation requirements for rice terrace agricultural heritage systems and sustainable agricultural and rural development needs, future rice terrace conservation research should focus on several aspects: First, conducting scientific research on problem diagnosis and generation mechanisms in specific regions to objectively reveal internal mechanisms; second, developing scenario simulation studies for specific problems to improve operability and effectiveness of conservation and management measures; third, advocating multidisciplinary comprehensive research to achieve holistic protection of ecological, economic, and socio-cultural systems; fourth, organizing long-term tracking studies to comprehensively understand terrace system changes and effectiveness of different conservation measures; and fifth, strengthening research on integration models and spatial layout of primary, secondary, and tertiary industries to construct new industrial systems for terrace agricultural systems.

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