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Study: Agrobiodiversity, Ecosystem Functioning and Adaptation to Climate Change

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Dr. Long Li, professor for Agroecology at China Agricultural University. His research interests have been focused on intercropping for about 30 years in terms of interspecific competition and facilitation between crop species, overyielding, root distributions, rhizosphere processes, phosphorus mobilization, biological N2 fixation and soil fertility etc. He published more than 50 peer-reviewed papers in international journals including PNAS, New Phytologist, Plant Soil, Field Crops Research etc. He also published more than 80 papers in Chinese journals. He endeavoures to combine the knowledge of agricultural intercropping into a more broaden context in ecology, which targeted a better understanding of intercropping systems and thus using them to develop intensively ecological agriculture.

Dr. Yunhui Liu, associated professor at China Agricultural University. Yunhui and her group study the patterns of insect and plant diversity in space and time within agricultural landscapes. Specifically, they focus on the impact of landscape structure, land use intensity and other environmental factors on these organisms and the associated ecological services like biological control and pollination. They also explore landscape approaches of management and restoration for biodiversity and ecological services for more sustainable development in agricultural landscapes.

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TABLE OF CONTENTS

List of Abbreviations

C	Carbon
CBD COP 5	Fifth Ordinary Meeting of the Conference of the Parties to the Convention on Biological Diversity, 15 - 26 May 2000 - Nairobi, Kenya
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross domestic product
GIAHS	Globally Important Ingenious Agricultural Heritage Systems
IRRI	International Rice Research Institute
Mg	Megagram
N	Nitrogen
Tg	Teragram
UNESCO	United Nations Educational, Scientific and Cultural Organization
YAU	Yunnan Agricultural University

1. Introduction

China is one of the most biologically diverse countries in the world. Looking back at a history of more than 7000 years of agricultural production, the traditional biodiversity-friendly land management contributed greatly to support China's ever-increasing human population without changing the stability of the agro-landscape. However, like in Western countries, China is now facing the problems caused by modern agriculture. Although high-yield varieties, irrigation and agrochemical inputs helped to improve agricultural productivity, intensification of agriculture is causing problems detrimental to human health, environmental quality and biodiversity. In face of population growth, limited arable land and climate change, new approaches for future agricultural development are needed. Agricultural diversity provides resources which are essential for human survival, and various ecosystem services associated with biological diversity are crucial to sustainable agriculture. A biodiversity-based paradigm for sustainable agriculture is a potential solution for improving productivity in an environmentally friendly way, and for greater resilience to uncertain environmental and socioeconomic risks in the future. In this paper, we review the status quo of agrobiodiversity utilisation in China and explore the potential to promote ecosystem restoration by conserving and utilising agrobiodiversity and its impact for adaption and resilience to climate change impacts.

2. Definition of Agrobiodiversity and its Importance

Agrobiodiversity refers to all components of biological diversity relevant to food and agriculture, and all components of biological diversity that constitute the agricultural landscape (CBD COP 5 Decision V/5). It includes biodiversity of crops and livestock chosen by the farmer, and the biota (e.g., soil microbes and fauna, weeds, herbivores, carnivores, etc.) colonizing and surviving in the agricultural landscape, croplands as well as non-crop habitats and species outside of farming systems. Along an ecological hierarchy, agrobiodiversity includes:

(1) *Genetic diversity*: is the total number of genetic characteristics in the genetic makeup of species, which serves as a way for populations to adapt to changing environments.

(2) *Species diversity*: refers to the number and abundance of species in the agricultural landscape.

(3) *Ecosystem diversity*: is the variation of ecosystems found in the agricultural landscape.

(4) *Landscape diversity*: refers to number and relative abundance of different patch or cover types in an agricultural landscape.

In agricultural landscapes, agricultural biodiversity contributes directly to production and productivity, ecosystem function and human well-being. It not only provides production of food, fibre, fuel, income, supports ecosystem services, like recycling of nutrients, control of local microclimate, regulation of local hydrological processes, regulation of the abundance of undesirable organisms, detoxification of noxious chemicals, but also supports agricultural lifestyle varieties, genetic material reservoirs, and pollinator sanctuaries. When these natural services are lost because of biodiversity loss, the economic and environmental costs can be quite significant, as expensive external inputs might be required to ensure crop supply. Therefore, agricultural biodiversity is extraordinarily important.

3. Legacy of Traditional Integrated and Diversified Farming Systems

With the philosophy of living in harmony with nature, traditional China had succeeded for thousands of years in supporting an ever-increasing human population without changing the stability of the agro-landscape. In the following chapter we introduce some examples for traditional integrated and diversified farming systems which are still functionable until present days.

3.1 Rice-Fish Co-Culture Systems

The Rice-fish co-culture system is a traditional integrated farming system model in China, which is listed as one of the Globally Important Ingenious Agricultural Heritage Systems (GIAHS) by FAO and UNESCO. In this cultivation system, rice fields with a suitable stable temperature, especially in the summer season, provide a habitat for fish. The decaying leaves of rice offer favourable conditions for the growth of microorganisms as food resources for fish. Simultaneously, fish loosen the surface soil in the paddy field, hence promoting permeability and oxygen availability in the soil, and further enhancing the vitality of microbes and accelerating the decomposition of nutrients in the soil which also facilitates the absorption of nutrients by the rice plants. Furthermore, fish also play a role as predator for controlling pests and weeds, while fish excrements act as a natural fertilizer for the rice. In this rice-fish system, specific rice varieties and fish species and varieties are required and therefore it contributes to the conservation of local rice species such as *Oryza sativa indica*, *O.s. japonica* and *O. s. javanica* (Wang and Wang, 1994; Ye *et al*., 2002), and fish species and varieties like *Ctenopharyngodon idellus*, *Cyprinus carpio* ("Feng carpio", "Heyuan carpio", "Oujiang red carpio"), *Carassius auratus* ("Silver Carasius auratus"), *Mylopharyngodon piceus*, *Hypophthalmichthys molitrix*, *Mysgurnus anguillicaudatus*, *Oreochromis niloticus* and *Barasilcorus asotus*. Meanwhile, in order to introduce fish into the rice fields, the traditional horizontal landscape structure of rice fields changed into a ridge–ditch pattern and led to a decrease in fertilizer applications, which enables the landscape to become more favourable to natural enemies such as spiders and parasitic wasps as well as other groups of organisms like higher plants, phyto- and zooplankton, cyanobacteria, soil and aquatic microorganisms, aquatic insects, water mice, water snakes and bird species (Li *et al*., 2001; Lu *et al*., 2001). With a healthy ecological environment greater yields can be achieved.

Figure 1: Picture of rice-fish system. (Picture source: MEE, 2019)

3.2 Mulberry-dyke & Fishpond System

This system can be traced back to 2500 years ago and therefore it includes tremendous traditional and agroecological knowledge. In the Mulberry-dyke & Fishpond system, mulberry trees are planted on dykes to provide leaves for silkworm rearing. Silkworm faeces provide food for the fish. Four different types of fish are raised in ponds located near the mulberry fields, each of them has different biological characteristics and respectively lives on different layers of the water body performing different “tasks” to reduce the threats of bio aggressors. Every winter, the rich mud at the bottom of the fishpond and the rivers is dug up to the dykes as mulberry fertilizer, while improving dyke soil and reducing chemical fertilizers. In addition, the existence of the ponds helps to minimize the impacts of flooding in rainy seasons and prevent the crops from drought-stress in dry seasons. The vast water surfaces also play an important role in regulating the regional microclimate. A typical model is the Mulberry Dyke & Fishpond System in Huzhou, Zhejiang province, which has been listed as one of the Globally Important Agricultural Heritage Systems.

Figure 2: Image (left figure) and photo (right figure) of an agro-ecological cycling model of a typical Huzhou Mulberry-dyke & Fish-pond System (Picture source: http://www.fao.org/giahs/giahsaroundtheworld/designated-sites/asia-and-the-pacific/huzhou-mulberry-dyke-fish-pond-system/detailed-information/en/,retrived on Dec 22, 2019)

3.3 Hani Terraced Paddy Fields

At the Honghe River, Yunnan province, China, this special landscape combines forest, village, rice terraces and a river. Villages are built on mountain sides, with natural forests and rice terraces located just above and below the villages, respectively, and the river flowing on the valley floor. The forest has played an important role in ensuring abundant water supplies and supporting diverse flora and fauna (figure 3). By taking advantage of the geographical position, a method of "fertilization of rice fields with hydropower" has been developed, with manure, cleaned dung and humus being washed into the terraced fields through irrigation ditches or natural precipitation. A complex series of rice-based agricultural systems has been developed, including combinations of rice–duckweed, rice–lotus, rice–fish and rice–duck with 195 varieties of local rice historically used, of which 48 varieties are currently still planted. The spatial structure of the Hani terrace performs various ecological functions, including soil and water conservation, control of soil erosion, village safety, maintenance of system stability and self-purification capacity, while the diverse planting and rice species ensures sustainable production for hundreds of years with little occurrence of pests and diseases.

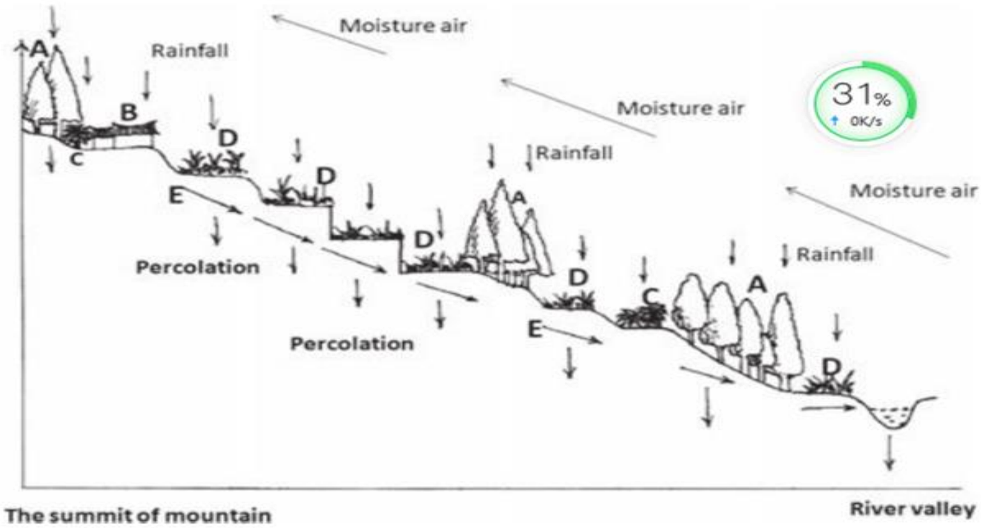

Figure 3: The vertical distribution of the forest-village-terrace-river ecological landscape in Hani, Yunnan province, China. (a) Forest; (b) village; (c) dry land; (d) water terrace; (e) surface runoff and spring flow carrying nutrients. Picture sources： Liu et al.,2014

3.4 Agroforestry

In China, both agriculture and agroforestry originated from forests and developed side by side from their very beginnings. As revealed by archaeological evidence from ancient times, ancestral Chinese inhabited forests which provided shelter from external hazards and food, such as the edible parts of plants and animals through hunting and gathering activities.

As early as the New Stone Age (7000 -8000 years B.C.) fire was commonly used to burn the forests for slash-and-burn cultivation which is a primitive form of agroforestry. Along with the rapid growth of population, the annexation of tribes, the collapse of clan society and the development of a slavery system, the nomadic mode of slash-and-burn farming evolved into settlement farming in the Xia Dynasty (2000-1600 B.C.) (Hsiung (Xiong) *et al*., 1995).

During the Shang and West Zhou Dynasty (1600-800 B.C.) perpetual settlement farming led to the development of private landownership. Peasants planted trees in or around the crop fields, grew fruit plants and vegetables and kept domestic animals in their home yards for self-sufficiency. Since then various forms of agroforestry have gradually developed and laid the fundamental framework of the Chinese small-farming economy for more than 3000 years.

Since the 1950s, there has been a rapid growth of population in China. At the same time along with industrialisation and urbanisation a dramatic decrease of arable land and degradation of the natural environment has been observed.

There are more than 50 types of traditional agroforestry, which may be grouped into five categories: 1) agroforestry with crop as main part, where trees are planted as individuals, or in clusters, patches, strips and belts in crop fields. Such as wheat/*paulownia fortune*, wheat/date (*Ziziphus jujube*) and crop/persimmon (*Diospyros kaki*) as intercropping in Shangdong, Anhui and Henan provinces. 2) agroforestry with forest as main part, where timber grows in orchards, special tree plantations, watershed forests, scenic forests (such as forest parks, historical relics, temples) and conservation forests and various crops (cereals, vegetables, cash crops, medicinal plants and forages) act as intercrops which enables multiple use of the fields without disturbance of their initial condition. 3) Agroforestry with pasture-husbandry as main part. Trees and shrubs are planted in clusters or belts on grazing land to provide protection for herds and to ensure herbage production as commonly seen in Inner Mongolia and the sparse forest areas in the south. 4) Agroforestry with fisheries as main part. Trees are planted along rivers, Iakes, reservoirs and fishponds not only for protecting dams against waves and preventing soil erosion but also for helping the fisheries business. 5) Homestead and four-side's management. Timber trees, fruit trees, vegetables and sometimes aquatic crops are grown and poultry animals and fish are raised on a small scale around farm houses near villages as well as on road and stream sides in order to make the best use of land and water resources (Hsiung (Xiong) *et al*., 1995).

Figure 4: Jujube/wheat agroforestry in Gansu province, Northwest China. Photo: Long Li

3.5 Intercropping

Intercropping means growing two or more crops simultaneously on the same field. According to row arrangement and co-growth time, intercropping can be divided into three types: mixed, relay or strip intercropping (Li *et al*., 2013). Mixed intercropping refers to growing two or more crops simultaneously with no distinct row arrangement. Relay intercropping means growing two or more crops simultaneously during part of the life cycle of each. A second crop is planted after the first crop has reached its reproductive stage of growth, but before it is ready for harvest. Strip intercropping means growing two or more crops simultaneously in different strips that are wide enough to permit independent cultivation but narrow enough for the crops to interact agronomically (Li *et al*., 2013).

Intercropping in China can be dated back to 100 years BC, Western Han Dynasty, as it was recorded in the *Fan Sheng-chih Shu,* which is the earliest agriculture book in China written in 100 years BC. There are also descriptions of mulberry intercropped with legumes (i.e. *Vigna radiate* or *Vigna angularis*) or cereals (*Setaria italic*) in the ancient agricultural handbook *Qimin Yaoshu* ('Techniques by which common people make their livelihood') published in 6th century AD.

Nowadays, intercropping in China is still important as an ecological and sustainable alternative to monocultures. In the last decade, there have been extensive studies on intercropping in China, leading to a better understanding. In rural areas, Chinese farmers are finding it hard to increase the size of their farm because of paucity of arable land; hence, the only way to maximize yields is to optimize crop management strategies such as using intercropping and rotation, which lead to high utilization of natural resources over space and time.

Strip and relay intercropping are the main intercropping systems in China. Strip intercropping means that species in intercropping are cultivated simultaneously in different strips that permit crop independent growth, and at the same time, species interact with each other (Li *et al*., 2013). In the relay intercropping system, which could increase total plant density, the preceding crop is planted at the same time as in monoculture, and the follow-up crop is cultivated between the preceding crop plants when they are maturing (Li *et al*., 2013). Strip and relay intercropping are practiced mainly in the north, such as Hetao in Inner Mongolia and the North China Plain, in the northwest such as Xinjiang and the Hexi Corridor in the Gansu, and along the Yangtze and Yellow rivers.

Figure 5: Faba bean/maize intercropping in the Hexi Corridor of Gansu Province, China. Photo: Long Li

3.6 Crop Rotation

Traditionally, crop rotation systems have been implemented for millennia in China and can be used to mitigate many ecological and environmental problems. Reasonable crop rotation can reduce weed, insect and pathogen pressures, as well as increase plant diversity and improve soil fertility. Crop rotation in China can be traced to the Western Han Dynasty (206 BC - 24 AD).

A meta-analysis on 45 studies with 214 comparisons examined the effects of crop rotation on yield and explored the importance of environmental factors and field management for yield variability (Zhao *et al*., 2020). Rotation increased crop yields by 20% on average when compared with continuous monoculture practices. Effects of rotation on crop yield were more pronounced in Southwestern China (+38%) than in Eastern China (+10%) and were notably less reliable and generally smaller in regions with moderate annual rainfall (400–550 mm). Rotation had greater yield benefits in soils with coarse or medium soil textures, intermediate levels of initial soil organic carbon (7–10 g kg^{-1}), and lower total nitrogen ($\leqslant$ 1.2 g kg^{-1}). Crop rotation largely increases agricultural production without extra inputs, although its design may need to consider diverse climates, soils, crops, and management practices to maximize its agronomic and environmental benefits (Zhao *et al.* 2020).

4. Challenges for Agrobiodiversity in China

In modern Chinese society agrobiodiversity is facing a whole range of challenges, as there are:

- **Loss of high-quality habitats.** Natural and semi-natural land, like wetland and grassland, are important habitats for biodiversity. Reclamation of wetlands and grasslands, as well as the loss of important habitats such as spawning grounds, feeding sites, wintering sites and returning channels are the main causes for a declining biodiversity. Despite reforestation efforts in many regions, the habitat quality of these artificial plantations is in most cases not good enough to maintain biodiversity.
- **Agricultural intensification.** To feed the increasing population, agricultural production has become more and more intensified in the last decades. Food supply relies on a few high-yield genotypes, requiring intensive input of fertilizers, agrochemicals, and irrigation. Along with a shrinking rural population, agriculture fields are enlarged to facilitate mechanized operations. The intensification is coming at serious environmental costs in terms of pollution of soil, ground and underground water, depletion of water resources, landscape simplification and finally, a loss of biodiversity in both agroecosystem and in natural landscape.
- **Invasion of alien species.** Invasive species are another threat to agricultural diversity. It was reported that the number of invasive alien species in China has exceeded 560 leading to increasing damages.
- **Overexploitation**. Overfishing leads to drastic reductions in the number of aquatic species and populations. Most economical fishes tend to be young and small-sized. Common or dominant fishes of over 100 species in the Pearl River have been gradually reduced to rare or endangered species (MEE at al., 2018). Land degradation resulted from overgrazing and reclamation pose a great threat to agricultural biodiversity as well.
- **Climate change**. Climate change is another factor threatening agricultural diversity. The changing climate resulted in loss and degradation of habitat, increasing rates of species extinction, shifting in species distribution, changes of biological phenology, reproduction time as well as inter-species relationships. All these bring a new challenge for agriculture biodiversity conservation.

5. Adapting Traditional Diversified Farming Systems to Requirements of Modern Society

5.1 Rice/rice Intercropping Controls Rice Blast

The experience on rice blast in Yunnan Province, China, is one of the most successful and widely publicized examples of genetic diversification for disease suppression in practice. The wet, cool climate of the province is susceptible to the development of rice blast epidemics. Before 1998, farmers had to spray fungicides three to eight times per cropping season to successfully grow a crop of glutinous or sticky rice. To reduce farmers' dependence on these harmful agrochemicals, a team of scientists from the International Rice Research Institute (IRRI) and Yunnan Agricultural University (YAU) initiated a project in Yunnan Province with the objective to explore the possibilities of using biodiversity as a means of control of blast outbreaks, and through the corresponding increase in productivity and income, to contribute to poverty alleviation. Field observation showed that the occurrence of rice blast of the susceptible variety of rice was reduced by 94% and grain yield was increased by 84%, compared with pure stand of susceptible rice variety (Zhu *et al*., 2000).

5.2 Agroforestry

The traditional labour-consuming and ineffective agroforestry management practice needs to be adapted. In view of economic, ecological and social benefits, conversion of relatively simple agroforestry production into a trinity system of agriculture, processing and marketing is suggested. Such a management system, known as modern agroforestry, could be very beneficial to the development of a modern rural economy and environmental conservation.

The main positive effects on the ecosystem service:

- intercropping vegetation can decrease splash erosion through low canopy height with a high sub-canopy coverage. For instance: intercropping tea (*Camellia sinensis*), cacao (*Theobroma cacao*), coffee (*Coffea arabica*) and shrubs (e.g., *Ficus macrophylla*) with rubber plantations.
- intercropping rubber plantations can improve water, soil and nutrient retention mainly through increasing fine root biomass and litter quantity. Intercropping rubber plantations have significantly higher fine root biomass and litter quantity, which contribute to increased soil and water conservation compared with monoculture rubber plantations. Furthermore, the economic income of rubber plantations can be increased by intercropping high-return crops. For example, intercropped rubber plantations may not only reduce the negative externalities but also increase other provisioning services from additional crop production beyond rubber (e.g., tea, coffee, cacao). In addition, by reducing reliance on a

single crop that is subject to crop failure or falling market prices crop diversification reduces risks to farm income (Zheng *et al*., 2019).


Figure 6: Monoculture rubber plantation (left) and intercropping rubber plantation (complex ecosystem management) (right) in the central mountainous EFCA of Hainan Island. Photo: Zheng et al. (2019). Source: https://www.pnas.org/content/pnas/suppl/2019/04/05/1819501116.DCSupplemental/pnas.1819501116.sapp.pdf

5.3 Intercropping

In the early years of the 1980's, wheat used to be the dominating crop in the irrigated area of Hexi Corridor in Gansu Province. In order to enhance crop yields per unit of arable land, agronomists studied and extended wheat/maize intercropping (figure 5) in the late 1980's. At the beginning farmers had difficulties to accept intercropping because of the high labour intensity and complexity in operation. Local agronomists and agricultural technicians demonstrated the practices in the field, showed them to farmers step by step and provided some chemical fertilizers and crop seeds with governmental subsidies.

Two and three years later, more than 50% of local farmers were willing to grow wheat/maize intercropping without subsidies, because it not only met their food demands (as wheat is staple food for local people), but also enabled farmers to earn money with the maize harvest by selling it in the markets or by using it in animal husbandry. Furthermore, the development of animal husbandry greatly enhanced farmers' income. Since the 1980's to early years of the 1990's, wheat/maize intercropping was well accepted by small farmers and became the dominating cultivation system in the Hexi Corridor for almost two decades. Using this intercropping system Linze County in Hexi Corridor, a region that only has one crop season per year, took the first place in 1988 in the Ministry of Agriculture's National Competition for the highest yield per land unit per cropping season.

As water shortage became more and more serious in the area, wheat/maize intercropping was increasingly limited by the water shortage as it required irrigation at least six or seven

times during the cultivation period. Consequently, the government requested farmers to reduce the growing area for wheat/maize intercropping.
As a result, agronomists started to seek for new water-saving cropping systems. Agronomists from local extension stations of agricultural technology together with scientists from research institutions and universities studied and extended pea/maize intercropping (figure 7, right) in the area, which requires irrigation only four times during the cultivation period. Although this adaptation resulted in lower grain yields compared to wheat/maize intercropping, it can reduce water requirement and save N fertilizer input.
Nowadays, pea/maize intercropping has replaced wheat/maize intercropping and became the dominant cultivation system, especially in the eastern part of the Hexi Corridor in Gansu Province.

Figure 7: Wheat/maize/soybean intercropping (left) and pea/maize intercropping in the Hexi Corridor of Gansu Province. Photo: Long Li

5.4 Landscape Diversity

In the past decades agriculture has become more and more intensified and cropping systems in the main agricultural region became very homogenous. To enlarge arable land for crop production, the landscape was highly simplified with little natural or semi-natural areas remaining. In some regions, the landscape is even seriously degraded due to the over reclamation or agricultural intensification. The issues mentioned above have led to problems such as a loss of diversity and a decline of ecosystem services, which is also to the detriment of human welfare. Only in recent years, in course with the government's call for ecological civilization and green development, landscape management for sustainable agricultural production received more attention. Landscape diversity is considered important to regulate biodiversity and ecosystem services essential to sustainable agriculture. Meanwhile, an increasing public demand for a good ecological environment and living conditions also calls for more diverse and multifunctional agricultural landscapes. In this context, scientists are seeking a better understanding of the relationship between landscape patterns, biodiversity and ecosystem services, and aim to develop approaches for landscape management to foster biodiversity and associated ecosystem services.

6. Case Studies

In the following chapter we introduce case studies of exemplary projects illustrating the benefits and challenges of agrobiodiversity in practice.

6.1 Case Study 1: Agroforestry Makes Rubber Plantation More Environmentally Friendly

In the past two decades, expanding rubber plantations in Hainan caused the loss of natural forests and their vital benefits like soil retention and flood mitigation. The intensive monocropping practices increased sediment runoff.

Researchers from Stanford University, McGill University and the Chinese Academy of Sciences (Shi *et al*., 2019) found out that rubber farmers who applied intercropping or cultivated other valuable plants in the understory of a main crop, maintained the same production levels as monoculture plantations while significantly increasing soil retention, flood mitigation and nutrient retention.

The Zheng *et al*. (2019) study showed that over the past 20 years (1998–2017), there was a 72.2% increase in rubber plantation area on Hainan Island, leading to decreases in soil retention (17.8%), water purification (reduced retention of nitrogen (56.3%) and phosphorus (27.4%)), flood mitigation (21.9%), carbon sequestration (1.7%), and habitat for biodiversity (6.9%). However, it was found out that intercropping rubber trees with other economic plant species can improve ecosystem functioning compared with monoculture of rubber plantation. This keeps carbon sequestration unchanged, and not only increases provisioning services (102%) but also significantly contributes to increased soil retention (37.4%), flood mitigation (20.6%), nitrogen retention (54.3%), and phosphorus retention (41.3%).

The study shows how regions can use natural resources to support economic growth without sacrificing ecosystem health or human well-being. According to the researchers, farmers who took environmental concerns into account doubled their incomes and reduced reliance on a single harvest while also gaining environmental benefits from the land.

This win−win approach has broad applicability in the plantation regions in China, across South and Southeast Asia, and beyond.

6.2 Case Study: Crop Diversity (Intercropping) Improves Agro-Ecosystem Functioning

Land equivalent ratios (LERs), an indicator of yield advantage of intercropping over monocultures are 1.13-1.43 for faba bean/maize intercropping (Li *et al*., 1999) and more than

1.0 for chickpea/maize intercropping systems. These intercropping systems have significant land use advantages such as:

- *Enhanced grain yields*. Grain yields of the intercropped maize and the faba bean on the equivalent area were 7.8% - 32.9% higher than those of sole maize and 23.7% - 63.8% higher than those of sole faba bean (Li *et al*., 1999).
- *Reduced rate of N fertilizer application*. Under field conditions, faba bean/maize intercropping can reduce N fertilizer application to 186 kg N /ha (about 38% reduction) from conventional 225 kg N /ha (Li *et al*., 2008).
- *Enhanced recovery of P fertilizer*. The apparent recovery of P fertilizer was examined in different soils under field conditions. Intercropping led to an average recovery of P fertilizer by at least 10 percentage points higher than sole cropping does in Sierozems soil at Jingyuan County, Gansu Province (Mei *et al*., 2012).
- *Cost saving and increased benefits for farmers*. Faba bean/maize intercropping can save N fertilizer costs from 140 to 900 Yuan (RMB)/ha, compared with maize grown in monoculture. Together with additional income from faba bean (around average 6000 Yuan (RMB)/ha), this intercropping system can increase total income by about 6,750 Yuan (RMB)/ha.
- *Improved ecosystem service functioning*. (1) Reduced mineral N residual in soils. For instance, faba bean/maize intercropping reduced soil mineral N concentrations by 75%, compared to crops in monoculture. These benefits reduce the risk of environmental N pollution (Li *et al*., 2008). (2) legumes/cereals intercropping maintained or improved soil fertility and resistance against soil degradation (Wang *et al*., 2015a; 2015b).

Figure 8: Wheat/soybean intercropping (left) and faba bean/maize intercropping (right) in the Hexi Corridor of Gansu Province. Photo: Long Li

6.3 Case Study: Diversification of Agricultural Landscape in Suburban Beijing

In some of China's most developed areas, such as Beijing, agriculture has become less important for local GDP. Instead, ecological services provided by agriculture, like erosion control, climate regulation, water retention as well as educational and recreational services became more important in recent years. Therefore, in the past decades a series of measures have been applied to develop diversified and multifunctional agriculture landscape. There are two examples from Beijing that show how agricultural landscapes have been diversified to satisfy the changing demands on agriculture in the developed suburban areas.

The first example is Beixiaoying. Rice planting in Beixiaoying can be traced back to Han Dynasity, about 2000 years ago. Until the 1980's, rice cultivation was still common in the Beijing area but was later gradually given up due to limited water resources. In 2016 the Beixiaoying village replanted rice in order to continue this tradition. Rice-fish and rice-duck cultivation systems were established. At the rice field margin, flowering strips were planted to promote the natural predator diversity, and soybean was planted as buffer zone to absorb the surplus nitrogen from rice production and also increase crop yields. In spring, before rice planting, oilseed rape is planted for aesthetic purpose and then returned to the fields as green manure. The diversified plantation over three seasons with oilseed rape flower in spring, colorful flowering strip-paddy field mixed landscape in summer and golden paddy field in autumn has created an attractive agriculture sight-seeing site. In addition, a museum was built to introduce the local rice plantation history and some farm leisure activities for visitors, such as participation in rice harvesting, are organized and contribute to farmers' income.

Figure 9: Oilseeds rape field(a) in spring and the flowering field margin and rice field (b) , and harvest experiencing activity in autumn (c) at Beixiaoying, Shunyi Distict, Beijing (Photos: Liu Keman, Farmer Daily)

Another example of adapting agricultural landscapes to modern agriculture is the Ecological Farming Park in Louzishui, Fangshan District, Beijing. In the mountain areas of Fangshan district there is the need to find new resources to raise local farmers' income and to implement environmental conservation. Developing ecological farming is seen as an efficient approach. In the ecological farming park, different functional zones have been classified, including a crop production zone, a sightseeing and leisure zone, an agricultural experiencing zone and a catering zone. In the crop production zone, traditional crops such as millet and buckwheat have been planted. In the sightseeing and leisure zone, oilseeds rape and other early spring flowering plants are planted in spring and sunflowers blossom in summer to create a colourful terraced landscape. In the flat area of the sightseeing and leisure zone, two different coloured chrysanthemums have been intercropped to form an orange and green striped landscape with other flowering strips planted on both sides of the farmland roads. In the agricultural experiencing zone, about four varieties of sorghum, two varieties of melons, four varieties of sesame, ten varieties of beans, five varieties of peanuts and seven varieties of sweet potatoes have been planted and can be picked by visitors in autumn. In the catering zone, vegetables and sunflowers were planted for ornamental purposes. By this, the traditional cereal plantation has been transformed into a multifunctional agricultural production, which greatly improved the landscape diversity and farmers' income.

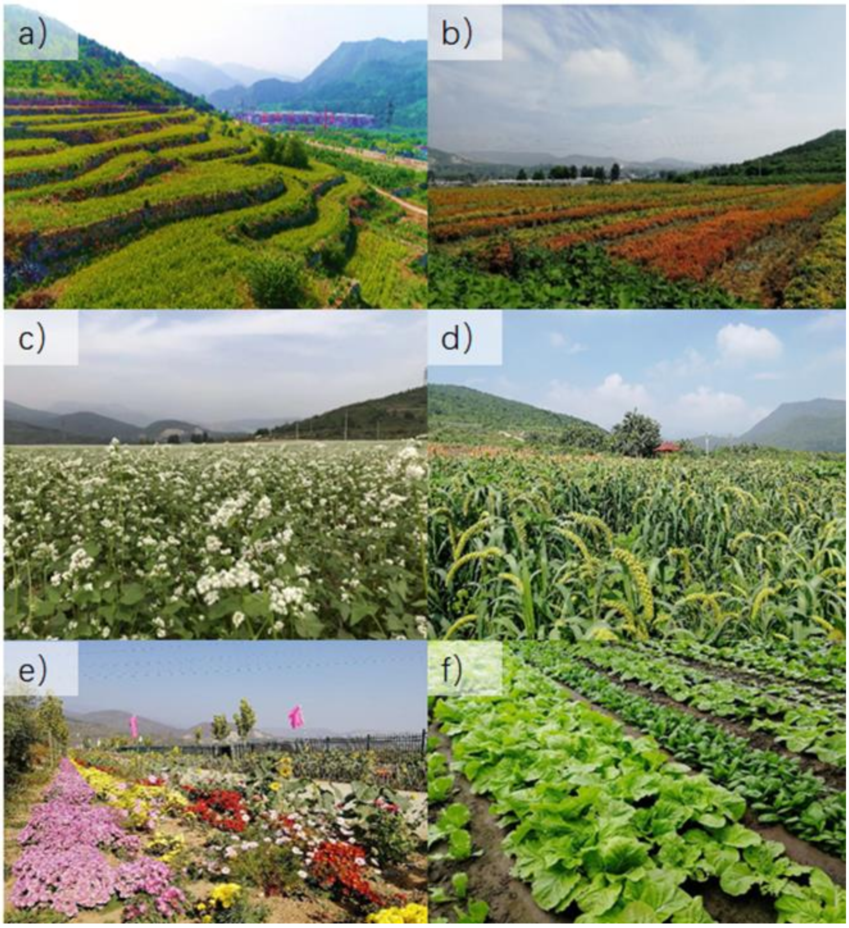

Figure 10: Adapting traditional mountain agriculture to ecological farming at Louzishui, Fangshan District. a) The oilseeds rape terrace; b) chrysanthemum strip landscape; b) the buckwheat flowering landscape in spring; d) the millet landscape in summer; e) the ornamental flowering strip along roadside; f) the vegetable strip. Photo: Li Ning and Nie Zijin.

6.4 Case study: Ecological Land Remediation Promoting Biodiversity Conservation

The overemphasis on the expansion of arable land and land consolidation in China until the early 2000's resulted in a loss of wildlife habitats and biodiversity. In line with the recent national call for ecological civilization, quality and quantity of farmland shall be improved by land remediation project. As an important indicator for ecological quality, biodiversity conservation is integrated in land remediation projects. A good example is the land remediation project of Changsha County, Hunan Province. A series of ecological conservation measures such as the construction of ecological ditches, ecological field roads, farmland waterlogging purification systems, ecological berms and corridors and ecological pools and habitats were established to foster local wildlife.

(1) Construction of a rhomboid buckle ecological ditch, which is beneficial to the growth of various aquatic animals and plants and provides a habitat for aquatic animals and helps to purify water by absorbing the excess nitrogen and phosphorus from the fields.

(2) Construction of ecological roads. The field roads are made of mudstone pavement which are permeable and serve as corridors or even habitats for animals and plants.

(3) Ecological ponds are built as a waterlogging purification system. Water in the farmland area can be collected and discharged to the pond and then purified by the plants in the pond. Later the water can be discharged into the river.

(4) Ecological slopes and biological corridors were built to provide a living space for aquatic animals and plants, allowing animals falling into the water to escape and migrate.

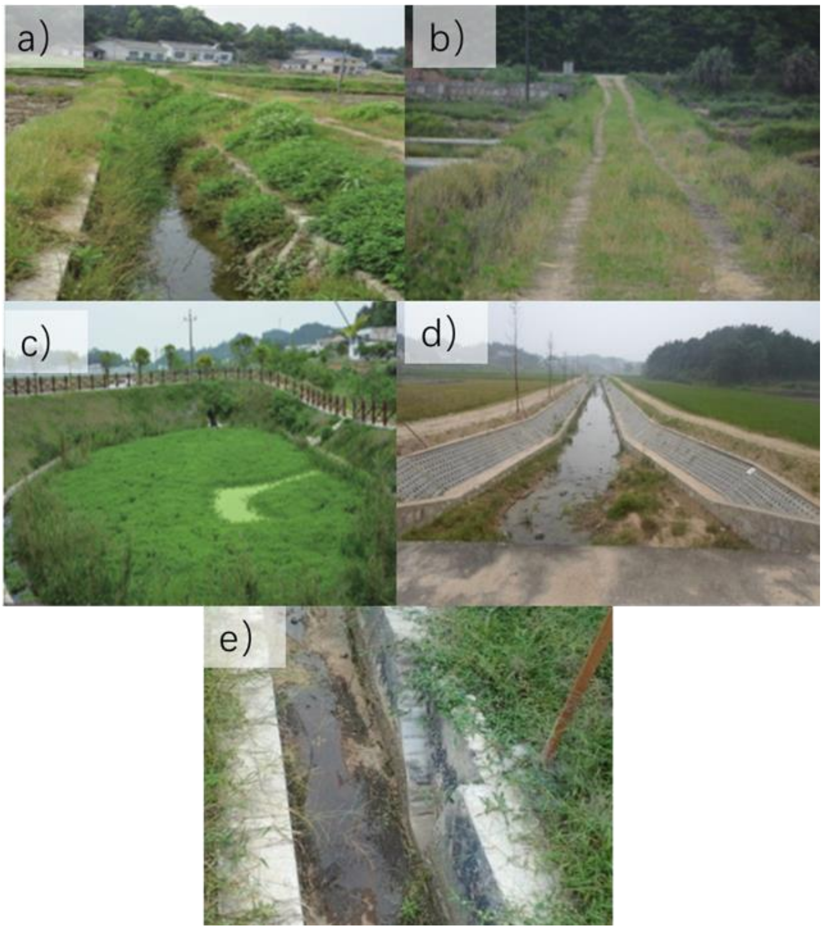

Figure 11: Ecological land remediation promoting biodiversity conservation. a) ecological ditch; b) ecological road; c) ecological pond; d) ecological slope; e) biological corridor (Photos: a,b,c: Jia Wentao and Yu Zhenrong, 2019; d,e: China's Sixth National Report on the Implementation of the Convention on Biological Diversity)

6.5 Case Study: Loess Plateau Rehabilitation in Northwest of China

The Loess Plateau, also known as the Huangtu Plateau, covers a 640,000 km^2 area in Northwest China. It almost completely covers the provinces of Shaanxi and Shanxi and extends into parts of Gansu, Ningxia and Inner Mongolia. The region was enormously important in Chinese history, as it is one of the early cradles of Chinese civilization. However, because of its highly erodible soil and centuries of overgrazing, subsistence farming, deforestation for fuel wood gathering and cultivation of crops on slopes and due to a high population pressure the region was characterized by highly degenerated ecosystems and poor local economies. To change this situation, since the 1950's the Chinese government launched a series of projects to rehabilitate the land and improve agricultural production. Several practices were proven to be efficient for eco-restoration in the region, including fixing and protecting the tableland by constructing ditches, replanting trees and shrubs and regenerating grass land at slop land, restoring the shallow slop area by terracing and replanting and reducing sediment runoff from slope lands and gullies through the construction of sediment retention dams. These efforts allowed a significant increase of the perennial vegetation cover by 59% in 2013 compared to 32% in 1999. Sediment loads of the Yellow River declined significantly from 1.6 billion tons/year in the late 1970s to 100 million tons in 2015. Finally, millions of people in this region were lifted out of poverty.

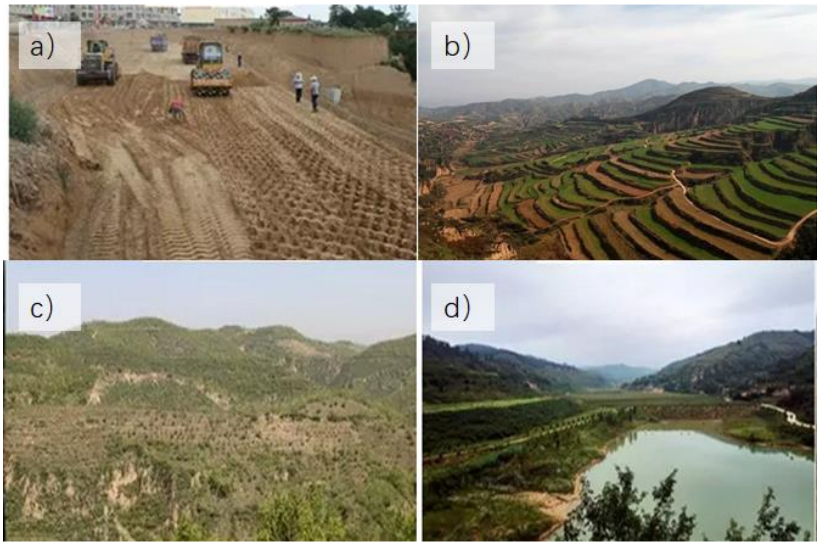

Figure 12: Loess Plateau Rehabilitation in Northwest of China: a) fixing and protecting the tableland by constructing ditches; b) restoring the shallow slop area by terracing and replanting； c) reforesting the slop land; d) reduction of sediment runoff from slope lands and gullies through the construction of sediment retention dams. (Picture source: http://www.ieexa.cas.cn/kxcb/kpdt/201901/t20190104_5225087.html, retrieved on Dec 29, 2019)

7. Outlook

7.1 Importance for Climate Mitigation

Major agroforestry systems are estimated to cover 45 million hectares in China. Agrosilviculture is a dominant practice. Aquasilvicultures, e.g. tree-fish-arable crop and tree-fish-livestock systems are alternatives for land use in the wetlands. Silvopastoral systems are popular in the northern and western regions. Compared to a monoculture, well-managed systems have many benefits. The recycling of residues is expected to increase the efficient use of natural resources. The carbon sink in the vegetation of major agroforestry systems in China is 179 Tg yr^{-1}, and agroforestry is reported to have a positive effect on soil conservation and biodiversity.

Shi *et al*. (2018) used a meta-analysis of 427 soil C stock data pairs divided into four main agroforestry systems – alley cropping, windbreaks, silvopastures, and home gardens – and evaluated changes in agroforestry and adjacent control cropland or pasture. Mean soil C stocks in agroforestry (1-m depth) were 126 Mg C ha^{-1}, which is 19% more than that in cropland or pasture. The highest C stocks in soil were in subtropical home gardens, agroforestry with younger trees, and topsoil (0-20 cm). Increased soil C stocks in agroforestry were lower than aboveground C stocks in most agroforestry systems, except for alley cropping systems. Home gardens stored the highest amount of C in both aboveground and belowground, especially in the subsoil (20-100 cm). Agroforestry could store 5.3 x 10^9 Mg additional C in soil on 944 Mha globally, with most in the tropics and subtropics. Agroforestry systems could greatly contribute to global soil C sequestration if established at a larger scale.

Suitable agroforestry can adapt to climate change

Agroforestry of coffee and *macauba* can represent a climate change mitigation strategy. *Macaubas* trees modify the microclimate of the coffee crop in the agroforestry system, leading to a reduction of maximum air temperatures, intensity and availability of photosynthetically active radiation. The agroforestry system of coffee intercropped with *macauba* trees provides advantages in coffee productivity and production efficiency when compared to unshaded crops and may be a mitigation strategy against future climatic variability and changes related to high temperatures and low rainfall (Sandro *et al*., 2018).

Using intercropping to reduce greenhouse gas emission

In the irrigated area of Hexi corridor of Gansu province, Northwest China, a study showed that the carbon emissions of wheat/maize intercropping were 18.9% lower than in maize monoculture (Yin *et al*., 2017). In North China Plain, a study found that the cumulative N_2O emission from the monocultured maize treatment over the entire growing season (three and a half months) was 16.9 kg ha^{-1}, which was significantly ($P < 0.05$) higher than in a maize/soybean intercropping system (Huang *et al*., 2019), indicating intercropping reduced N_2O emission in agroecosystems. In the Sichuan Basin, a study showed that the greenhouse warming potential and gas intensity of N_2O were significantly lower in the maize/soybean intercropping than in the respective monocultures. Furthermore, the transformation abilities of soil N denoted that intercropping strengthens ammonifying and nitrifying capacities to increase soil N residual while decreasing ammonia volatilization and N_2O emission. Therefore, the maize/soybean intercropping systems provides an environmentally friendly approach to increasing farmland productivity (Chen *et al*., 2019).

7.2 Importance of Agrobiodiversity for Ecosystem Conservation and Restoration

To ensure food security for an increasing population, agriculture faces great pressures to further intensify crop production while minimising negative environmental side effects. The integration of agrobiodiversity and associated regulating and supporting ecosystem services into agricultural management practices have been proposed as means to achieve the goal of balancing sustainable agricultural production and environment conservation (MEA, 2005; Bommarco *et al*.,2013). Measures of agrobiodiversity conservation include application of wildlife friendly practices, like less input of agricultural chemicals, application of organic manure and conservation tillage, as well as measures of habitat reestablishment and restoration. It further includes utilization of different varieties. Therefore, conservation of agricultural diversity is also a process to minimize pollution related to agriculture, which is one of the crucial steps towards ecosystem conservation. Furthermore, by contributing to adaptation, mitigation and resilience, biodiversity is an important strategy against agricultural risks in an uncertain future due to climate change (MEA, 2005).

As there is a great knowledge gap concerning the species and their function and efforts are still needed to investigate and fully understand the diversity and composition of organisms and their associated ecosystem services. Meanwhile, the role of different landscape elements for agricultural landscapes and for biodiversity maintenance and how diversity and composition of these elements affect biodiversity, ecosystem services and sustainable production still need to be better understood. Policies and engineering practices to improve landscape diversity and biodiversity as well as ecological services should be further developed. In addition, it is also essential to explore how landscapes could be designed and managed to harness biodiversity and ecosystem services for sustainable development (Landis, 2017).

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