Lulu Zhang · Kai Schwärzel *Editors*

Multifunctional Land-Use Systems for Managing the Nexus of Environmental Resources

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Preface

Environmental decline and deteriorating conditions of environmental resources are endangering water and food security globally. Deforestation can cause soil erosion while agricultural intensification can lead to water pollution and shortage. While nations across the globe are affected by these problems, the extent of the problem faced by decision-makers in China is particularly severe. China has implemented the world's largest afforestation and land restoration programme in decades. Yet the consequences of these programmes have raised greater doubts about the sustainability of the environmental restoration projects. This has sparked an intense debate among scholars of environmental management about the apparent contradiction between investing in environmental restoration and the outcomes in terms of water and food security.

We explore this fundamental question in this book based on the outcomes of a Sino-German funded project. Additionally, we make efforts to seek out options to overcome this problem. By bringing the current research and knowledge on managing forests, grasslands and agricultural ecosystems, this book suggests an alternative approach to harmonise sustainable nature and social development. With this contribution, the editors hope to encourage a dialogue on knowledge gaps and the way forward involving harmonised decision-making based on cooperation between officials, scientists, practitioners and stakeholders.

The editors are grateful to all authors and reviewers for their remarkable contributions to this book and for sharing their knowledge and experiences with us. Special thanks go to the German Research Foundation (DFG) and the copy editors of this book, without whose support, this book would not have come to fruition. Thus, this book is dedicated to everyone who has contributed to it in one way or another.

Dresden, Germany

Lulu Zhang
Kai Schwärzel

Contents

Chapter 1
Applying Multifunctionality to Address the Challenges and Benefits of Land-Use Management

Lulu Zhang and Kai Schwärzel

In the past half a century, the dryland part of China (e.g. the Loess Plateau, Northwest China) has experienced intensive alterations in land use due to extensive soil erosion control and vegetation restoration measures. These actions have led to some successes in improving the ecological and social conditions, but they have also increasingly drawn attention to the challenges of sector-oriented measures to manage natural resources and ecosystem services. To ensure sustainable regional development, harmonising the conflicts between environmental protection and human benefits, as well as adapting ecological restoration measures to natural conditions (e.g. climate, water availability) are critically important. To this end, multifunctional land use is considered as a promising solution to remedy negative impacts and challenges. It also presents advantages, such as (i) an increase in synergies and co-benefits across sectors and (ii) the connection of ecosystem functions to ecosystem services. Currently, there is no universal definition of multifunctional land use. Understandings of multifunctionality in land use vary between scientific communities, practitioners, and policymakers. In this book, we present the diverse understandings of multifunctional land use in different sectors, using the development of agriculture, grassland, and forest in the Loess Plateau region as examples. Building on these examples, we elaborate and address multi-functionality in land use more extensively, and define the relationship between ecosystem functions and ecosystem services more clearly. We believe that the experiences and insights gained from managing a dryland environment provide

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valuable lessons and knowledge for the advancement of the study of multifunctional land-use systems. Before we introduce the Loess Plateau region and sectoral management in agriculture, grassland, and forest, we would like to give you a short overview of the key problems regarding sustainable development in dryland China. In this context, the importance of multifunctional land use is discussed.

1.1 Development Problems in China

China has made tremendous efforts to improve the deteriorated environment on the Loess Plateau over the last few decades. These efforts have been effective in mitigating soil erosion and improving soil resources, but have also resulted in other environmental problems due to the sector-oriented nature of the policies. The two core goals of several implemented policies and programmes are to restore degraded land and improve fragile ecological circumstances by increasing forest resources or changing management practices for grassland and cropland. It is believed that these measures are able to achieve both ecological and social progress. However, the expected "win-win" outcome is not emerging due to degradation of other natural resources (e.g. water) as a result of afforestation and agriculture intensification. This is, in fact, not an exceptional case in a global context. An analysis of the World Bank-funded projects for alleviating poverty and protecting biodiversity showed that only 16% of the projects have succeeded in achieving both goals (Tallis et al. 2008).

Sustainable development requires the sustainable provision of natural resources such as water, soil or nutrients. Environmental resources are not isolated from one another but exist in a complex interconnected system. This interconnectedness is particularly evident when resource management practices are applied to ecosystems. In regions with natural constraints, such as drylands, resources sometimes even compete with each other. For example, while afforestation can mitigate soil erosion and promote water quality, it can also lower water supply due to an increased demand in water from exotic species (Cao et al. 2011), as has been observed in China. The challenges that China is confronting confirms that sectoral management, or maximising one ecosystem function, can result in a substantial decrease of other ecosystem functions or even dysfunction, and thus hamper the sustainable regional development (Blum 2005; Lal et al. 2013). For this reason, rather than a sector-oriented integrated management, we urgently need effective approaches that are able to balance and manage competition and emphasise the optimisation of ecosystem functions and minimise dysfunctions with minimum trade-offs. Such approaches should apply a holistic view of multifunctionality as a result of managing ecosystems at different spatial scales under changing environments.

1.2 Understanding Multifunctionality in Land Use and Landscape

Originally, multifunctionality in the context of land use is a common term used in the European agricultural system (Dwyer and Guyomard 2006; Mander et al. 2007), proposed by the Organization for Economic Co-operation and Development (OECD). According to OECD (2003), multifunctionality is defined as a combination of varying demands on agricultural land use and is based on the assumption that every economic action has a number of functions besides the main function (Wiggering et al. 2006). Since this definition was published, in addition to discussion and utilisation in the agricultural sector, the concept of multifunctionality has been applied to a general land use and landscape context, in which cross-sectoral is the major characteristic. For example, Sabogal et al. (2013) defined multifunctional forest management as "a concept of forest management that combines two or more purposes, such as wood production, water quality, wildlife, flood alleviation, soil protection, clean air, recreation, or aesthetics, etc." Laterra (2011) summarises multifunctional grassland as "enhancing or maintaining forage and/or animal production while simultaneously allowing for the maintenance of biodiversity, nutrients retention, erosion control, carbon storage, and/or other ecosystem functions, as well as the landscape structure". In some countries (e.g. Switzerland), multifunctionality of certain land-use types is even ensured by law (Herrmann et al. 2002). In some aspects, agroforestry can be considered a sort of multifunctional land-use system that provides a number of benefits through the integration of different land uses in agricultural settings, for instance, through the integration of fertiliser trees into food crop agriculture or the use of soil conservation hedgerows. The benefits of agroforestry include, but are not limited to, preserving soil, enhancing soil fertility and biodiversity, improving agricultural yield and water quality, and increasing carbon sequestration and incomes in marginal lands (Garrity 2004; Jama and Zeila 2005; Ramachandran Nair et al. 2009).

As we can see, multifunctionality can be addressed either through a single land-use type, such as multifunctional agriculture, or by integrating several land uses on one piece of land (e.g. agroforestry), in which the different goals have to be coordinated and achieved simultaneously or successively. Similarly, from a broader perspective, landscapes that consist of a set of different spatial units (e.g. land-use types) can also have spatial multifunctionality, depending on the functions of each piece of land (Carvalho-Ribeiro et al. 2010). In other words, in addition to cross-sectoral, cross-scale is another major characteristic of multifunctional landscape. It shall not only provide multiple goods and services to meet local demands, but also satisfy the social needs of other areas (e.g. downstream), while simultaneously maintaining and improving the environmental resources. A landscape (e.g. watershed, basin) that has this kind of integrated spatial multifunctionality can be referred to as a multifunctional landscape. Yet, at landscape level, spatial units are distinct in natural composition. Some areas may have superior soil quality and water availability that are particularly suitable for agricultural production, while others may have poor soils or low water content, or even both disadvantageous conditions so that it is more effective to use them for combating soil erosion. The mountainous area on the Loess Plateau has fertile soil and high coverage of forest, making it the water tower of the region. It provides water resources for the midstream and downstream areas to support agricultural and social development. In such a landscape, a healthy mountainous ecosystem is vital to determine the water quantity and quality passing through the region; ecological protection is thus much more important than any other economic benefit. In other words, changes in land use for other purposes should be prohibited or at least considerably reduced in this area to safeguard the water resources. Land-related problems are diverse and site specific, thus, changes in land use may be more feasible in certain areas more than others. Considering this aspect, landscape design is of vital importance for a multifunctional landscape, which should take spatial variability of natural elements and interests of stakeholders and policymakers into full consideration with the support of appropriate tools (Droogers and Bouma 2014).

1.3 Multifunctional Land Use Is Vital for Sustainable Land Development

As noted by the United Nations Food and Agriculture Organization (FAO), sustainable land management (SLM) is essential for sustainable development (e.g. the achievement of specific Sustainable Development Goals) due to its significant role in harmonising practices across production, economy, and environment. Yet, what does "sustainable land management" mean? Despite a number of efforts, there is still unfortunately no universally accepted definition. The World Bank (2006) defined SLM as "a knowledge-based procedure that helps integrate land, water, biodiversity, and environmental management (including input and output externalities) to meet rising food and fibre demands while sustaining ecosystem services and livelihoods". FAO adopts the definition from the UN Earth Summit in 1992, defining SLM as "the use of land resources, including soils, water, animals, and plants, for the production of goods to meet changing human needs, while simultaneously ensuring the long-term productive potential of these resources and the maintenance of their environmental functions". It is clear that the socioeconomic aspect is not included in this definition. Therefore, the definition was adapted and expanded further to "the adoption of land-use systems that, through appropriate management practices, enables land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources" (see http://www.fao.org/nr/land/sustainable-land-management/en/). In summary, there are three underlying issues that are central to SLM, namely ensuring primary production, preserving natural resources, and enlarging social and economic benefits without compromising the ability of future generations.

A major global concern for development is food production. The world population is projected to reach 9.2 billion by 2050, and food production needs to increase by 70–100% to meet the anticipated demand (Burch et al. 2007; Cordell et al. 2009; Godfray et al. 2010). In the past, the problem of food shortages was mainly addressed by expanding cropland from other land uses and adding additional energy and nutrients, such as water and fertilisers, to unproductive land (Scanlon et al. 2007; Dawson and Hilton 2011). But this, in turn, resulted in the decline of water quantity (Kendy and Bredehoeft 2006; Scanlon et al. 2007) and water quality (Chen et al. 2005; Brammer and Ravenscroft 2009). Moreover, a considerable amount of productive land has become degraded due to the removal of nutrients during the harvest (when not compensated by soil fertility enhancing measures), salinisation and soil erosion (Godfray et al. 2010; Dawson and Hilton 2011). It is estimated that health and livelihoods of 1.5 billion people are affected by land degradation (FAO 2011). Reducing land degradation and enhancing soil and land quality require revising current practices. Biomass production needs to be increased by using more inputs or by increasing the amount of cultivated land. However, the increase of primary production will be significantly restricted, on the one hand, by the exhaustion of phosphorus in soils if a sustainable solution cannot be found (Cordell et al. 2009; Dawson and Hilton 2011). On the other hand, the competition for land and resources due to other priorities (e.g. carbon sequestration, biodiversity protection, biofuel production, urbanisation) makes it unlikely that new land will be converted for agricultural purposes (Godfray et al. 2010). In addition, climate change accelerates land degradation by increasing frequency of extreme weather events, and its effects are difficult to anticipate (UNCCD 2011). Therefore, while humankind is facing many challenges, food security is a challenge that can only be realised by managing a number of relevant problems simultaneously with more or less the same amount of land.

Natural and managed ecosystems and landscapes can potentially provide numerous goods and services to humankind (Millennium Ecosystem Assessment 2005). Yet, most of the currently implemented environmental plans and management strategies have not taken these benefits into full consideration. Therefore, it is still a common phenomenon that land use is managed to serve a single function (e.g. farmland for food production or forest for timber) (de Groot and Hein 2007). In contrast to single-function-oriented systems, multifunctional land use promotes benefit sharing across sectors while increasing the balance between economic, environmental and social aspects, and considering the rise in social demands on land and resources. Such an approach can significantly reduce the risk of resource decline and enhance the resilience of communities and regions to changes in the environment. To this end, multifunctional land use is in line with the underlying goals of SLM identified before, namely reconciling the production, economy, and environment. Certainly, it will be a challenge to apply it. This will not only require innovative management options that can be accepted and implemented by society (Bouma 2010), but also enabling policies and effective incentives, clear property and user rights, strict enforcement capability and good governance (World Bank 2006). Misaligned policy and other problems may also increase the vulnerability of the region and have adverse impacts on natural resources, society, and economy.

1.4 Link Multifunctional Land Use to Ecosystem Services

There is still extensive debate on the issues associated with distinctions between ecosystem functions and services and rationalisation of their relationship (de Groot et al. 2010). In reviewing relevant literature, the term 'ecosystem function' is often regarded as a synonym of ecosystem processes, while ecosystem services are the benefits that people obtain from ecosystems (Millennium Ecosystems Assessment 2005; Wallace 2007). The concept of ecosystem services has attracted increasing attention in natural science in the last decade, including integrating this concept into landscape planning and implementation (de Groot et al. 2010; O'Farrell and Anderson 2010). In addition to many other advantages, one of the major contributions made by ecosystem services is to interlink humankind and the environment, and to reframe their relationships using concepts of economics. Multifunctional land-use systems require providing a number of ecosystem functions from which humans benefit. The decisions on implementing multifunctionality should be made based on an advanced understanding of changes in ecosystem processes induced by social and environmental changes and the correct calculation of trade-offs. However, it can be challenging to quantify and evaluate certain ecosystem functions using simple and relevant indicators. This is partly constrained by the insufficient knowledge of the ecosystem processes and functions (Barkmann et al. 2008; Dominati et al. 2014); more important, many ecosystem functions have indirect utility values—such as the regulation function of the water cycle—thus, it is challenging to assign a value to these functions using stated preference techniques (e.g. price) and to make the value perceived by the public. Since it is possible to translate ecosystem functions into valued services, for example, following the concept of de Groot et al. (2002), ecosystem services can be used as indicators to analyse and evaluate the multifunctionality of a certain ecosystem by linking its functions with human and benefit values. In this way, the relative contribution of services and their complementary availability or competitive capability can be used to imply the multifunctional capability, which can be achieved by trade-off analysis (DeFries et al. 2004; Laterra 2011).

The ultimate goal of multifunctional land-use systems is to increase synergies between the environment and society and minimise the trade-off of benefits. Yet, multifunctionality is difficult to foster by changing land management itself, since benefits (or services) generated by ecosystems and landscapes depend largely on the biophysical characteristics of the land, the coordination of many individual disciplines and the actions of stakeholders (Chen et al. 2010; Bouma 2014). This means, apart from innovative management concepts, additional support and investment are necessary to protect and enhance ecosystem processes and alter land-management approaches of society. Effective support/policy can facilitate the maintenance and improvement of ecosystem functions so that they are able to produce more ecosystem services; on the other hand, the investment in payment for benefits (in other words, payments for ecosystem services) has to be efficient so that the ecosystem can provide the desired benefits at a minimum cost. In fact, conservation management strategies, such as multifunctional land use, do not necessarily create a trade-off between environment and development, but investments in conservation and the sustainable use of ecosystems can bring substantial benefits to the environment, economy and society, which might not be visible in the short-term, but extremely valuable in the long run (de Groot et al. 2010).

1.5 Organisation of This Book

This book contains eight chapters. Chapter 2 gives an introduction of the Loess Plateau, with particular respect to features of regional geomorphology, climate, natural resources, ecosystem characteristics and risks, as well as socioeconomic conditions. Chapter 3 traces the evolution of China's environmental protection policy over the last few decades, such as "Arable Land Protection", "Three-North Shelterbelt", and "Grain for Green", among many others, with a special regard to the Loess Plateau region. The summary covers backgrounds, goals and development processes of every policy, the main measures and scopes of implementation, as well as major outcomes and shortcomings. In Chaps. 4, 5 and 6, development and management of agriculture, grassland, and forest ecosystems are presented separately with special consideration to their provision of ecosystem services (e.g. environmental and socioeconomic-related benefits), while new challenges due to sector-focused management are identified. In this context, discussions and suggestions for improving policy and research to advance and promote sustainable multifunctional land use are made; for example, principles and management options of multifunctional forestry are proposed in Chap. 6. Chapter 7 highlights the conflicts between forest development and water shortage in the dryland part of China, which has drawn the most attention of researchers. To moderate conflicts, principles for integrated management of forest–water–land and decision-making procedures for multifunctional forest are suggested. Based on the aforementioned chapters, Chap. 8 elaborates the different understandings of multifunctionality in land use and the challenges in implementation of sustainable multifunctional landscape. To overcome the difficulties in cross-sectoral management, an approach with emphasis on the nexus of resources is suggested. At the end, key research topics are proposed for advancing multifunctional land-use systems in the future.

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Chapter 2
The Loess Plateau

Xinzeng Wang, Feng Jiao, Xinping Li and Shaoshan An

The Loess Plateau (34°–40°N, 103°–114°E) is situated in the northern part of Central China (Fig. 2.1). It borders on North China Plain in the east, adjoins Qinghai-Tibet Plateau in the west, stands in the north of Qinling Mountains, and neighbors Inner Mongolia Plateau in the north. The Loess Plateau is a part of the dryland region in northwest China, with its altitude in the range of 800–3000 m, encompassing a vast expanse of 620,000 km^2. The Loess Plateau stretches over Shanxi province, northern Shaanxi province, Gansu province, northeastern Qinghai province, Hetao Plain, and Ordos Plateau of Inner Mongolia, and the western hilly land of Henan province—that is, 341 counties (cities) in seven provinces (or autonomous regions) (Fig. 2.2). The loess is perfectly arable due to its fine grains, loose texture, and high content of mineral nutrients. In fact, it is the cradle of the ancient Chinese civilisation, with a long agricultural history (over 6000 years) in its basins and river valleys. Standing between the developed eastern part and the less developed western part of the country, the Loess Plateau is one of the major regions selected for China's national eco-environment development programme.

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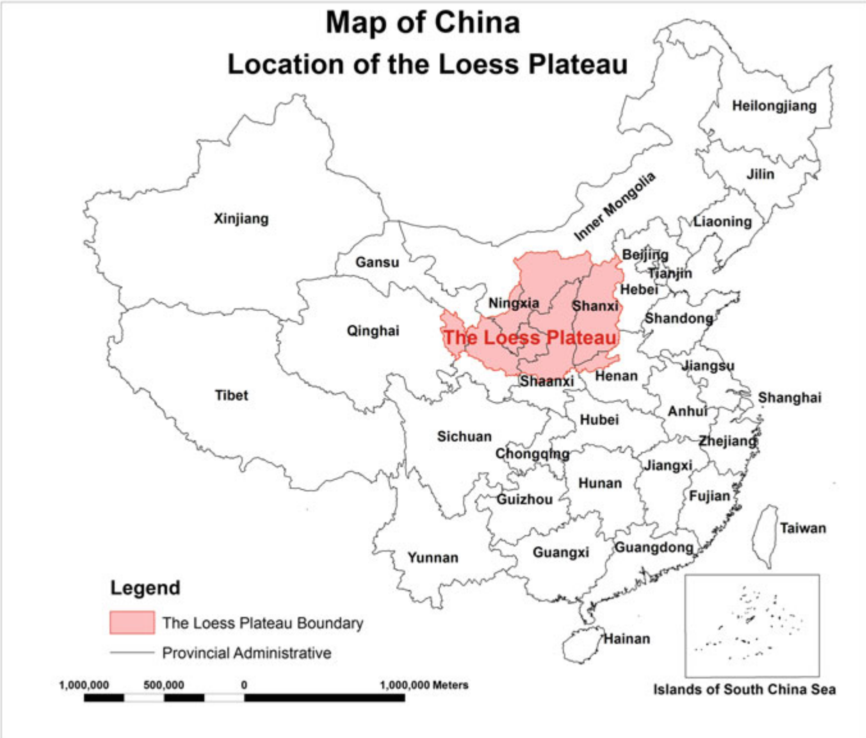

Fig. 2.1 The geographical location of the Loess Plateau in China

2.1 Geomorphology and Geology

The basic topographical pattern of the Loess Plateau emerged as early as in the late Mesozoic period. Its modern topographical features result from the tectonic movements and denudation during the Tertiary period and the loess accumulation and erosion processes during the Quaternary period. The large-scale sedimentation that started in the early fourth century brought Wucheng loess, Lishi loess, Malan loess, and Holocene loess in sequence of the original topographical pattern of the Loess Plateau. During that process, it went through multiple erosion and accumulation periods, giving birth to many river valleys and various landforms between these valleys. There are several classifications of the plateau's topography. For instance, Zhang and Qian (2009) based the classification on causes: tectonic features by erosion, denudation, denudation and accumulation, erosion and alleviation, accumulation, or accumulation by wind. Sheng and Ding (2002) divided the plateau's landforms into four major types: plain, tableland, valley, and mountain.

Fig. 2.2 The Loess Plateau boundary plan

Hu (2006) offered a general classification: hill, high tableland, terrace, plain, desert, and stony mountain. To sum up, the Loess Plateau area consists of three major topographical features—stony mountains, valley plains, and plateau hills (Fig. 2.3).

2.1.1 *Stony Mountains*

The Loess Plateau, both inside and in the surrounding areas, is dotted with many mountains of various sizes. These mountains affect the distribution and development of the loess topography. The soil erosion on the Loess Plateau is a natural process that occurs continuously and nowadays presents a tendency of acceleration under the influence of human activities (Liu 2005). Due to enduring soil erosion, the bedrocks along mountain ridges and valleys have been exposed, forming mountainous areas with a thin layer of soil. The valley bedrocks are mostly limestone, sandstone, and shale. In the eastern part of the Loess Plateau, there are many mountains of middle and high elevations. The mountains of middle and low

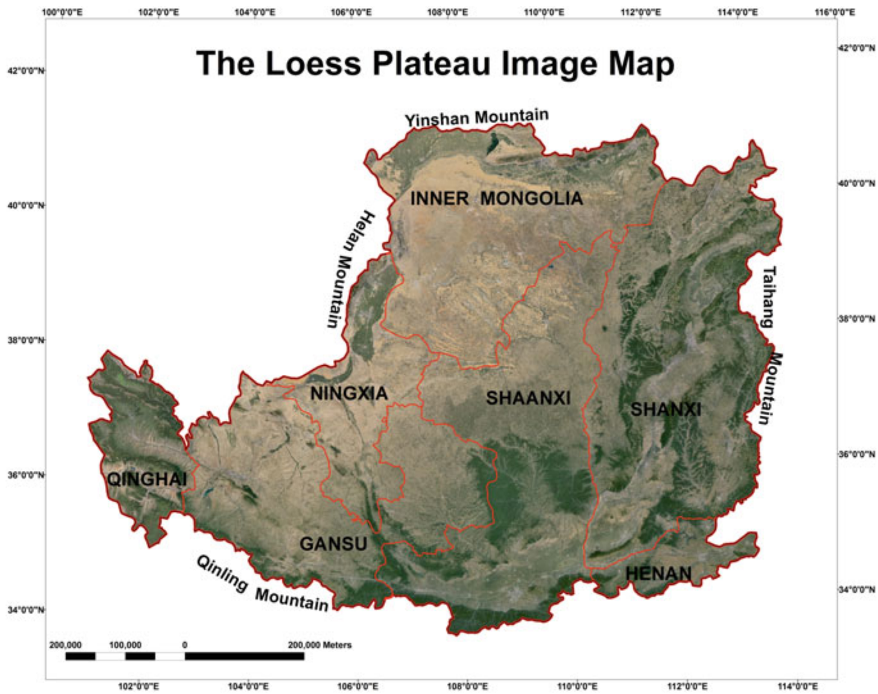

Fig. 2.3 The Loess Plateau image map

Fig. 2.4 Terrain of Liupan mountain in Ningxia Hui autonomous region

altitudes in central Loess Plateau are origins of many major rivers and thus form a number of watersheds. A typical example of such mountains is the Liupan Mountains (Figs. 2.4 and 2.5).

Fig. 2.5 Terrain of Liupan mountain in Ningxia Hui autonomous region

2.1.2 Valley Plains

Valley plains are a terrain with limited presence on the Loess Plateau, accounting for less than 15% of the total area. The Fenhe Plain and Weihe Plain, formed by the fault depression, constitute different levels of fluvial terraces and tablelands. Loess tablelands are a type of pedestal terrace under the influence of depression, which are distributed asymmetrically along the two sides of the river valley (Fig. 2.6). They are usually 10–20 m wide, with a layer of aeolian loess on the surface that can be over 100 m at maximum in thickness. The fluvial terraces in the Fenhe Plain and Weihe Plain are normally 20–30 m higher than the river level, with flat and broad surfaces—the largest width can reach 60–70 km. The Yellow River and its major tributaries have gone through a long process of erosion and cultivation, and in these processes, the fluvial terraces resulting from deposits of loess have become the major industrial and agricultural production bases in China (Liu 2005).

2.1.3 Plateau Hills

Plateau hills are the main topographic feature of the Loess Plateau region, accounting for over 60% of the total area (Liu 2005). Based on variations in paleo-geomorphology and erosive forces, the Loess Plateau hills can be divided into three parts. Lüliang Mountains are used as borderlines for division. The hilly region has its unique topographic features. For instance, the loess hills in the central Gansu region (the highest among the three hilly regions) have an altitude of

Fig. 2.6 Weihe Plain

1500–3000 m. In the north of this hilly region, the loess deposit is quite thin and the landform is featured by a combination of stony mountains and loess hills, while in the south, due to the higher rainfall and stronger erosion, the terrain is shattered (Fig. 2.7).

2.2 Soils

Loess is brownish yellow, loose, and relatively homogeneous in texture. It is aeolian, often silt loam or silty clay loam, as a result of wind deposit. The content of silt (particle diameter between 0.05 and 0.02 mm) is over 60% in loess. Loess soil has a strong vertical joint structure and soil cohesion relies mainly on calcium carbonate, which can be gradually dissolved if water permeates into soil. For this reason, loess is easy to break, collapses in water and thus highly erodible. The main soil types in the Loess Plateau include cinnamon soil, Lou soil, loessial soil, dark loessial soil, gray cinnamon soil, and sierozem (Table 2.1). With the exception of the stony mountainous areas, the thickness of the loess deposit is 50–80 m on average in most parts of the Loess Plateau; it may reach 150–180 m at maximum in some areas (Loess Plateau Scientific Expedition Team 1991).

Fig. 2.7 Terrain of the central Gansu area on the Loess Plateau

2.3 Water Resources

2.3.1 Rivers Characteristics

The main stream of the Yellow River in the Loess Plateau region has a length of 3000 km. At the transitional zone from more humid to more arid climate, there are many major tributaries of the Yellow River including Taohe River, Huangshui River, Zuli River, Qingshui River, Kuye River, Wuding River, Fenhe River, and Weihe River. The total drainage area of these rivers is 522,700 km^2, accounting for 84.1% of the overall Loess Plateau region (Loess Plateau Scientific Expedition Team 1991).

The annual natural runoff of the Yellow River is 58 billion m^3/a. Four of its tributaries—Weihe River, Taohe River, Huangshui River, and Yiluo River—have an annual runoff of more than 3 billion m^3. The Loess Plateau has thousands of ravines and gullies, more than 80% of which are dry and are usually plagued by mountain torrents and flash floods during rainstorms. In comparison with other regions of China, the Loess Plateau suffers from water shortage—the water amount per capita in the Loess Plateau region is only one-fifth of the national average—and the water availability for cultivated land is less than one-eighth of the national average. These facts make the Loess Plateau one of China's most water deficient

Table 2.1 Brief information on the main soil types (Yao et al. 2015)

Type	Distribution area	Physical property
Cinnamon soil	Under forest in semi-humid southeast of the Loess Plateau	Under natural vegetation, the soil normally contains 1–3% of organic matter. Where there are cultivation and farming activities, the organic matter content is usually below 1%. Hydromica and vermiculite are the main clay minerals, along with a slight amount of montmorillonite, kaolinite, and chlorite. Cinnamon soil has a well-developed argic horizon, thus can retain water and nutrients very well. It has a neutral or slightly alkaline reaction and is suitable for cultivating various crops. However, its organic matter content decreases sharply with cultivation; nitrogen and phosphorus contents are insufficient. Additionally, cinnamon soil in mountainous areas is often thin and has high content of rocks, not suitable for cultivation
Lou soil	Distributed on terraces, e.g., in the Fenhe Plain and Weihe Plain valley area, Guanzhong Plain	The clay content is 13–15%; the main clay mineral is illite in the upper layer, and illite and vermiculite in the lower layer. In general, the soil has a neutral or alkaline reaction, with a pH value of 7.0–8.5
Loessial soil	Widely distributed, particularly in the hilly and gully areas of northern Shaanxi, central and eastern Gansu, and western Shanxi, where soil erosion is severe	Weak soil forming process, soil profile presents uniform structure, strong lime reaction, with around 0.5% of organic matter content
Dark loessial soil	Mainly distributed in central and eastern Gansu, northern Shaanxi and northwestern Shanxi, with the greatest distribution in loess tableland	The soil layer is thick, normally 150–200 cm, with an organic matter content of 1.0–1.5%. The main clay minerals are illite and hydromica. Its pH value varies between 7.4 and 7.8
Gray cinnamon soil	Mainly distributed in Liupan Mountains, Lüliang Mountains, at an altitude of 1200–2600 m	The soil has neutral or slightly alkaline reaction. The content of organic matter is around 5% on average, and 10% at maximum
Sierozem	Limited distribution in the transitional area from grassland to desert	The content of organic matter is 0.7–1.5%. In terms of texture, clay accounts for 35–45%, with a variation of 10–20%. The main clay mineral is hydromica. Soil pH value is 8.0–9.5

regions. In terms of water resource per capita, Ningxia Hui Autonomous Region and Shanxi provinces rank the lowest in the loess region, which have only 200–400 m^3 per capita. The Yellow River runs through Ningxia Hui Autonomous Region. The northern part of Ningxia Hui Autonomous Region is relatively flat; it is thus easier to build channels and divert water for agriculture. In contrast, the southern mountainous area of the province suffers from drought and water shortage due to difficulties in water diversion. In addition, Dingxi region, eastern part of Gansu, highlands of Weibei region, and hilly loess region of Shaanxi are places with scarce water resources (National Development and Reform Commission 2010).

2.3.2 Groundwater

Groundwater in the Loess Plateau region mainly includes pore water stored in loose rock structures, water in karst carbonate rocks, fissure water from crystalline rocks, pore, and fissure water from clastic rocks, pore, and fissure water from loess and underlying bedrocks. Pore water in loose rock structures is mainly distributed in the hilly areas and alluvial plains, totalling 19.63 billion m^3/year, accounting for 56% of the region's total amount. Fissure water from crystalline rocks and fissure and pore water from clastic rocks is mainly distributed in mountains and flattened tableland areas, with the latter occurring in the hilly regions consisting of clastic rocks. Karst water is mainly distributed in mountainous areas, featured by large water quantity, good water quality, and easy accessibility, which accounts for 13% of the region's total resources. Fissure and pore water from loess and underlying bedrocks is mainly distributed in the expanse of hilly and gully regions, accounting for 7% of the region's total resources. It is obvious that with limited water resources, hilly and gully regions of the Loess Plateau suffer most from water shortage and poor water quality. Overall, the groundwater resources in the Loess Plateau approximate 33.6 billion m^3, of which 86% is potable and covers 88% of the entire loess area. In terms of quality, most of the water is freshwater of high bicarbonate level and low mineralisation (Loess Plateau Scientific Expedition Team 1991).

2.4 Climate

2.4.1 Temperature

The Loess Plateau region is susceptible to monsoons. However, it is distant from the ocean (its eastern edge is 500–800 km away from the ocean), hence it has strong characteristics of continental climate (Zhang et al. 2007). The Loess Plateau has three climatic zones in general: semi-humid climate in the southeast, semi-arid climate in the central part, and arid climate in the northwest. The lowest temperature appears in January, with an average temperature of below 0 °C, while the highest temperature appears in July, with an average temperature of 20–25 °C. The region is subject to dramatic temperature changes, the annual amplitude of temperature change is often over 25 °C in most parts and the amplitude has a tendency of increasing from south to north and from east to west. The ≥ 10 °C annual cumulative temperature is 2500–4350 °C (Liu 2005).

2.4.2 Precipitation

Rainfall in the Loess Plateau region is distributed unevenly over time and space. The average annual precipitation in the Loess Plateau region ranges from 200 to 600 mm. In the northern part, precipitation can be sometimes even less than 200 mm/a. Influenced by geographical location and topographic conditions, the average annual precipitation declines gradually from the southeast to northwest regions (Fig. 2.8). 50–70% of annual precipitation falls in July, August, and September and often in the form of heavy rainstorms. In addition, the interannual variations of rainfall are dramatic. The maximum annual rainfall can reach 1.5–2

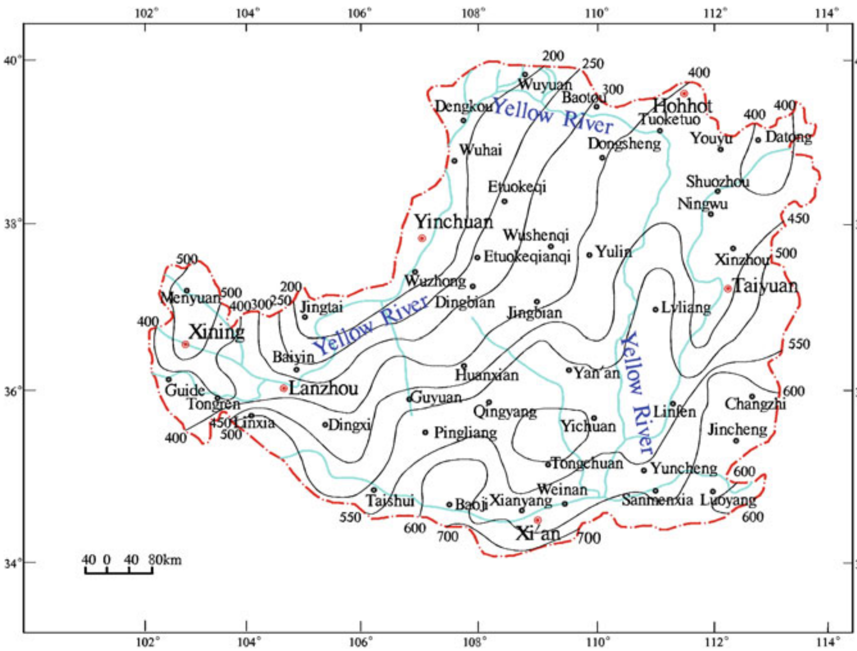

Fig. 2.8 Average annual rainfall isohyets in the Loess Plateau region (Liu et al. 2005)

times as much as the average annual rainfall, in most cases it is 1.5 times in the southeastern part and 2 times in the northwest (Huang and Li 1987).

2.4.3 Evaporation

The Loess Plateau's evaporation varies between 1000 and 2000 mm depending on the location—it is less than 1400 mm in southern Gansu, Liupan Mountains region of Ningxia Hui Autonomous Region, and south of the Weihe River in Shanxi; it is between 1600 and 2000 mm in Shanxi province, northern Shaanxi, most part of the Ningxia Hui Autonomous Region, and Gansu's Qilian Mountains region (Zhang et al. 2007).

2.5 Vegetation

The natural vegetation in the Loess Plateau has been destroyed for a long time. Therefore, to a certain extent, the existing vegetation does not fully reflect the true nature of vegetation zonality. Liu (2005) has divided the Loess Plateau into four vegetation zones: forest region, forest-steppe region, typical steppe region, and desert steppe region (Fig. 2.9). The covering area and vegetation features of each region are illustrated below.

2.5.1 Forest Region

The Forest Region is located in the southeastern part of the Loess Plateau. Broadleaved deciduous forests are the major forest types. The dominant species include *Quercus wutaishanica*, *Populus davidiana Dode*, and *Pinus tabulaeformis Carr*. There are also coniferous trees such as *Cunninghamia lanceolata* (*Lamb.*) *Hook* and *Platycladus orientalis* (*Linn.*) *Franco*. In addition, many other minor species such as *Koelreuteria paniculata Laxm*, and shrubs such as *Cotinus coggygria Scop*, *Forsythia suspensa* (*Thunb.*) *Vahl*, *Syzygium aromaticum* (*L.*) *Merr. Et Perry*, Vitex *negundo Linn. var. heterophylla* (*Franch.*) *Rehd*, *Ostryopsis davidiana Decaisne*, and *Lespedeza bicolor Turcz* also grow in this zone. *Quercus wutaishanica*, *Populus davidiana Dode*, and *Pinus tabulaeformis Carr* are the natural forests in this region. *Cotinus coggygria Scop* and *Forsythia suspensa* (*Thunb.*) *Vahl* are the region's typical shrubs, mostly distributed in low-altitude loess hills and tablelands. Major species for afforestation are *Pinus tabulaeformis Carr*, *Robinia pseudoacacia Linn*, *Paulowinia fortune* (*seem.*) *Hemsl*, along with others like *Ailanthus altissima* (*Mill.*) *Swingle*, *Koelreuteria paniculata Laxm*,

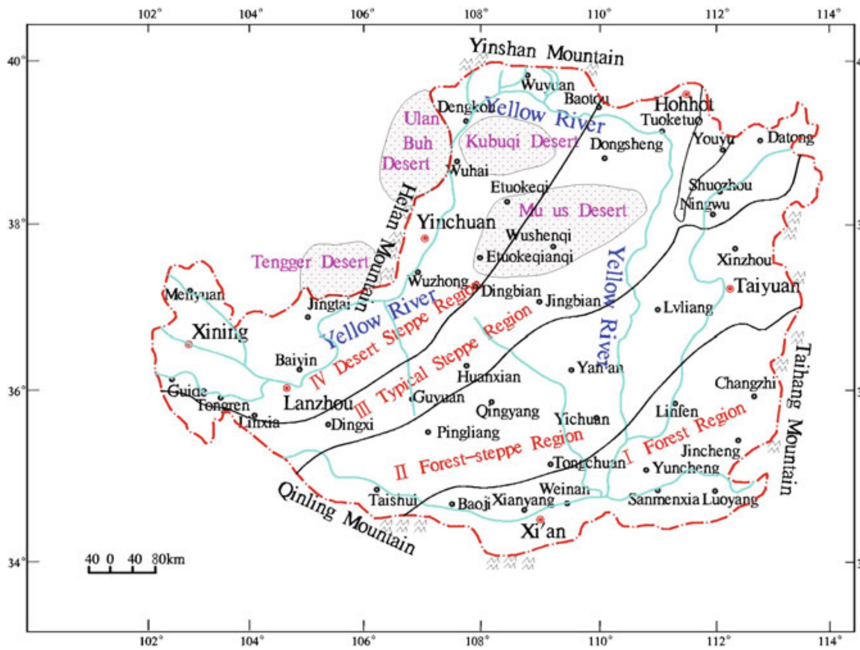

Fig. 2.9 Zonal distribution of vegetation in the Loess Plateau region (Liu et al. 2005)

Platycladus orientalis (*Linn.*) *Franco*, *Fraxinus bungeana DC*, *Morus alba L*, etc. (Loess Plateau Scientific Expedition Team 1991).

2.5.2 Forest-Steppe Region

This region covers the northern Huanglong Mountains, Ziwuling Mountains, and Liupan Mountains. Forests are formed mainly in high-altitude mountains, hills, and humid gullies. Shrubs are mostly mesoxerophytes and xerophytes, e.g., *Sophora moorcroftiana* (*Benth.*) *Baker*, *Prinsepia utilis Royle*, *Periploca sepium Bunge*, *Wikstroemia chamaedaphne Meisn*, etc. Mesoxerophytes are common in gullies and shady slopes, including *Syzygium aromaticum* (*L.*) *Merr. Et Perry*, *Spiraea fritschiana Schneid*, *Rosa xanthina Lindl*, *Ostryopsis davidiana Decaisneetc*. The environment in the loess hilly areas is getting drier (Cai et al. 2015). Steppe vegetation is becoming a dominant species, including *Bothriochloa ischcemum* (*Linn.*) *Keng*, *Stipa bungeana Trin*, *Lespedeza bicolor Turcz*, etc. In addition to natural vegetation, plantation is also carried out in this zone. Common afforested tree species are *Pinus tabulaeformis Carr*, *Robinia pseudoacacia Linn*, *Platycladus orientalis* (*Linn.*) *Franco*, etc.

2.5.3 Typical Steppe Region

Grass and shrubs are the dominant vegetation in this zone. The main grass species includes *Stipa bungeana Trin*, *Artemisia leucophylla* (*Turcz. ex Bess.*) *C.B. Clarke*, *Stipa capillata Linn*, *Thymus mongolicus Ronn*, etc.; while common shrubs species are *Caragana korshinskii Kom*, *Caragana microphylla Lam*, *Wikstroemia chamaedaphne Meisn*, etc. Shrubs used for plantation in this zone are *Hippophae rhamnoides Linn*, *Astragalus adsurgens Pall*, *Artemisia desertorum Spreng*, etc.

2.5.4 Desert Steppe Region

This region is located in the northern part of the Loess Plateau, bordering on the typical steppe region in the south. Among limited vegetation, *Stipa breviflora Griseb* is the most widely distributed one. Trees are rare in this region, only *Elaeagnus angustifolia Linn*, *Salix matsudana Koidz*, and *Ulmus pumila Linn* can be found. Compared to other regions, shrubs plantation covers a large area. However, it is still challenging to cultivate grass and shrubs in this zone due to the harsh conditions (Li et al. 2015).

2.6 Land Use and Agriculture Distribution

2.6.1 Current Status

It is estimated that 72.8% of the Loess Plateau region is affected by soil erosion. The annual sediment load into the Yellow River is 1.6 billion tons.a^{-1}. At the moment, the main land-use types are forestland (25.7%), grassland (25.4%), cultivated land (22.5%), orchards (1.9%), unused land (17.1%), and others (7.4%) (National Development and Reform Commission 2010).

2.6.2 Crop Farming

Wheat, maize, and millet are common grain crops in the Loess Plateau. Oil plants, cotton, beet, and tobacco are popular cash crops. The planting area of maize has been on the rise for years, and now takes the first place among all of the crops in terms of yield per unit area and total amount. Maize requires water and heat to grow. For this reason, maize is often planted in warm and humid valleys and flat areas, where the $\geq$10 °C cumulative temperature is >2800 °C, in some other cases also in mountainous areas (e.g., Taihang Mountains) where water is sufficient. Due to the properties of drought resistance and barren tolerance, millet is a popular crop in this region, widely grown on relatively dry slopes in the semi-arid northern part of the Loess Plateau. In addition, sweet potato is a major product of central and southern districts of the Loess Plateau, while potato is popular in the northern district. Among oil plants, rapeseed, cotton seed, peanut, and castor are popular in the central and southern areas, whereas flax and sunflower mainly in the cold northern region.

2.6.3 Forestry

Due to long-term improper use, most of the natural forests have been destroyed, leaving only part of secondary forests, the main tree species of which are *spruce*, Chinese larch, Chinese pine, Chinese white pine, birch, aspen, oak, Oriental arborvitae, lacebark pine, hornbeam, *P. betulaefolia*, and *Ulmus macrocarpa*. Despite the significant increase in forest cover due to the implementation of afforestation, the forest cover in the Loess Plateau remains low because of the arid climate. The main purpose of forest development on the Loess Plateau is to control soil erosion and improve the environment, while addressing the regional timber, wood fuel, and other needs.

2.6.4 Orchard

Apple, jujube, pear, grape, peach, and apricot are the main fruit products in the region. In addition, dry nuts and fruits such as walnut and Chinese prickly ash (Huajiao) are also preferred economic products for farmers. Jujube trees usually have a lifespan of over 100 years and are highly resistant to drought and infertility. By virtue of their well-developed deep root system and small canopy, jujube trees are suitable to be intercropped with other grains. By doing so, they are able to protect the soil from erosion and increase crop yield and income at the same time. For this reason, the jujube tree has become a popular species in the warm temperate area of the Loess Plateau.

2.6.5 Stockbreeding

In recent years, livestock breeding has been undergoing a booming development in the Loess Plateau region; its contribution to the gross regional agricultural product has risen from 10 to 25%. The primary and secondary varieties of animals for breeding are different among regions. Herbivores such as cattle and sheep are most common in the northwest, with pigs as secondary choice; while pig farms are most common in the warm, humid central and southern parts, where cattle is the secondary option instead.

2.7 Ecological Problems and Risks

The Loess Plateau suffers from severe soil erosion resulting from special environmental conditions and intense human activities. The unique environmental conditions refer to drought, rainstorms, unfavorable topography, erodible soil, and sparse vegetation. As a consequence of unfavourable natural conditions, landslides, collapses, and flood frequently occur, leading to the degradation of natural resources (e.g., water) and damages of lives and properties. Apart from the natural conditions, the environment of the Loess Plateau is further deteriorated by irrational land use, such as deforestation, overgrazing, and intensified cultivation. The land productivity decreased significantly and the land cover/vegetation diminished rapidly resulting in further soil erosion. Soil erosion can cause loss of fertile topsoil, therefore nutrients (e.g., N, P, and K). Furthermore, sediments can quickly fill up dams that are built for flood control. This could lead to failure of dam performance, resulting in disasters like flash floods. Moreover, the trapped sediments in reservoirs and dams raise the river bed, creating a ‘hanging river’ and increasing risks of flood (Wang 1999).

The ecosystem of the dryland is vulnerable. The livelihood of the people and socioeconomic development in the Loess Plateau depend significantly on the ecosystem health and services. To remedy the situation, ecological restoration has been carried out (details are given in Chap. 3). However, various problems related to monoculture with exotic species occur, such as reduction in streamflow due to excessive soil water use, low survival rate of trees, unstable ecosystem, and loss of biodiversity. Given the dry environment of the Loess Plateau and the increasing demands for water and food due to population growth, the current land management cannot support the sustainable development of the region and provide adequate ecosystem services for the regional population. Therefore, a more innovative, efficient, and sustainable land-use system needs to be developed for the region.

2.8 Socioeconomic Conditions

2.8.1 Population

The Loess Plateau is one of the most densely populated regions in China (Yan 2007). According to the regional census in 2014, the permanent residents totalled

109 million, approximately 70% of which are rural population. The mean population density in the region is 170 pop/km^2, far exceeding the internationally recognized threshold of capacity (100 pop/km^2) for dryland regions (Duan and Xu 1995). The total population of Shaanxi, Shanxi, and Gansu that live on the Loess Plateau accounts for 82% of the total regional population.

2.8.2 Economy

The gross regional product was RMB 4.92 trillion in 2014, with the primary, secondary, and tertiary industries accounting for 7.0, 50.3, and 42.7%. It is obvious that the secondary industry is dominant. They are mainly distributed in several large cities, such as Xi'an (Shaanxi province), Taiyuan (Shanxi province), and Lanzhou (Gansu province). The Loess Plateau region has abundant mineral resources and has undergone energy industry development including coal mining, petroleum and natural gas, and non-ferrous metal industry such as lead, zinc, aluminum, copper, molybdenum, tungsten, and gold, as well as rare earth. These industries are the driving forces promoting the regional economy.

Additionally, due to abundant sunshine and large temperature variations over the day, the Loess Plateau has an advantage of producing high-quality agricultural products. For example, it is the largest kiwi and second largest apple producer in China. At the same time, it is also a major growing district of high quality pears and jujubes, Chinese herbal medicine plants, and potatoes. With the exception of a few industrial cities, the Loess Plateau is mainly an agriculture dominated area. Nevertheless, its economy has the following features: (i) low economic growth compared to the national average; (ii) remarkable differences in development among areas within the region depending on quality of natural environment and availability of natural resource; (iii) underdeveloped agriculture, characterized by low crop yield and farmer income (Zhang 2005).

Recently, the Loess Plateau region has set its development goals and prioritized the goals for different areas. The ecosystem-related goals include provision of sufficient food, soil conservation, provision of water of high quality, and maintaining biodiversity. Despite rich land, energy, coal, mineral and other natural resources, its population carrying capacity is limited by severe water shortages and droughts. If Northwest China continues to implement the traditional model of development, it will be very difficult to solve the conflicts between economic development, resource conservation, and environmental protection fundamentally. It will also be very difficult to stop environmental degradation and environmental damage, thereby posing a serious threat to the sustainable development of Northwest China. Adjustment of the current land policy is required in order to achieve a more sustainable development of the region (Liu et al. 2012).

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Chapter 3
The Land-Use Protection Policy in China

Lin Zhen and Jie Hu

3.1 The Evolution of National Land-Use Policy in China

Before the introduction of reform and the opening up policy, the development of China's land-use policies has experienced four stages: (i) the inauguration period after the founding of the New China (October 1949–September 1956), (ii) the all-round construction period (September 1956–May 1966), (iii) the cultural revolution period (May 1966–October 1976) and (iv) the stagnation period (November 1976–November 1978) (Jiang 2003). Since the land reform, the development of China's land policy has gone through a collective land ownership system and a people's commune system. From the 1950s to the 1970s, some afforestation and dam construction projects have been conducted but only limited to a small scale in a few locations. After adopting the reform and the opening up strategy, the government put forward the policies for accelerating land reclamation, farmland construction, ecological restoration and agricultural development. In 1978, the State Council approved the Three North Shelterbelt Project. In June 1986, the rural household responsibility system was formally established in the country.

Intensive land reclamation and utilisation have resulted in land degradation and intensified the tension between land use and ecological protection. To protect farmland and promote sustainable agriculture, the State Council announced a national policy in July 1994 on demarcation, protection and supervision of farmland. In August 1998, it was clearly addressed for the first time that local governments should return the reclaimed land (including arable land) that had adverse

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effects to environment, to forests or grasslands. In 2000, conversion of degraded farmland into forests and grasslands was approved (the so-called "Grain for Green" Programme). In 2002, the State Council officially approved the implementation of the Returning Grazing Land to Grassland Program. In September 2006, the State Council furthermore set a goal that the total amount of arable land should be kept at ≥ 120 million ha for food security. In August 2007, the importance of the "Grain for Green" Programme has been further stressed by the State Council. The latest issued national land policy is outlined by the Provisions on the Economical and Intensive Use of Land in March 2014. Table 3.1 shows the milestones in the evolution of China's land policies since 1978.

The Loess Plateau has a unique role in the evolution of the land policy in China over the past half a century. Due to unfavourable natural factors (e.g. steep slope,

Table 3.1 Evolution of major land-use policies in China since 1978 [summarised from State Council (1978), State Council (2002), MOF (2011), MLR (2014)]

Year	Name of policy	Aim of policy
1978	Three North Shelterbelt project	Fundamentally change the hazards of sandstorms and condition of soil and water loss in the northwest, north and northeast regions of China
1986	The rural household responsibility system	Mobilise the enthusiasm of farmers, liberating agriculture productivity, to solve the problem of food and clothing of farmers
1994	Regulations on the protection of basic farmland	Special protection of basic farmland, to meet the needs of China's future population and national economic development of agricultural products, for promoting the sustainable development of agricultural production and socioeconomic conditions
2000	Grain for green project	To alleviate the situation of soil and water erosion on sloping farmland in the upper reaches of the Yangtze River and the Yellow River, and to improve the ecological environmental in the Western region, readjust the structure of agricultural economy and promote the sustainable development of the whole society
2002	Returning grazing land to grassland	To restore grassland vegetation, improve the ecosystem and productivity of grasslands and promote the coordinated development of grassland ecology and animal husbandry
2007	Further improvement of grain for green project	To consolidate the achievements of returning farmland to forests, and to solve the existing problems in farmers' living and long-term livelihood
2014	Provisions on the economical and intensive use of land	To carry out the policy of rational utilisation of land and effectively protect arable land, enhance the carrying capacity of land resources for economic and social development and promote the construction of ecological civilisation

loose soil and rainstorms) and human activities (e.g. deforestation, overgrazing and steep slope reclamation), environmental problems such as soil erosion, land degradation and alkalisation have become particularly severe in the Loess Plateau region. Several major land-use protection policies have been implemented in this region. In this chapter, we review these major policies implemented by local governments in the Loess Plateau region. The aim is to summarise the backgrounds, development processes, main measures, implementation scopes, outcomes and weaknesses of the major land management policies and programmes. Moreover, it aims to identify problems in the design and implementation process of land management policies/programmes and to provide a theoretical and scientific basis for development of a more sustainable use of natural resources such as land/soil and water.

3.2 The Land-Use Protection Policies Implemented in the Loess Plateau Region

In this section, we mainly introduce, in detail, representative land-use protection policy that have been implemented in the Loess Plateau region, such as the arable land protection policy, the Three North Shelterbelt project, the Grain for Green programme and the Returning Grazing Land to Grassland project.

3.2.1 Arable Land Protection Policy

3.2.1.1 Policy Background, Goals and Development Process

The importance of arable land had long been recognised. It was not allowed to be used for non-agricultural purpose in the 1950s. Yet, along with the growing social development and land demand, problems such as quantity depletion and quality degradation of arable land have appeared. To address these problems, the policy for arable land protection was introduced, aiming to achieve dynamic equilibrium of the total amount of arable land. Dynamic equilibrium of the total amount of arable land refers to a state of balance between arable land supply and demand within a specific region, which can be achieved by analysing the current amount of arable land, demand for arable land, back-up land resources and the surplus or deficiency of arable land resources in the region. Arable land protection measures consist of two aspects: quantitative protection and qualitative protection.

Quantitative protection of arable land includes the following aspects: (i) strictly controlling the shift from arable land to non-arable land and implementing a compensation mechanism for occupying arable land; for approved occupation of arable land for non-agricultural purpose, the occupier shall reclaim arable land of quantity and quality that is equal to the occupied land; when conditions do not permit or the reclaimed land cannot meet the requirements, the occupier shall pay a reclamation fee according to the regulation of the respective provinces, autonomous regions and municipalities, which is earmarked for land reclamation; (ii) implementing basic arable land protection system; the basic arable land areas are identified by the overall land-use plan. They include (a) arable land in grain, cotton and oil crop production bases approved by administrative departments or local governments beyond county level, (b) arable land with sound water conservancy and soil and water conservation facilities, mid- and low-yield land under remediation or can be remedied, (c) vegetable production bases, (d) agricultural research and education test fields and (e) other arable land that the State Council stipulates to include in protection; the area of basic arable land demarcated by provinces, autonomous regions and municipalities shall account for at least 80% of the local arable land area; (iii) promoting land development, reclamation and restoration; restore idle, scattered and abandoned land; improve land quality and raise the quantity of effective arable land, so as to improve agricultural production conditions and the ecological environment.

Qualitative protection of arable land includes the following aspects: (i) strictly prohibiting the discharge of industrial waste into arable land; (2) promoting conservation tillage. Conservation tillage is a farming practice that mainly uses mechanical approaches, no tillage or minimal tillage under the premise that seed germination is guaranteed; cover land surface with straw and stubble and use pesticides to control weeds and pests. The essence of this application is to reduce soil erosion, improve soil fertility and protect the environment and resources by covering land surface with crop stubble and minimising tillage. It can help to alleviate problems such as soil erosion, desertification, salinisation and degeneration of arable land.

3.2.1.2 Main Measures and Scope of Implementation

Land remediation is an urgent and important task on the Loess Plateau. It is closely related to not only the land use and sustainable agricultural development on the Loess Plateau, but also land desertification control in areas around the Loess Plateau, overall development and ecological improvement of the energy base in the northern Loess Plateau region, eradication of floods caused by the overflowing of the Yellow River and improvement of the ecological environment in Northwest China. To effectively protect arable land resources, authorities in Shaanxi province, located in the central part of the Loess Plateau, developed policies that took the national laws and regulations and the realities of the province into consideration to encourage practitioners to use crop straw cover, plant green manure and apply organic fertilisers; in addition, other farming technologies such as using soil test-based fertilisation, selective deep ploughing, crop rotation and minimum tillage or zero tillage have been suggested. The provincial administration offers support to farmers who have adopted these measures. Governments above the county levels are required to take the following measures to improve the quality of arable land: construct agricultural infrastructure, develop high-quality farmland, remediate low-yield farmland, remediate and restore disaster-induced damage on farmland; protect soil and remediate polluted soil, control soil erosion, salinisation, desertification, acidification and other problems.

3.2.1.3 Major Outcomes

Quantity of the Protected Arable Land

China's basic farmland protection efforts began in 1988, and the protected rate exceeded 80% at the end of 2009. From 2004 to 2007, the accumulated protected arable land reached 3,418,690 ha, effectively curbing the reduction of arable land (Zhong et al. 2012). According to Zhao (2011), majority of farmland resources are located in the North China Plain, the Guanzhong Plain, the Yangtze River Delta, the Pearl River Delta and the Sichuan Basin, where it is also heavily populated and economically well developed. In other words, areas in most urgent need of farmland protection coincide with the economic booming areas geographically, which not only increases the difficulty of protection efforts, but also brings regional imbalance between food supply and demand.

Quality of Protected Arable Land

The average annual loss of arable land due to soil erosion has reached 66,700 ha (Zhou and Cui 2010); with regard to salinised arable land, 73% is classified as having slight to medium pollution but it has insignificant impact on agricultural production, while 27% has a severe problem—arable land contaminated by pesticides reaches 10 million km^2, and land polluted by heavy metal exceeds 20 million km^2 (Zhang 2007). Therefore, effective measures need to be adopted to control soil erosion, salinisation, pollution and other problems of arable land. The improvement in the quality of arable land can be reflected in the increase in yield, decline in soil pollution and decrease in the soil erosion rate (Huang 2012). From 2000 to 2010, the area of arable land, in which soil erosion control measures were applied, had increased by 1.3 times; from 1978 to 2010, effective irrigation area had increased by nearly 1.35 times (Huang 2012). A study shows that the continuous growth of grain yield since 2000 is directly related to the use of agricultural plastic film and machinery, effective irrigation and improvement of production conditions (Wang and Li 2013). Quantity stability and quality improvement of arable land have led to the improvement of the overall agricultural production capacity of arable land. It is noticeable that fertilisation has improved the crop yield, but overdose of chemical fertilisers have also resulted in non-point source pollution and eutrophication in water bodies. At present, application of chemical fertilisers in agriculture still tends to increase (Zhang 2010). This will have a negative impact on farmland quality.

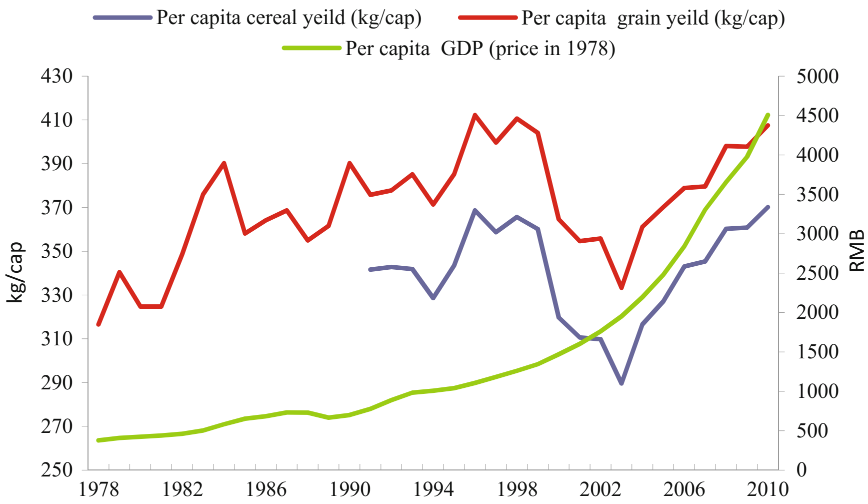

Fig. 3.1 Per capita amounts of food, grain, and GDP during 1978–2010 in China (China Statistical Yearbook 1978–2010)

Food Security

Ensuring food security is the most important objective of arable land protection policy. Even with a slight decline in grain sown area, the total crop yield and yield per unit area of China have been increasing. Since the mid-1980s, while the world's per capita share of food has declined (Chen 2010), in contrast, China's per capita share of food has increased by 50% over the past 40 years, despite a slowed growth rate after 1984 (Chen 2010). China's per capita share of food was 390 kg in 1984 and 408 kg in 2010 (Fig. 3.1). It is noticeable that the yield between the late 1990s and early 2000s was lower than the previous period; this is mainly due to the implementation of the Grain for Green Project at the end of the 1990s. The project reduced the area for agriculture, therefore causing declines in yield while the population was continuing to grow.

3.2.1.4 Weaknesses of the Policy

China's arable land protection measures have slowed down the reduction of arable land areas. The slight decline in area is mainly caused by ecological restoration programmes and agricultural structure adjustment (e.g. the proportion of grain and cash crops). Additionally, there is an increasing trend of cultivated land occupied by construction. In order to increase crop yield, farmers tend to use more fertilisers and pesticides than necessary and extract more groundwater for irrigation, resulting in depletion of water resources and overuse of chemical elements, leading to soil pollution and degradation. In order to maintain the dynamic equilibrium of the total arable land, some land of poor quality has been reclaimed so that the fertility of many newly reclaimed farmlands is not high; some cannot even be used for agricultural activity due to poor soil quality (Sun et al. 2014). Considering the varying qualities of arable land and economic developing needs, regions that cannot meet the assigned arable land protection responsibility may give compensation to other regions that are able to shoulder greater responsibility.

3.2.2 The Three North Shelterbelt Project

3.2.2.1 Policy Background, Goals and Development Process

The "Three North" refers to the northeast, northern and northwest China. These areas have a large number of desert-prone sandy lands. The desertified land in the Three North region, including the Gobi desert, spans across 1.48 million km^2, accounting for 85% of the total desertified land in China (State Forestry Administration 2008). The average annual rainfall in most parts of this region is below 400 mm. Vegetation in the Three North region was damaged and removed due to natural climatic factors and anthropogenic activities. The regional economic development is significantly restricted by sandstorms, drought and soil erosion. In order to improve the environmental quality, China launched the Three North Shelterbelt project in 1978. The Loess Plateau is one of the main implementing areas of Three North Shelterbelt project. The key measures of ecological restoration are planting trees for protection, planting fruit trees for cash and conserving soil and water resources. According to the plan, this project is expected to end in 2050. It is divided into three stages: the first stage is from 1978 to 2000; the second from 2001 to 2020; and the third from 2021 to 2050. By 2020, forest coverage is expected to reach 12%, and by 2050, the forest coverage shall be maintained stably at 15%.

3.2.2.2 Main Measures and Scope of Implementation

The Three North Shelterbelt Project has been implemented in 13 provinces, autonomous regions and municipalities, accounting for 42.4% of China's total land area. The Loess Plateau region, excluding the southeast part of Shanxi and southern part of Shaanxi, is one of the major implementing areas of the project (Fig. 3.2). According to the general plan, measures are diverse, such as afforestation by aerial seeding, closing hillsides to facilitate afforestation and grassland restoration, woody plantation for restoring ecological functions and services covering wind break, sand fixation, soil and water conservation, farmland and pasture protection, forest plantation for energy supply (e.g. charcoal and firewood) and commercial forests for trade. The measures applied on the Loess Plateau are mainly afforestation for trade and improvements in soil and water conservation.

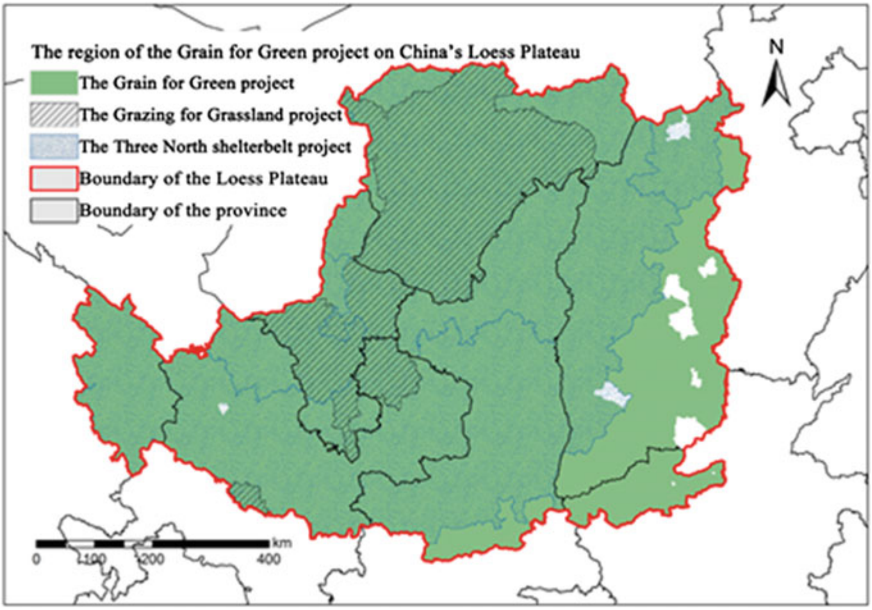

Fig. 3.2 Implementation area of various programmes in Loess Plateau Region (*Source* Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences)

3.2.2.3 Major Outcomes

Analysis by the State Forestry Administration showed that the forest coverage in the Loess Plateau Region increased from 11% in 1977 to 19.6% in 2014 after implementing the Three North Shelterbelt Project, among which 2.48 million ha was afforested in Gansu province and 2.93 million ha in Shaanxi province. Taking Jingchuan county in the gully area of the Loess Plateau (Gansu province) as an example, 82.4% of the whole area (144,000 ha) was applied with soil conservation measures including afforestation; the total afforested area was 61,100 ha (Liu et al. 2013). Another example is Zhongyang County in Shanxi province, where the soil erosion intensity was improved from extreme severe erosion to moderate erosion since implementing the Three North Project (Wang et al. 2012). Forests improve soil physical properties and air humidity while decreasing wind speed and air temperature. However, some studies also showed that afforestation reduces water yield in Northwest and North China during the spring time, while it increases water yield in the afforested Northeast China, in addition to offsetting greenhouse gases effect and reducing sandstorms (Liu et al. 2008).

Commercial forestry development taking into account local specific conditions is an important feature of the Loess Plateau ecological restoration policies. In terms of commercial forests, the established area under the Three North Project has reached 3.7 million ha in 2010, accounting for 19.1% of the total Chinese commercial forest area. They produce an annual fruit yield (including dry and fresh fruit) of >20 million tonnes, equivalent to a value of >30 billion RMB (Liu 2010a, b). In particular, the wolfberry plantation in Guyuan (Ningxia province) increased from 40,000 to 387,000 ha, which is equivalent to a value of >140 million RMB (Lin and Zhang 2014). The fruit income has become a major source of livelihood for farmers, accounting for 42.3% of the annual per capita net income with a value of 1600 RMB per capita (Liu et al. 2013). Gansu and Shaanxi are two major provinces for commercial forest development. They have 533,000 and 1,356,000 ha of commercial forests, respectively. In contrast, the area of afforestation for charcoal and firewood amounted to 1.07 million ha, with an annual firewood output of 8 million tonnes; the area of planted fodder shrubs was more than 5 million ha (Liu 2010a, b). By 2012, the annual output of timber in the Three North region reached 6.556 million m^3.

3.2.2.4 Weaknesses of Three North Shelterbelt Project

Man-made forest ecosystems in the Three North area are vulnerable. Frequent natural disasters (e.g. drought), plague of insects and poor management have led to some unsatisfactory outcomes. According to the State Forestry Administration (Huang et al. 2012), shelterbelts have shown evidence of degradation. Fifteen per cent of the total afforested area has degraded (Yang and Liu 2015). The main problems are low survival rate of woody plantation, high replanting rate and poor management and low forest quality. These problems weaken the implementation results and hamper achieving the desired effect of restoring vegetation and combatting natural disasters. Additionally, there are severe conflicts in land demands among agriculture, forestry and animal husbandry.

Moreover, the climatic condition is harsh (e.g. precipitation and temperature) and varies significantly across the Three North area. Applicability of large-scale afforestation over the vast area is still a matter of dispute. Yan et al. (2013) argued that most of the areas in the Northeast and North China Plain and the Loess Plateau region, where water constraints are relatively small, are suitable for afforestation, whereas most areas in the Northwest and northern desert, where water constraints are high, are not suitable for afforestation.

3.2.3 The Grain for Green Project

3.2.3.1 Policy Background, Goals and Development Process

Cultivation on slopes contributes to food production, but also removes permanent land cover and exacerbates soil erosion. The rooted cause for the catastrophic floods of China in 1998 was the failure to alleviate flash floods due to severe soil erosion at both upper reaches of the Yangtze River and the Yellow River (Yang 2013).

This resulted in increased amount of sediment yield into rivers, raised riverbeds and reduced discharging capacity of river networks. It was within this context that China's policy to return slope farmland to forests was formulated and issued. The goal of the policy is to improve the ecological environment, increase vegetation coverage and improve soil and water conservation capacity.

The Grain for Green Project was introduced in 2000; its original ecological target was to increase land surface cover and to improve environmental quality through returning degraded farmland to forests. However, significant socioeconomic changes had taken place in China, thus this policy has also been since fine-tuned by adding more socioeconomic objectives over the last 15 years. In general, the Grain for Green Project serves two purposes: ecological restoration and poverty alleviation. Compensation is paid to participating farmers (Table 3.2). Local governments are responsible for work related to adjusting industrial structure in rural areas, increase farmers' income and advance the process of urbanisation through the Grain for Green Project. The first phase started in 2001 and completed in 2010. During the first phase, 1.47 million ha of degraded farmland and 1.73 million ha of barren hilly land have been afforested. The grass coverage has increased by 4.5%. In 2013, the central government was determined to continue promoting this policy. The new target is to increase 2.8 million ha of forestland by 2020 through afforestation on slope farmland with an inclination greater than 25°, farmland with a slope inclination between 15° and 25° in areas of vital water sources and severely eroded arable land.

3.2.3.2 Main Measures and Scope of Implementation

The Grain for Green Project is implemented according to the following guidelines: return arable land to forest or pasture, close hillsides to facilitate afforestation, provide financial and grain support and clarify individual ownership by contract. Specifically, the government provides participants a given amount of grain plus payments for afforestation costs and living expenses within a certain period of time for an approved afforestation area (Table 3.2). In terms of afforestation, using county as a management unit, an afforested area shall be at least 80% of the returned farmland. For plantation of commercial forests that exceeds 20% of the area of returned farmland, the government will only provide subsidy for afforestation costs, while grain and living expense compensation will not be provided. Project participants will have the contract user right of the forest or pasture on the returned farmland and the contract term may be extended up to 70 years. Upon expiration of the contract term, the contractors may renew contracts with the government in accordance with relevant laws and regulations. Farmers are entitled by law to inherit and transfer the contract, including the right to manage afforested land and forest on it.

During the formulation and implementation process, several departments affiliated to the State Council are involved in the different stages for different tasks. For instance, the Leading Group for Western Region Development is responsible for

Table 3.2 Payment standards of the Grain for Green project across China

Subsidy standards (RMB/ha/year)			2000–2007		2007–2014		Rate of change	Payment standards of the revised grain for green project in some regions of China (2014–2020)
			Grain value	Cash	Grain value	Cash	Cash	
Nationwide	Yangtze River Basin and South China		3150	300	3150	1575	+425%	Payment for afforestation is 22,500 RMB per ha, in which 4500 RMB for sapling costs and the cash subsidy is 18,000 RMB (paid in three instalments: 7500 RMB in the first year, 4500 RMB in the third year and 6000 RMB in the fifth year); the payment for grass plantation is 12,000 RMB per ha, which is paid in two instalments: 7500 RMB (including 1800 RMB sapling cost) in the first year and 4500 RMB in the third year
	Yellow River Basin and North China		2100	300	2100	1050	+250%	
The loess plateau	Shaanxi province		2100	300	2100	1050	+250%	New payment standards became effective in 2014. The payment, including grain and cash subsidy, was 2400 RMB/ha/year before 2014. For Yan'an city, new payment standards started in 2013
	Ningxia Hui autonomous region		2100	300	2100	1050	+250%	No new standard
	Inner Mongolia autonomous region		2100	300	2100	1050	+250%	No new standard
	Gansu province	Yangtze River Basin part	3150	300	3150	1575	+425%	New payment standards became effective in 2014
		Yellow River Basin part	2100	300	2100	1050	+250%	

(continued)

Table 3.2 (continued)

Subsidy standards (RMB/ha/year)			2000–2007		2007–2014		Rate of change	Payment standards of the revised grain for green project in some regions of China (2014–2020)
			Grain value	Cash	Grain value	Cash	Cash	
	Shanxi province		2100	300	2100	1050	+250%	New payment standards became effective in 2014
	Qinghai province	Yangtze River Basin part	3150	300	3150	1575	+425%	No new standard
		Yellow River Basin part	2100	300	2100	1050	+250%	
	Henan province	Yangtze and Huaihe River Basin part	3150	300	3150	1575	+425%	No new standard
		Yellow and Hai River Basin part	2100	300	2100	1050	+250%	

coordination and arrangements for policy formulation and actions of implementation following plan; the State Forestry Bureau is responsible for preparing general and annual plans, guiding and supervising the implementation; the Ministry of Finance is responsible for allocation and supervision of the national budget and expense; the Ministry of Agriculture is responsible for plans of grassland restoration on returned farmland, providing technical support and supervising implementation; the Ministry of Water Resources is responsible for providing technical instructions for watershed management and soil and water conservation; the State Grain Administration coordinates and manages for grain distribution. Local governments at or above the county level undertake actual local implementation according to the plan. The central government covers the costs of preparation and technical support for the local government, but inspection and other relevant expenses incurred at the local level shall be covered by the finance departments of the local governments, while inspection and other relevant expenses incurred at the central government level shall be covered by the Ministry of Finance. The governments of provinces, autonomous regions and municipalities take full responsibility of task implementation (State Council 2002).

During the early years of the policy implementation on the Loess Plateau (2000–2007), the annual livelihood subsidy was 1500 kg raw grains and 300 RMB in cash per ha. Grain and cash subsidies were paid for a term of 8 years in the case of ecological forest plantation, 5 years in the case of commercial forests or 2 years in the case of pasture plantation. The value of raw grain was calculated at the price of 1.4 RMB per kilogramme. The sapling subsidy was 750 RMB per ha for afforested land. After completing the whole term, participants may cut trees upon approval by relevant authorities, as long as the ecological function of the forest will not be affected. After 2007, the cash subsidy was changed to 1050 RMB per ha. Local governments are allowed to raise the subsidy in accordance with the local situation (State Council 2007).

In 2014, the Grain for Green policy was modified (mainly in terms of payments); moreover the proportion of afforestation (ecological and economic forest) out of the total area is no longer restricted. Table 3.2 summarises the detailed payments across China. The Grain for Green project is implemented in four areas of the Loess Plateau: the sandy hills (6.5 million ha), the gully area of loess hills (21.9 million ha), and the Loess Plateau (3.3 million ha) and the farmland shelter area on fluvial terraces (Fig. 3.2) (Song 2007). The plan set for Shaanxi, Shanxi and Gansu provinces to afforest on the Loess Plateau were 40,000 ha, 10,000 ha and 43,300 ha in 2014, respectively (FDSP 2014; Zhang 2014; Shao 2015).

3.2.3.3 Major Outcomes

The Grain for Green project has profound ecological and socioeconomic impacts (Xu et al. 2007). We show the effects of the project from both aspects in the next section. Our data are mainly from the national reports on social and economic benefits of key projects. These data were collected from monitoring stations at 119 villages in 100 counties, covering 1156 farmer households, among which 48 counties, 58 villages and 580 households are located in the Yellow River Basin.

1. Ecological Outcomes

Forest Cover

The Grain for Green project increases forest resources. The forest cover has increased from 20.4% to 25.3% from 1998 to 2013 (Report on Social and Economic Benefits of National Key Forestry Projects 2014). Due to the shift in land use, the profit made from the afforested land was generally lower than that of the previous farmland. The average loss for participants was about 6000 RMB per year. Returning to pre-project use appears in some afforested areas (Report on Social and Economic Benefits of National Key Forestry Projects 2014).

Restored Area

The land cover has increased by 11.5% on the Loess Plateau from 2000 to 2008; the annual sediment load in the Yellow River has significantly reduced, dropping from 1.6 billion tonnes in the 1970s to less than 0.3 billion tonnes (Zhou and An 2014). By the end of 2013, the total afforested land in the Ningxia Hui Autonomous Region was 0.87 million ha, of which afforested farmland was 0.31 million ha and afforested barren hills was 0.51 million ha (Ningxia Forestry 2014). By the end of 2012, the total afforested land in Gansu Province was 1.88 million ha, of which afforested farmland was 0.67 million ha and afforested barren hills was 1.06 million ha (Shi 2013).

Survival Rate of Afforested Trees

The survival rate here refers to the ratio of the number of surviving trees against the number of planted trees within the first 3 years after afforestation. The national survival rate of trees planted under the afforestation project was 85% (Liu et al. 2011). Although the national rate is high, the survival rate is low in many regions, particularly in the arid and semi-arid parts of China (Cao et al. 2007). Use of non-native species that are hard to adapt to local natural conditions is the main cause (Xu et al. 2014). In order to receive subsidy, replanting trees on barren hills and wasteland to raise the survival rate is a common phenomenon, which not only increases the cost of investment, but also impairs ecological functions (Xu et al. 2004). Barren hills and wasteland in dry area normally have poor soil and water conditions, such as in the gully area of the Loess Hills; frequent droughts make it very difficult for trees to survive. Moreover, the ownership of barren hills and wasteland is often not clear, thus there is a lack of management after afforestation. All these factors led to a low survival rate of planted trees (Jia 2007).

Soil Conservation

Soil conservation can be reflected in the reduced number of sandstorms, degraded area and soil loss. According to the observations of 57 weather stations in the Loess Plateau region during 1958–2000, the occurrences of sandstorms on the Loess

Plateau have decreased significantly in the past four decades (Liu and Zhang 2013). The yearly number of sandstorms in Shaanxi province has dropped from 100 days to 35 days between 2000 and 2014, shown in the report on Monitoring and Assessment of Ecological Environment of Shaanxi province. During 1998–2006, the soil erosion area and the soil erosion rate in the Yellow River Basin have decreased by 37.4 and 11.6%, respectively (Report on Social and Economic benefits of National Key Forestry Projects 2008).

2. Socioeconomic Outcomes

Impact on Farmers' Income

The Grain for Green Project has changed land-use patterns with economic consequences. It leads to excessive rural labour and affects the income of farmers. In contrast to pre-programme, the composition of rural income has changed. The percentage of income from cultivation has dropped significantly in terms of total income of rural households, while the parts from forest, livestock breeding and other sidelines have increased (Zhao et al. 2010). Meanwhile, the project has also caused massive labour relocation from rural to urban areas, from the agriculture sector to the non-agricultural sectors such as the secondary and tertiary industries (Chen et al. 2009; Feng and Xu 2015). This has increased farmers' income and alleviated poverty on the one hand, but also caused loss of rural labour, decreased cultivation activities and increased abandoned arable land that have adverse effects on agricultural development. Yet, exceptions exist outside. Studies in Ningxia found little evidence for participating farm households having shifted labour to alternative off-farm activities due to lack of mobility, low education and preference to stay on the farm (Uchida et al. 2007; König et al. 2014).

In 2013, the net income per capita in rural areas of monitored counties was 6230 RMB, representing an increase of 9.2% compared to 2012 after adjustment for inflation (Report on Social and Economic Benefits of National Key Forestry Projects 2014). Moreover, project implementation has changed the traditional farming practices on the Loess Plateau and gave farmers more opportunities to engage in non-traditional agricultural activities. In 2013, the top three sources of farmer income in sampled counties were dry fruits, herbs and vegetables, while benefit from converted land accounted for only 30.7% of the households income in 2013 (Report on Social and Economic benefits of National Key Forestry Projects 2014). Therefore, the output of converted land has failed to become a major source of farmers' livelihood.

Food Production Capacity

Food production capacity is determined by the area of arable land and the grain output. The Grain for Green project has induced a slight decline in the total area of arable land. At the early stages of the project, grain yield displayed a short-term declining trend (Fig. 3.1). Nevertheless, the pre-programme grain yield on slope farmland was low; hence the project posed only an insignificant impact on food security in China. Moreover, the government made large investments in the development of agricultural infrastructure and associated subsidies, enabling the increase of grain yield per ha and total output (Liu 2009). In 2013, the grain output in observed counties increased by 24% in comparison to 1998, for which reason food security had not deteriorated (Report on Social and Economic benefits of National Key Forestry Projects 2014).

3.2.3.4 Weaknesses of the Grain for Green Programme

The Grain for Green project has improved land degradation and utilisation and brought economic benefits for local farmers. These advantages are more visible during the period of payment. Pressures on diversifying and increasing income and supporting rural livelihood increase in post-payment period. Hence, keeping the planted trees and grasses on land is a big challenge. Converting the land to its original use is easy to happen if no alternative is possible for rural households. How to achieve a synergy between environmental restoration (forest and grassland), agricultural development and socioeconomic benefits is a problem requiring urgent attention.

In addition, Cao (2008) argued that large-scale afforestation may lead to higher soil erosion in the long run as a result of planting non-native fast-growing tree species (e.g. Pine, Locust and Poplar), leading to water stress, tree mortality and damages to the existing native species (Cao et al. 2009). These problems make it more difficult to sustain and improve forest quality (Cao 2011). Farming activities on medium- and high-yield arable land are poorly managed. The main reason is lack of knowledge and guidance. Additionally, owing to the top-down approach, implementation and efforts have been applied in a simple way, namely one way in every aspect, including choice of plant species and spatial arrangement (Song et al. 2006).

3.2.4 Return Grazing Land to Grassland

3.2.4.1 Policy Background, Goals and Development Process

Natural constraints, climatic factors and human activities such as overgrazing have induced adverse impacts (e.g. degradation) on 90% of Chinese natural grassland with varying degrees. This not only harms the grassland ecosystem and associated animal husbandry, but also has negative influences on the sustainability of regional development. In 2002, the programme Returning Grazing Land to Grassland was announced for 11 provinces and autonomous regions in West China. A modification of this policy was made in August 2011. It is designed to restore grasslands, improve the productivity of grassland ecosystems and promote the co-development of ecology and economy. The goals of implementation are to restore degraded grassland and rangeland, establish grassland protection mechanisms, promote rotational grazing systems, adapt stocking methods and livestock species, raise and stabilise farmers' income and improve the household responsibility system (Bao 2006).

3.2.4.2 Main Measures and Scope of Implementation

In 2003, the State Council issued the measures for Returning Grazing Land to Grassland (Table 3.3). This programme is a joint effort of the central government, local governments and individual farmers and herders. Grazing ban, rotational and seasonal grazing and payment for compensation are the main measures. This programme has been implemented only in a few places of the Loess Plateau region and to a large extent in Ordos (Fig. 3.2).

Table 3.3 Summary of measures for the Returning Grazing Land to Grassland programme

Year	Major measures	Details
2003	Household responsibility system	Lease grazing land to individual household for management, issue grassland use right licenses to participating herders, and define their rights and obligations
	Determine livestock numbers and stocking rate based on grassland carrying capacity	Control livestock number and prevent grazing on banned area or rotational grazing according to pasture carrying capacity, prevent overgrazing and achieve ecological-economic balance
	Payments in forms of cash and forage	Forage subsidy is available for no-grazing and seasonal grazing (three months no-grazing), but not for rotational grazing. Herders who undertake no-grazing and seasonal grazing will receive 82.5 and 20.6 kg forage per ha per year; a subsidy of 247.5 RMB per ha is paid for herders who build fence around the own pasture. 70% of the subsidy is paid by the central government and 30% by the local governments; the value for provided forage is 0.9 RMB per kg. Forage subsidy will be paid for a period of five years. Provincial government may adapt the standards of subsidies to the local situation
	Provincial governments take full responsibility for implementation	Provinces and autonomous regions receive tasks, funds and forage from central government and then distribute tasks and funds to governments at municipal, county and township levels and build accountability in local governments

(continued)

Table 3.3 (continued)

Year	Major measures	Details
2011	Construction of fence	Construction of fence for rotational grazing and seasonal rest are priority of the programme. Implementation is expanded to Karst region
	Build livestock stables and cultivate man-made grassland	Build a livestock stable of 80 m^2 for each participating household who does not have one. Plant grass in areas where water condition is favourable for growth to overcome forage shortages
	Raise the contribution of investment and subsidy from the central government	Central government increased the contribution to payment for fence construction from 70 to 80%. For fence construction in the Qinghai–Tibet Plateau, the subsidy was increased from 262.5 RMB per ha to 300 RMB per ha, while in other areas it was raised from 210 RMB per ha to 240 RMB per ha. The seedling subsidy for plantation was raised from 150 RMB per ha to 300 RMB per ha. The subsidy for man-made grassland construction is 2400 RMB per ha and the subsidy for building livestock stable is 3000 RMB per household

3.2.4.3 Major Outcomes

The coverage of grasslands in Ordos has increased from 30 to 75% from 2000 to 2010, while the forage yield increased by 30% on sandy land and mountain ridge and the vegetation structure has significantly improved as well (Liu 2010a, b). Addition benefits for controlling soil erosion by water and wind and increasing biodiversity with vegetation restoration are also significant (Wang 2006). Animal husbandry is the main income source for herder households. Study in Uxin Banner of Ordos in Inner Mongolia showed the total income of herders had increased generally from 1998 to 2010, but there was a slight downward trend after 2005 (Gao et al. 2013). Grazing bans and seasonal grazing make it inevitable to add additional fodders for animals resulting in a rise in expenses, because it is impossible to support the livestock solely relying on the forage supplied by the state (Bao 2006). Other studies also found that the proportion of income from non-grazing work has increased by 8% whereas the proportion of animal husbandry income fell by 14% (Tian 2011; Zhen et al. 2014; Du et al. 2015).

3.2.4.4 Weaknesses of Return Grazing Land to Grassland Policy

Some problems are recognised during the implementation of the Returning Grazing Land to Grassland programme. First, payment standards are not very reasonable and regulations could be more flexible (Nie 2008). The western pastoral areas of China are much less developed than other regions; the ability of herders to invest is very limited. The amount of subsidy provided by the state is far below the average regional income level, thus it is very difficult to motivate herders to participate in the programme without economic benefits (Fan 2003). A variety of grasslands with varying degradation degrees and carrying capacity are included in the programme, subsidy standards should be adjustable and flexible rather than applying one-size-fits-all standard (Bao 2006). Second, the programme fails to resettle the herders who are affected by the grazing ban properly. So far, no mechanism and effective programme has been formulated for this purpose. Specific pending issues are where and how to resettle them, proper incentives to support livelihoods, alternative sources of livelihoods and social inclusion. All of these problems hindered the effective implementation of the programme (Hanguan et al. 2003). Third, the programme did not offer diverse restoration methods. Appropriate measures should be adapted to specific local conditions (e.g. extent and causes) (Bai et al. 2005), with regard to grassland improvement, desertification control and pest control (Xu and Yang 2014). Fourth, social issues have emerged. The programme has changed the traditional life and production methods of herders; less attention was paid to impacts on culture during the implementation (Bao 2006). Therefore, some herders are not willing to join the programme or conduct illegal grazing in banned area, leading to conflicts and social unrest (Li et al. 2005).

3.3 Conclusion and Outlook

The fundamental goals of land-use changes on the Loess Plateau are to protect limited land resources, promote rational and effective use of land resources and maintain a healthy ecological environment and virtuous cycle. Since the adaptation of the key ecological and land-use programmes, some successes have been achieved on the Loess Plateau (Table 3.4). Despite some successes, we should not overlook the problems that occurred during the policy implementation. Essential ones are, such as arable land protection only focuses on dynamic equilibrium of quantity without paying attention to the quality. To ensure sustainable agricultural development and food security, every region should define the area and size of arable land that needs to be protected. Due to distinct differences in land resources and economic demand, some regions may not be able to fulfil the tasks of land protection. Such regions may pay other regions that are able to achieve more land protection for them. Alternative options and flexible regulations are required during application.

The Three North Shelterbelt project is conducted in a typical top-down approach: subsidy is received from the state and tasks allocated by local

Table 3.4 Achievements of the major land-use programmes

Policy	Ecological and socioeconomic benefits
Arable land protection	Area and quality of arable land have been controlled and improved for ensuring food security; restore salinised land and raise irrigation efficiency
Three North Shelterbelt	Land cover, especially forest cover, has increased; soil structure has been improved; area of eroded and salinised land has reduced
Grain for green	Forest and grassland cover have increased; survival rate of woody plantation in relative humid areas is high; sandstorm has been mitigated; soil loss and erosion on steep slopes have been minimised; sediment yield in main streams and rivers has been reduced; farmers' income and grain yield have been improved
Returning Grazing land to grassland	Introduction of rational grazing; improvement in grassland coverage, quality and biodiversity; diversifies farmers' and herders' income

governments and implemented by local stakeholders; there is a lack of sufficient financial support and technical guidance; the success of the project largely deteriorated, particularly associated with improper selection of tree species, uniform implementation standard and one-size-fits-all measures without spatial differentiation. The implemented area is economically less developed in China, high investment by local government in subsidies and compensation has overburdened local finances and causes financial deficits. Effects of the project cannot be guaranteed without training and educating local implementers. Therefore, the expected outcomes are not realised. Similar problems also exist for the Grain for Green programme. The feasibility of the programme has not been sufficiently scientifically proven before application. Theoretical guidelines and local technical support were not formulated and organised prior to application. The measures of such a large comprehensive ecological restoration project are simplified to large-scale afforestation and grass plantation. There is no landscape design for woody and grass plantation on returned farmland; some regions conducted vegetation restoration (e.g. afforestation) on non-suitable sites. The Returning Grazing Land to Grassland Policy has four main problems: inadequate subsidy standard and inflexible policy, no support for resettlement of ecological migrants, uniform application method without landscape design and illegal grazing. Scientific debates and evidences are needed for rational measures to be taken and policymaking.

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Chapter 4
Multifunctional Agriculture and the Relationship Between Different Functions

Lin Zhen, Wenping Sheng, Chao Wang and Lulu Zhang

4.1 Introduction to Services of Agriculture

An agricultural ecosystem is a compound ecosystem coupled with social, economic and natural systems, thus provides social, economic and ecological services. Ecological services of the agricultural system mainly cover three aspects, namely ecological foundation, ecological conservation and ecological stress. Economic services of agricultural systems consist of agricultural production outputs and recreational benefits, while social services mainly include job opportunities, livelihood support, leisure and entertainment (Swinton et al. 2007).

Globally, agricultural ecosystems are primarily managed for food, fibre and fuel (Swinton et al. 2007; Zhang et al. 2007). With about 25 million ha of cultivated land, the Loess Plateau has been a centre for cultivation in northwestern China for 7000 years due to its fertile land (Zhao et al. 2013). The cultivated land of China covers a total area of 95 million ha, 65% of which is located in northern and northwestern China. However, the water resource in the area is in shortage, accounting for only 20% of the total of the whole country. For this reason, dryland (rain-fed) agriculture constitutes 70% of the total farmland in northern and northwestern China (Deng et al. 2006). Nowadays, the importance of food production has become more and more critical due to an increasing demand for agricultural products resulting from rapid population growth and economic development.

China launched a series of ecological restoration policies relating to cultivated land in the late 1990s. The Grain-for-Green policy, the largest land

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retirement/afforestation program in China, was launched in 1999 to mitigate land degradation (soil erosion) by returning steeply sloping cultivated land to forest area or grassland. The Grain-for-Blue policy was launched in 1998, aiming to return cultivated land to water areas, that is, relinquishing the cultivated land at the periphery of water areas. In the areas where the Grain-for-Green and Grain-for-Blue policies have been implemented, ecosystem service values increased by 24 and 43.1% during 2000–2008, respectively (Song et al. 2015).

The extension and reduction of the area of cultivated land has a strong spatial heterogeneity on the Loess Plateau. During the period of 1990–2000, the increased cultivated land was mainly located in Ningxia Hui Autonomous Region while the cultivated land in Inner Mongolia was diminishing (Fig. 4.1). From 2000 to 2010, there were more drastic changes in the plateau's cultivated land, with increases mainly in northern Inner Mongolia, central Ningxia, northwestern Shaanxi and western Shanxi, and decreases mostly in the middle and south of the Loess Plateau.

In addition to primary production, appropriate on-farm management practices can also enhance a number of other ecosystem services, such as pollination and pest control, soil fertility and conservation, water regulation and carbon sequestration (Power 2010; Swinton et al. 2007). Winter wheat (35% in area) and maize (30% in area) are the dominative crops in the Loess Plateau, and the agricultural management, like agroforestry or crop rotation with other cash crops, may improve the ecosystem services of pollinators and pest control. Soil erosion is severe on the Loess Plateau and undermines agricultural sustainability (Wang et al. 2016b). It is, hence, vital to conserve soil and maintain soil fertility to sustain agricultural productivity. Soil conservation measures, such as conservation tillage or no tillage and use of stubbles and straw cover, can prevent surface runoff and associated soil and nutrients loss, as well as improve soil quality. Meanwhile, they could improve soil infiltration, soil water available for plants and groundwater recharge. In this aspect, such on-farm practices can be regarded as a mitigation measure for water resources in areas where water is scarce. Based on the calculation with the revised universal soil loss equation (RUSLE) during the period of 1990–2010, the annual average

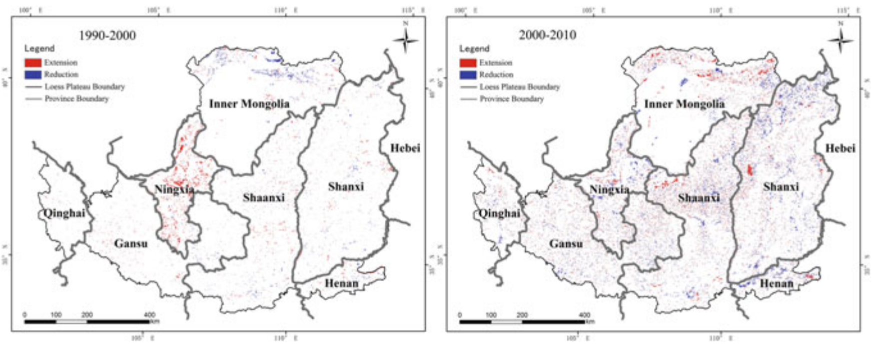

Fig. 4.1 Net change of cultivated land on the loess plateau during 1990–2000 and 2000–2010 (*Source* CAS Data Center for Resources and Environmental Sciences)

Table 4.1 Soil retention of different ecosystems on the Loess Plateau (Sun et al. 2014)

Type of ecosystem	Annual average amount of soil retention per unit area (t/ha·a)		Annual average amount of soil retention (10^8t)	
	1990–2000	2000–2010	1990–2000	2000–2010
Farmland	249	265	49	52
Forestland	640	688	54	64
Grassland	285	293	78	76

Note The amount of soil conservation in the table was calculated by the revised universal soil loss equation (RUSLE), $A = R \times K \times L \times S \times C \times P$, where A is the annual soil erosion rates (Mg ha^{-1} a^{-1}), R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} a^{-1}), K is the soil erodibility factor (Mg ha^{-1} a^{-1} per unit R), L is the slope length factor (dimensionless), S is the slope steepness factor (dimensionless), C is the cover management factor (dimensionless), and P is the support practice factor (dimensionless)

amount of soil conserved by agriculture on the Loess Plateau is 190×10^8 t, still lower than that retained in forest- and grassland (Table 4.1).

Furthermore, agriculture can enhance carbon storage and offset greenhouse gas emissions through various management measures (Lal 2008; Smith et al. 2008). Planting legume species or applying legume-cereal rotation can reduce CO_2 emission and increase N use efficiency. This will decrease the input of synthetic fertilisers and related NO_x and N_2O emissions (Power 2010). Additionally, agricultural land (rangeland in particular) can be used for bioenergy production that captures carbon through photosynthesis during plant growth, leading to increase in carbon sequestration on the one hand, while it, on the other hand, alleviates the national energy crisis (UNDESA et al. 2000). Surplus residues of crops from agricultural land, such as cereal and corn straw, can support the important ecosystem service, bioenergy production (Elmore et al. 2008). As a traditional agricultural region, the Loess Plateau has abundant crop residues (230.2×10^4 t/a); however, the utilisation of crop residues for energy is less developed than that in most other regions of China (Xu et al. 2013).

Agriculture is one of the major sources of support for rural livelihood (Wang et al. 2016a). Between 1990 and 2012, cultivated land-based income on the Loess Plateau presented an upward trend. In general, the peripheral parts of the Loess Plateau generate higher financial benefits than the central parts. Low-profit areas (e.g. Ordos region and northern Shaanxi province) commonly suffer from severe soil erosion and land degradation. As a result, the grain yield is generally low, whereas insufficient income in western Shanxi and Qinghai province are mainly attributed to limited area of cultivated land. In contrast, plentiful cultivated land with high grain yield and rising grain prices ensure a significant increase in cultivation-based income in other areas. Other benefits including recreational benefits (e.g. Nongjiale) and cultural heritage of rural life are also valuable services provided by agricultural landscape; yet, their valuations are particularly difficult (Ferretti and Comino 2015).

4.2 Interlinkages Between Primary Production Service and Other Services

Social, economic and ecological services are inextricable. Unquestionably, the production of food is the main task of agriculture, but the relationship between it and other services is influenced by management practices and also by policies. For instance, the increase of biomass production will have positive effects on food security. With more grain yield to support the increasing food demand, a region can meet a high ratio of self-sufficiency. At the same time, increased grain yield generates more straw and crop residues that enhance the service of bioenergy provision. Moreover, the growing primary production can lead to more agricultural income for farmers, which can be seen as the improvement of livelihood service. However, the increase in primary production is often achieved by greater use of resources and inputs, including land, water, fertilisers and pesticides, which may damage services such as ecological foundation and ecological conservation. Therefore, the ecosystem services provided by agriculture are not independent; moreover, the relationships between them are interactive and dynamic and change with the applied management practices, in which trade-offs are inevitable. In general, for agriculture, the problems are commonly related to trade-offs between provision services (e.g. primary production such as food, fibre and fuel) and regulation services (e.g. soil and water conservation, carbon sequestration) (MEA 2005). They are also the typical matters that the Loess Plateau region has to deal with now and in the future.

4.2.1 Primary Production and Food Security

Food self-sufficiency (or security) is a central issue in Chinese agriculture as the country has to feed 20% of the global population with only less than 9% of the world's cultivated land (Chen 2007). After 2000, a set of environmental programs were launched (Xu et al. 2006) and the cropland decreased by 1.02×10^6 hm^2 (Liu et al. 2014a, b). The Chinese urbanisation level was 18% in 1978 and increased to 40% in 2003 presenting a rate double of the global average; moreover, the level of urbanisation will continue growing and is projected to reach 50% by 2020 (Chen 2007). Urbanisation needs support from food and natural resources, but it also brings other problems to the environment (Chen 2007), such as loss of cultivated land and resources deterioration through accumulation and dissemination of waste. The total Chinese cultivated land is decreasing and now only 13% of the total land area is available for agriculture (Chen 2007). Similarly, the sown area in the Loess Plateau suffered a contraction from 1990s to 2010s. Such changes were attributed to the implementation of policies such as the Slope Land Conversion Program (also known as Grain for Green) since 1999. The loss of cultivated land affects primary production and indirectly poses a challenge to food security. For example, grain production in 2003 fell by 15% in comparison with 1999 (Xu et al. 2006). But some studies also showed that even though the area of the cultivated land is shrinking, the Grain-for-Green policy is not fully responsible for the reduction in yield, because the target of the policy is poorly cultivated land and remote mountainous areas, whose yields are only 30–50% of non-programmed cultivated land and the loss of yield accounts for only 10% of the total reduction (Feng et al. 2005; Uchida et al. 2005; Xu et al. 2006). But there is still growing concern that despite increasing grain yield of non-policy arable land (including wheat, maize, millet, buckwheat and potatoes), the grain demand is also increasing as a result of population growth and improved living standards, therefore, grain production is significantly being undermined by the loss of farmland for ecological conservation. Accordingly, the grain losses lead to serious worries about regional food self-sufficiency and may lead to a need to import food from outside the Loess Plateau region (Zhen et al. 2014), even though the food pressure is relatively slight in the region. Statistics show that Inner Mongolia (northern Loess Plateau) has the highest grain yield per capita (680 kg/cap) in 2012, which is above the national food security standard (400 kg/cap). This is attributed to the relative small population and a large area of cultivated land. In contrast, Qinghai province has the lowest grain yield per capita (216 kg/cap), which is below the food security standard due to the fact that Qinghai belongs to the alpine zone, thus has limited cultivated land and relatively low gross grain yield (Fig. 4.2).

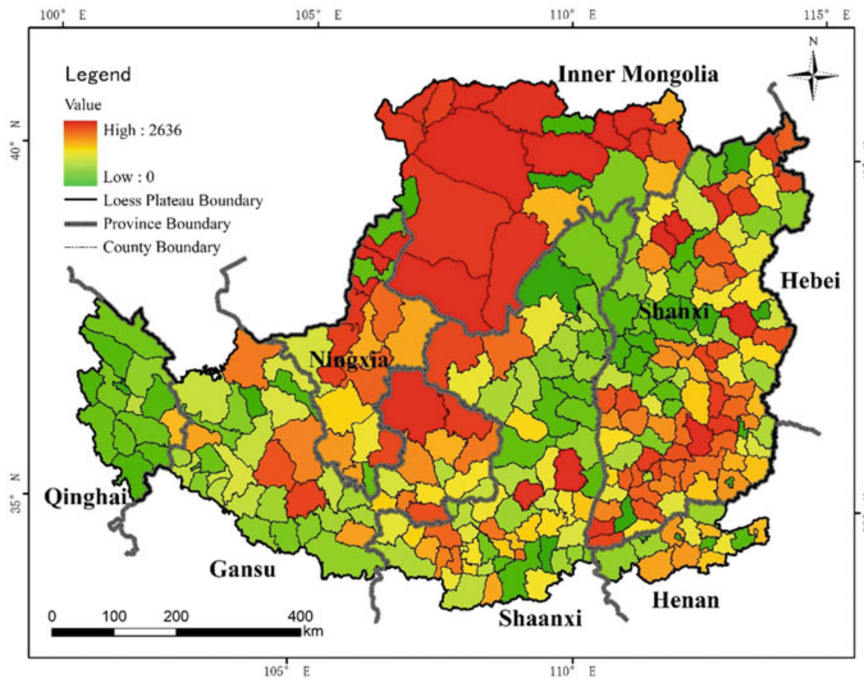

Fig. 4.2 Grain yield per capita on the Loess Plateau in 2012 (kg/cap) (China Statistical Yearbook 2012)

4.2.2 Primary Production and Soil Security

The Loess Plateau region is important for China's food and energy production, but severe soil erosion undermines the environmental sustainability of the region. Modern soil erosion of the Loess Plateau is a typical process resulting from both natural forces and inappropriate human activity, which occurs at a much higher rate than it ever happened before (Zhao et al. 2013). In Shuanglong catchment, the erosion rates estimated by Cs-137 averaged at 2133 $t/km^2 \cdot a^1$ under tillage and abandoned farmland over the erosion rate of non-cultivated sites (Niu et al. 2015). Agricultural intensification removes nutrients out of the soil faster and without efficient replenishment. In fact, the maintenance of soil fertility is vital for sustaining primary production and keeping the soil fertile at places. Organic matter in the soil provides necessary mineral nutrients for crop growth; additionally, 50% of soil organic matter is carbon that is essential for soil structure. Decomposed products can hold the mineral particles together to form soil aggregates (5–2 mm), which are basis for soil structure and responsible for porosity, infiltration and soil and water conservation (Swinton et al. 2007). Long-term cultivation, especially on steep slopes, stimulates soil erosion. Therefore, intensified agriculture accelerates soil erosion and degrades soil quality at a non-renewable rate that threatens national primary production and soil security.

4.2.3 Primary Production and Water Security

Water shortage is the main constraint for crop production in dryland areas (Debaeke and Aboudrare 2004). The Yellow River Basin receives an annual water supply of an amount of 750 m^3/capita, which corresponds to only 75% of the internationally accepted threshold of water shortage (1000 m^3 per capita) (Khan et al. 2009). Although the water availability per hectare of cultivated land in northern China is only 12% of southern China, the actual grain production has increased by 18% across the Loess Plateau during the period of 2000–2008, which is a result of agricultural intensification. At the same time, runoff has decreased at an average rate of 10.3 mm/a (Fig. 4.3) (Lü et al. 2012).

The observed decrease in the runoff of the Yellow River reflects both climate change impacts and over-extraction of water for irrigation, industry and domestic usage (Zhang et al. 2009). Excessive groundwater use happens in 70% of the North China Plain area and results in a decline of water table by 2 m/a in some areas (Khan et al. 2009). Worse, the excessive use of groundwater brings additional problems, including salt water intrusion, soil salinity and compaction, land subsidence and high costs of pumping and energy use. As a consequence, zero flow happens in lower reaches of the Yellow River (Wang et al. 2006). Increased withdrawals explain about 35% of the declining runoff observed at the Huayuankou station in the lower reaches over the last half-century (Fu et al. 2004). It means that

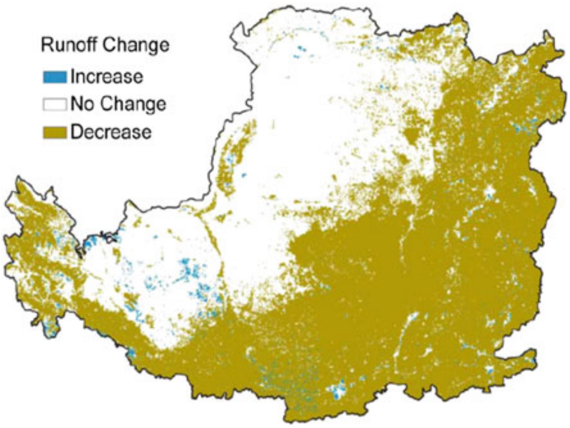

Fig. 4.3 Average water yield change due to land-cover change from 2000 to 2008 (Lü et al. 2012)

even for such a heavily managed river, the climate is dominant in controlling runoff. However, climate change impacts on water resources and agriculture would have been limited both because climate trends remained moderate compared to natural variability, and because of the overriding benefits delivered by technological progress, in particular improved agricultural practice (Piao et al. 2010).

Inefficient water use in agriculture is another issue contributing to water insecurity in the dryland of China. The water use efficiency (WUE) of grain production in the northern part of China is reported to be at around 0.9 kg/m^3 (Deng et al. 2006; Peng 2011), while it used to be 0.23 kg/m^3 in 1949 (Xu and Zhao 2001). Despite the improvement, the current crop productivity of water in northern China is still low accounting for only 50% of productivity in developed countries and even less than 40% of that in Israel (2.32 kg/m^3) (Khan et al. 2009). Intensified agriculture featured with low water productivity can lead to enormous water loss that further deteriorates the water shortage situation in dryland areas. Besides, enhancement in WUE has been often achieved through an increase in fertiliser and irrigation application (Fang et al. 2010); overuse without caution could have negative impacts on quality of return flow, therefore, the quality of water in the main stream.

4.3 Challenges of the Current Agricultural Development

4.3.1 Soil Erosion Control

70% of the Loess Plateau area is characterised by gully-hilly landscape because of lasting massive soil erosion in the past (Zhao et al. 2013). According to the Comprehensive Scientific Survey of Soil Erosion and Water Loss and Ecological Safety in China, the Loess Plateau (with a total area of 64×10^4 km^2) has a soil erosion area of up to 39 × 10^4 km^2, including a severe water erosion area of 3.67 × 10^4 km^2 with soil erosion modulus of ≥ 1.5 × 10^4 t/km^2·a^1, which accounts for 89% of similar areas in China (MWR, PRC et al. 2010). This means, sustainable agricultural development on the Loess Plateau has to cope with soil erosion control. Frequent farming on slopes can make the soil highly susceptible to erosion; it is particularly severe on slopes with an inclination degree of 10°–25°. The slope cultivated land account for about two-thirds of the total farmland area in the Loess Plateau, and are the main source of soil and water loss in the Loess Plateau, with an average soil erosion modulus of up to 25,000 t/km^2·a^1 (Gao et al. 2012). Converting such slope land into terraces can shorten slope length and level the ground, hence it is an efficient way to prevent soil erosion and intercept surface runoff to alleviate soil erosion (Waraich et al. 2011; Zhao et al. 2013). On gentle slopes (e.g. 6°–10°), planting crops along the contour and building trenches or ridges to reduce surface runoff can efficiently reduce soil erosion (Deng et al. 2006; Waraich et al. 2011).

In contrast to monoculture, intercropping is considered to be effective in reducing soil erosion, in addition to supplementary benefits including enhanced land utilisation and higher economic return. Yet, if the intercropping system has an overall negative or positive effect on soil is still an issue with considerable debate. The use of perennial forage plants intercropped with grain crops has shown a promising option for both sustainable soil management and sustainable production in no-till systems in Brazil (Kassam et al. 2013), while crop yield reduction associated with competition for water was reported for Australia (Unkovich et al. 2003). Similarly, both evidences of competition and no competition for nutrients have been found (Thevathasan et al. 2004; Yun et al. 2012). Tree-based intercropping system is common on the Loess Plateau due to its favourable ecological, social and economic benefits (Yun et al. 2012). To obtain more benefits in ecosystem services, diverse management measures are needed to alleviate the competition between trees and crops, this will cover strategies of selecting tree species, managing tree height and crown, distance between trees and crops above the ground and root barrier under the ground in dryland agricultural systems (Gao et al. 2012; Hou et al. 2003; Reynolds et al. 2007; Yun et al. 2012).

4.3.2 Water Shortage Mitigation

The Loess Plateau has vulnerable ecosystems with water shortage. In the past nearly 50 years, precipitation has been diminishing gradually, at a rate of 0.97 mm/a on average, and over 80% of the regional precipitation returns into air through evapotranspiration (Feng et al. 2012). Such change in precipitation is one of the main causes of the change in soil moisture on the Loess Plateau—after evaporation there is no effective water replenishment to the soil, which results in reduced soil water content in most areas. Rain-fed crop yield is primarily driven by rainfall (Huang et al. 2011). The average yield in tableland areas with higher annual rainfall, for example in Qingyang, are 3.5 t/ha for winter wheat and 6.5 t/ha for maize, whereas in the hilly area with lower rainfall, for example in Dingxi, is 1.0 t/ha for wheat (Nolan et al. 2008). Owing to population growth and scarcity of water resources, one of the challenges for agricultural development on the Loess Plateau is to increase food production with less water consumption, while it can still sustain a certain level of water resources for other users.

Technologies for improving crop WUE are critical for sustainable crop production and local food security. Straw or biofilm mulch is an efficient practice that can alter water partitioning between soil evaporation and plant transpiration. Straw and biofilm mulch can prevent soil from evaporation and increase soil temperature and water availability for crop growth; thus, it is able to increase the grain yield (Kasirajan and Ngouajio 2012). Some studies showed that straw mulch treatment was capable of producing a comparable wheat yield in comparison to an application of 10–15 mm irrigation (Huang et al. 2005). However, straw mulch can only decrease water stress and increase crop yield to a certain degree owing to limited amount of soil water. Alternatively, additional complementary irrigation could further enhance yield in contrast to single straw mulch application.

A core challenge for dryland agriculture is to overcome inefficient water use in consideration of increased demand for food production. Flood irrigation is still dominant on the Loess Plateau although a more efficient system is available (e.g. furrow, sprinkler and drip irrigation) (Deng et al. 2006). The central government has made efforts to encourage use of water saving irrigation; however, there is rare evidence of extensive application because of the low benefits for farmers due to poor incentives and low budgets (Deng et al. 2006; Khan et al. 2009). Thus, adaptation of water saving technology only exists within the research community. Moreover, water-saving technology includes more than simple water saving irrigation; it refers to any farming practice that makes full use of natural rainfall and irrigation so that a high yield can be achieved with a minimum input of irrigation and a maximum utilisation of rainfall (Deng et al. 2006). This will cover not only on-farm management but also efficient management of irrigation network. In China, 55% of irrigation water leaks during delivery, whereas 44% of rainfall runoff from the field is lost (Peng 2011). Measures to enhance water interception and harvesting to mitigate water shortage in dryland areas have to be exploited in rain-fed and irrigated cultivation activities.

4.3.3 Maintaining and Improving Soil Fertility

Apart from water scarcity, lack of nutrients is another factor restricting dryland productivity. Soil nutrient varies notably among different land uses and forms on the Loess Plateau (Table 4.2). In terms of landscape, flat valleys in gully area have more organic matter (OM) and total nitrogen (N) content than any other landforms, while phosphate (P) content does not vary much among different landforms. Improving the status of soil nutrients can positively affect the WUE (Deng et al. 2006;

Table 4.2 Soil nutrients under different land uses and forms (Xin et al. 2012)

	pH	Soil Organic Matter (g/kg)	Total *N* (g/kg)	Available *N* (mg/kg)	Total *P* (g/kg)	Available *P* (mg/kg)	Total *K* (g/kg)	Available *K* (mg/kg)
Forestland	8.3	18.1	0.96	60.4	0.69	1.9	16.6	120.3
Grassland	8.4	7.7	0.58	44.2	0.55	1.4	17.0	137.1
Orchard	8.4	11.9	0.71	42.7	0.60	4.7	16.5	144.8
Terraced Land	8.3	13.1	0.91	59.2	0.59	4.0	17.7	106.0
Cultivated Slope	8.4	13.4	0.91	51.0	0.53	4.7	16.1	166.6
Average	8.3	13.0	0.80	52.2	0.61	2.8	16.8	130.2
p Value	0.72	0.03	0.07	0.31	0.23	0.04	0.79	0.46

Note $p \leq 0.05$ means the result is significant, while $p > 0.05$ means the result is not significant

Fang et al. 2010). For example, adequate N can improve the development of root systems for better water and nutrient uptake at low and medium water stress conditions (Waraich et al. 2011), while P is particularly efficient in improving root growth and WUE at moderate and high water stress levels (Garg et al. 2004; Zhang and Li 2005).

Use of chemical fertilisers to increase productivity is one of the main drivers for growth of agricultural production in China over the last three decades, which overtook the use of organic fertilisers in the early 1980s (Liu and Chen 2007). The amount applied to cultivated land is considerably high so that the N consumption is 2.5 times higher than the world average while the P consumption is 1.9 times higher than the world average; on the other hand, the fertiliser use efficiency is quite low (30–40%), accounting for only 50% of that used in developed countries (60–70%) (Zhao et al. 2008). Careless overdose of artificial fertilisers causes a series of environmental problems such as groundwater pollution and eutrophication of surface aquatic water body, threatening the local food security, human health and biodiversity (Khan et al. 2009; Zhao et al. 2008). Moreover, OM in cultivated lands is low due to a deficiency of organic fertilisers resulting in imbalance in soil nutrients and decrease in soil fertility. The use of organic fertiliser can positively affect soil quality and improve economic benefits (Jacoby et al. 2002). There are several ways to do that. Crop cover increases soil organic matter and enhances fertiliser use efficiency, while increasing the proportion of legume and green manure crops or fertility-enhancing rotation can improve soil fertility, WUE and crop yield with less investment in inorganic fertilisers (Deng et al. 2006). Therefore, to address the issue of adverse impacts of intensive cultivation on the depletion of soil nutrients, more sustainable solutions for adaptation to dryland condition and projected climate change, e.g. closing nutrient cycles using organic wastes, improving cropping system to sustain soil fertility and balancing organic and inorganic fertilisers in time and ratio should be integrated.

4.3.4 Poverty Alleviation

In China, more than two-thirds of impoverished populations live in semi-arid and arid areas (Deng et al. 2006). The number of people living below the Chinese Low Income line decreased from 87 million in 2002 to 27 million in 2010 (Wang 2013). Previous works showed that poverty has been alleviated for the most areas of the Loess Plateau region over the last decade because of improved rural income (Uchida et al. 2007; Xu et al. 2006). In agriculture, this has been mainly achieved through intensified agricultural production in combination with livestock husbandry (Uchida et al. 2007). However, this kind of high agricultural yield comes along with misuse of natural resources (e.g. abuse of irrigation and chemical fertilisers) thus unsustainable. This means, the livelihood of farmers may become unreliable and risky when the natural resources are depleted and degraded in environmentally fragile dryland. Diversifying agricultural activities and income sources under a more sustainable agricultural development can reduce the risk significantly. To eliminate the risks from external artificial inputs in conventional agriculture, alternative cultivation, such as organic farming, is considered to be environmentally sound, economically viable and socially acceptable (Zhen et al. 2005). Some studies also showed that organic farming without proper soil nutrient management can have low yield and negative economic impacts (Rahman 2003).Therefore, competition of organic agriculture to conventional products will largely depend on the breakthrough towards higher yield and lower cost to make it more economically beneficial.

In addition to livestock breeding, eco-agriculture including agroforestry can contribute to sustainable agriculture development with both ecological benefits and economic returns (Zhao et al. 2008). Intercropping ecological trees (e.g. Chinese fir) or cash crop trees (e.g. walnut, chestnuts and apple) with crops (e.g. soybean and peanut) are popular on the Loess Plateau due to diverse incomes. In such combination, ecological trees are profitable after harvesting on a decade scale, while cash crop trees are able to produce fruits and nut production within a few years, in addition to crop production (Uchida et al. 2007). But the profits vary depending on the varieties of planted trees. Additionally, there are difficulties of managing water and nutrients in integrated cropping systems that can constrain economic return.

4.4 How to Achieve the Multifunctional Agriculture?

In order to ensure food security, increase cultivated land-based income, improve soil fertility and productivity and alleviate water scarcity, the current food-driven intensified cultivation practices in the arid and semi-arid parts of China are certainly unsuitable and have to be shifted into a style that can sustainably support local and regional development. This needs to take into full consideration the local and downstream demands for ecosystem services. In this context, balancing food production and environmental quality is becoming a central issue of agriculture in China. In the last decade, the multifunctional agriculture (MFA) has appeared as a key concept for future agricultural and rural development (Renting et al. 2009). It is believed that cultivation activity can have more functions beyond producing food, fibre and fuel, such as protecting and maintaining natural resources (e.g. soil and water) and biodiversity and contributing to livelihood viability and cultural heritage. Growing debate about MFA has been stirred within varying international organisations (e.g. OCED, FAO and EU), while many different approaches are being developed (e.g. market-based, land-use based and actor-oriented approach) (Renting et al. 2009). Dryland areas, such as the Loess Plateau, face many challenges in agricultural development (as discussed in 3.3) that are only possible to be solved in coordination across sectors, such as soil and crop management. Soil management has to deal with (i) soil erosion, (ii) fertility, (iii) infiltration, (iv) unproductive evaporation and (v) conservation tillage, while crop management has to deal with (i) crop rotation/intercropping, (ii) species and cultivars choice, (iii) seeding and stand density and (iv) fertiliser application. For these reasons, MFA is a promising concept to solve the problems between environmental management and economic development on the Loess Plateau. While continuing scientific research on MFA, policies that support the multifunctional roles of agriculture for contributing towards rural development have to be created. In addition, necessary training and guidance should be provided to local farmers to raise their awareness of multifunctional agricultural cultivation and develop more skilful cultivation so as to reduce reliance on irrigation and chemical fertilisers and increase cultivated land-based income.

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Chapter 5
Current State of Multifunctional Use of Grasslands

Shaoshan An, Man Cheng, Zhijing Xue and Rentian Ma

Grasslands are one of the main land-use forms in a dryland ecosystem. They provide many benefits for humans (e.g. herbal medicine and animal products) and the environment (e.g. promote water infiltration, sustain biodiversity and reduce soil erosion). China has abundant grassland resources. They cover 40% of the terrestrial area and are mainly distributed in arid and semi-arid regions. These areas are located in the upper and middle reaches of the major rivers in China such as the Yangtze River, the Yellow River and the Lancang (Mekong) River. The socio-economy in these regions is far behind the other parts of China. Therefore, the grassland ecosystem plays an important role in both sustaining environmental quality and contributing to regional socioeconomic development. However, as the population grows, overgrazing and other human activities have resulted in severe degradation of grassland ecosystems.

5.1 Grassland Ecosystem Services

This section summarises the ecosystem services provided by the grassland ecosystem on the Loess Plateau region, including environmental and socioeconomic-related services.

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5.1.1 Soil and Water Conservation

The soil in grasslands has rich fine roots, organic matter and microorganisms that interact with each other. They promote the formation of soil aggregates through the cementation of humus and calcium, thus leading to improved soil structure and fertility, and finally increases soil erosion resistance (Li et al. 2005). In some cases, grass is more capable of protecting soil than are shrubs and forests. For example, grass is a better option in areas that have a high content of gravel and a lack of nutrients since these factors constrain tree growth. In addition, many practices suggest that in steep mountainous areas on the Loess Plateau, where there are often cases of serious soil erosion, planting grasses or mixing them with woody plantation is more effective in reducing soil erosion than to rely merely on woody plantation (Wu et al. 2010).

Some studies (e.g. Jiao and Wang 2000; Gornish and Santos 2016) show that grasslands are only able to conserve soil effectively when the coverage of grass reaches a certain level. To evaluate the efficiency in soil conservation, two values are commonly used, namely critical coverage (lower tolerance) and effective coverage (upper tolerance). The critical coverage refers to the coverage level at which soil erosion reaches the highest allowable rate without hampering soil fertility in a certain region, while the effective coverage refers to the coverage level at which soil erosion reaches the minimum rate. At this point, the soil erosion rate will not decrease anymore with increasing grass coverage. Zhang and Liang (1996) found that the effective coverage is correlated with precipitation, terrain, soil and vegetation. For a given grassland, the effective coverage (percentage) shall fall between critical coverage and 100%. A simulation on flow and sediment yields in manmade grasslands indicated that soil erosion decreased with increased grassland coverage exponentially; 70% can be considered as the average effective coverage under experimental conditions (Zhang and Liang 1996). On the Loess Plateau, the coverage of grass has been investigated on many plots under different rainfall intensities and slope gradients (Jiao and Wang 2000). The results suggested that at a slope gradient of 20°, 25°, 30° and 35°, the critical coverage is 55, 60, 65 and 70%, whereas the effective coverage is 63.4, 71.1, 77.3 and 82.6%, respectively.

Apart from soil conservation, grasslands also intercept rainfall and promote water infiltration, thus are significant for water conservation. This is particularly important in water tower zones (e.g. sources of large rivers) in mountainous and hilly areas for purifying water, regulating runoff and alleviating flash floods. In arid and semi-arid regions, herbaceous plants convert surface runoff into soil water efficiently. Investigation on rainfall interception and partitioning in arid regions showed that the rainfall interception by herbaceous vegetation (38.4% ± 32.3%) is greater than that by trees (23.6% ± 14.9%) and shrubs (24.8% ± 12.9%) (Wu et al. 2010). In addition, the litters of grasses protect soils from evaporation thus increase soil water content. Taking the natural grasslands in the semi-arid Loess Plateau as examples, investigation showed that there were significant positive correlations between aboveground biomass, litter quality and soil water content (Zhang et al. 2014).

5.1.2 Carbon Sequestration and Climate Regulation

Grasslands are a potential carbon sink, but this is strongly influenced by human activities. According to Cui et al. (2000), the grassland ecosystem mainly serves as a carbon source during the non-growing season (from October to April) on the Loess Plateau, while it mainly serves as a carbon sink during the growing season (from May to September). On an annual basis, it remains a carbon sink. Deng et al. (2014) estimated that the average soil carbon fixation rates on the Loess Plateau after the farmland is returned to forests, shrubs and grassland are 0.19, 0.29 and 0.52 Mg ha^{-1} y^{-1}, respectively. This indicates that grasslands have the highest carbon fixation potential among the three land covers. In addition, Liu et al. (2011) estimated the average soil organic carbon content within a depth of 100 cm for natural grassland on the Loess Plateau and the result showed that the organic carbon content of natural grassland (5.4 kg m^{-2}) is lower than the national average (8.5 kg m^{-2}), which is attributable to the loss of soil organic material resulted from soil erosion.

Grasslands have the functions of shading, lowering wind velocity and reducing ground evaporation, and can thus moderate the changes in surface temperature, increase air humidity and accelerate vertical movement of vapour. As a consequence, rainfall occurs more frequently on vast grasslands, because the higher the grassland coverage is, the lower the reflectivity is, therefore more precipitation will fall. In contrast to large barren lands, air humidity on grasslands is 20% higher; even for small grass patches, air humidity is still 4–12% higher than that of an open area (Zhao et al. 2004).

5.1.3 Nutrient Pool

Grasslands are a prominent nutrient pool of carbon, nitrogen, phosphorus and potassium that provide products of high quality. Cheng (2014) investigated the accumulation and allocation of nutrient elements in the ecosystem of the *Stipagrandis* grassland. It is found that the plants accumulate most of the nitrogen, phosphorus, potassium and magnesium in underground. The underground accumulation of nitrogen and magnesium accounts for more than 90% of the total accumulation. The total accumulation of nitrogen, phosphorus, potassium and magnesium is 23.5, 0.3, 5.0 and 2.0 g m^{-2}, respectively. Nutrients in grazed pastures move between several various pools, including the atmospheres, soils, plants and grazing animals (Fig. 5.1) (Silveira et al. 2012). Several factors, such as climatic conditions, soil type, plant species and grazing management, can affect nutrient dynamics in these pools. Animal manure (excreta) and plant litter represent the most important pathways for nutrients to be recycled in grazed pastures. For example, in the grazing process, a large amount of animal excreta is scattered on the grassland, and degraded through natural weathering, leaching, biological fragmentation and microbiological decomposition; thus nutrients return to the soil and ecosystem (Silveira et al. 2012).

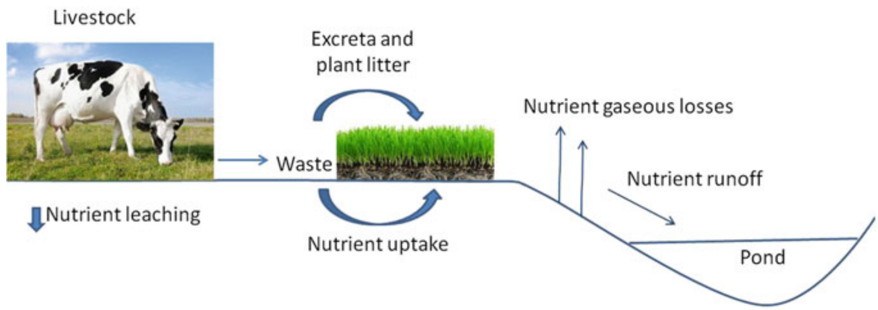

Fig. 5.1 Schematic diagram showing how nutrients move between several pools, including the atmospheres, soils, plants, and animals (Silveira et al. 2012)

5.1.4 Source of Forage Material

Forage material refers to all herbaceous and woody plants (including shrubs, twigs and leaves of trees) that can be used for livestock breeding. Forage materials can be grouped into four categories, namely gramineous, leguminous, cyperaceous and miscellaneous plants. The latter includes all of the forage plants excluding gramineous, leguminous and cyperaceous plants. Gramineous plants are common in existence in all but the alpine desert-steppe grass ecosystem in dryland China. In terms of composition, it often accounts for >50% in contrast to leguminous, cyperaceous and miscellaneous plants, according to a national grassland resource survey (Liu 1996). Leguminous plants have the most varieties among all categories of forage plants, but the presence of leguminous plants is generally low in most of the grassland ecosystems. Yet, they contain a high nutritional value and are a major source of proteins for animals. Similar to gramineous plants, cyperaceous plants have a wide distribution in natural grassland ecosystems and are particularly valuable for animals on alpine meadows and wetland meadows. In comparison, miscellaneous plants are large in quantity and widely distributed in many grassland ecosystems, but they are rarely dominant and often have low nutritional value except for a few species.

5.1.5 Source of Livelihood

Livestock husbandry is an important part of the agro-ecosystem of the Loess Plateau. Due to the natural and climatic constraints, grasslands in arid parts of the Loess Plateau can be low in productivity. Input of supplemental livestock feed from artificial grassland is necessary, in which leguminous plants such as alfalfa (*Medicago sativa*), erect milkvetch (*Astragalus adsurgens*), sweet clover (*Melilotus suaveolens*) and sainfoin (*Onobrychis vicifolia*) are the main species. Animals and associated products have become major sources of rural livelihoods (e.g. in the northern Loess Plateau area). For instance, the output of animal husbandry in Ningxia Province was always half of the output of agriculture in the past three years. Besides, grasslands provide abundant raw materials for food, fuel, pharmaceuticals and textiles, which make additional contribution to the livelihoods of farmers.

Grasslands in northwest China are widespread and feature an exotic landscape owing to a combination of unique animal and plant resources and cultural history. Due to the benefits that it potentially brings in terms of the development of tourism and protection of the grassland ecosystem, ecotourism has attracted more and more attention from local governments and farmers on the Loess Plateau. The development of grassland ecotourism increases rural income and attracts more investments from outside due to an improved local environment. In addition, it drives the developments of other related businesses along the progress of tourism development, such as special local products, trade and infrastructure construction (e.g. highway and public transportation), which promote local economic development.

5.2 Possibilities for Multifunctional Grassland Utilisation

5.2.1 Protection-Based Grazing Management

In the arid part of the Loess Plateau, the primary functions of grasslands are to protect land/soil from degradation/erosion and to promote groundwater recharge. Additionally, grasslands can also provide some secondary socioeconomic functions. The key for protection-based (such as soil and water conservation) grazing management is to determine a feasible stocking rate and method without harming the primary functions (Galt et al. 2000; Batabyal and Godfrey 2002). Proper grazing can stimulate the tillering of grass and promote nutrient cycle (nitrogen and phosphorus), thus increase biodiversity/species richness and the productivity and sustainability of natural grasslands (Silveira et al. 2012), but improper grazing/overgrazing will cause soil compaction and land degradation, finally reducing biomass and the quality of grass (Bedunah and Angerer 2012). The multifunctional use of grasslands for protection and grazing can bring maximum benefits for both the environment and economy. In special cases, such as severely degraded land, a complete ban on grazing can be implemented, while in other parts where protection-based grazing is acceptable, efforts should be made to study and determine the stocking rate, rotational grazing techniques and the use of leguminous plants.

5.2.2 Coupled Agriculture and Livestock

On the Loess Plateau, the transitional area of agriculture-dominant semi-humid zone and grassland-dominant arid and semi-arid zone has relatively higher water and heat availability. Farmlands and grasslands may combine and alternate with each other depending on the site specific soil, water and heat conditions. More attention should, on one hand, be paid to soil erosion and nutrient control and increasing soil water pool (as mentioned in the previous chapter on multifunctional agriculture) to ensure a high and sustainable agriculture production; on the other hand, a sustainable livestock and grazing management in grassland to prevent degradation needs to be established. This may serve as a leading model in the semi-humid and semi-arid transitional zone as they can ensure more sustainable environmental and economic benefits through non-intensive agriculture and non-pressured livestock breeding.

5.2.3 Grassland Ecotourism and Featured Goods and Services

Ecosystem and tourism have merged into a new genre of environmentally sound and socially responsible recreation (Honey 2008). The International Ecotourism Society (TIES) provides a substantial, contemporary definition of ecotourism, denoting the key features of ecotourism as minimising human impacts, improving the public's awareness of nature conservation, providing direct financial benefits to local residents and nature conservation and conserving local culture (Honey 2008). China has made significant efforts to reconcile environmental protection and social improvement with economic growth in areas with ecological fragility and poverty (Jiang 2006; Liu 2008). Ecotourism is viewed as an ecological approach to socioeconomic development and poverty reduction (Donaldson 2007), to the conservation of endangered species and habitats in developing countries (Bookbinder et al. 1998), and to manage protected areas (Cengiz 2007). Having various types of grasslands, northwest China is able to offer a variety of tours, such as grassland sightseeing tours, ethnic culture tours and minority life experience tours, while special goods and commodities are provided.

5.3 Challenges in Multifunctional Grassland on the Loess Plateau

5.3.1 Land Degradation and Grazing

Grasslands have encountered severe degradation over the past several years. As a result, the beautiful scenery as captured by the famous verses 'moderate wind blowing, flourishing grass swaying, flocks and herds playing' has almost disappeared. The causes for soil erosion are twofold: unfavourable climatic conditions and uncontrolled human behaviours. On the one hand, insufficient water availability due to the frequent drought in recent years has retarded grass growth. Furthermore, the fragile ecosystem has become more vulnerable to locust disasters, which further reduces the chances of grassland recovery. On the other hand, based on the Household Production Responsibility System, grasslands were distributed to herders, thus the economic interests of herders are directly reflected in the production of grassland. In order to increase their income, herders tend to increase livestock numbers and stocking rate. As a result, livestock numbers have increased three to four times over the past years (Zhang 2002), which have severely exceeded the carrying capacity of the pastures. In turn, grassland degradation can restrict grazing potential. The economic losses due to environmental degradation accounted for almost half of total expenditure (Li 2000). To ensure benefits for both the environment and economy, an alternative sustainable management strategy has to be implemented, such as grazing management strategy (stocking rate, grazing intensity, variety of livestock), nutrient addition, and the introduction of legumes to the grassland system.

5.3.2 Grassland Conservation and Ecotourism

In general, ecotourism is considered as a more environmentally friendly industry with strong economic motive, thus is a beneficial choice to partly replace livestock breeding and alleviate overgrazing and land degradation. The International Union for Conservation of Nature (IUCN) defines ecotourism as the 'environmentally responsible visitation to relatively undisturbed natural areas, in order to enjoy, study, and appreciate nature that promotes conservation, has low negative visitor impact, and provides for beneficially active socioeconomic involvement by local people' (Hanley 1989). This means it should (i) minimise negative social (culture) and environmental impacts (land degradation); (ii) maximise involvement and economic benefits of local people; (iii) increase the people's awareness of environmental conservation. Similarly, different from common tourism, grassland ecotourism on the Loess Plateau shall emphasise the significance and priority of environmental conservation, which may cover four essential aspects: (i) realise sustainable development of natural resources; (ii) obtain the maximum economic benefit from tourism and benefit local residents; (iii) improve the public's consciousness of natural conservation, and (iv) implement sustainable ecosystem management (Zhang 2002). However, currently, the economic benefit from ecotourism is still not substantial enough for local people to replace or partly reduce their livestock numbers to adapt to the carrying capacity of the grasslands. Therefore, it is important to investigate how to involve the local community in tourism and to ensure economic benefits. They are a key aspect in restoring the degraded grassland through developing tourism. In addition, strategies to prevent water pollution, waste accumulation and species losses in nature reserves have to be created (Li and Han 2001).

5.4 Concluding Remarks

Multifunctional grassland plays an important role in the sustainable development of the Loess Plateau. The grassland ecosystem provides a number of environmental and socioeconomic-related services, including soil and water conservation, carbon sequestration, nutrient pool and so on. At present, protection-based grazing, coupled agriculture and livestock, and grassland ecotourism are implemented for achieving multiple utilisation and benefits of the grassland ecosystem. These management strategies were found to be useful and beneficial for a more sustainable regional development. However, the inappropriate multifunctional utilisation of grasslands can also cause disservices of environment in the fragile ecosystem. Therefore, environmental protection and economic growth have to be balanced and harmonised in an optimal relation in multiple uses of grassland. This requires innovative frameworks of multifunctional grassland, cross-sectoral research, applicable approaches and supportive policy.

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Chapter 6
Multifunctional Forestry on the Loess Plateau

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To meet the fast increasing demand for the multiple and sometimes competitive services from forest and other ecosystems, forestry development and forest management has to move from the conventional form to embrace a multifunctional approach, especially in the dryland regions where there is a harsher environment, such as the Loess Plateau. Therefore, we need to understand the local features of multifunctional forestry and the corresponding technical requirements. In this chapter, we first take a look at the various forest functions and their complex relationship from a theoretical viewpoint, and then discuss the characteristics of demands of multifunctional forestry for sustainable development. At the end, we propose the principles and modes relating to the multifunctional forestry on the Loess Plateau.

6.1 The Classification of Forest Services

Forest ecosystem functions are the biological, geochemical and physical processes and components that occur within a forest ecosystem, and thus sometimes called ecological processes. They relate to the structural components of a forest ecosystem (e.g. vegetation, water, soil, atmosphere, and biota) and interact with each other. Maintaining forest functions is important for human well-being. However, forest functions are not equivalent to forest services. The Millennium Ecosystem

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Assessment has defined ecosystem services as the benefits people obtain from ecosystems (MA 2005), while forest functions are objective realities, and independent from human will, they can affect the human being and environment positively or negatively.

Forest services refer to natural conditions and utilities that are essential to the survival of human being, formed and maintained by forest ecosystems. There are many types of forest services. They are scientifically divided into four categories (MA 2005): provisioning services such as timber, non-timber products, water, food, raw materials, energy; regulating services such as regulation of floods, drought, climate, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious and other nonmaterial benefits. However, from the practical viewpoint, the main forest services on the Loess Plateau will be analysed below according to their relevance to income, society, and environment.

6.1.1 Income-Related Services

Forest services directly related to the income of forest owners mainly include timber production, non-timber products production, eco-tourism, and others. Due to the marked dry conditions with often severe droughts, forest cover on the Loess Plateau is lower than the national average, and the forests in this region generally do not grow well. Therefore, forest productivity, timber output, and other services related to the direct income of forest owners on the Loess Plateau are generally not high.

According to the 8th national forest inventory undertaken during the period 2009–2013 (Xu 2014), forest cover in the whole of China was 21.63%, with an average standing volume of 89.79 m^3/ha, while the forest cover in Shanxi, Henan, Shaanxi, Gansu, Qinghai, and Ningxia, all of which are located on the Loess Plateau, was 18.03, 21.50, 41.42, 11.28, 5.63, and 11.89% respectively, and their average standing volume was 46.28, 55.98, 61.93, 86.79, 114.43, and 41.66 m^3/ha respectively. Although most of the existing forests on the Loess Plateau are young or middle-aged and with low standing volume, the productivity of forests in some areas of the Loess Plateau with better natural conditions is high. For example, the standing volume of a 35-year-old black locust plantation and 25-year-old Chinese pine plantation in Weibei area can reach up to 123 and 191 m^3/ha (Peng 2001); the standing volume of a larch plantation with the age of 21 years in Liupan Mountains can reach 150 m^3/ha, with an annual growth rate of 10–17 m^3/ha (Wang et al. 2009). In addition, although the output of high quality timber is low, they can yield a lot of other products, including fresh and dried fruits, medicines, food (wild vegetables, edible mushrooms, oilseeds, spices, etc.), feed, fuel, bio-energy, fertiliser, weaving materials, and industrial raw materials, and thus have high economic value.

Due to the low annual precipitation in the semi-arid areas of the Loess Plateau, shrubs are the main vegetation type. Shrubs have relatively high biological yield and can be used as weaving materials and fertilisers. The leaves and other edible portions of shrubs can be used as livestock feed, especially in winter and spring when there is a lack of forage grass (Bai 1990). However, the current use of shrubs is still low. The development and utilisation of undergrowth species in forests mainly focus on mushrooms, wild vegetables, wild herbal medicines, pine cones, raw lacquer, etc.

The products from forests and shrubs often provide an important economic income for local farmers. For example, in the Guanshan Mountains area where the provinces of Shaanxi, Gansu, and Ningxia meet, there are rich timber products and non-timber products from forests, including herbal medicine as one of the main products. Planting and collecting herbal medicine in forests is the main income source of farmers engaging in the sale of agricultural and forestry by-products. Another example is the Jingyuan County of Ningxia, where the foresters make full use of forest resources by collecting or cultivating non-timber products such as wild herbal medicine and wild vegetables. According to the preliminary statistics in 2012, herbs and wild vegetables alone brought an average annual household income of over 1000 Yuan (1 USD equals about 6.58 Yuan) to some foresters; collection of tree seeds brought over 9 million Yuan annually to foresters throughout the county.

There are relatively rich fruit tree species on the Loess Plateau, such as apple, pear, persimmon, wolfberry, etc. The orchards of these fruit trees are not real forests because they do not produce timber, but they are perennial vegetation cover and can provide some ecological services as forests do. Thus, increasing orchard area is often used as an important measure for the increase of both income and ecological services on the Loess Plateau. For example, in the Pingliang City of Gansu and other places, fruits have become the main source of income for local farmers. The production bases of apples in the Jingning County and Jingchuan County, cherries in the Tianshui City, olives, walnuts, and pepper in the southern Gansu Province, have developed quite well.

6.1.2 Society-Related Services

The relationship between forestry and green economy has three aspects. First, forests can improve social well-being and alleviate poverty, guarantee long-term social and economic development by providing products and services, and reduce environmental risks and ecological vulnerability. Second, forestry plays a great role in global economic growth. Production, processing and trade of timber, forest products, and non-timber forest products can bring a great number of employment opportunities, improve farmers' well-being, and promote the development of forestry in rural areas. The forest services of reducing pollution and carbon emissions and disposing waste also play a role in the green economy. Third, green investment in forestry can bring long-term and secured returns and help to deal with financial risks.

The Loess Plateau has its unique characteristics in social economy, such as the poor natural conditions, the simple composition structure in agriculture, and the very low income of farmers. The impoverished population accounts for more than 25% of the total impoverished population in the whole of China. The natural conditions of fragile landform, high ratios of hilly areas and slope farmland, and middle-to-low-yielding farmland, the shortage of water resource, albeit the rich sunshine and heat resources, the relatively high biodiversity and abundant labour, require the development of specialty forestry and sidelines that fully utilise local land resources and natural conditions, and call for the need to coordinate the development initiatives of ecological forestry and livelihood-related forestry.

There have been a lot of successful practices. For example, in Pingliang City of Gansu, which is one of the most suitable areas for planting apple trees in China, from 1978 to 2012, forest land increased from over 67,000 to 339,000 ha; forest cover increased from 7.8 to 27.7%; the area suffered from soil erosion decreased from 6.6 to 2.8 million ha; the area of fruit trees increased from 47,000 to 140,000 ha and the fruit output reached one million tonnes. The output value of forestry exceeded 3.2 billion Yuan and the net income per capita of farmers from forestry reached 1667 Yuan, accounting for a third of the total net income per capita of farmers. Another example is Yanchuan County known as the "County of Jujubes", which is located in the north of Shaanxi Province, with a total land area of 198,500 ha. In 2012, the per capita net income of farmers in Yanchuan County was 5815 Yuan, the forestry-purpose land was 132,000 ha, accounting for 66.6% of the total land area. An area of 86,000 ha of the forestry-purpose land were used for planting trees, including the tree species of Chinese jujube, apricot, peach, and others that have both ecological and economic benefits. The plantation in this county has been shifted gradually from the focus of ecological forests to more economy-oriented forests. By the end of 2012, the income from jujubes accounted for 30.5% of per capita income of farmers in this county and became an important source of revenue.

6.1.3 Environment-Related Services

The main environment-related forest services include erosion control, water supply, water purification, carbon sequestration, oxygen release, biodiversity protection, etc., but the roles of these services and their importance vary distinctly from site to site and from region to region according to the varying conditions.

Water Cycle Regulation

The forest hydrological impact is very complex, because many hydrological processes are affected not only by the dynamical quantity, quality, and spatial distribution of forests, but also by other non-forest factors, such as weather, soil, landform, and bedrock geology. Forests can improve the hydrological and physical properties of soils through the development of an intense root system and the enhancement of soil biological activities, so that forest soil is generally more porous and highly permeable, which is conducive to the storage and movement of water in soil (Pilaš et al. 2010; Yang et al. 2006; Yu et al. 2015). Thus, some believe forests can increase total annual runoff by increasing underground runoff due to increased infiltration of rainwater. However, one the other hand, some believe that the higher biomass productivity of forests will lead to higher water consumption and lower runoff. These contradictory aspects and their complex interaction with other factors, such as climate, geography, basin size or even mankind disturbance, jointly determine the direction and amplitude of forest impact on runoff. This leads to a vast variation of forest impact on runoff, and this has always been a disputable topic worldwide (Andréassian 2004), as well as in China (Zhou et al. 2001). To study the isolate impact of forests, the rigorous experiment approach of paired catchment study was developed and used in many countries (Andréassian 2004), and its worldwide synthetic analysis showed that a forest increase will reduce annual runoff and this reduction may be most severe in drier regions (Farley et al. 2005); while the thinning and cutting of forests will increase annual runoff (Sahin and Hall 1996). However, no strict paired catchment study was carried out on the Loess Plateau. Thus the forest impact on runoff in the Loess Plateau region was studied mostly through the measurements at stand scale or water budget calculation at basin scale with statistical analysis or hydrological models.

The impact of forests on flood is an important aspect in evaluating the forest service of water regulation. However, this aspect is less studied due to the dryland nature of few floods on the Loess Plateau. Forest land with high water storage capacity can retain showery precipitation in the soil and reduce the fast and erosive surface runoff, decreasing peak flow and flood risk. For example, compared with the non-forested watershed of Dangjiachuan (48.8 km^2) on the Loess Plateau (Wang et al. 2004), the volume of rainstorm runoff was reduced by 37.4% (6.5–75.6%) in the forested watershed of Wangjiahe (47.1 km^2). The average peak flow in the non-forested watershed was 7.2 times of that in the forested watershed. The average flood duration of Wangjiahe and Dangjiachuan was 96.8 and 65.5 h respectively. Forests can reduce the regional flash floods to some extent, but cannot retain big floods, which are mainly determined by rainfall amount and intensity, as well as the pre-event soil moisture situation (Wahren et al. 2012).

Because of the severe water shortage and increasing challenge of water supply for sustainable development in the dryland region of Loess Plateau, the most important indicator of forest hydrological impacts is the impact on annual flow (water yield), and it is studied relatively more at basin scale. The annual runoff of many rivers has drastically declined since the 1960s. For example, in the Weihe River Basin, which has an area of 134,300 km^2 and is the largest tributary of the Yellow River, the runoff after the 1990s was only one-third of that before 1960s (Sun et al. 2013). Besides the decrease in precipitation and the increase in temperature, human activities are the main factors for the runoff decrease in Weihe River Basin, with a contribution rate of more than 80% (Hou et al. 2011). Another example is the Jinghe River Basin which is the largest tributary of Weihe Basin (Fig. 6.1), where the ratio of annual runoff to annual precipitation has decreased

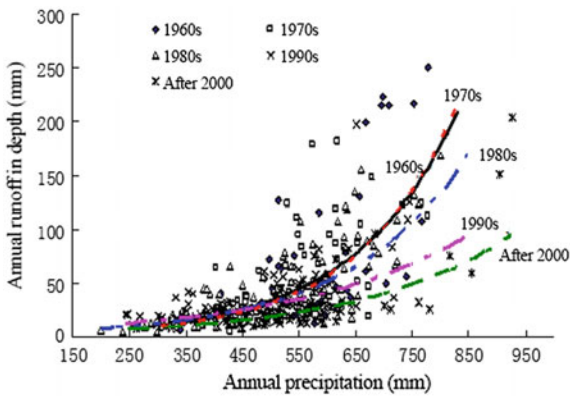

Fig. 6.1 Relation between annual runoff and precipitation of Jinghe Basin in different decades

drastically since the 1980s, compared with that in the 1960s and 1970s (Zhang et al. 2011a, b; Liu 2011). The annual runoff decreased from 50.1 mm in the 1960s to 22.3 mm in the early 2000s, and the runoff decrease in more humid sub-basins with better forest/vegetation was greater than that in dryer sub-basins. The dominant factor causing annual runoff reduction changed from the precipitation decrease in the reference period before 1980 to the increased human activities in the period after 2000 (Table 6.1), with a contribution rate of 76–98% in 2001–2005. This indicates that the growing human activities have become the most important dominant factors affecting runoff change. The relevant human activities mainly include the implementation of water and soil conservation techniques (such as terrace fields) and vegetation restoration programmes (such as afforestation) since the 1970s.

The study on the forest impact on annual runoff and evapotranspiration of basins on the Loess Plateau (Wang et al. 2011) surprisingly showed that the annual runoff and its ratio to annual precipitation did not increase with annual precipitations, but decreased as annual precipitation increased (Fig. 6.2), meaning the impact of other factors on water yield was greater than that of precipitation. Further analysis showed that the annual runoff and its ratio decreased as the forest cover in basins increased, indicating that the increase of water use associated with forests had a significant impact on the water yield. To quantify the forest impact on annual runoff, a regression analysis was done. Under the average annual precipitation of 463 mm for all basins, the annual evapotranspiration and runoff were 424 mm (91.7%) and 39 mm (8.3%) for non-forested lands, and 447 mm (96.6%) and 16 mm (3.4%) for forested lands, respectively. This indicates an average decrease of 23 mm in annual runoff due to forests, corresponding to 58% of annual runoff on non-forested lands.

The water budget components on plots of different vegetation types (Table 6.2) were measured during the growing season (June–September) of 2004 in the small watershed of Diediegou of Liupan Mountains (Wang et al. 2008). The evapotranspiration of grasslands (204 and 238 mm) was lower than that of shrubs (374 mm) and forests (384 and 416 mm). This leads to a higher water yield of grasslands

Table 6.1 Contribution of annual precipitation and human activities to annual runoff change in Jinghe Basin (Zhang et al. 2011a)

Period	Average annual precipitation (mm)	Runoff depth and its change (mm)				Precipitation		Human activities	
		Reference period	Actual runoff	Natural runoff	Change in runoff	Caused runoff change (mm)	Contribution rate (%)	Caused runoff change (mm)	Contribution rate (%)
Before 1980	519.8	41.2							
1980s	501.3	41.2	36.6	37.5	−4.6	−3.7	80.9	−0.9	19.1
1990s	474.5	41.2	29.9	33.5	−11.3	−7.7	67.8	−3.6	32.2
After 2000	539.3	41.2	20.6	45.8	−20.6	4.6	−22.3	−25.3	122.3

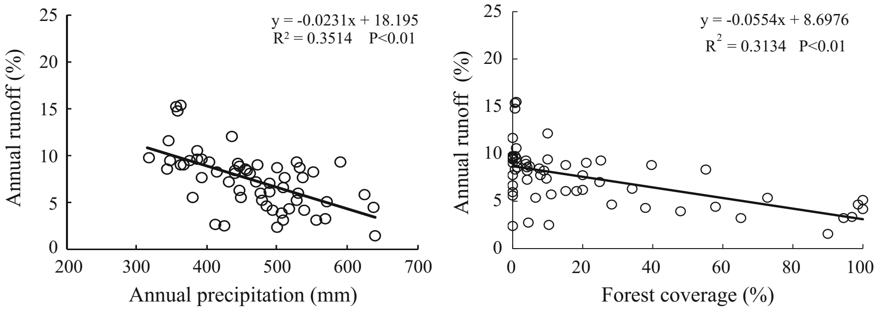

Fig. 6.2 Variation of annual runoff ratio with annual precipitation and forest cover in the basins of the Loess Plateau (Wang et al. 2011)

(120 and 162 mm) compared with that of shrubs (24 mm) and forests (4 and −58 mm). The surprising negative water yield of larch forests on gentle slope foot means that the water loss through forest evapotranspiration can exceed precipitation over the same period and sometimes forests need to deplete the soil moisture and lateral run-in of water from upper slope areas.

Figure 6.3 compares the water yield among different vegetation types measured at various times and locations in the semi-arid region of Liupan Mountains, using the ratio of evapotranspiration to precipitation over the same period (Wang et al. 2008). It can be seen that natural grasslands have the highest runoff and are the main water yielding vegetation type; the water output and input on the plots of shrubs and small trees are quite balanced, so they produce only a small amount of runoff; the arbour forests and artificial grasslands use a lot of water, which sometimes may exceed the precipitation input, making it very difficult to generate runoff. Therefore, choosing proper vegetation types is the most important measure to maintain certain levels of water yield.

The forest hydrological studies conducted on the Loess Plateau, like those mentioned above, have shown that the massive increase of forest area will reduce the water yield of watersheds and then affect the regional water supply. This effect should not be ignored; instead, it should be integrated into the forestry planning and policy (Wang et al. 2012), when we decide the quantity, quality, spatial distribution, and management of forests. In this way, we can obtain various services from forests while reducing the water consumption of forests in order to maintain a certain water yield and ensure the regional water supply, and to optimise the role of forestry in promoting regional sustainable development (Calder 2005; Pilaš et al. 2010).

Water Quality Regulation

Water purification is also an important forest service. There are not many studies on the forest impacts on water quality in China, especially in northwest China and on the Loess Plateau. However, studies in other areas of China confirm that forests can purify water. For example, in 2000 after the implementation of the Grain for Green

Table 6.2 The evapotranspiration (ET) and its compositions and water budget for 0–90 cm soil layer on the plots of main vegetation types in Diediegou of Liupan Mountains during growing season (June–September) of 2004

Sample plot and vegetation type	Precipitation (mm)	Canopy interception (mm)	Stand transpiration (mm)	Understory ET (mm)	Total ET (mm)	Soil water change in 0–90 cm layer (mm)	Surface runoff (mm)	Deep percolation (mm)	Water yield (mm)
Grasslands on sunny slopes	378.0 (100)	–	–	–	237.8 (62.9)	20.1 (5.3)	1.5 (0.4)	118.5 (31.4)	120.0 (31.8)
Grasslands on semi-shady slopes	378.0 (100)	–	–	–	204.2 (54.0)	12.4 (3.3)	1.1 (0.3)	160.4 (42.4)	161.5 (42.7)
Sea buckthorn shrubs	378.0 (100)	66.0 (17.5)	138.8 (36.7)	169.3 (44.8)	374.1 (99.0)	−20.2 (−5.3)	0.7 (0.2)	23.4 (6.2)	24.1 (6.4)
Larix principis-rupprechtii forests on steep shady slope	378.0 (100)	24.4 (6.5)	184.0 (48.7)	175.9 (46.5)	384.3 (101.7)	−10.2 (−2.7)	1.7 (0.4)	2.2 (0.6)	3.9 (1.0)
Larix principis-rupprechtii forests on gentle slope foot	378.0 (100)	35.8 (9.5)	202.7 (53.6)	177.1 (46.9)	415.6 (110.0)	20.2 (5.3)	1.2 (0.3)	−59.1 (−15.6)	−57.9 (−15.3)

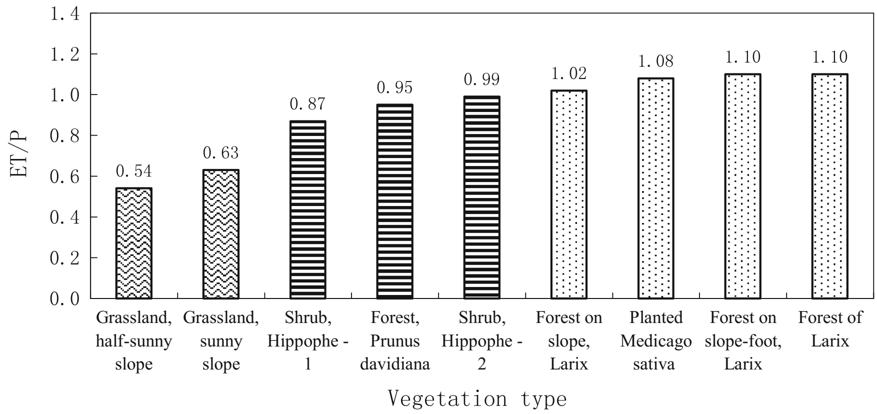

Fig. 6.3 Variation of the ratio of evapotranspiration to precipitation (ET/P) in growing season on plots of different vegetation types in the semi-arid region of Liupan Mountains (Wang et al. 2008)

Project (Li 2004) in Beizhuang Town, Miyun, an important headwater area for Beijing, the increase of forest area and the decreased use of fertilisers in farmland have led to the reduction of turbidity and lowered the concentration of ammonia nitrogen of surface water (Li et al. 2004). Another study carried out in Beijing showed that forest land is positively correlated with water quality and affects water quality significantly (Chen et al. 2016). The study in Qinling Mountains showed that the forest stands of *Quercus aliena var. acuteserrata* raised the quality of polluted rainwater from Class II to Class I (Lei and Lu 2003), as a result of the processes in the forest canopy layer and soil layer (Zhang and Li 2007). In the Taibai Forest Area of Qinling Mountains, a headwater area for the Xi'an City (Jin et al. 2013), the canopy, litter and soil layer of forests play a role in water quality regulation. The soil layer increases the pH value of precipitation; the litter layer makes a key contribution in absorbing the nitrate (NO_3^-); the canopy and the soil layer play a critical role in absorbing ammonium (NH_4^+) and heavy metals such as copper (Cu), lead (Pb), and zinc (Zn).

Excessive use of fertilisers and pesticides is a common problem in China's farmland and orchards, resulting in large areas of non-point source pollution (Yu and Guo 2014) and deterioration of the quality of surface water (Meng et al. 2007) and soil water, which will cause groundwater contamination in the long run. Forests/vegetation play a significant role in the regulation of non-point source pollution. Building vegetative filter strips on both sides of rivers, streams, farmland drains, and roads to intercept sewage from farmland, orchards, and roads, preventing sewage from being directly discharged into rivers and increasing infiltration and degradation time or allowing sewage to be absorbed by trees, is an effective measure, which has been widely adopted in the USA and Europe (Barling and Moore 1994; Gharabaghi et al. 2006; Norris 1993). However, the techniques of vegetative filter strips have not been widely used in China and on the Loess Plateau, although some studies implemented in recent years have shown their efficiency in water purification (Sun et al. 2016). In addition, the construction of roadside and farmland shelterbelts and promotion of agro-forestry will allow the trees to absorb some pollutants in deep soil water, thereby reducing deep soil and groundwater contamination.

Generally speaking, increasing forest cover can help maintain good water quality. With the increasing water pollution accompanied by rapid economic development, comprehensive pollution control measures are required, including forestry measures. However, improper forest management (such as large area clear-cutting, excessive soil disturbance, and destruction of ground cover), especially the overexploitation of commercial and economic forests, can have adverse impacts on water quality. Therefore, besides increasing forest cover, forests should be reasonably managed by taking into account their impacts on water quality.

Soil Erosion Control

Soil erosion in the Loess Plateau region is very serious. One of the direct reasons is the lack of coverage of forest/vegetation. Thus, the Chinese government has launched the Three North Shelterbelt Project, the Grain for Green Project, and other ecological projects in the past decades (Li 2004), mainly for controlling soil erosion. The increase of forest/vegetation cover has reduced soil erosion very effectively, as a result of several forest hydrological effects. For example, these effects include the rainfall interception by forest canopy and ground cover, which leads to a great reduction of raindrop impact on soil surface; the higher soil infiltration, which turns the erosive surface runoff into not erosive subsurface flow and percolation; the reduction of the velocity of erosive surface runoff by humus layer and ground vegetation; the enhanced stability of soil particles against erosion; etc.

Many studies have shown that ground cover is a key parameter for reducing soil erosion. No matter what type of vegetation (trees, shrubs, grass or litters), the intensity of soil erosion will decrease as the ground cover increases; once the ground cover reaches 60–70%, its capacity to reduce soil erosion will be very close to its upper limit (Hou et al. 1996; Wang 1986) (Fig. 6.4). There is generally no surface runoff or soil erosion in well-growing forests; if an area is lacking ground

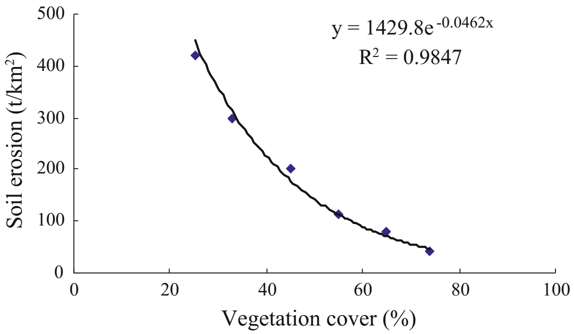

Fig. 6.4 Decreasing soil erosion with increasing vegetation cover on the Loess Plateau (Hou et al. 1996)

cover, even in woodlands, it will suffer from soil erosion. Therefore, increasing and maintaining a high ground cover and preventing any disturbance on it is the core of vegetation management. However, the drought limitation to growth and vitality of forests and the water yield reduction due to large-scale afforestation are also issues of great concern on the dry Loess Plateau. Maintaining a certain necessary level of ground cover (e.g. higher than 70%) to protect soil against erosion but without excessive eco-water consumption due to over-dense vegetation is the key to ecological restoration in this region. We must not neglect the restriction on water resources in the recovery of forests only due to its advantages in soil erosion control.

Biodiversity Conservation

Biodiversity is usually divided into three levels: ecosystem diversity, species diversity, and genetic diversity. It is estimated that over 50% of the worldwide species of 5–30 million live in forests. Therefore, forests are the most typical, diverse, and important terrestrial ecosystems—the decrease and degradation of forests will certainly lead to a sharp drop in species diversity. It is said that the extinction of a plant species often poses a serious threat to the survival of other 10–30 species. Thus, in a large sense, forest protection and restoration will help the biodiversity protection and restoration to a certain extent through various means, including establishing nature reserves, promoting rational forest harvesting modes, controlling and optimising the use of forest products, strengthening the cultivation of timber production forests, and thereby reducing reliance on natural forests, etc. (Yan and Chen 1995).

The study by Han et al. (2008) shows that the implementation of the Grain for Green Project (Li 2004) on the Loess Plateau has a great impact on biodiversity and the impact can be realised through many different ways. On one hand, due to the inappropriate choice of tree species and high planting density in plantations, a lot of trees fail to grow properly and some forests have withered due to the lack of soil water. The plant species diversity in plantations is clearly scant compared to natural forests. On the other hand, in the north of Shaanxi where the Grain for Green Project is implemented, grazing restriction and implementation of the project in sloping farmland lead to a rapid increase in plant diversity; the number of plant species in abandoned farmland reaches 31, significantly higher than that in the woodlands (9–14); five years after the conversion of farmland to forests or grassland, the semi-shrubs or shrubs began to grow. This suggests that, when implementing a large-scale ecological restoration programme in arid areas, the control of grazing is significantly more efficient than planting trees in terms of biodiversity protection.

A study conducted by Hao (2012) with the 25–30 years old larch plantations in Liupan Mountain of Ningxia showed that the number of undergrowth plant species increases with increasing stand density within the range of 500–1300 trees/ha (corresponding with canopy density of 0.3–0.7); reaches its maximum (37 shrub and herb species) at the stand density of 1300 trees/ha (corresponding with canopy density of 0.7); then decreases with further increases of stand density and plummeted to almost zero when the density is 2000 trees/ha or higher (corresponding with canopy density of 0.7–1.0). Therefore, it is believed that, under the forest age stage observed in this study, maintaining a stand density of 1300 trees/ha will help improve the undergrowth plant biodiversity and natural regeneration of trees. This density can be used as the benchmark density for converting the monoculture of plantation into close-to-nature forests with complex stand structure and balanced services.

Compared with the parameter of tree density, canopy density can more directly influence many forest functions/services including biodiversity protection. The natural understory growth and regeneration are highly dependent on the canopy density (Riepšas and Urbaitis 1996) because of its light regulation. A proper canopy density is conducive to the regeneration of shade-tolerant and relatively shade-tolerant species and the control of the invasion of photophilous grass (Wagner et al. 2011). The annual height increment of understory seedlings and saplings decreases with the increase of canopy density, and it becomes very small when the canopy density exceeds 0.7 (Chrimes and Nilson 2005). The total leaf area index (LAI) of the canopy, shrubs, and grass reaches the maximum when the canopy density is between 0.6 and 0.8 (Tong et al. 2011). This means that when maintaining a canopy density within the rational range of 0.6 and 0.8, the undergrowth biodiversity protection and many competitive functions/services (such as controlling excessive undergrowth, maintaining natural regeneration of understory plants and normal growth of saplings, producing high-quality and high-price timber, and increasing forest stand biomass) can be simultaneously realised.

Carbon Sequestration

The carbon sequestration capacity of forests is much higher than grasslands and farmlands, and can play an important role in the reduction of greenhouse gases and active climate change mitigation (Lorenz and Lal 2010). How to make full use of or enhance the carbon sequestration capacity of forests is a significant challenge in multifunctional forestry. We have to consider forests, climate and forest management in a bigger picture. First, it is estimated that about 15–20% of global greenhouse gas emissions are caused by deforestation. Thus, we should prohibit deforestation, prevent forest fires and diseases, and exterminate pests to ensure a healthy growth, and at the same time restore forests. Second, we need to manage existing forests reasonably (e.g. proper thinning and selective cutting, controlled rotation, intercropping, reducing disturbance to litters and soil, etc.) to strengthen the carbon sequestration capacity of forests.

Besides forest biomass growth, the carbon sequestration service of forests largely depends on the enhancement and maintenance of soil organic carbon, since the carbon pool in root zone soil layer is generally higher than that in vegetation layer and humus layer, also for the plantation on the Loess Plateau (Shen and Zhang 2014; Shen et al. 2015). Thus enhancing and maintaining soil carbon is an important issue in forest management, besides the increase of vegetation carbon in biomass. A study on the Liupan Mountains of the Loess Plateau (Liu et al. 2012) showed that soil disturbance during afforestation leads to a decrease of soil carbon pool, and it needs

16 years for the plantation on sunny slope to fully recover the soil carbon pool to the pre-plantation level of natural shrub land, and 32 years on shady/semi-shady slope to the pre-plantation level of natural secondary forests. Less disturbed afforestation (with sparse density) needs shorter time for the soil carbon pool recovery. This was approved by other studies, for example, the soil organic carbon density in the black locust plantation in the semi-humid loess region was lower than that of natural shrub-grass land at the plantation age of 10 and 26 years, but contrary at the age of 35 years (Song et al. 2015), meaning a positive contribution of plantation to soil carbon pool just appeared after a certain age. Another study carried out in the semi-arid loess region in southern Ningxia (Liu et al. 2005) showed the soil organic carbon content of top soil (0–20 cm) of natural grassland is higher than that in shrub land, farm land, artificial grassland, and orchard.

However, both the area expansion and biomass growth of forests are limited by water quantity and annual precipitation, especially in dryland regions such as the Loess Plateau, as discussed earlier in this chapter. The contradiction between water use of forests for carbon sequestration and water shortage is a challenge the international community must address (Farley et al. 2005). In addition, the amount and quality of soil organic carbon is also decisive for the water-related services of forest soil, for example, with respect to the capacities of filtering, buffering and transformation function, the capacities of water retention, and the quality regulation of seepage and groundwater (Feger and Hawtree 2013).

6.2 The Complex Relationship Between Forest Services

In order to fully maximise the multiple functions of forests to ensure sustainable development, we need to gain an in-depth understanding of the multifunctional feature of forests and the relationship between forest services. We ought to exercise rational forestry planning and sound forest management in accordance with the overall national and regional development plans, thereby maximising the multiple utilities of forests (Wang et al. 2010).

The complex relationship between forest services (Fig. 6.5) is first reflected by their various interactions (Bennett et al. 2009). The services provided by forests are not always coincident with each other (Wagner et al. 2013). It is not a given that forests will offer desired benefits proportionally and afforestation will solve all related problems. In some cases, the services of forests are not in synergy, but directly or indirectly competitive. The harsher the environment or the greater the development pressure, the more prominent the contradiction between services will be. Many studies can verify the complex relationship between forest services. For example, forest area increase can generally increase the services of carbon sequestration, soil protection and flood mitigation, but decrease water yield, which is vital for safeguarding the development in dryland regions; the increase of tree density will generally increase timber and biomass production, but decrease the plant biodiversity under forest canopy due to the lowered light intensity;

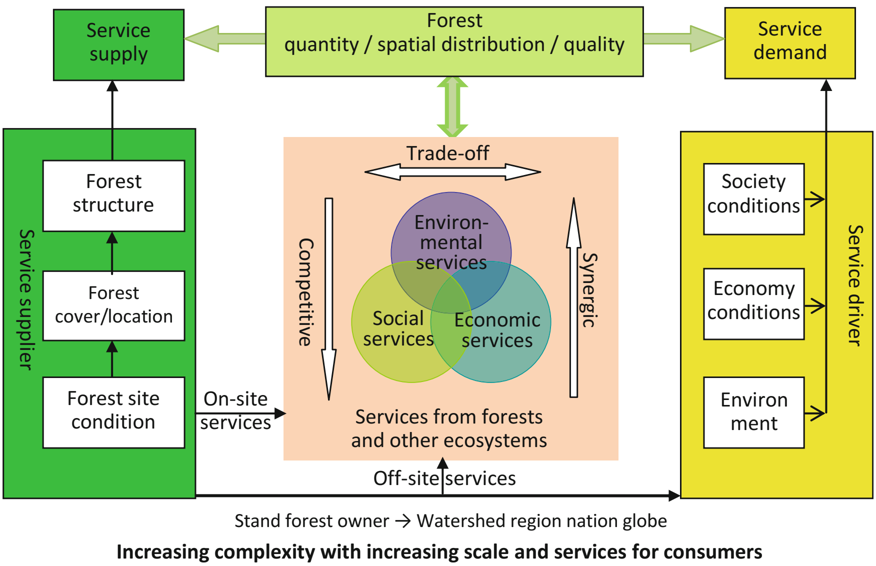

Fig. 6.5 The complex relationship between forest services and their demand and supply

the afforestation after clearing former forest/shrubs can quickly increase the vegetation-fixed carbon in the earlier stages of forest development, but decrease the soil carbon pool due to the accelerated mineralisation of soil organic matter.

Second, the complex relationship between forest services is reflected by the possible difference between the forest services composition provided in a natural way and the spatial–temporally varying services composition required by human beings. For example, the increase of rainwater infiltration through more afforestation is good for erosion control, crop/biomass production, and income increase of upstream local farmers, but not good for the water supply of downstream agriculture irrigation and industry development.

Therefore, from a holistic viewpoint, trade-offs among the multiple forest services are often required in forestry planning and forest management, to meet the varying and increasing needs in terms of forest services, especially on the Loess Plateau, characterised by a harsh environment, low forest cover, high population pressure, and shortage of arable land and water.

6.3 Principles of Multifunctional Forestry

6.3.1 Multifunctional Forestry Versus Other Concepts

Multifunctional forestry is related to but also differs from other forestry concepts, such as traditional forestry, ecological forestry, sustainable forestry, modern forestry, and close-to-nature forestry. First, unlike traditional forestry, which defines timber production as the main service of forests, multifunctional forestry highlights not only timber production but also considers other functions. Multifunctional forestry is also clearly different from ecological forestry, which has been promoted in the past two decades in China through the differentiated management of either "commodity forests" or "ecological forests". Multifunctional forestry covers not only the so-called commodity and ecological forests, but also the various intermediate states between these two extremes. It emphasises the versatile use and optimisation of the overall functions of forests, rather than the maximisation of just one or a certain type of benefits. Multifunctional forestry not only reflects the core and the purpose of sustainable forestry, but also focuses on and helps realise sustainable management objectives, so it is more promising and more balanced as compared with other concepts.

A similar concept to multifunctional forestry is the compatible forest management developed in the USA (Haynes et al. 2003). It means forest management should be compatible with commodity production and ecological, social, and cultural values of forests, or simultaneously produces multiple products of value without compromising other values. The emphasis of this concept is given to forest management at stand scale through the choice of management actions that meet relatively specific land management objectives, although it takes note of the cumulative effects of actions across neighbouring stands, watersheds or further larger scales. In terms of forest stand management, this concept is similar to multifunctional forestry, but differs in that compatible forest management stresses only on the management of existing forests and ignores the complex relationships between the services supplied by forests and other ecosystems, especially at a spatial scale of larger than a stand. In contrast, multifunctional forestry acknowledges the need to balance the competing services demanded by different ecosystems (land uses) and at different scales.

Generally speaking, the management approach of close-to-nature forestry (Duncker et al. 2012) is a practical, fast, high-quality, and low-cost measure to fully use the multiple services of forests at stand scale. It can maintain the biodiversity, ecosystem structure, and the diversified landscapes through maintaining a "permanent" forest cover with minimal management intervention compared with other active management approaches by simulating natural processes. However, the close-to-nature forestry developed in humid climates in central Europe is more experience-based, mainly for high-quality timber production. Therefore, it cannot always meet the technical requirement of multifunctional forestry, first because the services naturally provided by forests may not be entirely consistent with the needs of human beings; secondly because the dominant service(s) of forests may increasingly be or not be limited to timber production. Thus, we can take the close-to-nature forest management as the starting point to realise multifunctional forest management, especially when high-quality timber production is still included in the dominant services. However, if the site is poor like those on the dry Loess Plateau and the main objectives of forest management are shifted to the soil- and water-related services, other management techniques have to be adopted.

We need to constantly seek for further development and improvement of multifunctional forestry and forest management through research and exploration.

There are other similar concepts/terms to multifunctional forestry, including multi-purpose forestry (Lexer and Brooks 2005), multi-purpose forest management (Buttoud 2002), multiple use forest management (Innes 1993; Kessler et al. 1992), and ecosystem-based approach (Schlaepfer et al. 2002). The reason we prefer the term "multifunctional forestry" is that it is often difficult or even not possible to equally treat all functions (possible uses) of forests as management purposes or objectives in practical forest management and development planning. For example, we cannot quantify the objectives of wildlife number in a stand or even a forest farm, and the species and quantity of soil animal and microorganisms. However, we can select some dominant services/functions as management objectives while paying enough attention to other services/functions of forests, as will be discussed later.

6.3.2 Principles of Multifunctional Forestry

Within the past two decades, countries advanced in forestry have attached great importance to multifunctional forestry. For example, EU and Japan have promoted multifunctional forestry through the introduction of forestry laws. The EU formulated the EU Forestry Strategy in 1998, stressing the multiple functions and sustainable management of forests, and the EU Forest Action Plan in 2006 for the period 2007–2011 to promote sustainable management and multifunctional role of forests. In USA, the Forest Service has taken ecosystem management approach as a new direction in its research and management programmes to achieve broader multiple use objectives of forests (Thomas 1996).

Wang et al. (2010) have proposed to convert China's forestry to multifunctional forestry, based on their understanding of the complex interrelations among forest services, between services from forests and other neighbouring ecosystems, and between services supply and demand from human beings. Here multifunctional forestry is characterised by a rational choice and use of one or more dominant service(s) under the premise that other services will not be reduced too much so that the total services obtained by various stakeholders at different scales (e.g. forest owner, local people, and regional people) at unit space (e.g. forest stand, forest farm, watershed with forest and other land covers, and administrative divisions) within different time periods can be optimised. The choice of dominant services is based on the site- and region-specific service supply and service demand for socioeconomic development and environment protection.

It is believed that both the functions of forests and the function relations are jointly determined by the quantity, quality, and spatial distribution of forests. Therefore, multifunctional forestry should be realised in each development phase of forestry (from forestry planning, forest restoration, forest cultivation, forest management to forest utilisation practices) and from the viewpoints at multiple scales (from forest stand, forest farm, watershed, to national or even global level). Only in this way it can promote the reasonable protection and sustainable use of all services of forests and other related ecosystems, in order to meet the quickly increasing service demand in a sustainable manner and for ensuring the optimisation of forestry's role in sustaining socioeconomic development.

Forest stand is the basic spatial unit for multifunctional forest management. Therefore, multifunctional forestry encourages the establishment of multifunctional forests according to the site specific productivity and services requirements. However, the complex relationships among services of forests and between the services supply from various ecosystems (including forests) and the services demand from human beings vary with spatial scales and changing natural and socioeconomic conditions. They should be considered and not viewed in isolation from the other (Wagner et al. 2013). The emphasis is on the spatial optimisation of multiple forests and their services at multiple scales, from individual forest stand, forest owner, village, watershed, region, to the national or even global level. We need to group forest services into dominant, important, and other services in accordance with the site conditions and service demands. When planning, establishing, and managing forests, we need to consider the local characteristics, function conflicts, and regional differences rationally, and ensure that forests can meet the demands of dominant services with possibly higher supply of other services such that the overall services and values can be optimised at various scales (Fan et al. 2013). Since it is very difficult to create a forest that can fulfil all service demands equally, trade-offs among services should be addressed, with the support of proper policy, payment for ecological services, and other measures. Furthermore, we must realise the multifunctional forestry concept at each link, including the forestry development layout, forest management planning, forest benefits evaluation, payment for ecological services, and so on, and constantly improve the related technology, management measures, policy supports, etc. At the operational level, we need to develop and improve the practical technology of multifunctional forestry as soon as possible, through the full use of all existing experiences and through the promotion of scientific research, especially through the use of modern information technology to facilitate science-based decision-making.

6.3.3 Specific Requirements for Forestry in Dryland Regions

Mountains are the main water source areas as well as key forest areas in northwest China. Deforestation has led to severe soil erosion, droughts, and floods. Big efforts in afforestation over the past few decades have increased the forest cover and improved the environment significantly. However, the conflict between forests and water supply intensifies as the forest area continuously increases. First, drought stress has resulted in low survival ratio and growth rate of trees; second, the decrease in water yield due to large-scale afforestation has increased the competition for water. The future establishment of forests in mountainous areas should ensure both water supply and erosion control as dominant functions of forests, while considering the production and other services. In northwest China, we must strive to maintain a balance between forest/vegetation restoration and water management, so as to ensure ecological security, water security, and sustainable development at regional level. To ensure the integrated management of water, forest, and soil/land, we need to develop proper forestry strategies, planning methods, and management models. To fully take advantage of the multiple roles of mountainous areas as forest areas and water source areas, we need to reasonably determine the quantity, spatial distribution, composition, and structure of forest/vegetation based on the carrying capacity of water resources and through multifunctional forestry.

Protecting soil from erosion and sandstorms are the most important forest services required in northwest China. Thus, soil and water conservation forests and windbreaks account for a large area ratio in the forests of northwest China. Although significant multiple benefits have been obtained from the implementation of the Three North Shelterbelt Project, the Grain for Green Project, and other projects, a stable and efficient system of protective forests has not been formed because of the drought stress, exotic (not site adapted) tree species, single-species plantation, and other reasons. Consequently, most existing forests are plantations with single or a few tree species and low functionality. Their protection and productive functions are to be improved and their role in poverty alleviation and other aspects must be increased. When establishing soil and water conservation forests and windbreaks in the future, we need to firstly ensure their dominant services, but also improve the quality of protection forest system, optimise their spatial distribution and stand structures for increased multifunctionality. Furthermore, we need to give more consideration to the site specific water restrictions on forest/vegetation restoration. In order to restore stable, efficient, and close-to-nature forests, native tree species should be the first choice. The protection forest system needs to be a proper combination of trees, shrubs, and grasses according to local conditions. Comprehensive measures need to be adopted to effectively balance ecological and other functions. We should also properly develop undergrowth products and their related industries, to promote regional economy and increase farmers' income.

Agricultural areas in plains and oases, as the most densely populated areas in northwest China, are the most important bases for producing grain, cotton, and oil, but the frequent droughts, frosts, gales, and other meteorological disasters often decrease the yields. Thus, a shelterbelt system for protecting agriculture is highly needed. The dominant services of shelterbelts are to improve the environment in agricultural areas, protect crops, and ensure food security, followed by producing timber, offering various forest products, and increasing employment opportunities. In order to actively cope with the growing problem of arable land shortage, when establishing shelterbelts in agricultural areas, we should further optimise the relationship between land uses for agriculture and forestry, and develop high-standard shelterbelt systems that use less land and water but have high efficiency. We need to further improve the production capacity of shelterbelts and increase their yields of timber, woody grain, and oil, and other products, in order to increase the economic income and employment opportunities in rural areas; and at the same time fully use other forest functions such as farmland pollution control and landscaping.

The so-called economic forests (or cash trees), with a dominant function of providing a variety of unique non-timber forest products such as fruits, food, and oil, occupy a large ratio in the total forest area in northwest China. Such forests also occupy an important position in the national commodity forest products, as they are the most direct way to increase farmers' income. There are numerous forest products with a brand name in this region, such as the apples in Northern Shaanxi, the jujubes in Shaanxi, the wolfberries and grapes in Ningxia. If managed properly, the economic forests can also offer ecological services such as air cleaning, erosion control, water regulation, and so on. However, there are still many problems in their management, such as the too quick area increase without a proper development plan, lack of technological guide for choice of appropriate species and varieties, lack of technical support, lack of standardisation, inconsistency in fruit quality, and lack of deep processing. A problem that needs special attention is the overuse of chemical fertilisers and pesticides, which not only increases soil/water contamination and reduces soil/water quality, but also endangers food safety and people's health. In future multifunctional management of economic forests, we need to attach great importance to solving the problems mentioned above, to increase both their economic potential and ecological services.

6.4 Multifunctional Management of Main Forest Types

In the dryland regions of northwest China, such as the Loess Plateau, the multiple utilisation technology of forest functions is still at the initial exploration stage. Therefore, the multifunctional forest management has to be further explored and refined. The following discussion about multifunctional management of the main forest types (Fan et al. 2013) is just an exploratory analysis and further researches are surely required.

6.4.1 Multifunctional Protective Forests

Protective forests are a major type of forests on the Loess Plateau, also in the whole of China. If other functions other than the predetermined dominant protective function(s) can be utilised properly, then the protective forest can be referred to as multifunctional. In areas suffering from one obvious natural disaster (such as soil erosion, sandstorms, hot and dry winds, etc.), the protective forest system is often composed mainly by one type of protective forest—for example, soil and water conservation forest in soil erosion areas, farmland shelterbelt in sandstorm-prone areas.

When managing multifunctional protective forests, we must adopt measures suitable for local conditions, choose preventive measures according to local problems, achieve reasonable stand structure, optimise the spatial distribution of forests, and maintain the multifunctional use. To adopt measures suitable for local conditions, we need to consider the local natural, social, and economic conditions, especially the limitations of the environment (e.g. water scarcity) on forest restoration and establishment, and try best to develop close-to-nature forest, so that the forests can effectively play the protective role for the long term. To choose preventive measures according to local problems means to focus on the use of particular protective functions to solve local problems, such as erosion control, regulation in water cycle, and farmland protection, rather than pursuing only the timber production function. To achieve reasonable stand structure means that the spatial structure of a forest needs to be conducive to maximise the dominant protective functions. For example, soil and water conservation forests shall have sufficiently high ground cover to prevent and control soil erosion; farmland shelterbelts need to have a high enough tree height and reasonable optical porosity in order to sufficiently reduce the wind damage to farmlands; riparian filter strips must be sufficiently wide to protect rivers from non-point pollution from farmland. To optimise the spatial distribution of forests is to achieve the best overall protective effect by optimising land use and creating a reasonable spatial pattern of forests. To maintain multifunctional use means that other services and productive functions should be fully used, without compromising the dominant protective function of protective forests, such as the full use of timber production and recreation functions of water-retention forests, the full use of timber production function of farmland shelterbelts, so that the overall role of forests in regional development is maximised.

There have been a lot of researches on the management technology of various protective forests, especially farmland shelterbelts, soil and water conservation forests and windbreaks. People have been studying how to efficiently manage these forests for several decades. However, as influenced by conventional single-function use of forests or by the development history of forestry, the traditional management of protective forests often overemphasises the use of dominant functions, but overlooks other functions more or less. It is evident, that such concepts have failed to attach sufficient importance to the relationship between different services offered by forests. Furthermore, as the spatial unit of such traditional management practices is often limited within forest stand (or plots), this will inevitably limit the full use of multiple functions offered by forests.

In order to give full play to the role of forestry in regional sustainable development, we need to consider the multifunctional management of protective forests in several spatial scales. First, at the scale of a region (large watershed), we need to consider the optimal forest cover—it should comply with the overall regional land use plan, but also take into consideration the limitation of climate (precipitation, temperature, etc.), soil, water yield, and other factors (Calder 2005; Pilaš et al. 2010). Accordingly, we should strive to achieve the maximum protective benefits with the minimum land use of forests. For the Loess Plateau region, this means that the proper forest cover shall be 5–10% in the plains with dominant land use of farmland or pasture, but generally not be less than 30% in mountainous and hilly areas. However, the specific forest cover needs to be decided based on local environmental conditions. Second, at the scale of within a watershed, we must consider the rational spatial distribution of forest/vegetation, because we should strive to obtain the best overall protective effect through a minimal use of water and land by forests through cultivating protective forests in accordance with site conditions and the spatial distribution of problems that can be prevented by forest/vegetation. Third, at the scale of an individual site, we need to determine the proper vegetation types and tree species composition, according to the principle of matching plant/tree species to site quality for a higher survival and growth rate of trees, and according to the principle of meeting the diverse demands on forest functions as much as possible. Finally, at the scale of forest stand, we need to determine and maintain a proper structure of forest/vegetation for a full play of both the dominant and other functions of forests; this will be explained in greater detail with several examples in Chap. 7.

6.4.2 Multifunctional Timber Production Forests

The main purpose of timber production forests is to produce wood. Generally speaking, ideal timber production forests are fast-growing, high-yielding, and high-quality timber plantations. To cultivate such forests, we need to shorten the time to produce specified timber, increase timber volume and growth of trees per unit area, and meet quality requirements relating to stem form, knots, wood properties, and other factors. A multifunctional timber production forest is a forest that can meet the demands of both timber production as its dominant function and other functions, especially the demands for ecological services. Multifunctional timber production forests are usually planted in sites with superior conditions. Thus, they can easily provide a variety of functions and such forest sites are main areas for multifunctional forest management.

Numerous studies conducted in China and other countries on management of timber production forests have put forward complete technical systems. Although such systems are mainly developed for maximising timber production and do not meet the requirements of multifunctional management, this does not prevent us from applying the suitable technology under such systems to the multifunctional management of timber production forests. However, we shall take into account the characteristics of multifunctional forestry and close-to-nature forest management, when we use such technologies. Taking the example of the choice of logging methods (e.g. clear-cutting, thinning, and selective cutting), clear-cut practices will destroy the forest structure and is not conducive to the formation of a complex structure that is multi-layer and multi-species. Thus, thinning and selective cutting should be the main logging methods. Cutting intensity must be kept at a moderate level in which the permanent and proper cover of forest canopy can be maintained. If possible, close-to-nature forest management techniques shall be adopted. In terms of forest regeneration, it would be better if we do not rely on artificial regeneration, but use natural regeneration whenever possible; and just when it is impossible to fully rely on natural regeneration, artificial methods may be used to supplement natural regeneration. In terms of forest tending and harvesting, the management techniques of close-to-nature forestry originated mainly from central Europe have great utility value, but they should be tested and improved before being implemented in China to solve local problems.

6.4.3 Multifunctional Economic Forests

Economic forests are forests or shrubs with the main purpose of supplying non-timber forest products such as fruits, edible oil, industrial raw materials, herbs, and other products (starch, rubber, medical materials, spices, paint, etc.). They have a special economic value and play a very prominent and important role in realising short-term economic benefits of forestry.

On the Loess Plateau and in northwest China, there are many favourable conditions that are conducive to the cultivation of economic forests (Zhang and Gao 1987), such as the vast land area and the great variety of economic tree species. There are also a lot of wild economic forest resources, such as sea buckthorn, wild apricots, and wild jujubes. Due to the high altitude, plenty of sunlight, and huge temperature difference between day and night, the fruit quality is very high. The dry air in this region leads to fewer pests and diseases. In addition, because the increase of timber production forests in northwest China is restricted due to their long cultivation period, severe water shortage, and low growth, existing conditions on the Loess Plateau are rather favourable for economic forests.

However, many problems exist in the management of economic forests, such as serious soil erosion, land degradation, overuse of fertilisers and pesticides, premature aging of forest, low and unstable yields and income. These not only reduce the productive functions, but also decrease the ecological services and other functions of forests. Therefore, we need to implement standardised management as soon as possible under the guidance of multifunctional forestry, including soil and water conservation, water and fertiliser management, tree surgery, and pest control.

In terms of soil and water conservation, economic forests should not be planted on steep slopes. When cultivating economic forests on gentle slopes with a gradient of $<25°$, soil preparation in fish scale, terrace or strip should be implemented, with vegetation cover in between being retained as much as possible. Minimum tillage or no-tillage farming methods should be adopted to retain water, lower temperature, prevent droughts, reduce soil erosion, and increase soil fertility.

In terms of water and fertiliser management, which is very important in mountainous and hilly areas, attention should be given to the water management measures (mainly including water storage, water conservation, and drought prevention) and fertilisation management measures (mainly including rational fertilisation, strict control of fertilisers, utilisation of organic and biological fertilisers, full utilisation of green manures). Density control, pruning, thinning, and other measures are also needed to regulate water and nutrient conditions.

In terms of pest control, we must first recognise that the cultivation of single-species forests in large areas and the overuse of broad-spectrum pesticides are important causes of the worsening damage caused by pests and diseases. Therefore, we need to promote mixed forests and comprehensive management, and strictly control the concentration, dose, using time, and residual volume of pesticides. Use of any pesticide and fertiliser on organic products is strictly prohibited. For example, the European Union has formulated detailed regulations on planting materials, origin selection, irrigation, fertilisation, pesticides, harvesting, processing, storage and transportation, and other aspects of the production of medicinal and aromatic plants, with an especially strict control on the use of fertilisers and pesticides and herbicides. These are good lessons that can be exemplified in the promoting of multifunctional management of economic forests in China.

6.4.4 Multifunctional Scenic and Recreational Forests

Multifunctional scenic and recreational forests are forests that not only offer recreational functions and landscaping functions (providing attractive scenery with their unique colours, shapes, smells, etc.), but also provide a variety of other functions, including protective functions (erosion control, water retention, wind damage prevention, air cleaning, pollution reduction, species protection, climate regulation, dust and noise reduction, carbon sequestration, etc.), and health care functions.

When establishing multifunctional scenic and recreational forests, the multifunctional native tree species (or exotic species with proven adaptability) need to be chosen based on site conditions, forest types, succession regulations, and recreational needs of humans. How to strengthen the seasonal variation of forest scenery should also be considered (Zhang 2006). Some scenic and recreational forests may also have a particularly prominent function. For example, they may provide an important source of a certain type of recreational activities, including harvesting, forest bathing, and tree planting on memorial events. The tree species of such forests should be chosen based on their unique functions (Zhang 2006). In this way, we can create multi-species, multi-layer, multi-colour, multi-view, multi-flavour, and multifunctional scenic forests. When establishing and managing scenic and recreational forests, we must take into account the multiple functions of forests, especially their ecological functions. To this end, it is necessary to adjust the structure and management model of forests (e.g. tree density, canopy density, forest cover, etc.) to meet the needs of both recreation and other functions, so as to achieve the efficient multiple use of scenic and recreational forests.

The current management technologies of scenic and recreational forests in China include the spatial configuration of tree species and forests, the seasonal configuration of sceneries, tree tending and shaping, regeneration, and protection measures.

The management measures mainly include the cultivation of large-dimension trees, improvement of stand conditions, increase of the consistency of forest sceneries, enrichment of scenic tree species, and creation of mixed forests. The purpose of these measures is to cultivate multi-species, multi-layer, multi-colour, multi-view, multi-flavour, and multifunctional scenic and recreational forests.

The impacts of human activities on scenic recreational forests are exceptionally strong, and therefore they need to be carefully protected in order to prevent fire, pest, tree damage, soil trampling, biodiversity loss, destruction of ground cover and soil porosity, and the corresponding decrease in multifunctionality.

The well-maintained forest scenery is the premise for the sustainable use of scenic and recreational forests. Selective cutting should be adopted to remove the severely damaged trees, to improve forest health and scenery and to prevent the spread of pests. Trees that compete with target trees, or lower the scenery quality, should be properly removed in time.

6.5 Conclusion

Forests can supply numerous functions/services, which influence people's income, socioeconomic development, and environmental safety. Their importance and interrelations are site and regional specific. On the dry Loess Plateau of northwest China, soil protection against erosion is usually the dominant service; water cycle regulation is also important, but drought stress and water yield reduction after afforestation are factors which must be considered in forestry planning and forest management. The relationships among services of forests and between the service supply and service demand are very complex, and they vary with changing spatial scale and natural and socioeconomic conditions. Not all forest services are synergic, in contrary, many of them are competitive. Therefore, trade-offs often have to be addressed to optimise the overall value of the services from forests and adjacent ecosystems per unit space area to various stakeholders at different spatio-temporal scales, through the rational regulation of forest/vegetation traits [e.g. forest quantity (forest cover), forest distribution, and forest quality (forest structure)] in the way of multifunctional forestry. The comparison with other forestry concepts showed that multifunctional forestry is a promising approach to balance the competing demands of ecosystem services, in which the dominant services can be met but without too much loss of other services. Finally, the requirements and technical points in multifunctional management for forests in general and for the main forest types (protective forest, timber production forest, economic forest, scenic and recreational forest) to balance the potential services competition are briefly suggested. These preliminary achievements may be helpful to guide and promote future multifunctional forestry on the Loess Plateau and in other similar dryland regions.

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Chapter 7
Multifunctional Forestry and Forest Management: Eco-hydrological Considerations

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The eco-hydrological studies in numerous basins/sites on the Loess Plateau observed a drastic reduction of water yield after afforestation. It is believed that this will threaten the regional water supply, since massive afforestation has been implemented in the past and is planned for the future. This chapter proposes that the multifunctional forestry and forest management in dryland areas, such as the Loess Plateau, should pay special attention to the forest–water relationship by considering the vegetation carrying capacity of regional water resources. This chapter will also discuss the principles and techniques of multifunctional forestry decision-making, which gives significant consideration to the forest–water relationship. To illustrate these points, the authors discuss cases of multifunctional forest management on the scales of stand and watershed.

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7.1 Need for Multifunctional Forestry

In the Loess Plateau region, forest vegetation plays an invaluable role in conserving water and soil, purifying water quality, and regulating discharge. Therefore, as discussed in Chap. 2, increase of forest cover is one of the most important measures to ensure the sustainable development of this region.

While forest ecological restoration in the Loess Plateau region has significantly reduced soil erosion, due to the lack of insight into and proper handling of the forest–water relationship, the plantations grow slowly, suffer from serious diseases and insect pests, yield poor ecological benefits, and show soil desiccation and poor vegetation stability (Yang 1996). In particular, the large-scale afforestation resulted in significant water yield reduction and exacerbated the water shortage and water use competition in this region (Wang et al. 2011; Zhang et al. 2014, 2015). Based on previous studies (Wang et al. 2012), it can be concluded that forestry development in this region should not exceed the vegetation carrying capacity of water resources at the scales from site to region. Besides the water used by forest and other vegetation for improvement of the environment, it is also necessary to consider the water supply needs of downstream water users when the water-yielding capacity of watersheds is managed; that is, besides the traditional forestry principles of “Act in light of local conditions and set up protection in light of dangers”, new principles of “Set production quotas in light of water supply” and “Set afforestation quotas in light of water supply” should be followed in dryland regions.

These issues raise a variety of pressing questions: (1) How to achieve rational development, rational planning, and rational management of forestry/forests in arid and water-deficient regions? (2) How can the benefits of forestry be increased without endangering the water supply capacity of watersheds? (3) How to mitigate the conflict between increased water consumption by forests and aggravated water shortage in the region? Answering these questions requires the development of site and regional-specific forest management strategies and rational planning methods, as well as science-based decision-making tools that simultaneously consider the management of water, soil/land, and vegetation. The quantity, distribution, constitution, and structure of forests should be rationally determined based on the vegetation carrying capacity of water and land. In a word, the dryland regions should take a specific multifunctional forestry path that gives consideration to the requirements of water and land management, or in other words as an integrated forest–water–land management. Design and implementation of such multifunctional forestry needs to be planned at multiple spatial scales, ranging from stand, slope, to the basin. To this end, the operating units (forest owner, forest farm, forestry bureau) have to understand the carrying capacity of water and land for forests, and what ecosystem services the afforested land could potentially provide. Based on that understanding, the site-specific management aims can be prioritised before the establishment of multifunctional forests and realised through their multifunctional management.

The stony mountainous areas are the main sites for afforestation on the Loess Plateau. Due to a relatively higher precipitation, these areas are also the most important water sources for downstream water consumers. Thus, afforestation in the stony mountainous areas focuses on the establishment of water-retention forests, which is a forest type with the main purpose of adjusting hydrological phenomena and protecting water supply, according to the forest classification system in China. However, this type of forests can also play a role in protecting soils against erosion, producing timber and other services. Afforestation has been effective for soil erosion control, but accompanied by a drastic reduction in water yield in the main tributaries of the Yellow River. This has led to an emerging debate notably about the increase of forest area. Increased temperature and decreased precipitation may also have contributed to the water yield reduction. As a consequence, better water-saving forest management prioritising the balancing of soil erosion control and water supply needs to be established. Timber production and other services should be secondarily considered. This requires a well-balanced compromise between forest restoration and water resource management. It is imperative to rationally determine the types and quantity of forest/vegetation to be restored based on the carrying capacity of land/soil and water resources in the region and to develop water-saving multifunctional forestry in consideration of water resource management in order to maximise the multifunctional roles of mountainous areas as both forest zones and waterhead zones.

The area of protective forests (mainly for soil and water conservation and windbreaks) established on the Loess Plateau takes up a large part of the Three North Shelterbelt Project and the Grain for Green Project (Li 2004). These programmes will be continued until 2050 but a stable and effective shelterbelt system has yet to be formed because most of these forests are even-aged monocultures and suffer from drought stress. The future forestry development in the Loess Plateau region needs thus to be revised. It should still focus on control of water and wind erosion, but it needs to enhance the quality of protective forests by transforming the single tree species forests into multi-layered mixed forests. More attention should be paid to the limitations of water shortage, the site-specific water carrying capacity, and the natural regeneration of established forests. Moreover, new forest management strategies should also effectively consider ecological and other benefits, rationally coordinate the relationships among different benefits, properly develop economic forests and related industries, and fully explore the potential and comprehensive benefits of forests.

7.2 Basic Principles for the Integrated Forests–Water–Land Management

The integrated management of forests, water, and land in the Loess Plateau region needs to conform to the following principles:

(1) **Enable multiple functions (services) of forests simultaneously**: All forests have a variety of functions, such as productive functions (e.g. timber,

raw materials), protective functions (e.g. soil, water, infrastructure), and recreational functions; but the priorities of these functions vary between regions and sites due to different boundary conditions and human needs. Therefore, it is necessary to distinguish between dominant, important, and general functions. Natural or socioeconomic limitations or contradicting needs of functions may sometimes prevent different forest functions from being enabled simultaneously. In such cases, the dominant functions should be first and foremost guaranteed, while minimising the negative effects on other important or general functions, so as to maximise the overall functions of the forests.

(2) **Never reduce the dominant function of soil erosion control**: In the Loess Plateau and Liupan Mountains regions, soil erosion control is a serious environmental issue as discussed in Chap. 1. Therefore, a high level of vegetation coverage must by all means be maintained while interferences should be minimised.

(3) **A certain water-yielding capacity must be satisfied and prioritised**: Previous studies have shown that forests in dryland regions often consume much more water than shrubs and natural grasslands. Thus, the increase of forest cover, forest density, and forest leaf area index (LAI) will reduce watershed discharge. To cope with these challenges, forest management practices (e.g. forest cover in watershed, tree stand density, selection of tree species, canopy LAI, etc.) have to ensure that a certain water-yielding capacity of forestlands and watersheds is maintained.

(4) **Maintain the drought-resisting stability of forests**: Dryland areas are water-scarce because of the lower annual precipitation than potential evapotranspiration and the extreme temporal variation of rainfall. These unfavourable conditions affect the health of forests. Therefore, it is necessary to quantitatively determine the vegetation carrying capacity as defined mainly by water conditions (including water-yielding requirement) on different spatial scales, including region, watershed, sub-catchment, slope, and site, and on this basis, to rationally determine the forest cover as well as its spatial distribution pattern and the community structure of forests.

(5) **Attempt to restore close-to-nature and multi-layered mixed forests**: The current forests in the Loess Plateau and Liupan Mountains regions are mostly even-aged single-species plantations. Repeated damages of these plantations result in declining ecosystem services such as protection or production functions. Efforts must thus be made to improve the quality of the existing forests by transforming pure stands into mixed multi-layered stands. Moreover, their spatial distribution and system structure needs to be optimised. Native tree species should be adopted as far as possible. Natural regeneration of forests should be promoted to enable the development of a stable high-quality protective forest system that organically combines the multi-layered trees with shrubs and grasses layers at low cost, and to well meet the requirements of both ecological benefits and other functions of forests.

These five principles are the essence of multifunctional forestry and multifunctional forest management in the Loess Plateau region. They may also apply to other dryland regions with conditions similar to that of the Loess Plateau.

7.3 Decision-Making Procedures for Forestry Planning and Forest Management

Compared with other land-use types on the Loess Plateau, forests consume the largest amount of water per unit area (Wang et al. 2008; Zhang et al. 2015). As such, any large-scale change in forest cover or modification of existing forests may result in runoff change. Therefore, forestry planning and forest management in dryland regions have to consider the causality between forest increase and water yield decline, following the concept of vegetation carrying capacity of regional water resources. This concept is defined by the maximum vegetation load supported by the water and land resources under the requirements of a certain water yield for maintaining a harmonious development of economy, society, and environment in a region/watershed, and this carrying capacity can be expressed by the index of quantity (e.g. forest cover), spatial distribution, and quality (e.g., LAI, tree species composition, etc.) of forest/vegetation. Thus, we propose the following decision-making procedures for the establishment or modification of forests in the Loess Plateau region:

1. Determination of acceptable forest cover in a catchment, basin or region
2. Optimal spatial distribution of forests, i.e. identification of suitable areas for forests
3. Selection of site-specific species composition
4. Design and regulation of site-specific stand structure.

7.3.1 Determination of Acceptable Forest Cover

When estimating the acceptable forest cover of catchments, basins or regions, a distinction is made between potential, rational, and feasible forest cover. The estimation of potential forest cover is based only on precipitation limitations, whereas the rational forest cover also takes into account water yield requirements of downstream water users. In contrast to the potential and rational forest cover, the estimation of feasible forest cover needs to add the consideration of the demand of other land uses. An example will be given.

In order to analyse the impact of forest cover on annual runoff, a meta-analysis was carried out using data from 57 catchments across the Loess Plateau (Wang et al. 2011). In a first step, vegetation in catchments was divided into forestland and non-forestland. If changes in soil water and groundwater storage are assumed to be negligible over a long period of many years, the impact of forest cover on the catchment mean annual evapotranspiration (ET, mm a^{-1}) can then be estimated as follows (Wang et al. 2011):

$$ET = P - R = ET_f \cdot f + ET_{nf} \cdot (1 - f), \tag{7.1}$$

where P is the mean annual precipitation (mm a^{-1}), R is the mean annual runoff (mm a^{-1}), ET_f and ET_{nf} are the mean annual ET of forestland and non-forestland, f is the forest area ratio (decimal), and 1-f is the non-forest area ratio in a catchment. In the dryland areas of the Loess Plateau, the annual ET depends mainly on the annual P (Zhang et al. 2015). This was also shown by Wang et al. (2011). Thus, the relationship between P and ET is almost linear. In order to consider the dependency between ET and P, Eq. 7.1 was expanded into (Wang et al. 2011):

$$ET = P - R = P \cdot (a_f \cdot f + a_{nf} \cdot (1 - f)), \tag{7.2}$$

where a_f and a_{nf} are the ratios of annual ET to P in forestland and non-forest land, as determined by linear regression analysis (Wang et al. 2011). Taking the a_f and a_{nf} values of 0.966 and 0.917 fitted for the entire Loess Plateau region, Fig. 7.1 shows the impact of forest cover and mean annual precipitation on the mean annual runoff based on Eq. 7.2. Figure 7.1 enables the estimation of a rational forest cover compliant with the requirements of downstream water users, so as to maintain regional water supply while increasing forest cover and improving ecosystem services. For example, assuming a mean annual precipitation of 600 mm, the rational forest cover should not be higher than 23% if a mean annual runoff of 40 mm would be demanded by downstream water users. The forest cover should be significantly smaller in drier catchments if the same amount of annual runoff would be requested. For instance, if the mean annual precipitation is about 500 mm, the rational forest cover should be less than 10% to meet the downstream water users' request of 40 mm annual runoff. It can be thus concluded that an unregulated increase of forest cover should be avoided in dry regions such as the Loess Plateau.

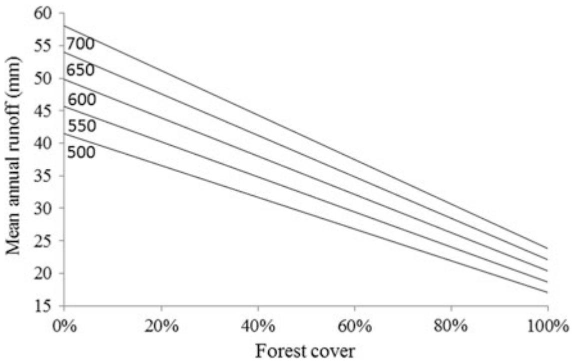

Fig. 7.1 Impact of forest cover and mean annual precipitation on mean annual runoff of basins on Loess Plateau. The numbers in the graph represent mean annual precipitation

We can also calculate the rational forest cover of loess basins in two sub-regions separately, with the fitted a_f and a_{nf} of 1.064 and 0.903 for basins with *P* of <450 mm, and with 0.962 and 0.925 for basins with *P* of >450 mm. However, it should be noted that the rational forest cover computed in this way is still a rough estimate, because it simplifies the relationship between forest cover and annual runoff and neglects the seasonal variation of runoff. Important factors such as the impact of relief on the redistribution of energy and water are not considered. More accurate rational forest cover can be obtained using eco-hydrological models and vegetation carrying capacity decision-making support tools. More details will be discussed below.

7.3.2 Optimal Spatial Distribution of Forests

In order to mitigate the conflict between ecological water needs of forests and socioeconomic needs in the Loess Plateau region, a decision supporting tool on vegetation carrying capacity of regional water resources (Pan 2013) has been developed. The core element of this tool is the distributed eco-hydrological watershed model of SWIM (Soil and Water Integrated Model) (Krysanova and Wechsung 2000). SWIM takes into consideration the spatial heterogeneity of hydrological elements such as geographical environment and vegetation characteristics within the watershed, divides the watershed into sub-watersheds based on the digital elevation model (DEM), and then further divides them into a series of hydrological response units (HRU) according to a number of factors such as gradient, soil, and vegetation type. It hypothesises that each HRU is homogeneous and has the same hydrological responses. Besides SWIM, the decision supporting tool consists of other elements such as modules for data management, data analysis, carrying capacity computation, and visualisation of results. This tool has been applied to the upstream watersheds of the Jinghe mainstream. On the premise of taking into consideration the impacts of forests on the mean annual runoff, peak discharge, and dry season runoff in the catchment, the vegetation carrying capacity (including the quantity, quality, and spatial distribution of forests) of water resources corresponding to the different requirements of regional water supply were worked out.

In determining the vegetation carrying capacity of regional water resources, the "scenario analysis method based on distributed hydrological model" was adopted. The procedure is as follows: (1) Formulate a series of vegetation restoration schemes (scenarios) according to the appropriate vegetation types of each site type and the region-specific limitations of related policies and regulations; (2) Simulate the impact of each restoration scheme on catchment hydrology; (3) Identify—in an iterative process where necessary—the appropriate regional vegetation restoration scheme (that is, the vegetation carrying capacity of regional water resources), according to the ecological and socioeconomic water resources needs.

The following section takes the upstream catchment of Jinghe Basin as an example to illustrate how to use the decision supporting tool to determine the vegetation restoration scheme compliant with specific water yield requirements. First, the hydrological impacts of forest restoration scenarios are demonstrated. Then, different vegetation restoration schemes are determined, based on the comparison of the simulated hydrological impacts.

The Jinghe Basin originates from the Liupan Mountains and traverses the Loess Plateau. It has an area of 45,421 km^2 and supports a population of 9.48 million, with a typical temperate continental climate. The middle and lower reaches are important agricultural areas that rely on the runoff from upstream, and the northern part is a transition zone from forestland to steppe and desert. The soil in the headwater mountain areas is dominated by grey-cinnamonic soil, and deep loess with average thickness of 50–80 m in the remaining areas. Water resources of the basin are mainly used for irrigation and industry, but have significantly decreased since the 1960s (Zhang 2011). The upstream catchment of the mainstream of Jinghe Basin is located in the southwestern part of this basin (106°11′–107°21′E, 35°15′–35°45′N), with an area of 3,164 km^2 and an elevation range of 1026–2922 m. It is composed of stony mountain areas with elevation of above 1750 m and the loess areas with elevation between 1026 and 1750 m. The annual precipitation is 614 mm and annual air temperature is 6.5 °C in the mountain areas, and 475 mm and 8.8 °C in the loess areas. Existing forests are mainly distributed in the mountainous areas, mostly secondary natural forests of *Betula albo-sinensis*, *Pobulus davidiana*, *Pinus armandi*, *Quercus liaotungensis*. The plantation is mainly the monoculture of *Larix principis-rupprechtii* in the mountainous areas and *Robinia pseudoacacia* in the loess areas. Farmland is one of the most important land-use types in the loess areas with the main crops of wheat and maize. Grassland is widely distributed in the catchment, with coverage of 50–70% in the mountainous areas and 40–59% in the loess areas.

Impact of Forest Restoration on Catchment Hydrology

As previous research has shown that the effects of tree species variation on annual discharge are insignificant in comparison to the variation of LAI (Yu et al. 2009), we only consider forest cover, LAI, and spatial distribution of forests when formulating scenarios. All in all, 14 different afforestation scenarios were developed (e.g., scenario 11 in Fig. 7.2), whereby the forest cover of the catchment increases at the expense of grassland, in order of decreasing suitability from good to poor sites and keeping the spatial distribution and LAI of existing forests unchanged. In these afforestation scenarios, the forest cover in the stony mountainous areas (headwater) varies between 17.5% (current forest cover) and 26.8%, and in the loess areas between 28.9% (current forest cover) and 43.3%. Moreover, each forest cover scenario includes 7 LAI variations ranging from 0.5 to 3.5. To ensure the feasibility of forest restoration schemes, the following principles were applied: (1) farmland area kept constant, in line with the national red line policy dictating that farmland area should not decrease; (2) proper trees at proper sites, which means no afforestation at sites unsuitable for forests (such as sites in the Liupan Mountains

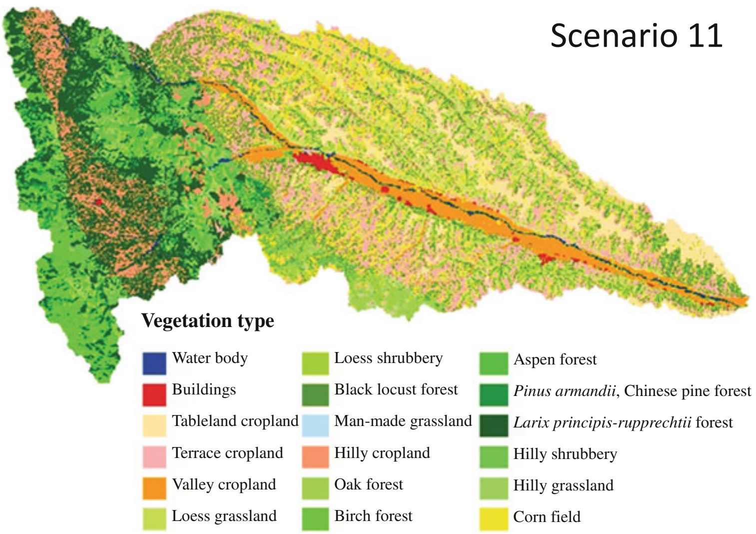

Fig. 7.2 Example of one forest restoration scenario for Jinghe upstream

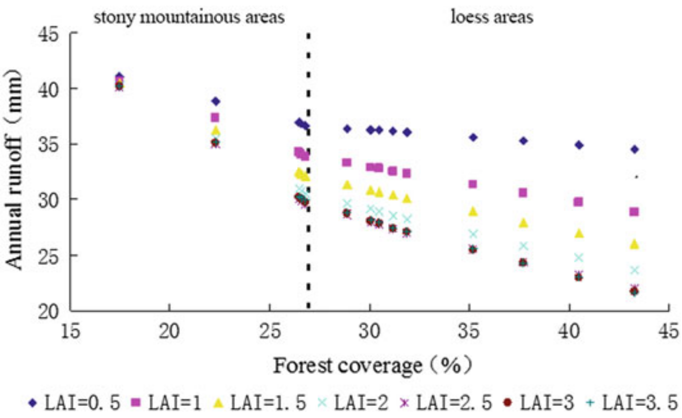

Fig. 7.3 Variation of annual runoff with forest cover and LAI in the Jinghe upstream

areas with elevation above 2700 m, which is the upper limit for forest growth, and the hilltop site in the arid loess areas); (3) economic benefits principle, which means giving priority to forest restoration at suitable sites and not at very steep slopes that pose great restrictions on afforestation.

Figure 7.3 demonstrates that the annual runoff decreases significantly with the increase of forest cover and LAI. When the forest LAI is at 0.5, every 10% increase in forest cover will cause an average decrease in annual runoff by 5.4 mm in stony mountainous areas and 1.3 mm in loess areas. In forests with completely closed canopies (it corresponds to a LAI of 2.5 and higher), every 10% increase in forest cover causes the annual runoff in stony mountainous areas and loess areas to decrease by 10.8 mm and 4.5 mm, respectively, which are respectively 1 and 3.5 times of that when the LAI is 0.5. The rate of decline of annual runoff resulting from the increase of forest cover in loess areas is significantly lower than that in stony mountainous areas. For example, when the LAI is 0.5 and 2.5, the rate of decline of annual runoff in loess areas is less than 1/4 and 1/2 of that in stony mountainous areas. This is because the annual precipitation in stony mountainous areas (610 mm) is about 100 mm higher than that in loess areas, with more water available for evapotranspiration. Figure 7.3 reveals that any LAI increase above 2.5 does not result in a further decline of annual runoff because evapotranspiration is limited by soil water availability. This is similar to the findings of studies on other arid regions (Wang et al. 2009; Johns and Lazenby 1973).

In dryland regions such as the Loess Plateau, precipitation takes place mainly in summer, while most storm events. Therefore, the reduction of flood peak discharge is a service anticipated from forests. Figure 7.4 reveals that in contrast to the loess areas, the increase of LAI and forest cover have almost no effect on the peak discharge in the mountainous areas. This is because the vegetation coverage in the stony mountains is generally higher than in the loess areas. Moreover, the soil in stony mountainous areas has higher gravel content and better infiltration capacity; even if an area is covered with grass or shrubs, not much surface runoff will be produced. On the contrary, the base of vegetation coverage in loess areas is poor, resulting in poor soil infiltration capacity, which promotes the formation of surface runoff during storms. Increased forest cover in the loess areas will thus enhance the soil infiltration capacity, allowing a large amount of rainwater to infiltrate, and thus greatly reduce surface runoff and significantly decrease peak discharge (Fig. 7.4).

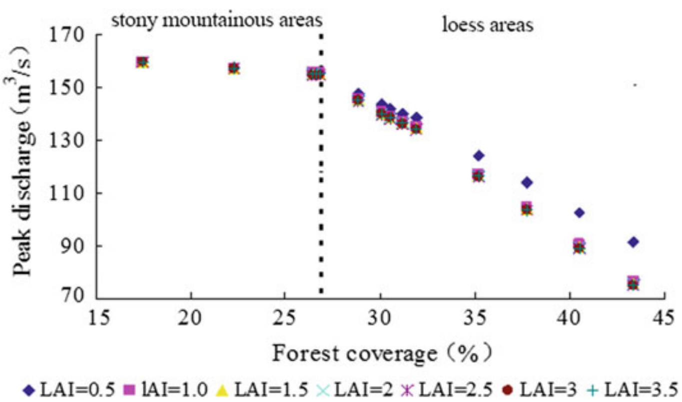

Fig. 7.4 Variation of maximum peak discharge with forest cover and LAI in Jinghe upstream

Forest Restoration Schemes

Based on the above discussed relationships between the quantity, quality, and spatial distribution of forests on the one hand, and catchment hydrological responses on the other hand, we can derive the vegetation restoration (notably afforestation) plans with consideration for the demands of water resource management.

The loess areas in the upstream of Jinghe have severe soil erosion, with an erosion modulus of as high as 3800–5500 t/km^2 a, which is far above the tolerance value (1000 t/km^2 a). It is a key area for soil erosion control and urgently needs forest restoration. However, the long-term mean annual runoff is only 42.4 mm, indicating a severe shortage of runoff water resources. Therefore, the afforestation that aims at reducing erosion should be strictly controlled and scientifically planned, so as to try to prevent the further decline of runoff water resources in the catchment. Compared to the loess areas, the stony mountainous areas have higher vegetation coverage and little soil erosion. Moreover, the runoff reduction due to afforestation in loess areas is much weaker than that in stony mountainous areas (cf. Fig. 7.3). Therefore, the priority of vegetation restoration should be given to the loess areas.

The soil erosion in the loess areas includes gully erosion and slope erosion, and it is better to treat them simultaneously. The gully bottom has abundant water and thus can be planted with gully shelter forests in sections, playing a role in filtering water, fixating soil, and blocking sediment. The tableland, hill ridge, and hilltop should be allocated for farmland, grassland, or forestland. On hill slopes, a proper land-use composition should be determined based on the erosion amount and site productivity. In this study, we choose the gully bottom and the lower part of hill slopes as the two site types preferred for afforestation.

To effectively control soil erosion, the ground coverage should be maintained above 50–60% (Wei 2010), corresponding to an LAI of above 1.5 (Wu et al. 2002). Comprehensive consideration should be given to reduce the water consumption of vegetation, strengthen the stability of vegetation against drought, and make full use of site productivity. On sites with relatively high soil water availability, such as the valley bottom, the forest LAI can reach 7; on other sites with poor soil water conditions, such as the steep sunny slope with an annual precipitation of less than 550 mm, the forest LAI should not exceed 2. On the basis of these principles, and the use of decision supporting tools on vegetation carrying capacity of regional water resources, we have determined the forest restoration schemes (vegetation carry capacity) that allow the annual runoff of the upstream catchment of Jinghe Basin to be above 90, 80, 70, and 60% of the current annual runoff, including the attainable forest cover, the spatial distribution (site types), and the quality (LAI) of newly increased forests.

If the annual runoff shall be maintained above 90% (37.8 mm) of the current situation, all the grassland slopes with a gradient of 0–15° and the gully grassland in loess areas can be afforested with an LAI >1.5; at this point, the forest cover reaches 27.2%. On those sites with annual precipitation >550 mm and valley bottom with good water conditions, the LAI can be greater than 2.5; however, on other sites with annual precipitation < 550 mm, the LAI should be smaller, maintained between 1.5 and 2.

If the annual runoff should be maintained above 80% (33.9 mm) of the current situation, all the slopes with a gradient of <25° and gullies in loess areas as well as valleys in stony mountainous areas can be afforested, reaching a forest cover of 34%, with LAI of >2.5 on the shady slopes for sites having annual precipitation of >550 mm and for sites in gullies of both the loess and stony mountainous areas, and a LAI of 1.5–2 on other sites.

If the annual runoff should be no less than 70% (29.7 mm) of the current situation, the forest cover can be further increased to 38.8%, the shady slope grassland in stony mountainous area with elevation below 2300 m can be afforested based on the above vegetation restoration scheme maintaining 80% of annual runoff, and the LAI should be maintained above 2.5.

If the annual runoff can be reduced to above 60% (25.4 mm) of the current situation, the sunny slope grassland with elevation below 2300 m can be afforested based on the vegetation restoration scheme maintaining 70% of annual runoff, but the LAI of additional forests should not be higher than 2; at this point, the forest cover can reach 43.0%.

If the annual runoff can be reduced to above 50% (21.3 mm) of the current one, the simulation suggests that all the grassland suitable for forests in the catchment can be afforested, and the forest cover can reach 43.3%.

7.3.3 Selection of Site-Specific Species Composition

The first and most critical step in the decision-making process on forest/vegetation restoration is to select the suitable vegetation type and tree species. For each region, the site-specific selection of tree species is generally based on overarching information including micro-climate, topography (elevation, slope aspect, slope position), and soils (type, texture, soil thickness, root restrictive depth). All existing practical experiences and research achievements should be used for decision on tree species. The suitable tree species for afforestation have been suggested for the concrete site types of the Loess Plateau, for example, in the work of Luo et al. (1985) for the loess areas in Shaanxi Provinces (not shown here) and from the decision support tool of ReVegIH developed for determining the priority (and target) revegetation sites and corresponding species in the Loess Plateau (McVicar et al. 2007).

The drought-resisting capacity of trees is a key factor in maintaining forest stability in dryland regions. It is generally accepted that the osmotic potential at incipient plasmolysis (Ψ_o) is a suitable index to assess the drought-resisting capacity of plants. This parameter was determined for 10 main tree species in Liupan Mountains. We found that the drought-resistant capacity of these tree species is ranked in the following order: *Betula utilis* > *Betula platyphylla* > *Betula albo-sinensis* > *Quercus liaotungensis* > *Larix principis-rupprechtii* > *Pinus* *armandii* > *Tilia paucicostata* in the semi-humid small watershed of Xiangshuihe, and *Prunus davidiana* > *Populus davidiana* > *Larix principis-rupprechtii* > *Hippophae rhamnoides* in the semi-arid small watershed of Diediegou. This order of drought-resistant capacity can be used as a reference for the selection of drought-resistant trees.

However, the tree species selection from the viewpoint of multifunctional forestry must involve more aspects than traditional afforestation. Besides the requirements of high survival ratio and growth rate, the effects on water resources and anticipated ecosystem services should also be considered in arid and water-deficient regions.

7.3.4 Design and Regulation of Stand Structure of Water-Retention Forests

Multifunctional Management Requirements for Water-Retention Forests

Mountain watersheds provide simultaneously numerous important services including water supply and purification, food and fibre production, and recreational opportunities. In dryland regions, mountain areas are the main waterhead areas for downstream water consumers. The establishment and management of water-retention forests should thus focus on regional water security. However, the dominant function of water-retention forests in mountainous areas has long been obscure. Afforestation and the management of it basically follow the practices applied to fast-growing and high-yield timber forests; as a result, the water-retention forests are ill-structured, poor in quality, and cannot fulfil their important functions. Here we take the Liupan Mountains in Ningxia as an example to illustrate the multifunctional management of water-retention forests.

As the Liupan Mountains are an important waterhead area in the Loess Plateau, water-retention forests there have a primary objective in their multifunctional management, that is, to protect the thin soil on slopes. On this premise, they should also provide as much runoff water as possible for downstream water consumers. In addition, biodiversity protection, carbon sequestration, and oxygen release are also important ecosystem functions. Finally, in such an economically underdeveloped region, timber provision and tourism development are needed for income generation. Therefore, the multifunctional management of water-retention forests must (1) rationally classify site types and determine the multiple functions and priorities of each site; (2) quantify the structure requirements of an ideal multifunctional forest, which is closely related to the needs for multiple main functions of forests (to be elaborated below); (3) adopt targeted management measures in different developmental phases, so as to promote the formation of ideal structure of multifunctional close-to-nature forest (to be elaborated below as well); (4) fully exert their hydrological function; and, in the meantime, put their various other functions into use.

Ideal Stand Structure of Multifunctional Water-Retention Forests

To establish a stable and multifunctional water-retention forest, Wang et al. (2015) determined the ideal stand structure. In the following, this concept will be briefly discussed.

Soil erosion control is the most important goal of forest restoration in the Loess Plateau region (Renard et al. 1991; Zhao et al. 2002; Hartanto et al. 2003). Studies on the Loess Plateau (Hou et al. 1994, 1996; Wang 1986) show that soil erosion decreases exponentially with the increase of ground coverage, and when ground coverage reaches about 70%, soil erosion approaches its minimum. Therefore, it can be suggested that the basic index of above 70% of ground coverage must be maintained in all growth stages of forests as well as during all forests management. It may not be difficult to maintain ground coverage of 70% in humid regions, but it can be difficult in dryland regions with sparse vegetation. Especially at the afforestation and early growth phases, efforts must be made to carefully protect all sorts of ground coverage including the ground vegetation and litter.

Canopy density and understory growth are important indices to assess forest stand structure, and they are closely related to various forest functions/services such as soil erosion control, biodiversity protection, and nutritional balance. The canopy density directly controls the natural understory regeneration (Riepšas and Urbaitis 1996). Maintaining a proper canopy density (0.6–0.8) will help realise many competitive forest functions/services simultaneously, such as the regeneration of shade-tolerant and relatively shade-tolerant species and the control of the invasion of photophilous grass (Wagner et al. 2011), the relative higher growth of understory seedlings and saplings (Chrimes and Nilson 2005), higher stand biomass increment and carbon sequestration (Tong et al. 2011), protecting plant diversity, and producing high-quality and high-value timber.

With enhanced impacts of climate change and increased extreme weather events, forest disasters caused by snow/ice and storm (fall, snap, uprooting, etc.) become increasingly prominent; for example, the ice and snow disaster in China in the winter of 2008 affected 19.3 million ha of forestland in 18 provinces and resulted in a direct economic loss of 57.3 billion Yuan (1 USD = 6.6 Yuan). How to reduce and prevent forest ice and snow disasters is a challenge to future forestry. Weather conditions (Solantie 1994) and site conditions (Li et al. 2004, 2005; Lafon et al. 1999; Bragg et al. 2003) are all important factors influencing forest snow disasters but are hard to control. On the contrary, stand structure and tree form (Boerner et al. 1988; Smith 2000) can be regulated to some extent, such as the forest density, branch angle, tree height (H), DBH, and H/DBH ratio (m/cm) (Li et al. 2005). The tall and thin trees in overly dense forests face greater risks in snow disasters (Hao et al. 2012). Thinning to lower the forest density is the only possible measure to strengthen the forest's capability in resisting snow disasters (Petty and Worrell 1981), but an overly thin forest stand is also susceptible to snow disasters because of its increased branch angles and long branches (Tang et al. 2008). The study of a *Larix principis-rupprechtii* plantation in the Liupan Mountains (Hao et al. 2012) suggests that forest snow disasters begin to appear when the H/DBH ratio exceeds 0.7; they strengthen gradually as the H/DBH ratio increases within the range of 0.7–0.9, but rapidly as the ratio increases between 0.9 and 1.0 and drastically after the ratio exceeds 1.0. This suggests that in order to maintain the forest's ability to resist snow disasters, measures must be taken to limit the H/DBH ratio to below 0.7, or at most at 0.9.

The European close-to-nature management of forests emphasises minimising disturbance to forests, in pursuit of promoting natural regeneration and the production of high-quality timber (Duncker et al. 2012). Its requirements on stand structure are (1) only use native tree species or species that have already adapted to the local environment, so as to increase the growth speed and enhance their capacity for resisting various disasters, but do not use genetically improved new species; (2) stimulate the dynamic process of the typical structure of similar natural forests to promote the formation and maintenance of a complex stand structure with diversified tree species, layers, and tree ages; and (3) maintain the canopy density at around 0.7, so as to promote natural understory regeneration and growth while preventing massive invasion of weeds and shrubs into forestland.

To sum up the discussion above, the ideal stand structure of water-retention forests should have (1) a ground coverage of above 0.7, so as to effectively control soil erosion (as well as sequester carbon and reserve nutrients); (2) a canopy density of around 0.7 (0.6–0.8), so as to maintain natural regeneration and prevent understory shrub growth; and (3) an H/DBH ratio (m/cm) of below 0.7 (or 0.9 at most), which can be regulated by thinning, so as to minimise snow disasters. In addition, it is recommended to draw on the useful experiences of close-to-nature forestry, conform to the requirements of a multi-species, multi-generation, multi-layer, stable, and efficient stand structure, give full consideration to the demand for forests to exert multiple functions and the rigid demand on the water-yielding function of mountainous watersheds (as well as the vegetation carrying capacity of water resources), and try as far as possible to select broadleaf trees that can save more water.

Decision-Making in Management of Multifunctional Water-Retention Forests

Based on the analysis above, five decision-making steps for multifunctional management of water-retention forests in mountainous areas can be proposed as follows:

(1) *Site quality investigation and classification*
Site investigation is the foundation of management decision-making, because the stand structure, function, and management measures are all closely related to site quality. In China, all regions have been classified into different site types, but it was done for the purpose of afforestation, and thus shall inevitably deviate somehow from the current requirements of multifunctional forest management. Therefore, the original site classification should be adjusted if necessary.

(2) *Site-specific determination of the main functions and their priorities*
According to the theories of multifunctional forestry and multifunctional forests, a trade-off among the various competitive functions is often necessary to face. To do so, the order or the priorities of the services/functions of different

site types should be determined and ranked according to their importance in meeting the demands of humans.

(3) *Investigation of current stand structure characteristics*
To provide guidance to decision-making in multifunctional forest management, a quantitative investigation should be conducted on the current forest structure characteristics, including tree species composition, age of stand, origin of stand, forest density, tree height and diameter at breast height, clear bole height, dominance index of trees, thickness and composition of litter layer, as well as canopy density, understory natural regeneration, ground coverage, tree health conditions, degree and causes of damage, etc. If possible, the soil profile and physicochemical properties of the soil should also be investigated.

(4) *Diagnosis of structure and functions of current stand*
The diagnosis of stand structure and functions should be based on the site quality and expected services. Taking the example of poor sites (such as the dry south slope with thin soil and low elevation) with the expected main services of erosion control and water yielding, it is not necessary to plant trees or maintain unhealthy forests, but it is actually beneficial to maintain high ground coverage comprised shrubs and grass that consume less water. For the fertile and relatively fertile sites with the expected main services of high-quality timber production on the premise of controlled soil erosion and relatively high water yield, the stand developmental phase must be assessed before making any management decisions. If the forest is still young or sparse so that the qualified trunks (straight, no knurs, enough clear bole height, e.g. 8 m for Chinese pine) of target trees are not yet formed, then there is no need for any thinning; instead, it is necessary to maintain a high canopy density for keeping natural pruning to form qualified target trees. If the trunks of target trees are qualified, then the stand structure should be compared with the aforementioned ideal forest (principally the canopy density, ground coverage, H/DBH ratio, species composition, natural regeneration, and tree health), in order to find the inadequacies of stand structure and take targeted management measures.

(5) *Planning of structure/function-oriented management measures*
Forest functions are mainly related to stand structure. Thus, the stand structure-oriented management is conducive to improving forest services. The management measures mainly include (i) mountain closure to maintain ground cover, to use natural regeneration for getting enough young trees at low cost, and to use nature pruning for forming qualified target trees; (ii) thinning (selective cutting) to maintain the canopy density within 0.6–0.8, to facilitate the target trees' growth, to enhance the forest's ability against ice-snow/storm disasters, and to yield more water; (iii) promoting advanced regeneration under canopy by forming some gaps after cutting competitive or low-quality trees; (iv) applying the research results on forest–water relationship; and (v) adopt the management ideas and techniques of close-to-nature forestry to minimise disturbances on vegetation and soil. After the management measures have been made clear, the time, intensity, and frequency of each measure shall be determined, thus forming a detailed and feasible forest management scheme.

7.4 Examples of Multifunctional Management of Water-Retention Forests

7.4.1 *Case on the Rational Density of* Larix Principis-Rupprechtii *Plantation*

As a technical key to multifunctional forest management, a stand structure that can simultaneously meet the requirements of multiple functions should be put forth on the basis of quantitative understanding of the stand structure and its relations with various functions. Targeting the problems in the management of water-retention forests, such as the ambiguity of dominant functions, single focus on the timber production function in the long term, and neglect of the functions of water-yielding and biodiversity protection, the study by Hao (2012) selected the *Larix principis-rupprechtii* plantations with average age of 26 years in the small watershed of Xiangshuihe of Liupan Mountains and investigated the stand structure (density) and its quantitative relations with tree growth and timber production, diversity of undergrowth plant species, plant biomass and fixed carbon storage, water yield, and snow damage (Fig. 7.5). Since no soil erosion appears with the high ground coverage of litter and vegetation, the erosion control function is not illustrated here.

Based on this study, a rational density range of 1000–1200 trees/ha of multifunctional stand (with the age of 26 years) in the study region has been suggested. With this density, it can reduce the snow damage to ensure the stand structure stability, lower the evapotranspiration to maintain the relatively higher water-yielding capacity, promote the growth of large trees to produce high-value timber, maintain undergrowth to protect biodiversity, and sustain a high vegetation

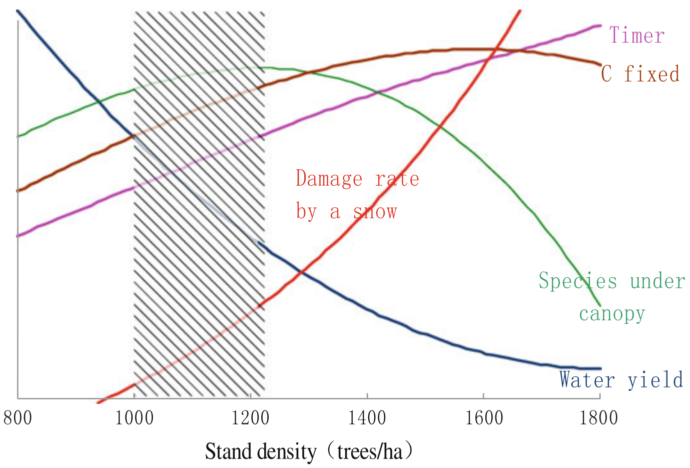

Fig. 7.5 Derivation of a stand density range that supports multiple functions of *Larix principis-rupprechtii* plantation in Liupan

biomass to exert the function of sequestering carbon and releasing oxygen. These findings can provide a theoretical basis and technical guidance for the multifunctional forest management in the region studied or other similar regions.

7.4.2 *Cases of Close-to-Nature Management of Multifunctional Water-Retention Forests*

The close-to-nature forest management can realise the main objective of producing high-quality large timber, while forming and maintaining a good stand structure as it reduces disturbance to forests. It can also be used to guide the management of water-retention forests, but the management objectives of maintaining water-yielding capacity and preventing soil erosion precede the objective of producing high-quality large timber. So its use should be combined with the above-mentioned requirements, ideas, and principles of multifunctional forestry. Below are some cases of the application in several forest stands (Wang et al. 2015). Although these cases come from the multifunctional management of water-retention forests in the mountainous areas of Beijing, they can also be applied to the water-retention forests in mountainous areas of the Loess Plateau with similar natural conditions.

The water-retention forests in the mountainous areas of Beijing are mostly aged around 30 years, although some young forests arising from afforestation or mountain closure have existed only since 2000. The excessively high stand density, resulting from many years of logging ban policy, has led to a disproportionate competition of trees, and consequently reduced water yield and lowered capacity of trees resisting against ice/snow disasters. These forests lack understory regeneration, and are mostly monoculture with low timber value. To improve the stand structure while enhancing the water-yielding capacity for the downstream big city of Beijing that has serious water shortage, the stand structure adjustment targets in the next 10 years and corresponding management measures have been proposed, taking the pine plantation as example, as listed in Table 7.1.

The following section will compare the pictures of several typical forest stand sample plots, so as to introduce vividly and briefly the key points of multifunctional management techniques under different growth conditions.

A young sparse *Platycladus orientalis* forest on a sunny slope with thin soil: Fig. 7.6 shows a sparse *Platycladus orientalis* forest of about 10 years old on a sunny slope. It grows on thin soil with weak drought-resisting capacity and low productivity. This site is expected to maintain the coverage of shrubs and grass that consume less water, provide as much runoff water as possible on the premise of no soil erosion. In other words, preventing erosion and yielding water are the dominant functions. The management measure needed currently is merely enclosure, i.e., to protect the current vegetation coverage. There is no need to grow more trees or prune them. Nor is there any need to continue building facilities to collect runoff for

Table 7.1 Stand structure targets and management measures for pine plantation

Forest management modes		Medium-term targets in 10 years and corresponding management activities		
Current density	Tree height classes	Medium-term targets	Density in 10 years (trees/ha)	Management activities to be conducted
Open forest: canopy density ≤ 0.7, forest density <1200 trees/ha	All	Canopy closed, so as to start the natural pruning process, to acquire target trees with high-quality trunks	Natural variation	None
Young forest: any canopy density and stand density	<4 m			
Normal forest stand: canopy density 0.8, forest density 1200–1500 trees/ha	4–6 m	Canopy density of 0.8, improved tree height structure and forest stand stability	1125–1450	One selective cutting in the 8th–10th year
	6–8 m	Canopy density of 0.7; improved tree height structure, tree quality, and forest stand stability; promoted understory natural regeneration; promoted growth of target trees and first-class trees through eliminating competitive trees; more special target trees in forest gaps	915–1260	Two selective cuttings in the 2nd–4th year and the 8th–10th year. Cut down about 2 competitive trees for each target tree, and cut down most poor/damaged trees
	8–10 m		735–1020	
	10–12 m		600–825	One selective cutting in the 2nd–4th year; and perhaps another cutting in the 8th–10th year. Cut down about 2 competitive trees for each target tree, and cut down most poor/damaged trees
	>12 m		525–675	
Dense forest stand: canopy density 0.9, forest density 1500–1800 trees/ha	4–6 m	Canopy density of 0.8, improved tree height structure and stand stability	1125–1575	Two selective cuttings in the 2nd–4th year and the 8th–10th year, and perhaps an additional cutting in the 5th–7th year. Cut down about 2 competitive trees for each target tree, and cut down most poor/damaged trees
	6–8 m	Canopy density of 0.7; improved tree height structure, tree quality, and forest stand stability; promoted understory natural regeneration; promoted growth of target trees and first-class trees through eliminating competitive trees; more special target trees in forest gaps	915–1260	
	8–10 m		735–1020	
	10–12 m		600–825	Two selective cuttings in the 2nd–4th year and the 8th–10th year. Cut down about 2 competitive trees for each target tree, and cut down most poor/damaged trees
	>12 m		525–675	One selective cutting in the 2nd–4th year; perhaps another cutting in the 8th–10th year. Cut down about 2 competitive trees for each target tree, and cut down most poor/damaged trees

(continued)

Table 7.1 (continued)

Forest management modes		Medium-term targets in 10 years and corresponding management activities		
Current density	Tree height classes	Medium-term targets	Density in 10 years (trees/ha)	Management activities to be conducted
Very dense forest: canopy density ≥ 0.9, forest density >1800 trees/ha	4–6 m	Canopy density of 0.8, improved tree height structure and forest stand stability	1200–1650	Two (three) selective cuttings in the 2nd–4th year, (5th–7th year) and 8th–10th year. Cut down about 2–5 competitive trees for each target tree, and cut down most poor/damaged trees
	6–8 m	Canopy density of 0.7; improved tree height structure, tree quality, and forest stand stability; promoted understory natural regeneration; promoted growth of target trees and first-class trees through eliminating competitive trees; grow more special target trees in forest gaps	990–1335	Three selective cuttings in the 2nd–4th year, 5th–7th year and 8th–10th year. Cut down about 2–4 competitive trees for each target tree, and cut down most poor/damaged trees
	8–10 m		810–1095	
	10–12 m		675–900	Two (three) selective cuttings in the 2nd–4th year, (5th–7th year) and 8th–10th year. Cut down all the competitive trees for each target tree, and cut down most poor/damaged trees

Fig. 7.6 A sparse forest of *Platycladus orientalis* on a sunny slope with arid thin soil

Fig. 7.7 A young oak coppice forest on a shady slope

trees or prepare soil for this end because this would disturb land coverage and trigger/aggravate soil erosion.

An oak coppice forest on a shady slope: Fig. 7.7 shows an oak coppice forest generated from mountain closure under the “Grain for Green” Project implemented about 10 years ago. The canopy of this young forest has been closed. It has high tree density but qualified trunks have not yet formed. In the next few decades, no trees will be able to produce high-quality timber, although the potential productivity of this site is high. The local forestry policy encourages the restoration and increase of native oak forests, which are currently scarce and have deficient afforestation seedlings. Therefore, this forest should not allow for any substitution of tree species except for the understory planting of some target trees. The long-term dominant function is to provide as much runoff as possible while providing other services such as erosion control. Therefore, there is no need to take any management measures at present or in the next 10 years, until qualified trunks of target trees are formed.

Fig. 7.8 A sparse mixed forest of coniferous and broadleaf trees at a stony site

Fig. 7.9 A poplar coppice forest at a fertile site

A sparse mixed forest of coniferous and broadleaf trees at a stony site: Fig. 7.8 shows a sparse mixed forest of Chinese pine and various broadleaf trees at a stony site, whose canopy density is about 0.6, with fine natural regeneration of understory broadleaf trees and relatively good ground coverage. However, due to low canopy density, the tree trunks are of poor quality, with curved trunks, clearly low trunk height, and many knurs. This site has low productivity. Its dominant function is to produce more water. Some target trees may be able to produce timber in the far future on the premise of no soil erosion. Currently, there is no need to carry out any management measures such as intermediate thinning (selective cutting), pruning, or understory planting, except to promote the natural regeneration of broadleaf trees that are likely to become future target trees.

A pioneer poplar forest at a fertile site: Fig. 7.9 shows a coppice forest of the short-lived and pioneer tree species of *Populus davidiana*. The trees are about 12 m tall, with a canopy density of around 0.7. The understory oak trees and other broadleaf trees have good natural regeneration. This site is at the foot of a slope, with superior water and fertility conditions. Its dominant functions are to produce high-quality oak timber several decades later and provide a certain amount of runoff and other ecological functions on the premise of no soil erosion. The current poplar trees can only produce low-value thin timber, but they cannot be cut down completely because they are needed to provide shade for understory trees until their qualified trunks are formed. The management measure should be thinning the poplar trees until the canopy density reaches 0.3–0.4, so as to promote the growth of oak saplings and form high-quality trunks of target trees, and in the meantime, reduce water consumption of trees and provide as much runoff as possible. Natural regeneration of more oaks and other broadleaf trees is expected a few years after the selective cutting; then a second round of selective cutting may be needed. Figure 7.10 shows the forest after the first selective cutting.

A medium-dense forest of *Larix principis-rupprechtii* with good regeneration: Fig. 7.11 shows a medium-dense *Larix principis-rupprechtii* plantation mixed with some trees of *Pinus tabulaeformis*. It has a canopy density of about 0.8, abundant understory plants, and good natural regeneration of oaks and other broadleaf trees. This site is located at a small gully, with good water and nutrient

Fig. 7.10 The poplar forest after the first thinning

Fig. 7.11 A medium-dense larch plantation mixed with some pine trees at a gully, with good undergrowth and natural regeneration

conditions. Its dominant function is expected to be producing high-quality timber of *Larix principis-rupprechtii* and *Pinus tabulaeformis*. But in the future after successful conversion of tree species composition, it will also produce high-quality oak timber; in the meantime, it will provide water and other ecological functions on the condition of no soil erosion. Currently, there is no urgent need to carry out selective cutting, but a limited degree of selective cutting may be needed in the future (which should result in a canopy density of 0.6), so as to promote the growth of *Larix principis-rupprechtii* and *Pinus tabulaeformis* target trees as well as understory broadleaf saplings, facilitate natural regeneration, and enhance the water-yielding capacity. However, it still needs some canopy to provide shade to ensure the oaks, as future target trees, can form good trunks.

An overly dense plantation of *Pinus tabulaeformis* at a rich site: Fig. 7.12 shows an overly dense plantation of *Pinus tabulaeformis* whose canopy density is about 1.0. Due to the fertile gully bottom, the understory vegetation coverage is relatively good, but the trees are thin and vulnerable to snow and storm disasters; the understory broadleaf trees have very limited natural regeneration; the intense competition among individual trees has lowered the value increment of target trees. The dominant function expected for this stand is to produce quality timber, and meanwhile some other services and a certain amount of runoff should also be produced. The forest urgently needs selective cutting, but as the cutting shall be conducted on a large proportion of trees, it should take place 2–3 times with an interval of 2–3 years, so as to prevent high-intensity selective cutting from drastically reducing the canopy density and resulting in lodging and leaning of trees. The competitive trees, overly thin trees, crooked trees, and lopsided trees around target trees should be cut down, to promote the growth of target trees and natural regeneration of broadleaf trees in the future. The canopy density after 2–3 selective cuttings is set to be around 0.7.

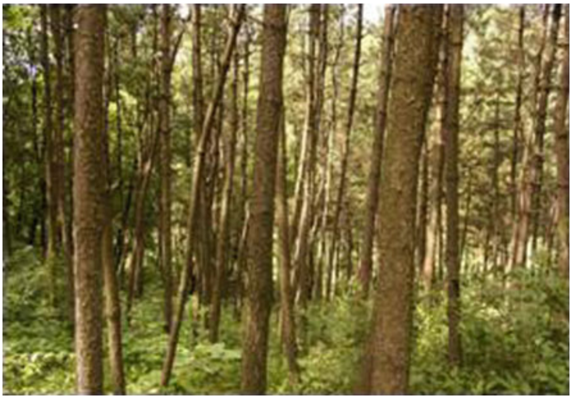

Fig. 7.12 An overly dense plantation of *Pinus tabulaeformis* at a rich site

7.5 Conclusion

In summary, the dryland regions certainly need multifunctional forestry as the most important component of multifunctional land use. However, special attention should be given to the forest–water interrelation at various scales, since drought will limit forest growth and large-scale afforestation will drastically reduce water yield and therefore endanger regional water supply. Based on long-term forest eco-hydrological studies in the Loess Plateau and the development of decision supporting tools on vegetation carrying capacity of regional water resources, the decision-making procedures for multifunctional forestry and forest management were suggested, including the determination of rational forest cover, the optimal spatial distribution of forests, the selection of site-specific species composition, and the design and regulation of stand structure. Especially at the stand level, the indexes of ideal stand structure of multifunctional water-retention forests were set up, the steps in management decision-making were proposed, and some management cases were illustrated. These preliminary achievements may be helpful to guide and promote future multifunctional forestry in the Loess Plateau and other similar dryland regions.

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Chapter 8
Implementation of Multifunctional Land Management: Research Needs

Lulu Zhang and Kai Schwärzel

8.1 Why Do We Need to Foster Multifunctionality in Land Management on the Loess Plateau?

The significant changes in land use in the Loess Plateau region over the last five decades have improved soil resources and economic development. But they have also contributed to a decline in water resources. The root of the problem is ascribed to the siloed and sectored management of land use. Shifting from single-sector/resource-focused land-use management to multifunctional land-use management is thus a more sustainable way to deal with the complexity of interactions between sectors and resources in a changing environment (Pérez-Soba et al. 2008). For this reason, we consider multifunctionality as a way towards sustainability. The Loess Plateau has to provide a number of ecosystem services for the local and downstream users, among which food production, soil conservation, and water availability are the most important. Of the three services, soil conservation is a central issue because it supports crop growth and serves as an intermediary of major hydrological processes determining water availability, such as groundwater recharge and flood and sediment alleviation. Current soil conservation measures aiming to inhibit soil erosion have not embedded the key services in an operational balanced setting, resulting in shrinking water resources and deteriorating soil productivity for farming. To reverse this trend, integrated soil and water management measures—from reducing erosion and associated surface runoff and soil evaporation, to increasing and maintaining soil quality—shall improve the multiple uses of the land. This, in turn, will increase water infiltration to make more water available for the root zone and underground aquifers. Furthermore, such integrated management measures are also beneficial for the downstream users in view of replenishment of

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groundwater, regulation of river flow (high and low peaks), and diminishment of sediment in network.

There is a disparity in the understanding of multifunctionality and in the vision for future development of operation and management among sectors in China. In the agro-ecosystem and grassland ecosystem on the Loess Plateau, multifunctionality is less defined by a specific location (e.g., on-site or off-site) or a landscape. Rather, it is interpreted in most cases as a summation of different single services provided by arable lands or grasslands at locations without relevant context (e.g., in many different watersheds). For example, the grassland of catchment *A* in the south is only used for eco-tourism, whereas the grassland of catchment *B* in the north is only used for soil conservation. In such cases, no multifunctionality (e.g., secondary functions in addition to primary function) is addressed in the grassland management since only one function has been utilised for each catchment. On the contrary, grassland has a variety of functions and values that include, but are not limited to, providing forage for animals, enhancing groundwater recharge and water quality, sequestering carbon, protecting soil from erosion and improving soil organic matter, supporting biodiversity and rural economy, and providing recreational opportunities (USDA 2009). In the northern part of the Loess Plateau, precipitation is low and the soil is highly prone to erosion. In such an environment, reducing soil erosion is the primary function of the grassland. Measures for other ecosystem functions (e.g., promoting groundwater recharge) can be added after soil conservation is ensured. For additional benefits in groundwater recharge, plant species and spatial arrangements (e.g., vegetation structure, patch density, and functioning diversity) are key factors affecting hydrological behaviour in semi-arid environments (Bautista et al. 2007). Similarly, its possible contribution to agriculture production can be considered and included if no adverse impact on the regional water regime will be incurred. This implies a possible way beyond soil conservation (i.e., one ecosystem service) towards a multiple use of grassland (i.e., diverse ecosystem services) for the arid part of the Loess Plateau.

Enhancing food productivity and associated rural incomes are the most important goals in agricultural management of the Loess Plateau. Such goals drive the intensification of biomass production in China; more and more agricultural inputs are used on land of high quality (e.g., terrace and tableland) but also on land of low quality (e.g., slope farmland). Soil and water conservation are often seen as an advantageous side-effect of such measures that are applied to increase productivity. For example, plastic films are frequently applied to rain-fed cultivated land to prevent water loss from evaporation and increase energy for crop growth; at the same time they can also protect the soil from erosion. This gives the appearance that multifunctionality is addressed in agriculture. Yet, this is not true, because intensification of crop production can reduce soil water and fertility rapidly so that it prevents groundwater recharge and results in land degradation, or the over-use of fertilisers can lead to eutrophication of water bodies used for irrigation and other purposes.

Increase of forest cover in drylands is important for reducing soil erosion, purifying water, and regulating discharge; however, it was shown that forest development may significantly contribute to the already existing water shortage due to higher root water uptake by trees in comparison to that by grassland or crops. But previous chapters have also demonstrated that forest management—if based on a more advanced understanding of the concept of multifunctionality—can ensure more benefits from a single piece of forestland or an afforested sub-catchment of a watershed, in which environmental (e.g., soil and water resources) and social benefits are well balanced through optimisation.

Thinking in silos is still the main feature in land and resources management in China. This type of management is less efficient and has high risk of unsustainability. It is thus urgent to foster land management based on the principles of multifunctionality. Such management practices enhance the synergies among sectors, and ensure sustainable regional development. But how can we proceed with it? Multiple use of land is not simply an operational technique, but has intricate socioeconomic consequences. The success of the implementation of multifunctional land use largely depends on the coordination across sectors and society, in which a unified understanding of multifunctionality in land use and landscape and shared benefits among users, stakeholders, and politicians have to be reached.

8.2 Obstacles to Implementation of Sustainable Multifunctional Landscapes

To date, despite a substantial increase in the number of publications, evidence from applied examples of multifunctionality are still lacking. A large proportion of the work associated with multifunctional land-use systems have been produced by European countries, North America, and Australia (Otte et al. 2007); furthermore, the majority of these works—according to the best of our knowledge—investigated theory and projections based on the calculation and simulation under scenarios (Boody et al. 2005; Plieninger et al. 2007; Reagain and Bushell 2008; Tassone et al. 2008; Carvalho-Ribeiro et al. 2010). Even in studies of agroforestry, as part of a multifunctional landscape, available evidences of providing ecosystem services are found mostly in a single ecosystem service (Jose 2009), in addition to economic benefits.

Several issues discourage and impede the implementation of multifunctional land-use systems at present. They include ineffective dialogue between participants involved in land-use decision-making, lack of tools to support implementation processes, and the absence of supportive incentives and policies (Jose 2009; de Groot et al. 2010; O'Farrell and Anderson 2010; Bouma et al. 2011). Since multifunctional landscapes are dynamic interactive systems of nature and society, negotiation and co-development of future visions of landscapes have to be conducted with a full engagement of scientists, practitioners, stakeholders, and decision makers who often hold conflicting visions and interests (O'Farrell and Anderson

2010). Decisions without full consideration of interests of any participant (like in the Loess Plateau region) are hard to guarantee the sustainable provision of multiple ecosystem services. A ruthless lesson (a so-called knowledge paradox) we should bear in mind is that numerous contributions to innovation and sustainability have not been applied because they were not accepted by society (Bouma 2010; Bouma et al. 2011). Besides, over the last few decades, researchers have developed plenty of landscape analysis tools, but integrated tools for implementation of multifunctional landscape planning that address essential global issues, such as water and food insecurity, are limited (O'Farrell and Anderson 2010). Relevant problems are data monitoring, methods, and indicators for valuing and assessing various ecosystem services (O'Farrell and Anderson 2010; Tallis et al. 2012). Remarkable achievement is available but rare. Polasky et al. (2008) presented a promising exercise of integrating ecological and economic aspects into decision-making on zonal structures in landscape planning.

Many countries provide financial incentives, such as subsidies for agriculture or afforestation (e.g., in the Loess Plateau of China). In many cases, governments subsidise seeds, saplings, fertilisers, and pesticides regardless of production methods and impacts on environment. As a consequence, direct and indirect negative effects on ecosystem health and services are generated due to excessive use of fertilisers and pesticides and intensification of monoculture (FAO 2013). Tassone et al. (2008) found that providing subsidies for afforestation increases social losses because it drives private incentives; conditional subsidies that take environmental effects into consideration can reduce the loss, however, environmental costs resulting from reduction of seepage and groundwater recharge due to afforestation are inevitable. Therefore, sustainable multifunctional land management calls for changes in policy and incentives, in which environmental costs have to be internalised. For example, in the future a farmer will not only be paid for producing food and other goods but also for protecting the environment, and thus ecosystem services (FAO 2013).

In summary, there are considerable barriers and insufficient knowledge in the scientific, social and political sectors that prevent the realisation of multifunctional land-use systems. The scientific community is devoted to seeking out and creating systematic approaches that are able to disentangle the complexity and underline the relevance of these aspects. Such work and associated debates are invaluable to enrich our knowledge in order to overcome difficulties and advance progress. From our perspective, focus on critical linkages in land systems that have a nexus relation to the ecological system (including processes and services that human society relies on) and social acceptance could offer more opportunities to unpuzzle the complexity of multifunctionality to bring synergies in diverse functions of ecosystems. However, such approach and framework are still rare.

8.3 Advancing Multifunctionality in Ecosystems Through Emphasis on the Nexus of Resources

Despite efforts of two decades, a majority of studies still focus on one or two aspects regarding ecosystem services. It is thus argued that an integrated approach for practical application using landscape functions and ecosystem services is still missing (ICSU-UNESCO-UNU 2008). In this respect, Hoff (2011) advocates a Nexus Approach to manage environmental resources that underlines increasing synergies in a set of ecosystem services. He believes that it could reduce trade-offs and generate additional socioeconomic values with strong cross-sectoral integration. He regards it as a solution towards a practical application of sustainability. In contrast to sectoral integrated management concepts (e.g., soil, water, forest and agriculture), the Nexus Approach focuses on increasing resource efficiency and promoting the overall shared benefits (human and environment) as it takes relationships, interactions, and interdependencies across sectors into consideration. In terms of objectives and characteristics (e.g., cross-sectoral coordination), the multifunctional land-use system concept shares many similarities with the Nexus Approach, or in other words, multifunctional land use can be considered a particular form of the Nexus Approach.

It is challenging to quantify the demand and supply on ecosystem services, because they vary in time and space with nonlinearity; trade-off analyses are only meaningful if the scales are clearly defined (DeFries et al. 2004). Therefore, a step forward may be to identify the interconnectivities of benefits across environmental resources, because at the heart of multifunctional land-use system is the nexus of resources such as soil, water, and waste. The soil-water nexus in an ecosystem has been well-illustrated in previous chapters. In contrast, considering organic wastes from households and farmlands, or properly treated wastewater as resources that provide water and nutrients for higher biomass production has been less common. Pressure on resources could result in food and water shortage, hamper economic growth, and cause irreversible environmental damage (Ringler et al. 2013). In dryland environments (e.g., the Loess Plateau), the ecosystem shall provide adequate biomass, water, and livelihood for population. To achieve this, the land should be managed in a way that while it reduces the on-site land degradation (soil erosion) it has to ensure the water supply (quantity and quality) for downstream and agriculture, as well as increase rural income. Such a strategy requires a synergy in the management of soil conservation, use of organic waste for maintaining and enhancing soil fertility, reduction in evaporation from soils, and increase in rainwater infiltration as basis for increasing available soil water pools as well as seepage and recharge, improvement of water use efficiency, etc. In addition, the linkages of resources sustainability to human wellbeing and environment must be clearly presented. If we succeed in managing resources in time and space under changing environments, we would be able to manage the ecosystem services accordingly. However, the linkages of resources sustainability have not been fully considered in the landscape management plan of the Loess Plateau, therefore additional water resource-related problems have emerged while the problems associated with soil erosion have been significantly ameliorated (Zhang et al. 2014, 2015). To combat the vicious circle of 'solutions to one problem leading to a new problem', solutions need to merge the managements of the natural resources and their supplied ecosystem services in a spatiotemporal balanced range, in which both environment and society can have benefits to support further development. Yet, such a solution requires deeper knowledge and a cooperative society.

8.4 Research Needs to Realise Multifunctionality in Land-Use Systems

Currently, the research community is in the process of figuring out how to integrate the concept of multifunctional goals and ecosystem services and values into our daily landscape planning and decision-making processes (Deybe 2007; Meyer and Degorski 2007; Wallace 2007; Fisher et al. 2009; de Groot et al. 2010; Seppelt et al. 2011). The issues include optimal allocation and management of different land-use options, valuation of ecosystem services, decision on services demand of a wide range of stakeholders and policy supporting tools (Kremen 2005; Daily and Matson 2008; de Groot et al. 2010; Seppelt et al. 2011). For example, de Groot et al. (2010) proposed five main issues—namely (i) understanding and (ii) valuing ecosystem services, (iii) use of ecosystem services in trade-off analysis, (iv) decision-making and planning and management, (v) financing ecosystem services—that need to be resolved for the full integration of ecosystem services concept into management planning and decision-making. Deybe (2007) summarises the challenges (e.g., full integration of environmental dimension into agricultural policy, develop 'win-win' solution for environment and economy, joint actions at all levels of governance) that the European Union has to deal with to achieve sustainable land use due to the current agriculture policy. Sustainable development has been highly regarded as a comprehensive conceptual approach for the future and has become a global programme for governments since the United Nations Conference on Environment and Development in 1992 (Wiggering et al. 2003). Yet, this concept was rather vague and abstract for the public and hard for the politicians to follow up on over a long period. In September 2015, Sustainable Development Goals (SDGs) (Table 8.1) are defined in the 2030 Agenda for Sustainable Development (United Nations 2015) and they make the sustainability concept tangible and actionable. Some of these goals (e.g., Goal 1, 2, 6, 7, 12, 13, 14, 15) are intrinsically linked to the planning and management of the sustainable use of natural resources (e.g., land, water and biodiversity) through support of good governance (Blum 2016). This implies that there is a need to shape more sustainable land-use systems on regional and global scales to address the above discussed issues for the process of sustainable development.

Table 8.1 Sustainable Development Goals for the period 2015–2030 (United Nations 2015)

Goal	Description
1	End poverty in all forms
2	End hunger, achieve food security and improved nutrition and promote sustainable agriculture
3	Ensure healthy lives and promote well-being
4	Ensure inclusive and equitable quality education and promote lifelong opportunities for all
5	Achieve gender equality and empower all women and girls
6	Ensure availability and sustainable management of water and sanitation for all
7	Ensure access to affordable, reliable, sustainable and modern energy for all
8	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
9	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
10	Reduce inequality within and among countries
11	Make cities and human settlements inclusive, safe, resilient and sustainable
12	Ensure sustainable consumption and production patterns
13	Take urgent action to combat climate change and its impacts
14	Conserve and sustainably use the oceans, seas, and marine resources for sustainable development
15	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss
16	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels
17	Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

The investment (via programmes and activities) in western China has improved soil conditions and developed the economy to some extent. However, due to the low degree of coupling between ecological and economic systems, the rapid growth has come at the expense of environmental resources (Lü et al. 2014). Intensified monoculture in agriculture combined with the vulnerable nature of dryland ecosystems can cause negative impacts as discussed in the previous chapters and significantly impair the sustainable development of the region. Conflicts between environmental protection agendas and agriculture-related farmer livelihood, inconsistency between restoration measures and natural conditions, and policy inflexibility and compensation inefficiency are urgent regional problems (Liu et al. 2014). From previous chapters we have learnt that there is an urgent need for multifunctionality in land use in the Loess Plateau region to moderate the conflicts and increase co-benefits in development of environment, society, and economy. For establishing multifunctionality, relevant goals and associated ecosystem services of the regional land use/landscape have to be determined using a participatory approach for reaching consensus among the stakeholders. With the identified goals, we will be able to visualise the problems that impede achieving goals and even possibly highlight the relevance of the existing problems. This will facilitate better understanding of the system and identification of the critical linkages for solutions. The assumption is that rather than working on the whole system, targeting at the critical linkages is a more efficient way to improve the behaviour of the system. More importantly, critical linkages are often the opportunities for increasing synergies, and thus the points for policy intervention to fulfil multifunctional goals (Alcamo 2015). Therefore, research priorities for multifunctional land-use systems in the future should focus on the following issues:

- Defining multiple aims of land-use management—particular needs of local and regional users, environment suitability, and socioeconomic pressure have to be taken into account.

Where to put what? This is a specific and unique question for every region. Landscapes consist of natural and human-induced patches that are heterogeneous in nature, form, and arrangement. Some unique composition of natural elements can denote preferable environment for certain land use. For example, agricultural production requires good soil, water, and heat conditions so that only limited sites in a watershed are suitable for farming, such as flat fertile tableland. In contrast, slopes under perennial influences of rainfall and wind are erosion-prone and less accessible; tillage for cultivation could further weaken soil structure and accelerate occurrence of erosion, thus it is more useful to be covered with year-round vegetation and use them for controlling soil erosion. Lack of differentiation in spatial distribution of land use is still a crucial problem in conversion of land use on the Loess Plateau. Additionally, social needs and economic pressure are also major forces affecting rural landscape dynamics (Vanacker et al. 2003). Both short-term economic benefits (e.g., livelihoods) and long-term ecological benefits (e.g., soil conservation, water availability, and biodiversity) have to be safeguarded during the definition of multifunctionality of land management on the Loess Plateau.

- Understanding ecosystem behaviour—systematic approaches and models can be used for mapping problems and quantifying the interactions.

Operational problems at small scales are challenging for policy makers and practitioners. To act locally, options for future and possible sustainable adaptations can be explored by using appropriate tools for analysis (Droogers and Bouma 2014). Ecosystem behaviours are complex, diverse, and often even co-evolved. Model application is an indispensable analysis approach because it is able to express biophysical impacts of operations to clarify and interpret ecosystem-internal interactions and conduct scenario analyses that are impossible to measure. More importantly, a logical and meaningful sequence of analysis is vital for understanding of ecosystem behaviours. Taking the Loess Plateau as an example, soil erosion is the central ecological matter that is closely related to other regional ecological problems, such as water shortage, natural disaster, and agricultural development. Making soil as a starting point, analysis framework can be used to quantify the effects of a range of soil conservation measures to reduce soil erosion on agricultural and non-agricultural fields in a watershed. An acceptable threshold of sediment yield/inflow can be set and used for such evaluation. Based on a number of satisfying results, hydrologists can use appropriate tools to assess the responses of individual hydrological process and water cycle to those measures in a second stage. If the measures are effective in combating erosion and beneficial for water supply, chemical (e.g., water quality) and biological (e.g., crop yield and water productivity) analyses can be added subsequently in further steps. This underlines a more transparent and logical order of research to better understand the ecosystem.

- Identifying critical linkages and thresholds of sustainability—impact assessment tools can be used to highlight the opportunities and limitations in system.

What does 'sustainability' mean for the dryland Loess Plateau? The UN SDGs (United Nations 2015) give a clear answer to this question. Although they are universal goals, actions have to be taken at smaller scales (countries, regions) to achieve these goals. At least four goals (Goal 2, 6, 13 and 15) are directly relevant for land management, whereas some other goals (Goal 1, 7, 12 and 14) are also indirectly relevant. Blum (2016) presents an explicit clarification about how a set of SDGs are achievable through a sustainable agricultural land management since it is not only able to produce biomass (food, fibre, bioenergy), but also promote water infiltration, minimise surface runoff and sediment yield, avoid water contamination, mitigate greenhouse gas emission, and conserve biodiversity. To string the goals together, ecosystem services can be used as a focal point because services cannot be provided by a single sector or discipline thus motivating ideas for special roles of different sectors and disciplines to play in relevant contexts of sustainability (Bouma 2014). Ecosystem may also have constraints; moreover, knowledge about thresholds is critical for management since it might be impossible to recover land functions once a threshold is crossed.

- Diversifying policy instruments to improve efficiency of investment and support—alternative options should be made available for optimal targeting to enhance benefits and lower costs.

The development of soil and water conservation policies on the Loess Plateau is executed in a top-down approach. However, without considering the particular needs and wishes of the stakeholders, proper implementation is difficult to be guaranteed long-term. Ecological conservation was still under control during the period of subsidies, but a large proportion of land would possibly return to pre-policy use after the subsidies cease (Liu et al. 2014). This will cause tremendous investment losses. Obviously, there is still a huge gap between the scientifically defined 'optimal' system and the actually performed 'practice'. Bouma et al. (2011) presents a study on how to bridge this gap for Dutch agricultural land use (dairy farming) through a process of blood-sweat-and-tears covering communication and negotiation, comprehensive analysis, and making alternative management options to meet diverse needs of different parties (government, entrepreneurs, NGOs). In this work, they considered the role of scientists as a 'knowledge broker' rather than defining the 'optimal system' and gave the right to farmers to make a choice from a range of possibilities, which assured the implementation of sustainable agricultural land use at the end. Payment for ecosystem services (PES) is an investment support to land users for practices that have long-term environmental benefits beyond land users' own commercial interests, thereby of particular relevance for soil and land management (Kauffman et al. 2014). But even with innovative knowledge, PES could only be efficient and effective when it is applied in the right places for the right person at the right time. Recently, China introduced a new alternative eco-compensation scheme that developers could pay the government and authorities directly to opt out of restoring ecosystems (Fang and Elliott 2016). Such compensation options further stimulate concerns about misuse of payments, because it gives the developer the right to buy environmental damage, which is time- and cost-consuming and science-demanding to restore. Therefore, even for alternative payment schemes ecological restoration has to be an obligation at any rate of compromise. By contrast, the case study of Green Water Credits (GWC) in Kenya (Kauffman et al. 2014) clarified the importance of PES for the practical soil conservation implementation upstream for benefiting downstream water users. The GWC is effective because the interactions with all stakeholders started from the beginning to reach agreement on relevant norms, values, and knowledge, while the commercial interests of upstream farmers were captured in a series of cost-benefit analyses. Clear and transparent processes between experts, officials, and stakeholders made the GWC convincing and relevant. Thus, this concept was accepted and applied to watersheds. These real-world experiences demonstrate that choices and dialogues are indispensable preconditions for improving the efficiency of policy intervention, which is still absent on the Loess Plateau.

Addressing the above listed issues is regarded as a key step towards the realisation of multifunctional land use in the Loess Plateau regions to address the emerging ecological and socioeconomic issues in a global context. Experiences and results of studies on multifunctional land use in the Loess Plateau region will not only enhance regional resilience to environmental changes, but also provide valuable knowledge and information for other similar regions towards a more sustainable development.

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